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437	225

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UTILITY SERIAL NUMBER	PATENT DATE JAN 25 2000	PATENT NUMBER 6017221

SERIAL NUMBER	FILING DATE	CLASS	SUBCLASS	GROUP ART UNIT	EXAMINER
08/866,040	05/30/97	~~216~~ 4	225	~~1104~~ ~~164~~ 1642	L Scheiner

6017221

APPLICANTS DANIEL L. FLAMM, WALNUT CREEK, CA.

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CONTINUING DATA********************

VERIFIED THIS APPLN IS A CIP OF 08/736,315 10/23/96 ABN
WHICH IS A CON OF 08/567,224 12/04/95 ABN

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FOREIGN APPLICATIONS**********

VERIFIED

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TITLE PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

U.S. DEPT. OF COMM./PAT & TM—PTO-436L (Rev.12-94)

PARTS OF APPLICATION FILED SEPARATELY

Applications Examiner

NOTICE OF ALLOWANCE MAILED		CLAIMS ALLOWED	
		Total Claims	Print Claim
9-27-99	Assistant Examiner	7	1

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Amount Due	Date Paid		Sheets Drwg.	Figs. Drwg.	Print Fig.
605.00	10-17-99	LAURIE SCHEINER PRIMARY EXAMINER Primary Examiner	13	15	None

ISSUE BATCH NUMBER C07

Label Area

PREPARED FOR ISSUE

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(Rev. 8/92)

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ISSUE FEE

(FACE)

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08/866040
05/30/97

PATENT APPLICATION

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US006017221A

United States Patent [19]

Flamm

[11] **Patent Number: 6,017,221**

[45] **Date of Patent: Jan. 25, 2000**

[54] **PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING**

[76] Inventor: **Daniel L. Flamm**, 476 Green View Dr.,
Walnut Creek, Calif. 94596

[21] Appl. No.: **08/866,040**

[22] Filed: **May 30, 1997**

Related U.S. Application Data

[63] Continuation-in-part of application No. 08/736,315, Oct. 23, 1996, abandoned, which is a continuation of application No. 08/567,224, Dec. 4, 1995, abandoned.

[51] **Int. Cl.**^{7} **H01L 21/00**

[52] **U.S. Cl.** **437/225**; 437/228; 437/233; 156/643; 156/192.25; 204/192.32

[58] **Field of Search** 118/50.1; 156/643, 156/345, 646, 659.1; 219/121.41, 121.44; 204/192.1, 192.12, 192.25; 427/12; 216/2; 437/225, 228, 233

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,873,884	3/1975	Gabriel .	
4,368,092	1/1983	Steinberg et al. .	
4,918,031	4/1990	Flamm et al. .	
4,943,345	7/1990	Asmussen et al.	156/643
5,234,529	8/1993	Johnson .	
5,241,245	8/1993	Barnes et al. .	
5,304,282	4/1994	Flamm .	
5,361,016	11/1994	Ohkawa et al.	315/111.41
5,431,968	7/1995	Miller et al. .	
5,534,231	7/1996	Savas .	
5,637,961	6/1997	Ishii et al. .	

OTHER PUBLICATIONS

Asmussen et al., "The Design of a Microwave Plasma Cavity," *Proc. of IEEE,* 62(1):109–117 (Jan. 1974).

Eckert, "The Hundred Year History of Induction Discharges," 2^{nd} *Ann. Int'l Conf. Plasma Chem. Tech.*, (1984).

Fossheim et al., "Broadband tguning of helical resonant cavitites," *J. Phys. E. Sci. Instrum.,* 11:892–893 (1978).

Niazi et al. "Operation of a helical resonator plasma source," *Plasma Sources Sci. Technol.,* 3:482–495 (1994).

Roppel et al., "Low temperature oxidation of silicon using a microwave plasma disk source," *J. Vac. sci. Technol.,* B4(1):295–298 (Jan./Feb. 1986).

Zverev et al., "Realization of a Filter with Helical Components," *IRE Trans. on Component Parts,* pp. 99–110, (Sep. 1961).

Primary Examiner—Laurie Scheiner
Attorney, Agent, or Firm—Townsend and Townsend and Crew LLP

[57] **ABSTRACT**

A process for fabricating a product **28**, **119**. The process comprises the steps of subjecting a substrate to a composition of entities, at least one of the entities emanating from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure substantially balances.

7 Claims, 13 Drawing Sheets

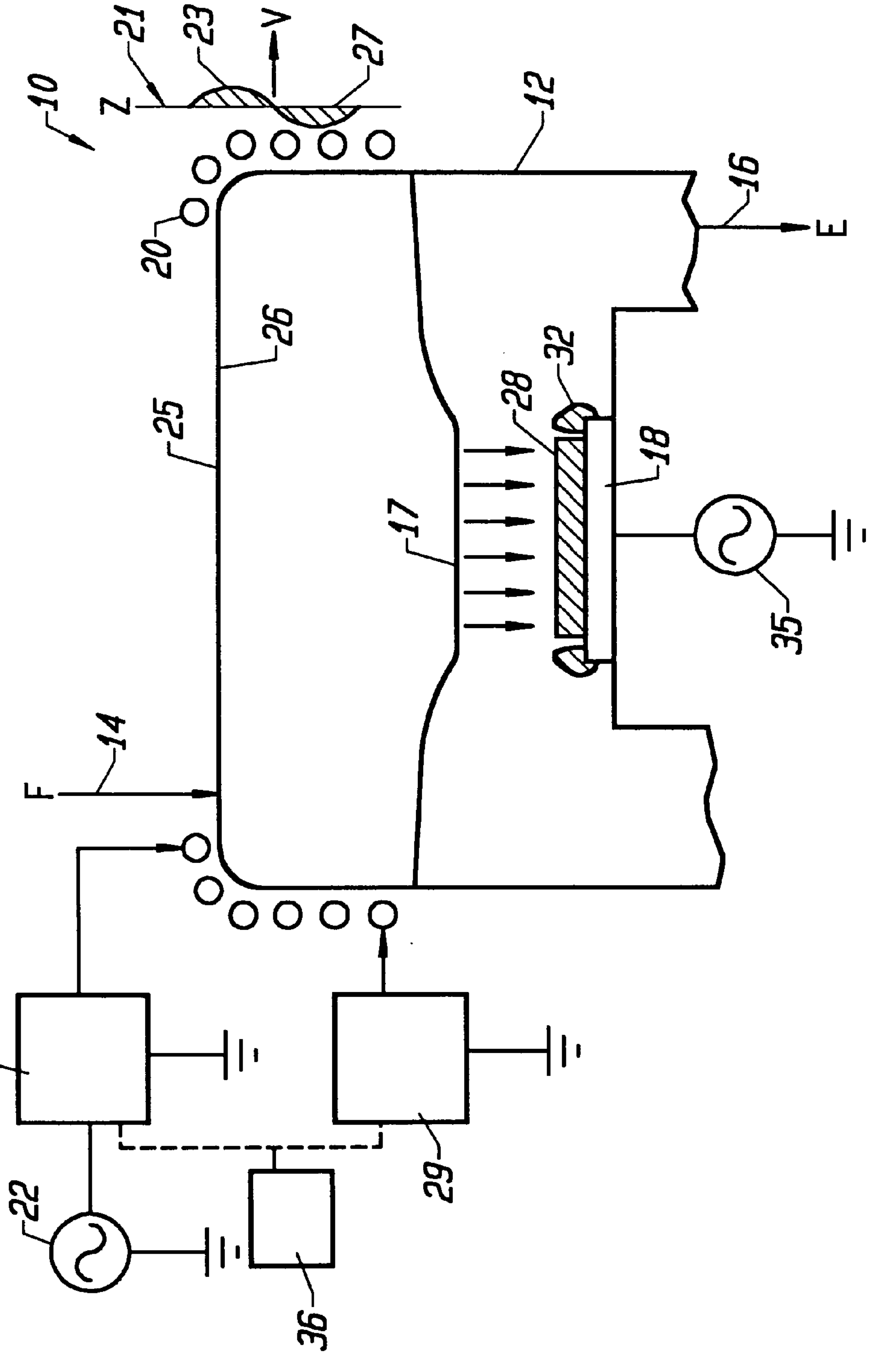


FIG. 1

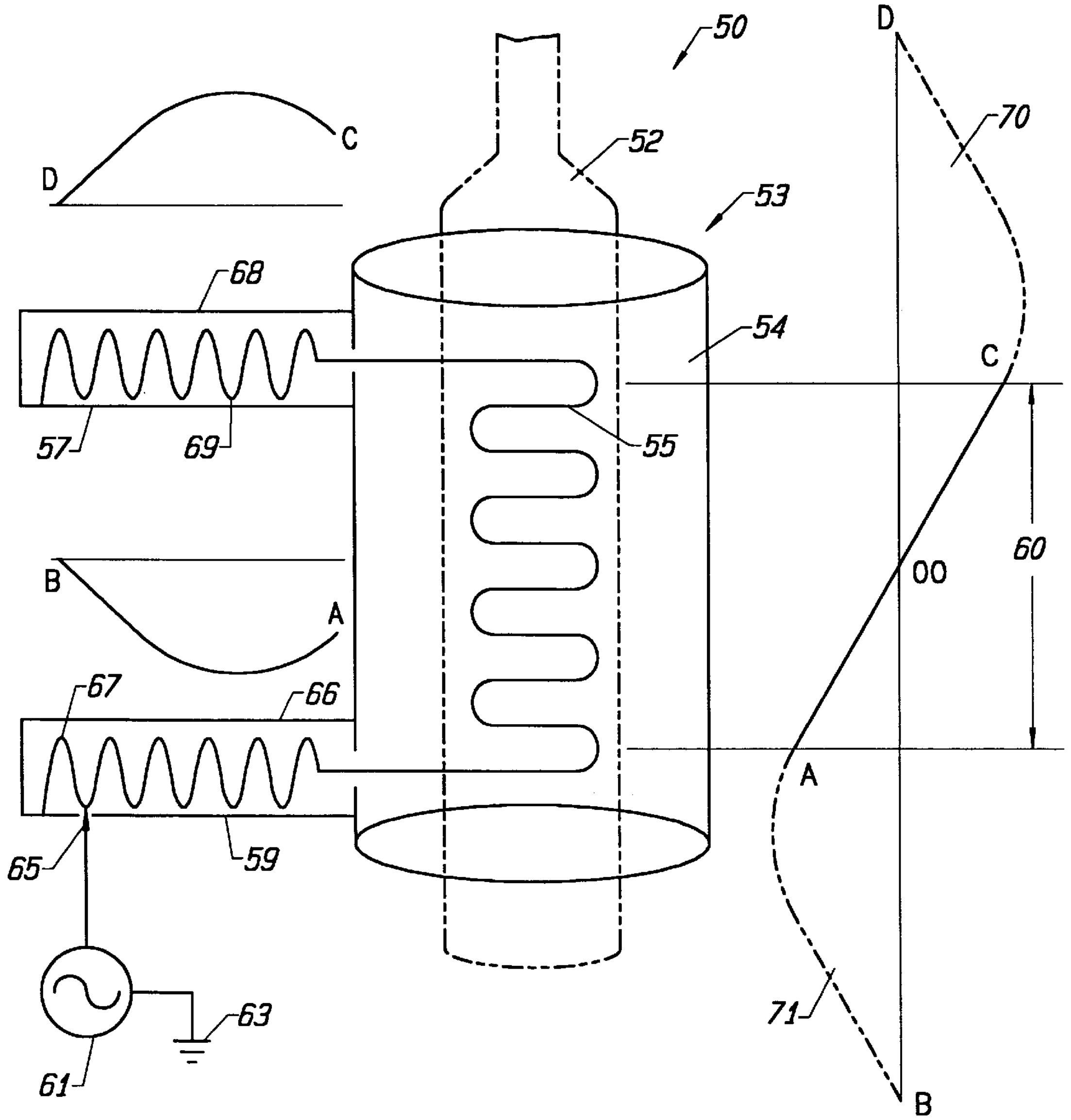


FIG. 2A

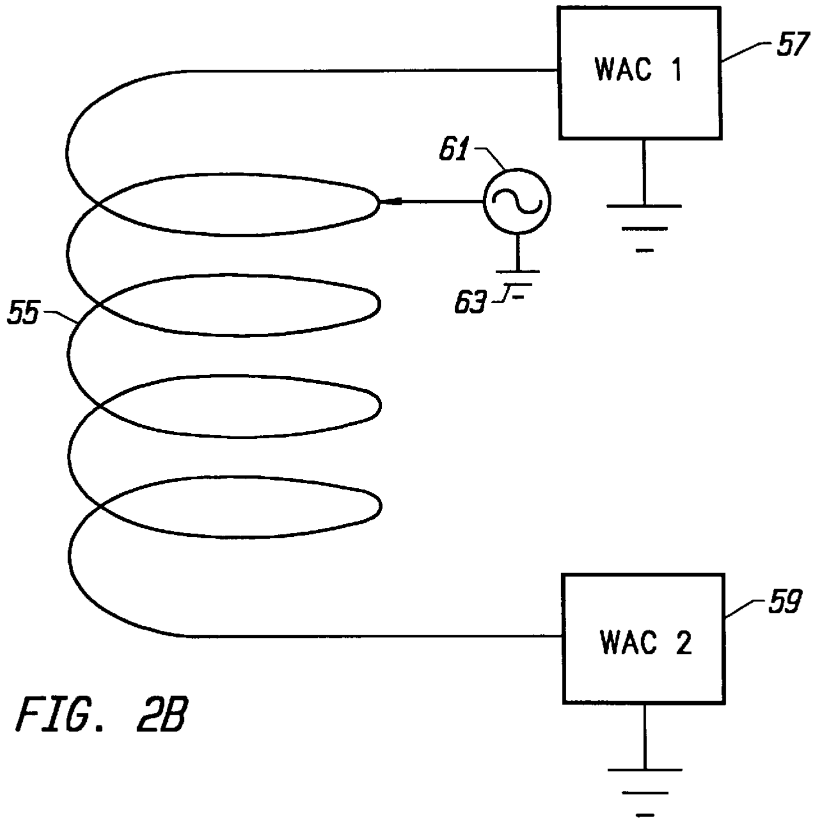


FIG. 2B

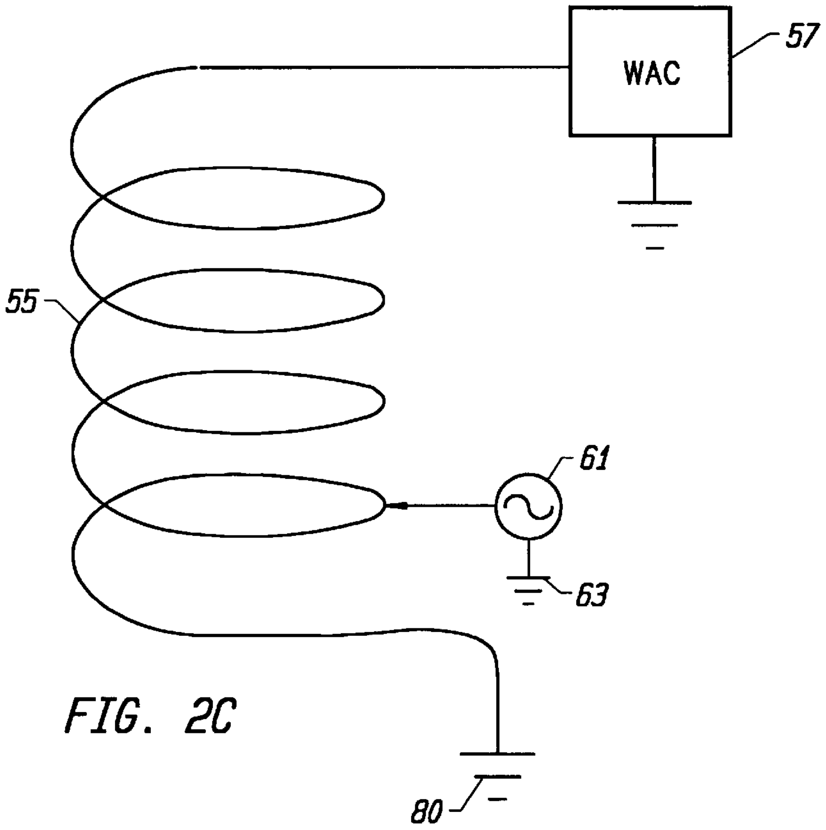
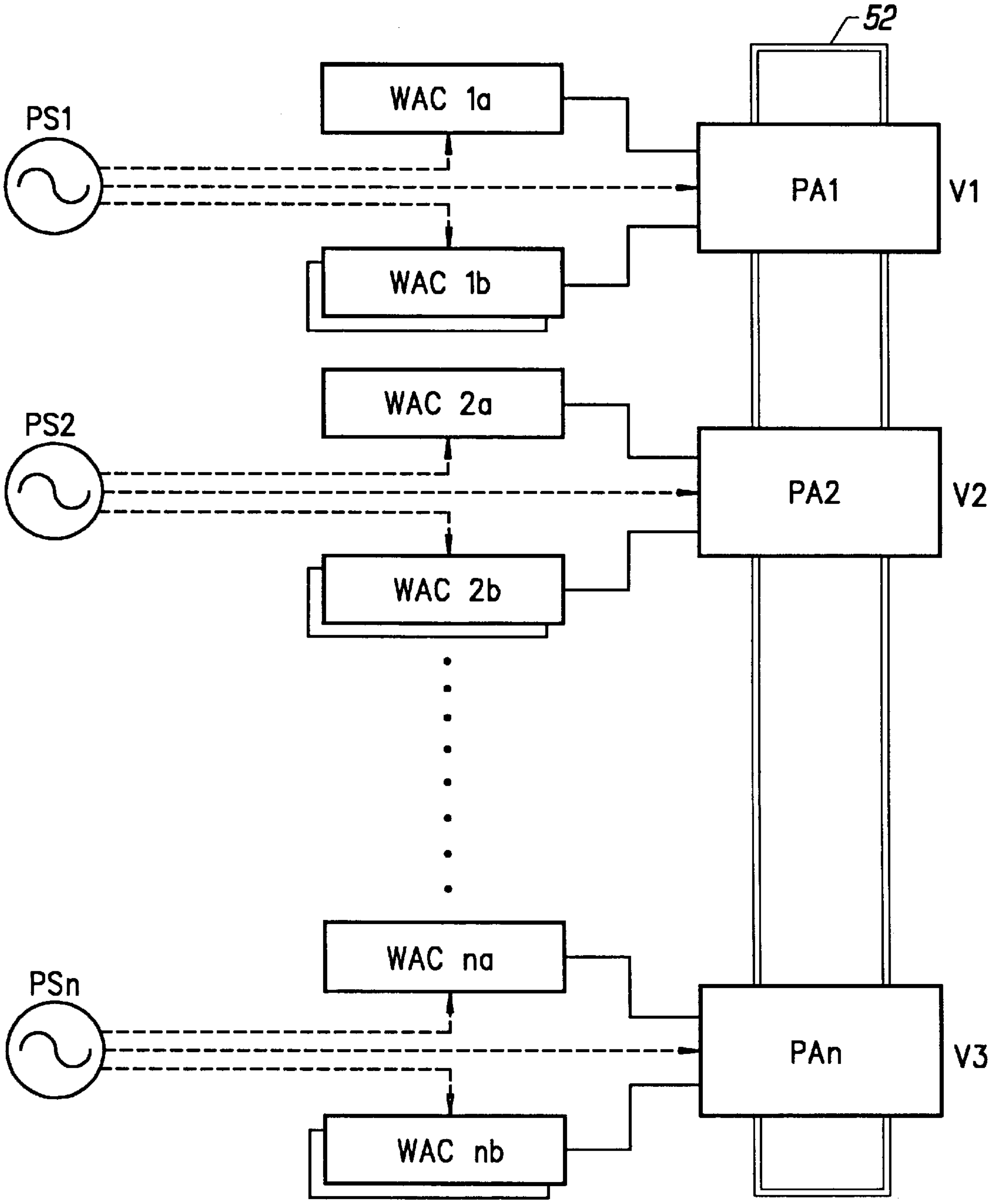


FIG. 2C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PS1
PA1
V1
WAC 1b
WAC 2a
PS2
PA2
V2
WAC 2b
WAC na
PSn
PAn
V3
WAC nb

FIG. 2D

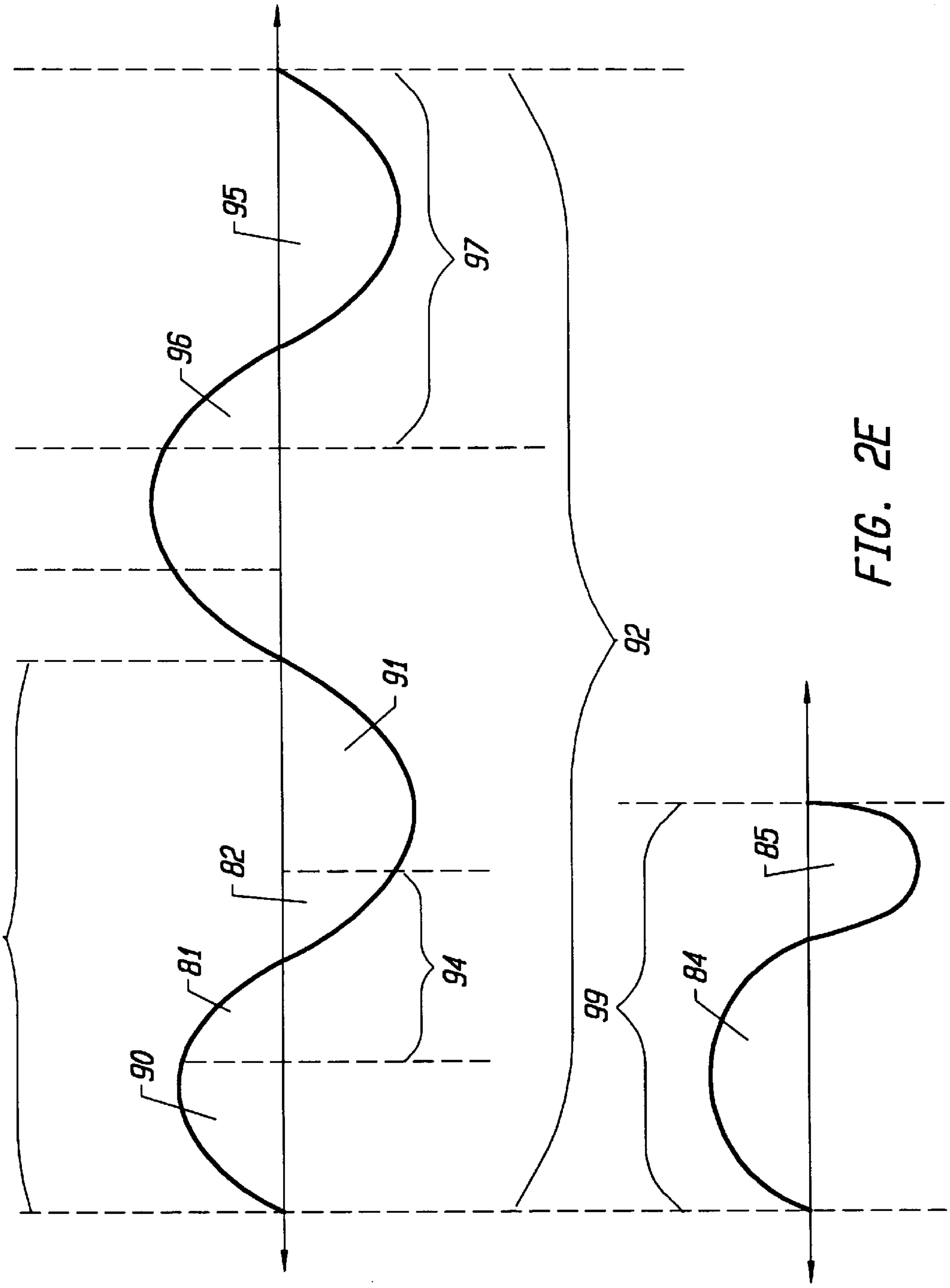

FIG. 2E

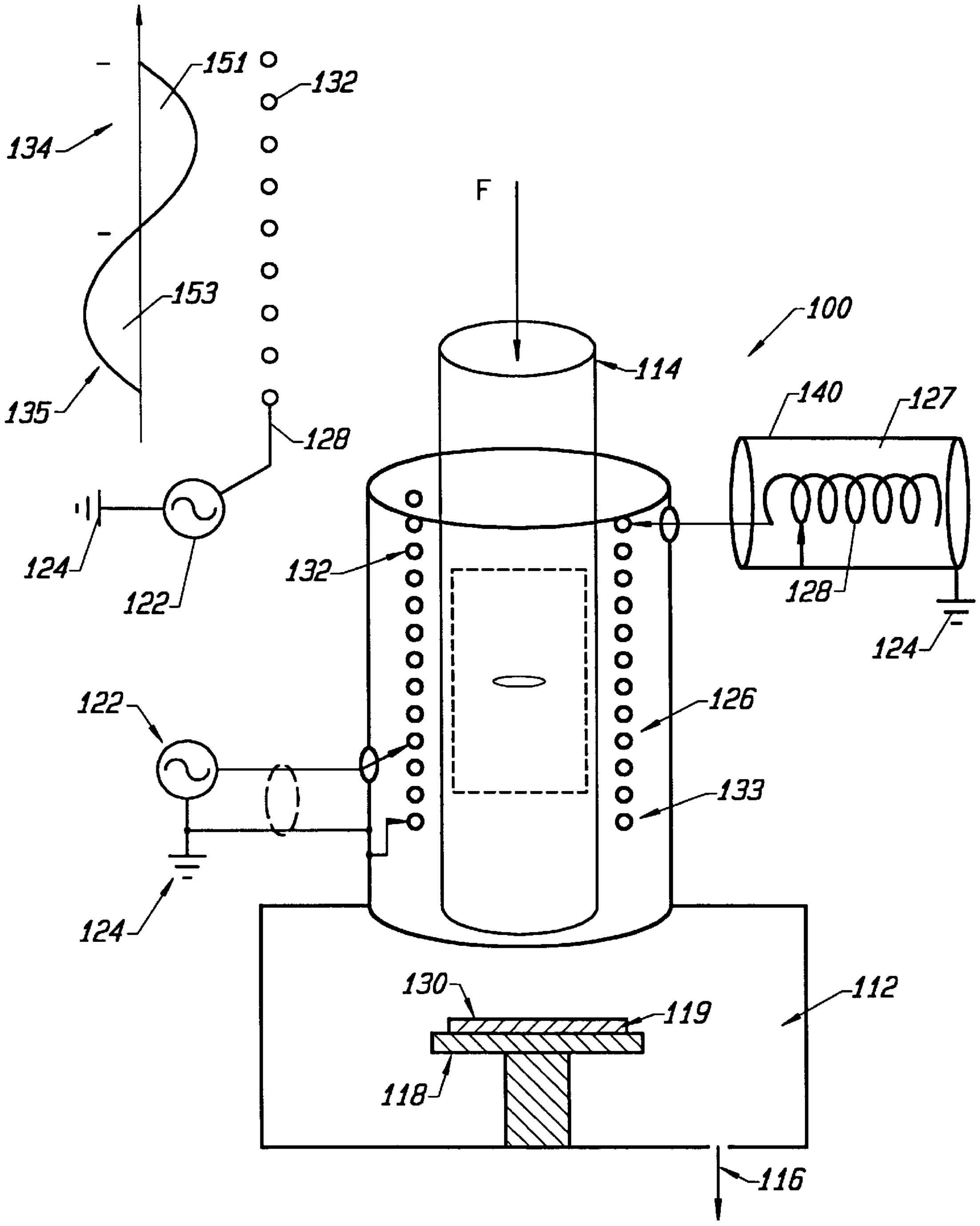
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FIG. 3

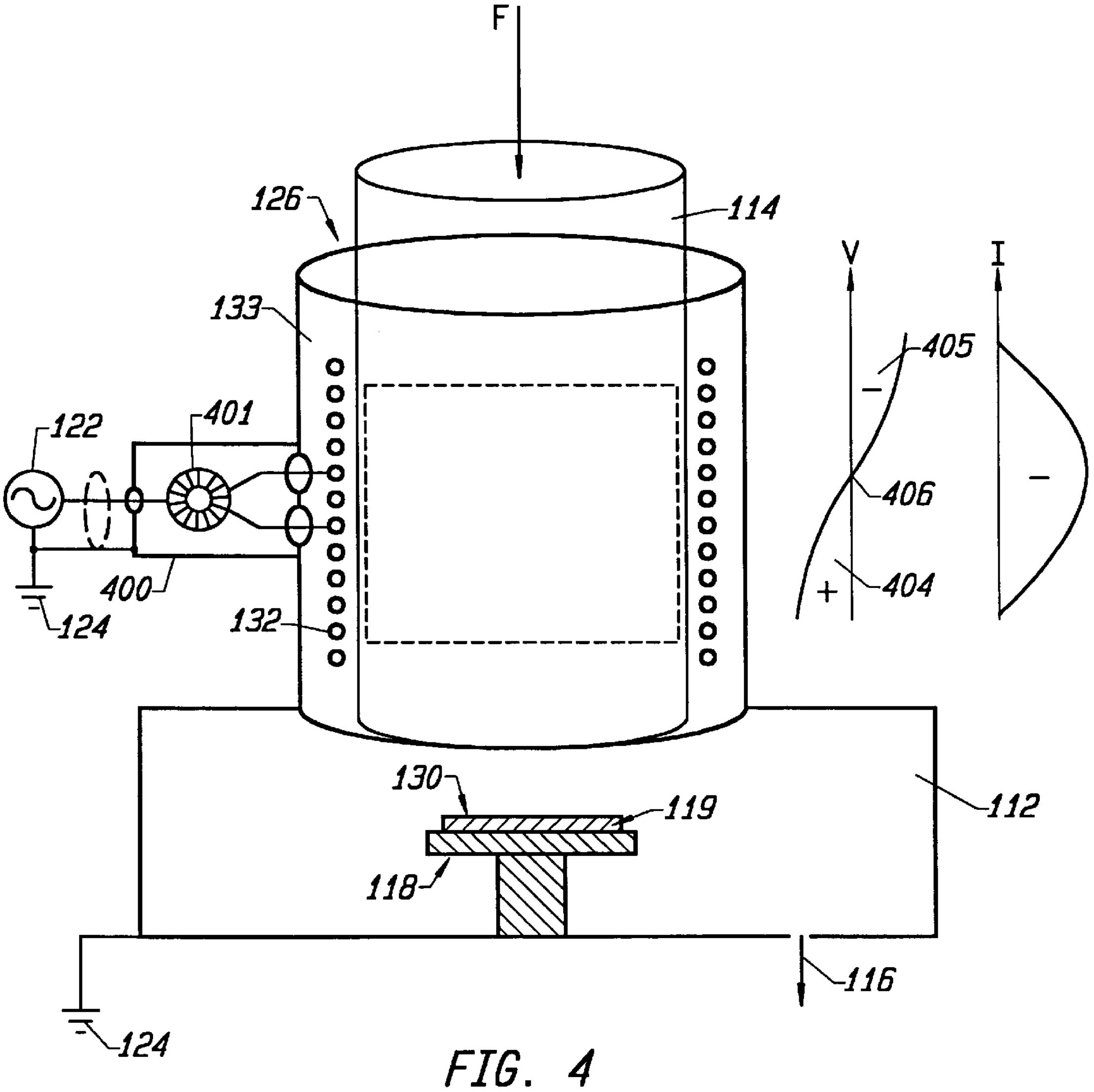
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FIG. 4

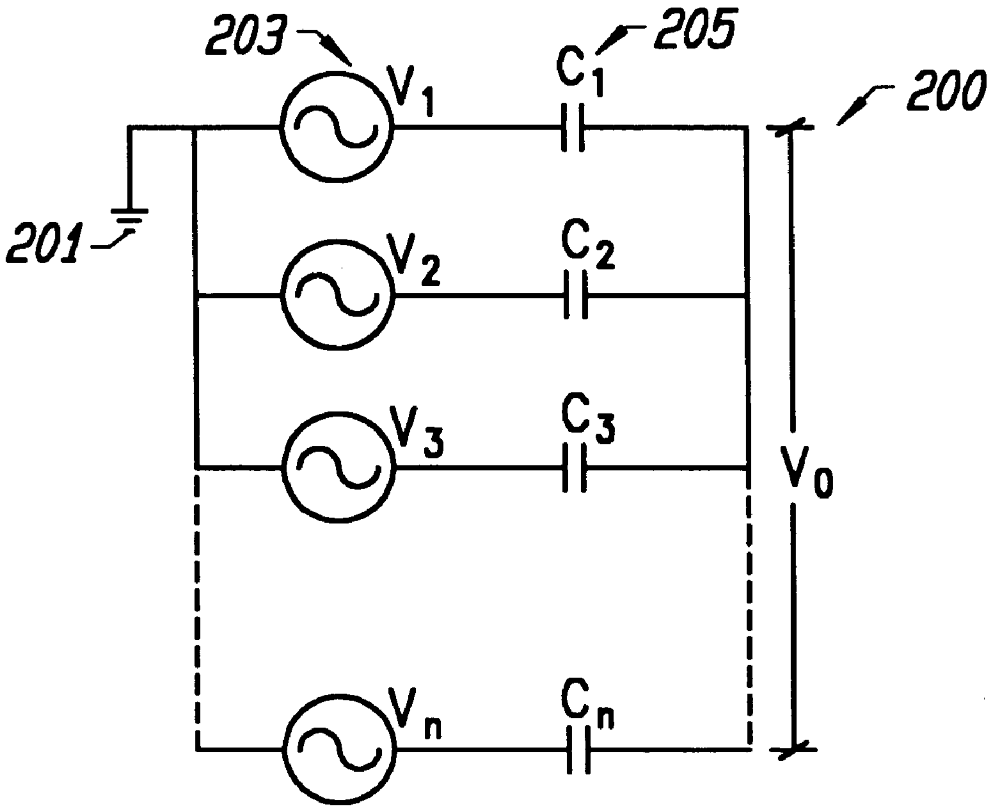


FIG. 5A

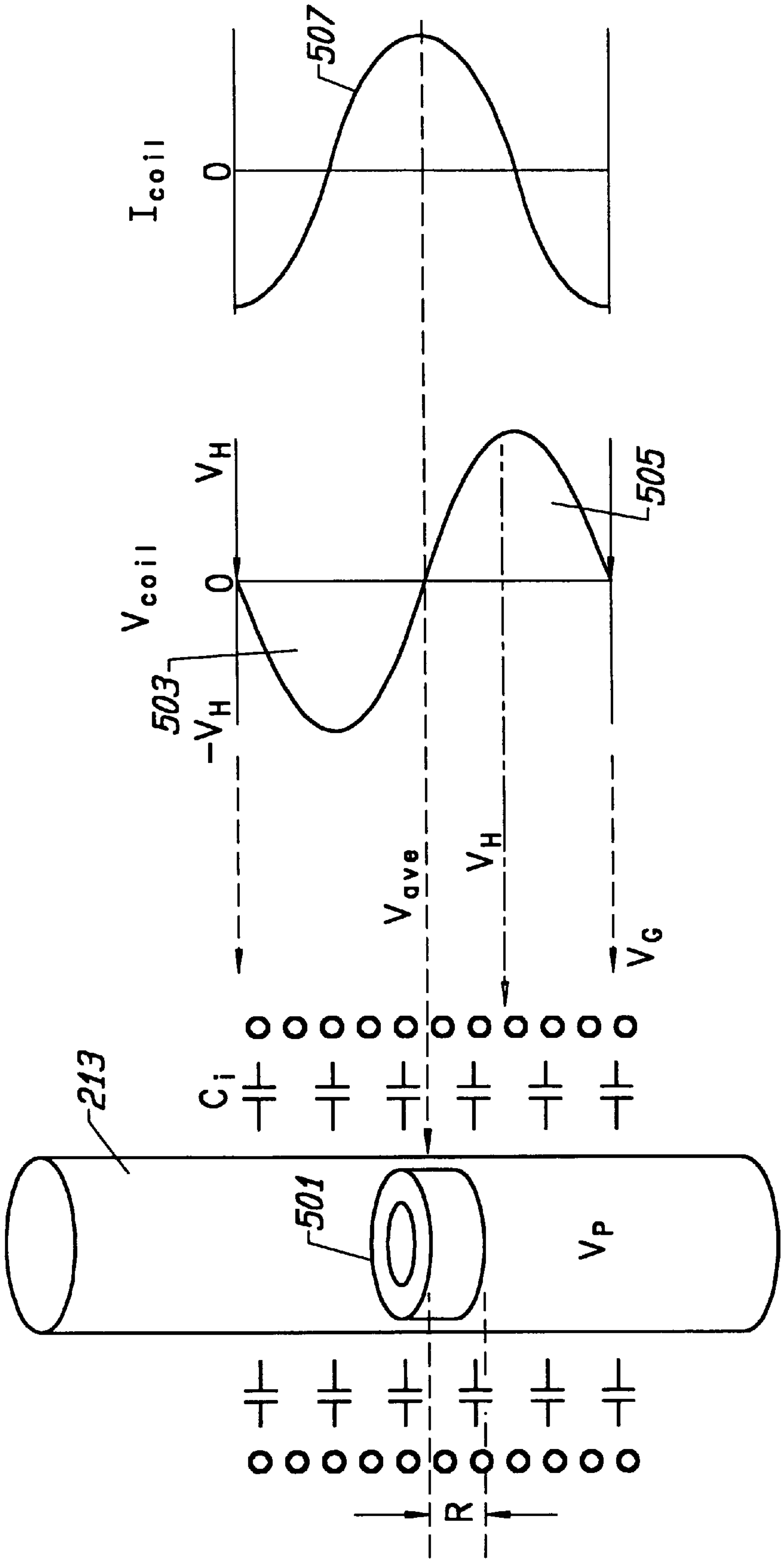
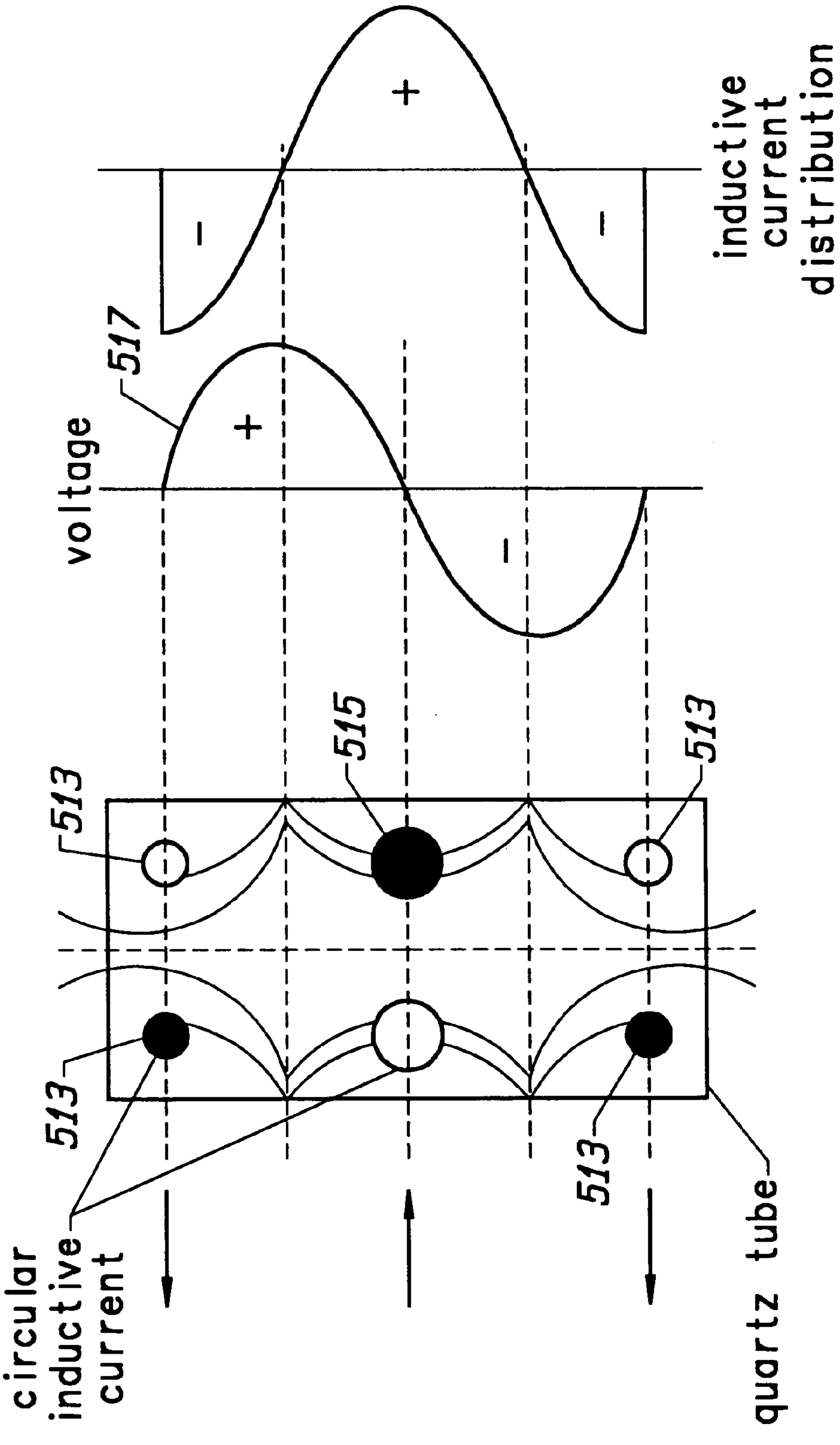


FIG. 5B



inductive current distribution
+
-
-
voltage
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+
-
513
515
513
513
513
circular inductive current
quartz tube

FIG. 5C

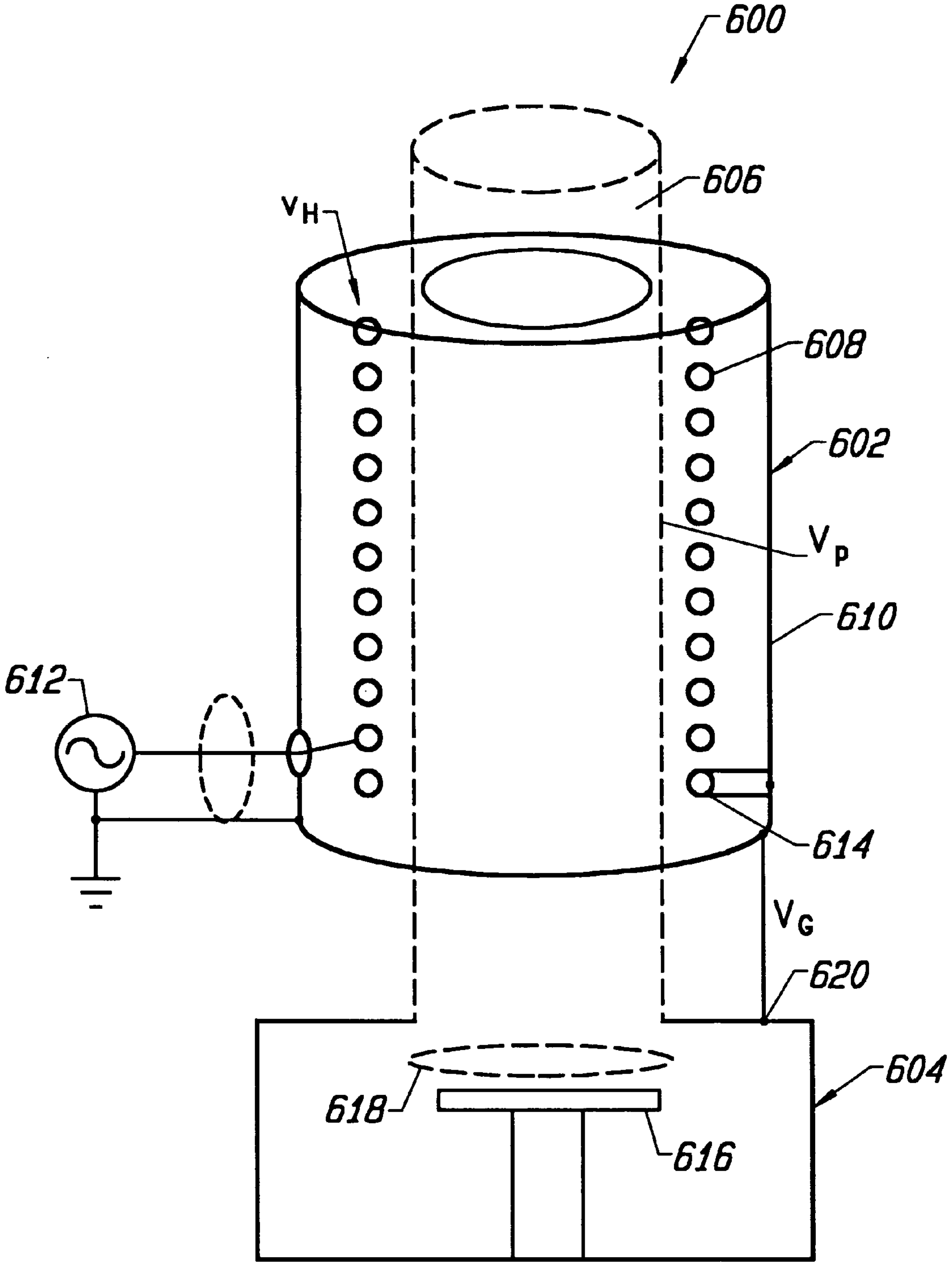

FIG. 6

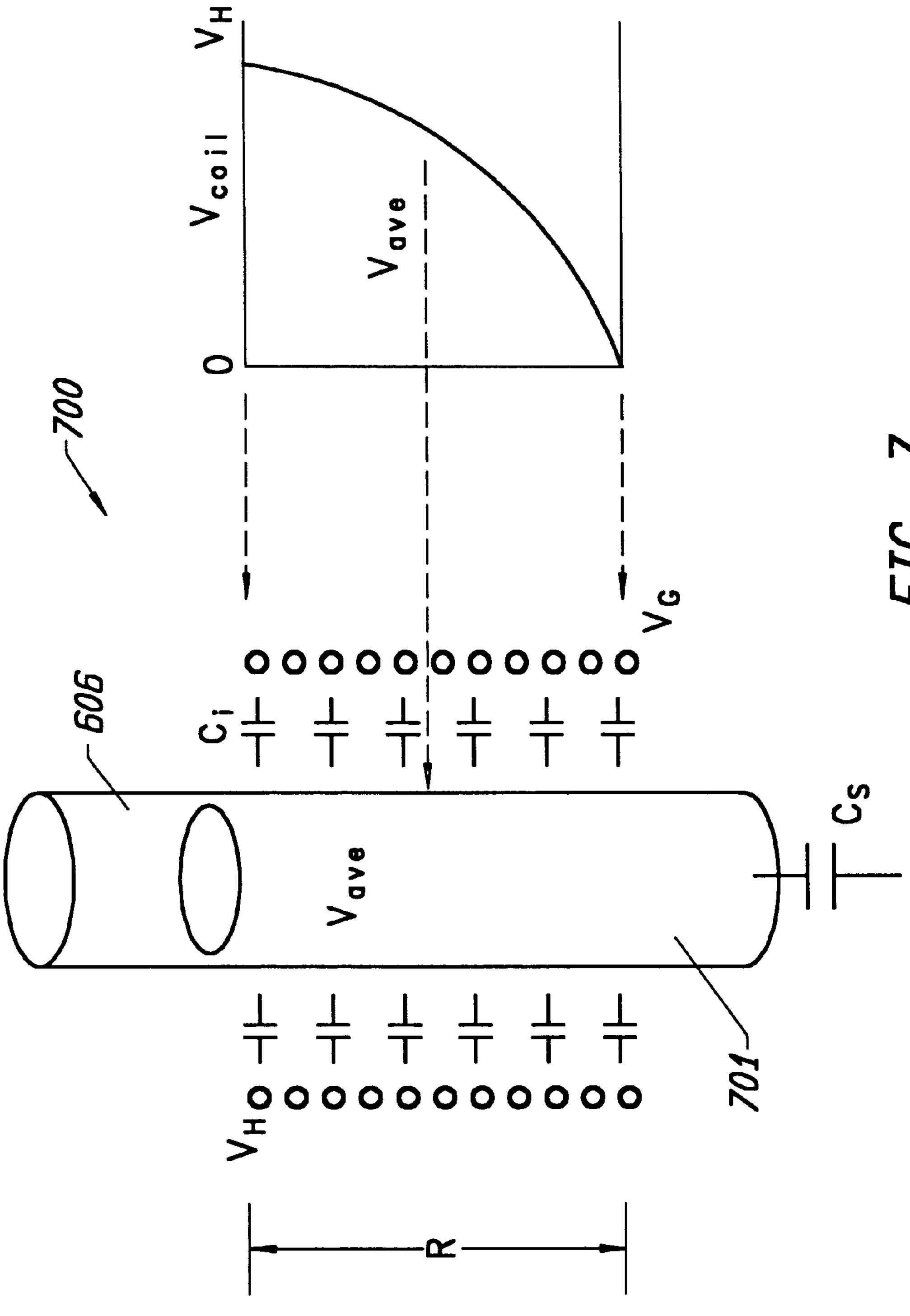

FIG. 7

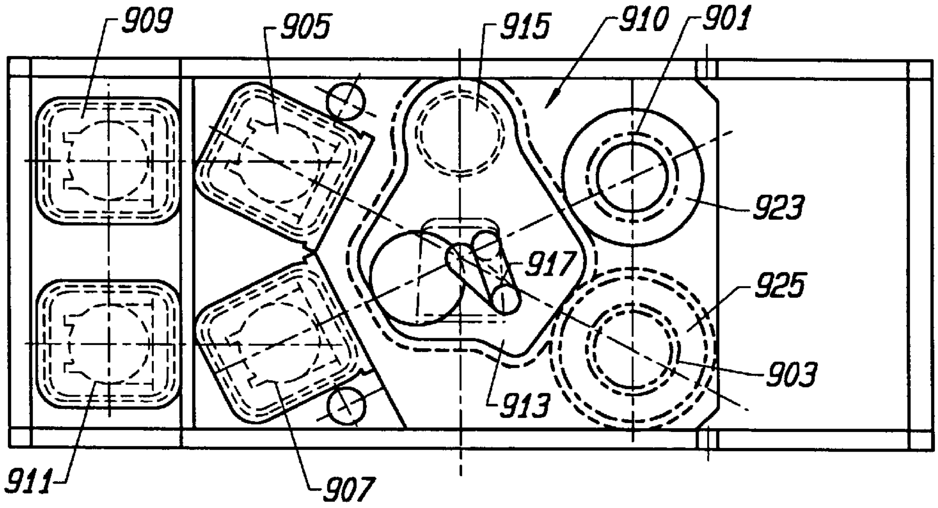
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FIG. 8

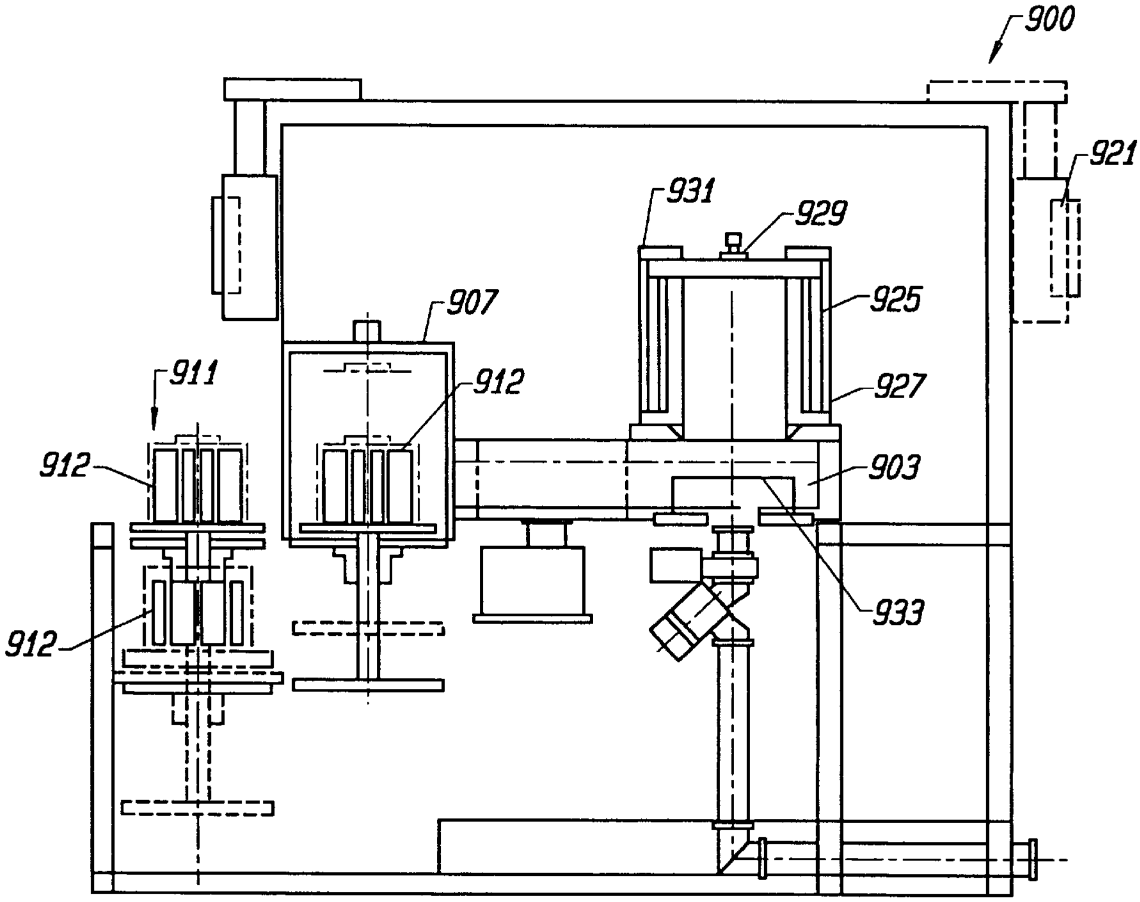
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FIG. 9

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 08/736,315 filed Oct. 23, 1996, now abandoned, which is a continuation of application Ser. No. 08/567,224 filed Dec. 4, 1995, now abandoned. All of these documents are hereby incorporated by reference for all purposes.

BACKGROUND OF THE INVENTION

This invention relates generally to plasma processing. More particularly, the invention is for plasma processing of devices using an inductive discharge. This invention is illustrated in an example with regard to plasma etching and resist stripping of semiconductor devices. The invention also is illustrated with regard to chemical vapor deposition (CVD) of semiconductor devices. But it will be recognized that the invention has a wider range of applicability. Merely by way of example, the invention also can be applied in other plasma etching applications, and deposition of materials such as silicon, silicon dioxide, silicon nitride, polysilicon, among others.

Plasma processing techniques can occur in a variety of semiconductor manufacturing processes. Examples of plasma processing techniques occur in chemical dry etching (CDE), ion-assisted etching (IAE), and plasma enhanced chemical vapor deposition (PECVD), including remote plasma deposition (RPCVD) and ion-assisted plasma enhanced chemical vapor deposition (IAPECVD). These plasma processing techniques often rely upon radio frequency power (rf) supplied to an inductive coil for providing power to gas phase species in forming a plasma.

Plasmas can be used to form neutral species (i.e., uncharged) for purposes of removing or forming films in the manufacture of integrated circuit devices. For instance, chemical dry etching generally depends on gas-surface reactions involving these neutral species without substantial ion bombardment.

In other manufacturing processes, ion bombardment to substrate surfaces is often undesirable. This ion bombardment, however, is known to have harmful effects on properties of material layers in devices and excessive ion bombardment flux and energy can lead to intermixing of materials in adjacent device layers, breaking down oxide and “wear out,” injecting of contaminative material formed in the processing environment into substrate material layers, harmful changes in substrate morphology (e.g. amophotization), etc.

Ion assisted etching processes, however, rely upon ion bombardment to the substrate surface in defining selected films. But these ion assisted etching processes commonly have a lower selectivity relative to conventional CDE processes. Hence, CDE is often chosen when high selectivity is desired and ion bombardment to substrates are to be avoided.

One commonly used chemical dry etching technique is conventional photoresist stripping, often termed ashing or stripping. Conventional resist stripping relies upon a reaction between a neutral gas phase species and a surface material layer, typically for removal. This reaction generally forms volatile products with the surface material layer for its removal. The neutral gas phase species is formed by a plasma discharge. This plasma discharge can be sustained by a coil (e.g., helical coil, etc.) operating at a selected frequency in a conventional photoresist stripper. An example of the conventional photoresist stripper is a quarter-wave helical resonator stripper, which is described by U.S. Pat. No. 4,368,092 in the name of Steinberg et al.

Referring to the above, an objective in chemical dry etching is to reduce or even eliminate ion bombardment (or ion flux) to surfaces being processed to maintain the desired etching selectivity. In practice, however, it is often difficult to achieve using conventional techniques. These conventional techniques generally attempt to control ion flux by suppressing the amount of charged species in the plasma source reaching the process chamber. A variety of techniques for suppressing these charged species have been proposed.

These techniques often rely upon shields, baffles, large separation distances between the plasma source and the chamber, or the like, placed between the plasma source and the process chamber. The conventional techniques generally attempt to directly suppress charge density downstream of the plasma source by interfering with convective and diffusive transport of charged species. They tend to promote recombination of charged species by either increasing the surface area (e.g., baffles, etc.) relative to volume, or increasing flow time, which relates to increasing the distance between the plasma source and the process chamber.

These baffles, however, cause loss of desirable neutral etchant species as well. The baffles, shields, and alike, also are often cumbersome. Baffles, shields, or the large separation distances also cause undesirable recombinative loss of active species and sometimes cause radio frequency power loss and other problems. These baffles and shields also are a potential source of particulate contamination, which is often damaging to integrated circuits.

Baffles, shields, spatial separation, and alike, when used alone also are often insufficient to substantially prevent unwanted parasitic plasma currents. These plasma currents are generated between the wafer and the plasma source, or between the plasma source and walls of the chamber. It is commonly known that when initial charged species levels are present in an electrical field, the charged species are accelerated and dissociative collisions with neutral particles can multiply the concentration of charge to higher levels. If sufficient “seed” levels of charge and rf potentials are present, the parasitic plasma in the vicinity of the process wafer can reach harmful charge density levels. In some cases, these charge densities may be similar to or even greater than plasma density within the source plasma region, thereby causing even more ion flux to the substrate.

Charge densities also create a voltage difference between the plasma source and processing chamber or substrate support, which can have an additional deleterious effect. This voltage difference enhances electric fields that can accelerate extraction of charge from the plasma source. Hence, their presence often induces increased levels of charge to be irregularly transported from the plasma source to process substrates, thereby causing non-uniform ion assisted etching.

Conventional ion assisted plasma etching, however, often requires control and maintenance of ion flux intensity and uniformity within selected process limits and within selected process energy ranges. Control and maintenance of ion flux intensity and uniformity are often difficult to achieve using conventional techniques. For instance, capacitive coupling between high voltage selections of the coil and the plasma discharge often cause high and uncontrollable plasma potentials relative to ground. It is generally understood that voltage difference between the plasma and ground can cause damaging high energy ion bombardment of articles being processed by the plasma, as illustrated by U.S. Pat. No. 5,234,529 in the name of Johnson. It is further often understood that rf component of the plasma potential varies in time since it is derived from a coupling to time varying rf excitation. Hence, the energy of charged particles from plasma in conventional inductive sources is spread over a relatively wide range of energies, which undesirably tends to introduce uncontrolled variations in the processing of articles by the plasma.

The voltage difference between the region just outside of a plasma source and the processing chamber can be modified by introducing internal conductive shields or electrode elements into the processing apparatus downstream of the source. When the plasma potential is elevated with respect to these shield electrodes, however, there is a tendency to generate an undesirable capacitive discharge between the shield and plasma source. These electrode elements are often a source of contamination and the likelihood for contamination is even greater when there is capacitive discharge (ion bombardment from capacitive discharge is a potential source of sputtered material). Contamination is damaging to the manufacture of integrated circuit devices.

Another limitation is that the shield or electrode elements generally require small holes therein as structural elements. These small holes are designed to allow gas to flow therethrough. The small holes, however, tend to introduce unwanted pressure drops and neutral species recombination. If the holes are made larger, the plasma from the source tends to survive transport through the holes and unwanted downstream charge flux will often result. In addition, undesirable discharges to these holes in shields can, at times, produce an even more undesirable hollow cathode effect.

In conventional helical resonator designs, conductive external shields are interposed between the inductive power (e.g., coil, etc.) and walls of the vacuum vessel containing the plasma. A variety limitations with these external capacitive shielded plasma designs (e.g., helical resonator, inductive discharge, etc.) have been observed. In particular, the capacitively shielded design often produces plasmas that are difficult to tune and even ignite. Alternatively, the use of unshielded plasma sources (e.g., conventional quarter-wave resonator, conventional half-wave resonator, etc.) attain a substantial plasma potential from capacitive coupling to the coil, and hence are prone to create uncontrolled parasitic plasma currents to grounded surfaces. Accordingly, the use of either the shielded or the unshielded sources using conventional quarter and half-wave rf frequencies produce undesirable results.

In many conventional plasma sources a means of cooling is required to maintain the plasma source and substrates being treated below a maximum temperature limit. Power dissipation in the structure causes heating and thereby increases the difficulty and expense of implementing effective cooling means. Inductive currents may also be coupled from the excitation coil into internal or capacitive shields and these currents are an additional source of undesirable power loss and heating. Conventional capacitive shielding in helical resonator discharges utilized a shield which was substantially split along the long axis of the resonator to lessen eddy current loss. However, such a shield substantially perturbs the resonator characteristics owing to unwanted capacitive coupling and current which flows from the coil to the shield. Since there are no general design equations, nor are properties currently known for resonators which are "loaded" with a shield along the axis, sources using this design must be sized and made to work by trial and error.

In inductive discharges, it is highly desirable to be able to substantially control the plasma potential relative to ground potential, independent of input power, pressure, gas composition and other variables. In many cases, it is desired to have the plasma potential be substantially at ground potential (at least offset from ground potential by an amount insignificantly different from the floating potential or intrinsic DC plasma potential). For example, when a plasma source is utilized to generate neutral species to be transported downstream of the source for use in ashing resist on a semiconductor device substrate (a wafer or flat panel electronic display), the concentration and potential of charged plasma species in the reaction zone are desirably reduced to avoid charging damage from electron or ionic current from the plasma to the device. When there is a substantial potential difference between plasma in the source and grounded surfaces beyond the source, there is a tendency for unwanted parasitic plasma discharges to form outside of the source region.

Another undesirable effect of potential difference is the acceleration of ions toward grounded surfaces and subsequent impact of the energetic ions with surfaces. High energy ion bombardment may cause lattice damage to the device substrate being processed and may cause the chamber wall or other chamber materials to sputter and contaminate device wafers. In other plasma processing procedures, however, some ion bombardment may be necessary or desirable, as is the case particularly for anisotropic ion-induced plasma etching procedures (for a discussion of ion-enhanced plasma etching mechanisms See Flamm (Ch. 2, pp.94–183 in Plasma Etching, An Introduction, D. M. Manos and D. L. Flamm, eds., Academic Press, 1989)). Consequently, uncontrolled potential differences, such as that caused by "stray" capacitive coupling from the coil of an inductive plasma source to the plasma, are undesirable.

Referring to the above limitations, conventional plasma sources also have disadvantages when used in conventional plasma enhanced CVD techniques. These techniques commonly form a reaction of a gas composition in a plasma discharge. One conventional plasma enhanced technique relies upon ions aiding in rearranging and stabilizing the film, provided the bombardment from the plasma is not sufficiently energetic to damage the underlying substrate or the growing film. Conventional resonators and other types of inductive discharges often produce parasitic plasma currents from capacitive coupling, which often detrimentally influences film quality, e.g., an inferior film, etc. These parasitic plasma currents are often uncontrollable, and highly undesirable. These plasma sources also have disadvantages in other plasma processing techniques such as ion-assisted etching, and others. Of course, the particular disadvantage will often depend upon the application.

To clarify certain concepts used in this application, it will be convenient to introduce these definitions.

Ground (or ground potential): These terms are defined as a reference potential which is generally taken as the potential of a highly conductive shield or other highly conductive surface which surrounds the plasma source. To be a true ground shield in the sense of this definition, the RF conductance at the operating frequency is often substantially high so that potential differences generated by current within the shield are of negligible magnitude compared to potentials intentionally applied to the various structures and elements of the plasma source or substrate support assembly. However, some realizations of plasma sources do not incorporate a shield or surface with adequate electrical susceptance to meet this definition. In implementations where there is a surrounding conductive surface that is somewhat similar to a ground shield or ground plane, the ground potential is taken to be the fictitious potential which the imperfect grounded surface would have equilibrated to if it had zero high frequency impedance. In designs where there is no physical surface which is adequately configured or which does not have insufficient susceptance to act as a "ground" according to the above definition, ground potential is the potential of a fictitious surface which is equi-potential with the shield or "ground" conductor of an unbalanced transmission line connection to the plasma source at its RF feed point. In designs where the plasma source is connected to an RF generator with a balanced transmission line RF feed, "ground" potential is the average of the driven feed line potentials at the point where the feed lines are coupled to the plasma source.

Inductively Coupled Power: This term is defined as power transferred to the plasma substantially by means of a time-varying magnetic flux which is induced within the volume containing the plasma source. A time-varying magnetic flux induces an electromotive force in accord with Maxwell's equations. This electromotive force induces motion by electrons and other charged particles in the plasma and thereby imparts energy to these particles.

RF inductive power source and bias power supply: In most conventional inductive plasma source reactors, power is supplied to an inductive coupling element (the inductive coupling element is often a multi-turn coil which abuts a dielectric wall containing a gas where the plasma is ignited at low pressure) by an rf power generator.

Conventional Helical Resonator: Conventional helical resonator can be defined as plasma applicators. These plasma applicators have been designed and operated in multiple configurations, which were described in, for example, U.S. Pat. No. 4,918,031 in the names of Flamm et al., U.S. Pat. No. 4,368,092 in the name of Steinberg et al., U.S. Pat. No. 5,304,282 in the name of Flamm, U.S. Pat. No. 5,234,529 in the name of Johnson, U.S. Pat. No. 5,431,968 in the name of Miller, and others. In these configurations, one end of the helical resonator applicator coil has been grounded to its outer shield. In one conventional configuration, a quarter wavelength helical resonator section is employed with one end of the applicator coil grounded and the other end floating (i.e., open circuited). A trimming capacitance is sometimes connected between the grounded outer shield and the coil to "fine tune" the quarter wave structure to a desired resonant frequency that is below the native resonant frequency without added capacitance. In another conventional configuration, a half-wavelength helical resonator section was employed in which both ends of the coil were grounded. The function of grounding the one or both ends of the coil was believed to be not essential, but advantageous to "stabilize the plasma operating characteristics" and "reduce the possibility of coupling stray current to nearby objects." See U.S. Pat. No. 4,918,031.

Conventional resonators have also been constructed in other geometrical configurations. For instance, the design of helical resonators with a shield of square cross section is described in Zverev et al., IRE Transactions on Component Parts, pp. 99–110, Sept. 1961. Johnson (U.S. Pat. No. 5,234,529) teaches that one end of the cylindrical spiral coil in a conventional helical resonator may be deformed into a planar spiral above the top surface of the plasma reactor tube. U.S. Pat. No. 5,241,245 in the names of Barnes et al. teach the use of conventional helical resonators in which the spiral cylindrical coil is entirely deformed into a planar spiral arrangement with no helical coil component along the sidewalls of the plasma source (this geometry has often been referred to as a "transformer coupled plasma," termed a TCP).

From the above it is seen that an improved technique, including a method and apparatus, for plasma processing is often desired.

SUMMARY OF THE INVENTION

The present invention provides a technique, including a method and apparatus, for fabricating a product using a plasma discharge. The present technique relies upon the control of the instantaneous plasma AC potential to selectively control a variety of plasma characteristics. These characteristics include the amount of neutral species, the amount of charged species, overall plasma potential, the spatial extent and distribution of plasma density, the distribution of electrical current, and others. This technique can be used in applications including chemical dry etching (e.g., stripping, etc.), ion-enhanced etching, plasma immersion ion implantation, chemical vapor deposition and material growth, and others.

In one aspect of the invention, a process for fabricating a product is provided. These products include a varieties of devices (e.g., semiconductor, flat panel displays, micromachined structures, etc.) and materials, e.g., diamonds, raw materials, plastics, etc. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages (e.g., AC plasma voltage) from the inductive coupling structure substantially balances. This process provides for a technique that is substantially free from stray or parasitic capacitive coupling from the plasma source to chamber bodies (e.g., substrate, walls, etc.) at or near ground potential.

In another aspect of the invention, another process for fabricating a product is provided. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure is selectively maintained. This process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential.

A further aspect of the invention provides yet another process for fabricating a product. This process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure is selectively maintained. A further step of selectively applying a voltage between the at least one of the entities in the plasma source and a substrate is provided. This process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential, and provide for a driving voltage between the entities and a substrate.

Another aspect of the invention provides another process for fabricating a product. The process comprises steps of subjecting a substrate to a composition of entities and using the resulting substrate for completion of the product. At least one of the entities emanates from a species generated by a gaseous discharge provided by a plasma applicator, e.g., a helical resonator, inductive coil, transmission line, etc. This plasma applicator has an integral current driven by capacitive coupling of a plasma column to elements with a selected potential greater than a surrounding shield potential substantially equal to capacitive coupling of the plasma column to substantially equal elements with a potential below shield potential.

In a further aspect, the invention provides an apparatus for fabricating a product. The apparatus has an enclosure comprising an outer surface and an inner surface. The enclosure houses a gaseous discharge. The apparatus also includes a plasma applicator (e.g., helical coil, inductive coil, transmission line, etc.) disposed adjacent to the outer surface. A high frequency power source operably coupled to the plasma applicator is included. The high frequency power source provides high frequency to excite the gaseous discharge to provide at least one entity from a high frequency field in which the vector sum of phase and anti-phase capacitive current coupled from the inductive coupling structure is selectively maintained.

In another aspect, the present invention provides an improved plasma discharge apparatus. This plasma discharge apparatus includes a plasma source, a plasma applicator (e.g., inductive coil, transmission line, etc.), and other elements. This plasma applicator provides a de-coupled plasma source. A wave adjustment circuit (e.g., RLC circuit, coil, transmission line, etc.) is operably coupled to the plasma applicator. The wave adjustment circuit can selectively adjust phase and anti-phase potentials of the plasma from an rf power supply. This rf power supply is operably coupled to the wave adjustment circuit.

The present invention achieves these benefits in the context of known process technology. However, a further understanding of the nature and advantages of the present invention may be realized by reference to the latter portions of the specification and attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified diagram of a plasma etching apparatus according to the present invention;

FIGS. **2A–2E** are simplified configurations using wave adjustment circuits according to the present invention;

FIG. **3** is a simplified diagram of a chemical vapor deposition apparatus according to the present invention;

FIG. **4** is a simplified diagram of a stripper according to the present invention;

FIGS. **5A–5C** are more detailed simplified diagrams of a helical resonator according to the present invention;

FIG. **6** is a conventional quarter-wave helical resonator plasma etching apparatus with stray plasma which results from the coupling in the conventional design;

FIG. **7** is a simplified diagram of the rf voltage distribution along the coil of the FIG. **6** apparatus;

FIG. **8** is a simplified top-view diagram of a stripping apparatus according to the present experiments; and

FIG. **9** is a simplified side-view diagram of a stripping apparatus according to the present experiments.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a simplified diagram of a plasma etch apparatus **10** according to the present invention. This etch apparatus is provided with an inductive applicator, e.g., inductive coil. This etch apparatus depicted, however, is merely an illustration, and should not limit the scope of the claims as defined herein. One of ordinary skilled in the art may implement the present invention with other treatment chambers and the like.

The etch apparatus includes a chamber **12**, a feed source **14**, an exhaust **16**, a pedestal **18**, an inductive applicator **20**, a radio frequency (rf) power source **22** to the inductive applicator **20**, wave adjustment circuits **24**, **29** (WACs), a radio frequency power source **35** to the pedestal **18**, a controller **36**, and other elements. Optionally, the etch apparatus includes a gas distributor **17**.

The chamber **12** can be any suitable chamber capable of housing a product **28**, such as a wafer to be etched, and for providing a plasma discharge therein. The chamber can be a domed chamber for providing a uniform plasma distribution over the product **28** to be etched, but the chamber also can be configured in other shapes or geometries, e.g., flat ceiling, truncated pyramid, cylindrical, rectangular, etc. Depending upon the application, the chamber is selected to produce a uniform entity density over the pedestal **18**, providing a high density of entities (i.e., etchant species) for etching uniformity.

The present chamber includes a dome **25** having an interior surface **26** made of quartz or other suitable materials. The exterior surface of the chamber is typically a dielectric material such as a ceramic or the like. Chamber **12** also includes a process kit with a focus ring **32**, a cover (not shown), and other elements. Preferably, the plasma discharge is derived from the inductively coupled plasma source that is a de-coupled plasma source (DPS) or a helical resonator, although other sources can be employed.

The de-coupled source originates from rf power derived from the inductive applicator **20**. Inductively coupled power is derived from the power source **22**. The rf signal frequencies ranging from 800 kHz to 80 MHz can be provided to the inductive applicator **20**. Preferably, the rf signal frequencies range from 5 MHz to 60 MHz. The inductive applicator (e.g., coil, antenna, transmission line, etc.) overlying the chamber ceiling can be made using a variety of shapes and ranges of shapes. For example, the inductive applicator can be a single integral conductive film, a transmission line, or multiple coil windings. The shape of the inductive applicator and its location relative to the chamber are selected to provide a plasma overlying the pedestal to improve etch uniformity.

The plasma discharge (or plasma source) is derived from the inductive applicator **20** operating at selected phase **23** and anti-phase **27** potentials (i.e., voltages) that substantially cancel each other. The controller **36** is operably coupled to the wave adjustment circuits **24**, **29**. In one embodiment, wave adjustment circuits **24**, **29** provide an inductive applicator operating at full-wave multiples **21**. This embodiment of full-wave multiple operation provides for balanced capacitance of phase **23** and anti-phase voltages **27** along the inductive applicator (or coil adjacent to the plasma). This full-wave multiple operation reduces or substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential. Alternatively, the wave adjustment circuits **24**, **29** provide an inductive applicator that is effectively made shorter or longer than a full-wave length multiple by a selected amount, thereby operating at selected phase and anti-phase voltages that are not full-wave multiples. Alternatively, more than two, one or even no wave adjustment circuits can be provided in other embodiments. But in all of these above embodiments, the phase and anti-phase potentials substantially cancel each other, thereby providing substantially no capacitively coupled power from the plasma source to the chamber bodies.

In alternative embodiments, the wave adjustment circuit can be configured to provide selected phase and anti-phase coupled voltages coupled from the inductive applicator to the plasma that do not cancel. This provides a controlled potential between the plasma and the chamber bodies, e.g., the substrate, grounded surfaces, walls, etc. In one embodiment, the wave adjustment circuits can be used to selectively reduce current (i.e., capacitively coupled current) to the plasma. This can occur when certain high potential difference regions of the inductive applicator to the plasma are positioned (or kept) away from the plasma region (or inductor-containing-the-plasma region) by making them go into the wafer adjustment circuit assemblies, which are typically configured outside of the plasma region. In this embodiment, capacitive current is reduced and a selected degree of symmetry between the phase and anti-phase of the coupled voltages is maintained, thereby providing a selected potential or even substantially ground potential. In other embodiments, the wave adjustment circuits can be used to selectively increase current (i.e., capacitively coupled current) to the plasma.

As shown, the wave adjustment circuits are attached (e.g., connected, coupled, etc.) to ends of the inductive applicator. Alternatively, each of these wave adjustment circuits can be attached at an intermediate position away from the inductive application ends. Accordingly, upper and lower tap positions for respective wave adjustment circuits can be adjustable. But both the inductive applicator portions below and above each tap position are active. That is, they both can interact with the plasma discharge.

A sensing apparatus can be used to sense plasma voltage and use automatic tuning of the wave adjustment circuits and any rf matching circuit between the rf generator and the plasma treatment chamber. This sensing apparatus can maintain the average AC potential at zero or a selected value relative to ground or any other reference value. This wave adjustment circuit provides for a selected potential difference between the plasma source and chamber bodies. These chamber bodies may be at a ground potential or a potential supplied by another bias supply, e.g., See FIG. **1** reference numeral **35**. Examples of wave adjustment circuits are described by way of the FIGS. below.

For instance, FIGS. **2**A to **2**E are simplified configurations using the wave adjustment circuits according to the present invention. These simplified configurations should not limit the scope of the claims herein. In an embodiment, these wave adjustment circuits employ substantially equal circuit elements (e.g., inductors, capacitors, transmission line sections, and others) such that the electrical length of the wave adjustment circuits in series with the inductive applicator coupling power to the plasma is substantially an integral multiple of one wavelength. In other embodiments, the circuit elements provide for inductive applicators at other wavelength multiples, e.g., one-sixteenth-wave, one-eighth-wave, quarter-wave, half-wave, three-quarter wave, etc. In these embodiments (e.g., full-wave multiple, half-wave, quarter-wave, etc.), the phase and anti-phase relationship between the plasma potentials substantially cancel each other. In further embodiments, the wave adjustment circuits employ circuit elements that provide plasma applicators with phase and anti-phase potential relationships that do not cancel each other out using a variety of wave length portions.

FIG. **2**A is a simplified illustration of an embodiment **50** using wave adjustment circuits according to the present invention. This embodiment **50** includes a discharge tube **52**, an inductive applicator **55**, an exterior shield **54**, an upper wave adjustment circuit **57**, a lower wave adjustment circuit **59**, an rf power supply **61**, and other elements. The upper wave adjustment circuit **57** is a helical coil transmission line portion **69**, outside of the plasma source region **60**. Lower wave adjustment circuit **59** also is a helical coil transmission line portion **67** outside of the plasma source region **60**. The power supply **61** is attached **65** to this lower helical coil portion **67**, and is grounded **63**. Each of the wave adjustment circuits also are shielded **66**, **68**.

In this embodiment, the wave adjustment circuits are adjusted to provide substantially zero AC voltage at one point on the inductive coil (refer to point 00 in FIG. **2**A). This embodiment also provides substantially equal phase **70** and anti-phase **71** voltage distributions in directions about this point (refer to 00-A and 00-C in FIG. **2**A) and provides substantially equal capacitance coupling to the plasma from physical inductor elements (00-C) and (00-A), carrying the phase and anti-phase potentials. Voltage distributions 00-A and 00-C are combined with C-D and A-B (shown by the phantom lines) would substantially comprise a full-wave voltage distribution in this embodiment where the desired configuration is a selected phase/antiphase portion of a full-wave inductor (or helical resonator) surrounding the plasma source discharge tube.

In this embodiment, it is desirable to reduce or minimize capacitive coupling current from the inductive element to the plasma discharge in the plasma source. Since the capacitive current increases monotonically with the magnitude of the difference of peak phase and anti-phase voltages, which occur at points A and C in FIG. **2**A, this coupling can be lessened by reducing this voltage difference. In FIG. **2**A, for example, it is achieved by way of two wave adjustment circuits **57**, **59**. Coil **55** (or discharge source) is a helical resonator and the wave adjustment circuits **57**, **59** are helical resonators.

The discharge source helical resonator **53** can be constructed using conventional design formulae. Generally, this helical resonator includes an electrical length which is a selected phase portion "x" (A to 00 to C) of a full-wave helical resonator. The helical resonator wave adjustment circuits are each selected to comprise a portion (2-x) of full-wave helical resonators. Physical parameters for the wave adjustment helical resonators can be selected to realize practical physical dimensions and appropriate Q, Z_o, etc values. In particular, some or even all of the transmission line parameters (Q, Z_o, etc.) of the wave adjustment circuit sections may be selected to be substantially the same as the transmission line parameters of the inductive applicator. The portion of the inductive plasma applicator helical resonator, on the other hand, is designed and sized to provide selected uniformity values over substrate dimensions within an economical equipment size and reduced Q.

The wave adjustment circuit provides for external rf power coupling, which can be used to control and match power to the plasma source, as compared to conventional techniques used in helical resonators and the like. In particular, conventional techniques often match to, couple power to, or match to the impedance of the power supply to the helical resonator by varying a tap position along the coil above the grounded position, or selecting a fixed tap position relative to a grounded coil end and matching to the impedance at this position using a conventional matching network, e.g., LC network, network, etc. Varying this tap position along the coil within a plasma source is often cumbersome and generally imposes a difficult mechanical design problems. Using the fixed tap and external matching network also is cumbersome and can cause unanticipated changes in the discharge Q, and therefore influences its operating mode and stability. In the present embodiments, the wave adjustment circuits can be positioned outside of the plasma source (or constrained in space containing the inductive coil, e.g., See FIG. **2**A. Accordingly, the mechanical design (e.g., means for varying tap position, change in the effective rf power coupling point by electrical means, etc.) of the tap position are simplified relative to those conventional techniques.

In the present embodiment, rf power is fed into the lower wave adjustment circuit **59**. Alternatively, rf power can be fed into the upper wave adjustment circuit (not shown). The rf power also can be coupled directly into the inductive plasma coupling applicator (e.g., coil, etc.) in the wave adjustment circuit design, as illustrated by FIG. **2**B. Alternatively, other application will use a single wave adjustment circuit, as illustrated by FIG. **2**C. Power can be coupled into this wave adjustment circuit or by conventional techniques such as a tap in the coil phase. In some embodiments, this tap in the coil phase is positioned above the grounded end. An external impedance matching network may then be operably coupled to the power for satisfactory power transfer efficiency from, for example, a conventional coaxial cable to impedances (current to voltage rations) existing between the wave adjustment circuit terminated end of the applicator.

A further embodiment using multiple inductive plasma applicators also is provided, as shown in FIG. **2**D. This embodiment includes multiple plasma applicators (PA1, PA2 . . . PAn). These plasma applicators respectively provide selected combinations of inductively coupled power and capacitively coupled power from respective voltage potentials (V1, V2 . . . Vn). Each of these plasma applicators derives power from its power source (PS1, PS2 . . . PSn) either directly through an appropriate matching or coupling network or by coupling to a wave adjustment circuit as described. Alternatively, a single power supply using power splitters and impedance matching networks can be coupled to each (or more than two) of the plasma applicators. Alternatively, more than one power supply can be used where at least one power supply is shared among more than one plasma applicator. Each power source is coupled to its respective wave adjustment circuits (WAC**1**, WAC**2** . . . WACn).

Generally, each plasma applicator has an upper wave adjustment circuit (e.g., WAC **1***a*, WAC **2***a* . . . WACna) and a lower wave adjustment circuit (e.g., WAC1*b*, WAC2*b* . . . WACnb). The combination of upper and lower wave adjustment circuits are used to adjust the plasma source potential for each plasma source zone. Alternatively, a single wave adjustment circuit can be used for each plasma applicator. Each wave adjustment circuit can provide substantially the same impedance characteristics, or substantially distinct impedance characteristics. Of course, the particular configuration used will depend upon the application.

For instance, multiple plasma applicators can be used to employ distinct excitation frequencies for selected zones in a variety of applications. These applications include film deposition using plasma enhanced chemical deposition, etching by way of ion enhanced etching or chemical dry etching and others. Plasma cleaning also can be performed by way of the multiple plasma applicators. Specifically, at least one of the plasma applicators will define a cleaning plasma used for cleaning purposes. In one embodiment, this cleaning plasma can have an oxygen containing species. This cleaning plasma is defined by using an oxygen discharge, which is sustained by microwave power to a cavity or resonant microwave chamber abutting or surrounding a conventional dielectric vessel. Of course, a variety of other processes also can be performed by way of this multiple plasma applicator embodiment.

This present application using multiple plasma applicators can provide a multi-zone (or multi-chamber) plasma source without the use of conventional mechanical separation means (e.g., baffles, separate process chambers, etc.). Alternatively, the degree of interaction between adjacent zones or chambers can be relaxed owing to the use of voltage potential control via wave adjustment circuits. This plasma source provides for multiple plasma source chambers, each with its own control via its own plasma applicator. Accordingly, each plasma applicator provides a physical zone region (i.e., plasma source) with selected plasma characteristics (e.g., capacitively coupled current, inductively coupled current, etc.). These zones can be used alone or can be combined with other zones. Of course, the particular configuration will depend upon the application.

In the present embodiments, the wave adjustment circuit can be made from any suitable combination of element(s) such as various types of transmission lines, circuits, etc. These transmission lines include conventional solid or air dielectric coaxial cable, or ordinary, repeating inductor/capacitor discrete approximations to transmission lines, and others. These types of transmission lines are co-axial transmission lines, balanced parallel transmission lines, so called slow wave transmission lines with a spiral inner conductor (e.g., selected portions of a helical resonator, etc.), and others. Individual lumped, fixed, or adjustable combinations of resistors, capacitors, and inductors (e.g., matching networks, etc.) also can be used in place of transmission line sections for the wave adjustment circuit. These general types of wave adjustment circuits are frequency dependent, and can be termed frequency dependent wave adjustment circuits (or FDWACs).

Frequency independent elements also can be used as the wave adjustment circuits. These wave adjustment circuits can be termed frequency independent WACs (or FIWACs). Frequency independent wave adjustment circuits include degenerate cases such as short-circuit connections to ground or an infinite impedance (i.e., open circuit), and others. Frequency independent wave adjustment circuits can be used alone, or in combination with the frequency dependent wave adjustment circuits. Alternatively, the frequency dependent wave adjustment circuits can be used alone or in combination with other wave adjustment circuits. Other variations, alternative constructions, and modifications also may be possible depending upon the application.

With regard to operation of the wave adjustment circuits, various embodiments can be used, as illustrated by FIG. **2**E. The wave adjustment circuits are used to select a wave length portion to be applied in the plasma applicator. In some embodiments, the average rf plasma potential is maintained close to ground potential by providing substantially equal phase **90**, **81** and anti-phase **91**, **82** capacitively coupled portions of the inductive applicator. This can occur in multi-wave embodiments **92**, full-wave embodiments **93**, half-wave multiple embodiments, quarter-wave multiple embodiments, or any other embodiments **94**.

In alternative embodiments, it is desirable to maintain an elevated source plasma voltage relative to ground potential to induce a controlled ion plasma flux (or ion bombardment) to the product substrate (or any other chamber bodies). These embodiments are provided by selecting distinct electrical lengths for each of the wave adjustment circuit sections such that the capacitive coupled current from a phase section of the inductive plasma applicator is in excess of capacitive coupled current from its anti-phase portion. In these embodiments, the wave adjustment circuit provides a deliberate imbalance between the phase and anti-phase of the coupled voltages. In some embodiments **97**, this occurs by shifting the zero voltage nodes along the process chamber axially, thereby achieving a bias relative to the plasma discharge. As shown, the phase **95** is imbalanced relative to its anti-phase **96**. In other embodiments **99**, one phase portion **84** is imbalanced by way of a different period relative to its complementary phase portion **85**. Other embodiments are provided where the source plasma voltage is lower relative to ground potential. In the embodiments were imbalance is desirable, the potential difference between the phase and anti-phase potential portions is reduced (or minimized) when the amount of sputtering (e.g., wall sputtering, etc.) is reduced. The amount of sputtering, however, can be increased (or maximized) by increasing the potential difference between the phase and anti-phase potential portions. Sputtering is desirable in, for example, sputtering a quartz target, cleaning applications, and others. Of course, the type of operation used will depend upon the application.

Current maxima on an inductive applicator with distributed capacitance (e.g., helical resonator transmission line, etc.) occur at voltage minima. In particular, conventional quarter-wave helical resonator current is substantially at a relative maximum at its grounded end of the coil, and to a lesser extend in the nearby coil elements. Therefore, partial inductive coupling of power, if it occurs, will tend to be at this grounded end. In conventional half-wave helical resonators, inductive coupling tends to occur at each of the two grounded ends.

In the present invention, substantially anti-symmetric phase and anti-phase inductive half-wave and other fractional wave applicator sections support substantially more inductive coupling at a selected rf voltage node, e.g., FIG. **2**A reference numeral **00**. This effect is caused by high current flow in the inductor applicator zones (or sections) both directly above and below the node (corresponding to inductor elements in the phase and anti-phase sections at and immediately adjacent to the rf voltage zero point). It should be noted that conventional quarter and half-wave inductively coupled inductive applicators have inductive coupling which abruptly declines below the grounded coil locations because the coil terminates and voltage extrema are present at these locations. This generally produces conventional quarter and half-wave helical resonators that tend to operate in a capacitive mode, or with a substantial fraction of power which is capacitively coupled to the plasma, unless the plasma is shielded from coil voltages, as noted above.

In a specific embodiment, the power system includes selected circuit elements for effective operation. The power system includes an rf power source. This rf power source can be any suitable rf generator capable of providing a selected or continuously variable frequency in a range from about 800 kHz to about 80 MHz. Many generators are useful. Preferably, generators capable of operating into short and open-circuit loads without damage are used for industrial applications. One example of a suitable generator is a fixed frequency rf generator 28.12 MHz–3 kW CX-3000 power supply made by Comdel, Inc. of Beverly, Mass. A suitable variable frequency power supply arrangement capable of the 3 kW output over an 800 kHz to 50 MHz range can be made by driving an IFI Model TCCX3500 High

Power Wide Band Amplifier with a Hewlett Packard HP116A, 0–50 MHz Pulse/Function Generator. Other generators including those capable of higher or lower power also can be used depending upon the application.

Power from the generator can be transmitted to the plasma source by conventional coaxial cable transmission line. An example of this transmission line is RG8/U and other higher temperature rated cable (e.g., RG1151U, etc.) with a coaxial TEFLON dielectric. In some embodiments, power is fed to conventional end-grounded half-wave helical resonators by positioning a movable tap on the helical coil and connecting a power source between the tap and the ground. In other embodiments, matching networks can be introduced between the coaxial cable power feed and the helical coil tap for flexibility. The matching network will depend on the selected wave configuration and wave adjustment circuits. In a balanced half-wave helical resonator embodiment, for example, the ends of the resonator coil can be terminated with wave adjustment circuits which substantially have zero susceptance. In particular, the wave adjustment circuit is designed as an open circuit by making no electrical connections to the ends of the coil, or establishing an electrical equivalence thereof. Alternatively, the ends of the coil are isolated by chokes series resistance, thereby DC coupled to a fixed reference potential. These types of wave adjustment circuits are frequency independent and are "degenerate" cases. In these embodiments, the rf power is provided such that the phase and anti-phase current flows above and below the electrical midpoint of the coil. This provides for substantially balanced phase and anti-phase current flow from the power source stabilizing desired operation in coil voltages above the midpoint of the coil, and also provides substantially equal phase and anti-phase voltages.

The embodiments described above also can be applied to other plasma processing applications, e.g., PECVD, plasma immersion ion implantation (PIII), stripping, sputtering, etc. For instance, FIG. **3** is a simplified CVD apparatus **100** according to the present invention. The present CVD apparatus includes a chamber **112**, a feed source **114**, an exhaust **116**, a pedestal **118**, a power source **122**, a ground **124**, a helical resonator **126**, and other elements. The helical resonator **126** has a coil **132**, an outer shield **133**, and other elements. The chamber can be any suitable chamber capable of housing a product **119** such as a wafer for deposition, and for providing a plasma discharge therein. Preferably, the chamber is a right circular cylinder chamber for providing an uniform plasma species distribution over the product. But the chamber can also be configured in the form of rectangular right cylinder, a truncated cone, and the like. The chamber and fixtures are constructed from aluminum and quartz, and other suitable materials. The plasma discharge is derived from a plasma source which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phase-anti-phase potentials. The present CVD apparatus provides for deposition of a dielectric material, e.g., silicon dioxide or the like.

The product **119** having an upper surface **130** is placed into the present CVD apparatus for deposition, e.g., plasma enhanced chemical vapor deposition (PECVD), and others. Examples of deposition materials include a dielectric material such as a silicon dioxide (SiO_2), a phosphosilicate glass (PSG), a borophosphosilicate glass (BPSG), a silicon nitride (Si_3N_4), among others.

In one embodiment, the deposition occurs by introducing a mixture comprising organic silane, oxygen, and an inert gas such as helium or argon according to the present invention. The organic silane can be any suitable organic silicate material such TEOS, HMDS, OMCTS, and the like. Deposition is also conformal in selected instances. As for the oxygen, it includes a flow rate of about 1 liter/per minute and less. A relative flow rate between the organic silane such as TEOS and oxygen ranges from about 1:40 to about 2:1, and is preferably less than about 1:2 in certain applications. A deposition temperature of the organic silane-oxygen layer ranges from about 300 to about 500° C., and can also be at other temperatures. Pressures in the range of 1 to 7 Torr are generally used. Of course, other concentrations, temperatures, materials, and flow rates can be used depending upon the particular application.

This chamber also includes a wave adjustment circuit **127**. The wave adjustment circuit **127** is used to provide a helical coil operating with capacitive coupling to selected phase and anti-phase voltages. This portion **127** of the wave adjustment circuit coil also is shielded **140** to prevent rf from interfering with the plasma discharge or external elements, e.g., equipment, power, etc. The coil shield **140** is made of a conductive material such as copper, aluminum, or the like. In one embodiment, an operating frequency is selected and the wave adjustment circuit is dadjusted to short circuit the upper end of the helical applicator coil to ground **124**. This provides a helical coil operating at approximately a full-wave multiple and has substantially equal phase and anti-phase sections. This full-wave multiple operation provides for balanced capacitance of phase **151** and anti-phase **153** voltages along the coil **132** adjacent to the plasma source. Full-wave multiple operation reduces or even substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential.

In the present embodiment, the wave adjustment circuit **127** is a variable coil portion **128** of a spiral transmission line, which is selectively placed outside the outer shield **133**. Accordingly, when the wave adjustment circuit is adjusted to become a short circuit, the plasma source "sees" only a selected full-wave multiple comprising substantially equal phase **151** and anti-phase **153** of the entire instantaneous AC voltages **134**, **135**. In this embodiment, stress of the deposited oxide film is often tensile, which can be undesirable.

Alternatively, the wave adjustment circuit **127** provides a helical resonator operating at selected phase and anti-phase voltages that are not full-wave multiples. This wave adjustment circuit provides for a selected amount of capacitive coupling from the plasma source to the chamber bodies. Stress of the deposited oxide film in this embodiment can be made to be zero or slightly compressive. In some embodiments, the oxide films can be deposed with an rf plasma potential of several hundred volts between the plasma source and the substrate to decrease the tendency of the oxide film to absorb moisture. This can occur by adjusting the wave adjustment circuit to add in a small section of transmission line outside of the source and correspondingly shortening the applicator coil (by moving the lower point at which the applicator coil is short-circuited and thereby decreasing the inductance of the applicator coil and electrical length of the helical resonator **126** (e.g., spiral transmission line, etc.)). Of course, the selected amount of capacitive coupling will depend upon the application.

FIG. **4** is a simplified diagram of a resist stripper according to the present invention. The present stripping apparatus includes similar elements as the previous described CVD apparatus. The present stripping apparatus includes a chamber **112**, a feed source **114**, an exhaust **116**, a pedestal **118**, an rf power source **122**, a ground **124**, a helical resonator **126**, and other elements. The helical resonator **126** includes a coil **132**, an outer shield **133**, a wave adjustment circuit **400**, and other elements. The chamber can be any suitable chamber capable of housing a product **119** such as a photoresist coated wafer for stripping, and for providing a plasma discharge therein. The plasma discharge is derived from a plasma source, which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phaseanti-phase potentials. The present stripping apparatus provides for stripping or ashing photoresist, e.g., implant hardened, etc. Further examples of such a stripping apparatus are described in the experiments section below.

In this embodiment, the wave adjustment circuits rely upon open circuits (i.e., zero susceptance). Power transfer can be occurred with a balanced feed such as an inductively-coupled push-pull arrangement such as coupled inductors. Techniques for constructing these coupled inductors are described in, for example, "The ARRL Antenna Book," R. D. Straw, Editor, The American Radio Delay League, Newington, Conn. (1994) and "The Radio Handbook," W. I. Orr, Editor, Engineering Ltd, Indiana (1962), which are both hereby incorporated by reference for all purposes. In one embodiment, a ferrite or powdered iron core "balun" (balanced-unbalanced) toroidal transformer (i.e., broadband transmission transformer, broadband transformer, etc.) **401** can be used to provide balanced matching from a conventional unbalanced coaxial transmission line. Techniques for constructing toroidal baluns are described in, for example, "Transmission Line Transformers," J. Sevick, 2nd Edition, American Radio Relay League, Newington, Conn. (1990). The toroidal transformer is coupled between the rf power source **122** and the coil **132**. The midpoint **406** between the phase **405** and anti-phase voltage on the coil is effectively rf grounded, hence it may be convenient to directly ground this midpoint of the inductive application in some embodiments for stability. This permits alternate operation in which power may be coupled into the inductive applicator (e.g., coil, etc.) with a conventional unbalanced feed line tapped on one side of the center. Push-pull balanced coupling ignites the plasma more easily than conventional unbalanced coil tap matching and generally is easier to adjust in selected applications.

Referring to the helical resonator embodiments operating at substantially equal phase and anti-phase potentials, FIG. **5**A is a simplified diagram **200** of an equivalent circuit diagram of some of them. The diagram is merely an illustration and should not limit the scope of the claims herein. The equivalent circuit diagram includes a plurality of rf power supplies (V_1, V_2, V_3 . . . V_n) **203**, representing for example, a single rf power source. These power supplies are connected in parallel to each other. One end of the power supply is operably coupled to a ground connection **201**. The other end of the power supplies can be represented as being connected to a respective capacitor (C_1, C_2, C_3 . . . C_n). Each of these capacitors are connected in parallel to each other. During this mode of operation, substantially no voltage difference exists between any of these capacitors, as they are all connected to each other in parallel.

FIG. **5**B is a simplified diagram of instantaneous AC voltage and current along a helical resonator coil of FIG. **5**A where each end of the inductive applicator is short circuited. The diagram is merely an illustration and should not limit the scope of the claims herein. This diagram includes the discharge tube **213** and an inductive plasma discharge (or plasma source) **501** therein. As shown, the plasma discharge includes an intensified "donut-shaped" glow region **501** that occupies a limited range (R) of the discharge tube **213**. The plasma discharge has an average voltage potential (V_{ave}) of substantially zero volt between the ground potential (V_G) and the high voltage potential (V_H). As can be seen, the plasma discharge **501** has capacitively coupling elements to V_H and V_G. But the average voltage potential of this plasma discharge is zero. This operation provides for balanced capacitance of phase **503** and anti-phase **505** voltages along the coil adjacent to the plasma, thereby substantially preventing capacitively coupling from the plasma source to chamber bodies. As also shown, a current maxima **507** exists at V_{ave}, which corresponds to an inflection point between the phase **503** and the anti-phase **505**.

In an alternative operating mode, dim rings of plasma caused by inductively coupled plasma current are visible near top and bottom extremes of the inductive application, as illustrated by FIG. **5**C. This operating mode is generally for a full-wave **517** inductive coupling coil operated at a very high power, e.g., maximum power input to the inductive applicator is often limited by thermal considerations and breakdown. The rings **513**, **515** of current in the plasma discharge are simulated by maximum coil current areas corresponding to voltage minima at the top and bottom shorted ends of the coil. Under these high power conditions, subordinate current rings are detectable and some excitation is often visible in the intermediate regions. This excitation is partially caused by capacitively driven currents within the discharge coupled to the voltage maximum and voltage minimum positions along the inductive applicator.

Alternatively, subordinate inductive plasma current rings at the top and bottom ends **513** of the resonator do not appear with limited input power. The coil current and inductive flux fall beyond the ends of the inductive applicator so that a single inductive ring **515** in the center portion is more stable, provided that the conductivity of the plasma is large enough to support a single current ring at a specified input power.

In alternative applications using high power operation, no secondary plasma current rings may be desirable. These applications often have substantially minimum internal capacitive coupling. In these applications, the inductive applicator (e.g., coil) abutting the vacuum vessel may be shortened from a full wave to an appropriate length such that only the central current maxima exists on the coil abutting the plasma source and the potential difference between maximum and minimum voltage on the applicator is substantially reduced. The present application is achieved by stabilizing the desired waveform along the applicator by appropriate impedance wave adjustment circuits.

Referring to the above embodiments, the present invention provides for processing with an inductively coupled plasma in which the plasma potential from coupling to a phase portion of the inductive applicator is substantially not offset by capacitive coupling to anti-phase voltages on selective portions to the inductive coupling element. Conventional inductive sources (e.g., conventional helical resonators, etc.), however, have hitherto been operated in quarter-wave or half-wave modes. These modes provide only phase capacitive coupling to the plasma, which raises the plasma potential toward the coil without compensation anti-phase coupling. Conventional inductive sources that are longer than a half-wave have been generally considered cumbersome and impractical for plasma reactors. In particular, these inductive sources are large in size, and have nodes along the helical coil, which have been believed to create a non-uniform plasma. In order to operate a substantially inductive plasma in a helical resonator, conventional inductive sources relied upon shielding the plasma tube from electrical fields originating on the coil. Shielding occurred, for example, by inserting a longitudinally split shield between the coil and plasma tube.

The present invention provides for a substantially pure inductively coupled power source. A benefit of this inductively coupled power as a primary means to sustain plasma excitation is that electric field lines produced by inductive coupling are solenoidal (e.g. they close on themselves). Since solenoidal electric field lines have zero divergence, they do not create or support a scalar potential field (e.g. a voltage difference) within the plasma volume. Thus, in an ideal case, inductively coupled power can be transferred into a plasma without no direct relationship between the plasma potential and the voltages on coupling elements (e.g. the voltage on the coil in a helical resonator) or voltages on rf matching networks, if such are used. Furthermore, when transferring power to the plasma by purely inductive means, power transfer does not require any significant potential difference to be maintained between elements of the plasma and ground potential (e.g. the potential difference between the plasma and ground can be fixed by factors which are substantially independent of inductive excitation power). Although in theory, inductive power transfer does not require raising the AC or DC potential of the plasma with respect to ground, in practice there has been substantial shift and harmful alteration in the plasma potential found in unshielded current art inductive sources.

As previously noted, and further emphasized herein, the most effective conventional method employed to avoid plasma potential shift in conventional commercially available inductive sources is to shield the plasma from the electrical fields on the inductive coupling element (commonly a multi-turn coil) by inserting a grounded conductive member between the inductive driving element and the plasma discharge tube. Shielding is, however, cumbersome and inconvenient and has serious disadvantages in practice. Shields couple to inductive applicator elements and can cause wide excursions in the natural resonance frequency, which are not predicted by conventional design formulae. This often results in laborious trail and error and iterative mechanical designs to achieve a desired resonance. Another disadvantage of shielding is that shields often make it difficult to achieve initial ignition of the plasma since shields generally exclude capacitive electric fields in the plasma discharge tube. In particular, ignition (known as plasma breakdown) of inductive breakdown generally begins with a capacitive electric field discharge, which is stable at lower currents and powers (S, for example, J. Amorim, H. S. Maciel and J. P. Sudana, J. Vac. Sci. Technol. B9, pp. 362–365, 1991). Accordingly, shields tend to block capacitive electric fields, which induce plasma ignition.

Insertion of the shield close to high voltage RF point in a network (such as the voltage maximum points in a helical resonator or the high potential driven side of a TCP coil) also causes large displacement currents to flow through the capacitance between the shield and coil. This high potential difference is also a potential cause of damaging rf breakdown across the air gap, hence the gap may require protection by inconvenient solid or liquid dielectric insulation. The displacement current flow causes power loss and requires that higher power RF generating equipment be used to compensate for the power loss. Coupling loss in the plasma source structure is also undesirable from the standpoint of thermal control. These limitations are overcome by the present invention using the wave adjustment circuits, an inductive applicator of selected phase length, and other elements.

Experiments

To prove the principle and demonstrate the operation of the present invention, a helical resonator plasma source was used in a photoresist stripper. Conventional helical resonators also were evaluated in these experiments. These experiments are merely examples, and should not limit the scope of the claims herein. One of ordinary skill in the art would easily recognize other experiments, uses, variations, and modifications of the inventions defined by these claims.

I. Conventional Photoresist Stripper

In this experiment, the conventional resist stripper was a prototype made by MC Electronics, present assignee. Of course, other stripper platforms also can be used depending upon the application. A conventional quarter-wave helical resonator resist stripper **600** was constructed with a quarter-wave helical resonator source **602** upstream of a processing chamber **604**, shown in FIG. **6**. This quarter-wave helical resonator **602** included a coil **608** and other elements.

Coil **608** consisted of 5.15 turns of 0.4 inch diameter copper tubing would with a pitch of 0.5 turns per inch with a mean radius of 6.4 inches and centered radially and vertically inside an outer copper shield **610**. Coil **608** is operably coupled to a power source **612** and operated at about 13 MHz radio frequency. A 17 inch long, 9.25 inch diameter quartz tube **606** was centered inside of the copper coil **608**. The shield **610** was 16 inches inside diameter, approximately 0.08 inches thick and 18 inches long. This shield **610** also was connected to a ground (V_G) connection on the aluminum process chamber body (except when making the current measurements described below).

The process chamber **604** was for a conventional resist stripper. This resist stripper included a wafer support **616** (or pedestal) and other elements. Process chamber **604** is operably coupled at an outer location **620** to ground via shield **610**. Wafer support **616** has a wafer **618** disposed thereon.

The wafer **618** is a 6-inch (250 mm) <100> type wafer with approximately 1.25 microns of spin-coated Mitsubishi Kasei positive photoresist MPR-4000. This wafer was ashed on the grounded 10 inch diameter wafer support **616**. This support was resistivity heated and the temperature of the substrate support was sensed with a thermocouple.

After the helical resonator plasma was ignited, visible plasma filled the quartz plasma tube under all of the conditions used for processing. In addition, a strong plasma glow was always visible above the wafer in the downstream processing chamber which was indicative of secondary plasma discharge to the substrate support. This secondary plasma discharge was also accompanied by current flow from the resonator shield to the chamber of approximately 5–10 Amperes rms (and sometimes even more) which could be measured by elevating the shield on insulating blocks and monitoring the current flow through a 2 inch long 1.5 inch wide strip of copper braid which was passed through a Pearson Current probe used to monitor the current.

FIG. **7** is a simplified diagram **700** of the rf voltage distribution along the coil for the quarter-wave helical resonator of FIG. **6**. This diagram includes the quartz tube **606** and a plasma discharge (or source) **701** therein. As shown, the plasma discharge includes a glow region that **701** occupies a large range (R) of the quartz tube **606**. The plasma discharge has an average voltage potential (V_{ave}) between the ground potential (V_G) and the high voltage potential (V_H). As can be seen, the plasma discharge **701** has capacitively coupling elements to V_H and V_G due to its average voltage potential V_{ave}. In fact, as previously noted, the current flow from the resonator shield to the chamber was at least 5–10 Amperes rms. In high power applications, intense sparking was observed in the chamber from the capacitively coupled plasma source.

II. Present Photoresist Stripper

To prove the principle and operation of the present inventions, experiments were performed. These experiments used a photoresist stripper apparatus. This resist stripper apparatus in a cluster tool arrangement used a helical resonator according to the present inventions. One of ordinary skill in the art, however, would recognize that other implementations, modifications, and variations may be used. Accordingly, the experiments performed herein are not intended to limit the scope of the claims below.

The photoresist stripper apparatus was configured with multiple process chambers in a cluster tool arrangement, as illustrated by FIGS. **8** and **9**. FIGS. **8** and **9** illustrate a simplified top-view diagram **800** and a simplified side-view diagram, respectively. Two process chambers, e.g., chamber **1 901** and chamber **2 903**, were used. Chamber **1 901** was used for stripping implant hardened resist crust (or skin). Chamber **2 903** was used for stripping the remaining photoresist. Alternatively, the chambers can be both used for stripping implant hardened resist crust and stripping remaining photoresist. Of course, the particular use depends upon the application. These chambers also were made of aluminum with ceramic inserts, which is highly resistant to chemical attack.

The apparatus also used a microprocessor based controller to oversee process operations. This microprocessor based controller can be accessed through a control panel **921**. The present apparatus used a controller made from a 486DX processor PC made by EPSON, with a color LCD touch panel display. This controller also is shielded and highly resistant to chemical attack.

An automatic wafer handling system **910** was also provided. The automatic wafer handling system used standard cassettes **912** for transferring the photoresist coated wafers to and from the process chambers **901, 903**. The automatic wafer handling system included a robot **917**, cassette chamber **1 905**, cassette chamber **2 907**, cassette stage **1 909**, cassette stage **2 911**, and other elements. The wafer handling system **910** used a conventional interlock system for providing the cassettes **912** from the cleanroom into the process chambers **901, 903**. A main shuttle chamber **913** housed the robot **917** in the cluster tool arrangement. The controller oversees the automatic wafer handling system operations. The present wafer handing system is made by JEL Co., LTD of Japan.

A cooling plate **915** was included in the main chamber **913** housing the robot **917**. The cooling plate **915** was of conventional design, and was capable of cooling the wafer after being stripped, which often occurs at elevated temperatures. Alternatively, the cooling plate can be used to thermally adjust the wafer temperature either before, after, or even between selected process operations.

The process chambers **901, 903** were disposed downstream from respective plasma sources **923, 925**. Each helical resonator included a coil **927** disposed around a quartz tube **929**. The coil consisted of 11.5 turns of 0.4 inch copper tubing wound with a pitch of 0.9 turns per inch with a mean radius of 9.4 inches and centered radially and vertically inside an outer copper shield **931**. The coil is operably coupled to a power source (not shown). A 17 inch long, 9.25 inch diameter quartz tube was centered inside of the copper coil. The shield was 16 inches inside diameter, approximately 0.08 inches thick and 18 inches long. The shield is operably coupled to a lower portion of the coil.

In one experiment, processes were used for stripping photoresist from wafers, e.g., See FIG. **9** reference numeral

933. The processes involved the use of a multi-step stripping operation to remove implanted photoresist from semiconductor wafers. Samples were prepared using eight-inch wafers. These wafers were spin coated with Mitsubishi Kasei positive photoresist MPR-4000. Spin coating occurred at 1,200 rpm and 120° C. for 90 seconds. The resulting photoresist was about 1.2 microns in thickness in the sample wafers. These sample wafers were implanted to form a implanted hardened resist layer near the top of the photoresist.

An implant resist stripping process was performed to remove the top implant hardened resist. This occurred by stripping using an “un-balanced” phase and anti-phase coupling relationship in a half-wave helical resonator. The half-wave helical resonator was configured in one of the process chambers. In this chamber, the pedestal had a temperature of about 40° C. to maintain a low wafer temperature. This low wafer temperature was maintained to reduce the possibility of “popping.” Popping occurs when vapor in the underlying photoresist explodes through the implant hardened resist.

After the top hardened layer was removed. The wafer was transferred into a chamber operating at a full-wave multiple. This chamber operated at a frequency of about 27.12 MHz at a full-wave multiple. The pedestal of this chamber was at 150 to 200° C. The full wave structure provided for balanced phase and anti-phase coupled currents, thereby reducing the amount of capacitively coupled plasma, which can be detrimental to the underlying substrate. In this step, overashing was performed to substantially remove all photoresist material from the wafer. No damage occurred to the underlying substrate during this overashing step.

Once the photoresist has been stripped, the wafer is cooled. In particular, the wafer is removed from the full-wave multiple process chamber, and placed on the cooling station. This cooling station reduces the temperature of the wafer (which was heated). This wafer is then reloaded back into its wafer cassette. Once all wafers have been processed in the cassette, the cassette comprising the stripped wafers is removed from the cluster tool apparatus. Characteristics of this half-wave helical resonator were described in detail above. In the present experiments, the following tests also were performed.

Test 1: 6-inch wafers were ashed at a total pressure of 0.13 Torr using a gas flow of 0.2 standard liter per minute of pure oxygen, forward rf power of 2200 watts and a reflected power of 150 watts at an excitation frequency of 13.4 Mhz. The substrate was held at 60° C. and wafers were ashed and then the discharge was extinguished). The ashing rate across the wafer was determined to vary between approximately 3411 Å/min and 3139 Å/min with the rates approximately symmetric about the center of each wafer and the maximum ashing rate at the center. The average etching rate was 3228 Å/min and etching uniformity was approximately 4 percent.

Test 2: 6-inch wafers were ashed at a total pressure of 1 Torr using a gas flow of 1 standard liter per minute, forward rf power of 2200 watts and a reflected power of 160 watts at an excitation frequency of 13.0 MHz. The substrate was held at 60° C. and the ashing rate was determined to very between approximately 3144 Å/min and 3748 Å/min depending on position on a wafer. The etching uniformity was approximately 9 percent.

Test 3: Resist coated wafers were implanted with a selected dose of 5×10^{15} atoms/cm^2 at 40 kev arsenic (As). The wafers were cleaved into samples approximately 3 centimeters square. Two samples were then ashed on the substrate support simultaneously, under the various conditions listed in Table 1.

TABLE 1

Experimental Results for Ashing

Run	Time(s) (sec.)	Pressure (Torr.)	O_2 Flow (slm)*	Fwd Pwr (W)	Refl. Pwr (W)	rf freq. (MHz)	Temp (C.)
A	180	0.23	0.5	2,000	180	13.2	68
B	132	0.06	0.2	2,150	180	13.3	90
C	180	0.13	0.2	2,200	150	13.3	60
D	300	0.13	0.2	2,200	150	13.3	40
E(I)	90	0.09	0.1	2,200	80	13.4	40
F(II)	150	0.09	0.1	2,200	80	13.4	40

*slm = standard liters per minute (or 1000 sccm)

(I) Unimplanted resist was used in this test and ashing was terminated before endpoint was reached to test unifomrity. The average ashing rate was 5259 Å/min and uniformity was 7.5%.

(II) Implanted resist was etched for 150 sec, but endpoint was visible at 100 seconds.

Under conditions used for Run D, it was determined that resist was cleared from the entire wafer after 3 minute and 15 seconds. Consequently, the ashing time in the table included approximately 100 sec. overetching. Under conditions where practical ashing rates were attained, a visible plasma discharge and sheath could be observed over the wafer.

Diagnostic measurements of current similar to those performed in the conventional stripping apparatus were performed. In these measurements, currents from the shield of the resonator to the processing chamber gave values of at about 0.1 to 0.5 Amperes rms and less. These measurements were limited by error using available instrumentation. Accordingly, these currents were at least an order of magnitude below those currents measured above in the conventional stripping apparatus.

A visual inspection of the stripped wafers shows extremely good results. That is, the wafers were stripped at a sufficient rate for production operation and no substantial damaged occurred to the wafers. This provides for effective wafer tum-around-time and substantially no damage caused by the plasma. In addition, current measured from the shield to the chamber by elevating the shield on insulating blocks was less than about 0.5 Amperes rms and, in some instances, at or below measured error using available instrumentation. This current was substantially less than those measured in the conventional stripping apparatus.

While the invention has been described with reference to specific embodiments, various alternatives, modifications, and equivalents may be used. In fact, the invention also can be applied to almost any type of plasma discharge apparatus. This discharge apparatus can include an apparatus for plasma immersion ion implantation or growing diamonds, TCPs, and others. This discharge apparatus can be used for the manufacture of flat panel displays, disks, integrated circuits, diamonds, semiconductor materials, bearings, raw materials, and the like. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

What is claimed is:

1. A process for fabricating a product using a plasma source, said process comprising the steps of subjecting a substrate to entities, at least one of said entities emanating from a gaseous discharge excited by a high frequency field from an inductive coupling structure in which a phase portion and an anti-phase portion of capacitive currents coupled from the inductive coupling structure are selectively balanced;

wherein said inductive coupling structure is adjusted using a wave adjustment circuit, said wave adjustment circuit adjusting the phase portion and the anti-phase portion of the capacitively coupled currents.

2. The process of claim **1** wherein the wave adjustment circuit selectively adjusts a frequency of an rf power supply.

3. The process of claim **1** wherein the high frequency field is adjusted using a variable frequency power supply.

4. The process of claim **1** wherein the wave adjustment circuit comprises a transmission line.

5. The process of claim **1** wherein said process is provided in a chamber.

6. The process of claim **5** wherein the chamber is provided for a process selected from etching, deposition, sputtering, or implantation.

7. The process of claim **1** wherein said inductive coupling structure provides a wave multiple selected from a one-sixteenth wave, a one-eighth-wave, a quarter-wave, a half-wave, a three-quarter wave, and a full-wave.

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A/NO fee

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APPLICATION TRANSMITTAL

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 94111-3834
(415) 326-2400

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PATENT APPLICATION
ASSISTANT COMMISSIONER FOR PATENTS
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By

Sir:
Transmitted herewith for filing is the [ ] patent application, [ ] design patent application, [X] continuation-in-part patent application of

Inventor(s): Daniel L. Flamm

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

[X] This application claims priority from each of the following Application Nos./filing dates:
08/567,224 / December 4, 1995 ; 08/736,315 / October 23, 1996 ; ______ / ______

[ ] Please amend this application by adding the following before the first sentence: --This application claims the benefit of U.S. Provisional Application No. 60/______, filed ________, the disclosure of which is incorporated by reference.--

Enclosed are:
[X] Patent Application (incl. 36 pages spec., 1 pages claims, 1 page abstract).
[X] 13 sheet(s) of [ ] formal [X] informal drawing(s).
[ ] An assignment of the invention to ________________.
[ ] A [ ] signed [ ] unsigned Declaration & Power of Attorney.
[ ] A verified statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27 [ ] is enclosed [ ] was filed in the earliest of the above-identified patent application(s).
[ ] A certified copy of a ________________ application.
[ ] Information Disclosure Statement under 37 CFR 1.97.
[ ] A petition to extend time to respond in the parent application of this continuation-in-part application.
[X] Postcard.

Pursuant to 37 CFR 1.53, Applicant requests deferral of the filing fee until submission of the Missing Parts of Application.

Respectfully submitted,
TOWNSEND and TOWNSEND and CREW LLP

Richard T. Ogawa
Reg. No.: 37,692
Attorneys for Applicant

Telephone:
(415) 326-2400

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PATENT APPLICATION

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Inventor:

Daniel L. Flamm, a citizen of the United States, residing at 476 Green View Drive, Walnut Creek, California 94596;

Entity Status:

Small

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 94111-3834
(415) 326-2400

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a continuation-in-part of Application Serial No. 08/736,315 filed October 23, 1996, now abandoned, which is a continuation of Application Serial No. 08/567,224 filed December 4, 1995, now abandoned. All of these documents are hereby incorporated by reference for all purposes.

BACKGROUND OF THE INVENTION

This invention relates generally to plasma processing. More particularly, the invention is for plasma processing of devices using an inductive discharge. This invention is illustrated in an example with regard to plasma etching and resist stripping of semiconductor devices. The invention also is illustrated with regard to chemical vapor deposition (CVD) of semiconductor devices. But it will be recognized that the invention has a wider range of applicability. Merely by way of example, the invention also can be applied in other plasma etching applications, and deposition of materials such as silicon, silicon dioxide, silicon nitride, polysilicon, among others.

Plasma processing techniques can occur in a variety of semiconductor manufacturing processes. Examples of plasma processing techniques occur in chemical dry etching (CDE), ion-assisted etching (IAE), and plasma enhanced chemical vapor deposition (PECVD), including remote plasma deposition (RPCVD) and ion-assisted plasma enhanced chemical vapor deposition (IAPECVD). These plasma processing techniques often rely upon radio frequency power (rf) supplied to an inductive coil for providing power to gas phase species in forming a plasma.

Plasmas can be used to form neutral species (i.e., uncharged) for purposes of removing or forming films in the manufacture of integrated circuit devices. For instance, chemical dry etching generally depends on gas-surface reactions involving these neutral species without substantial ion bombardment.

In other manufacturing processes, ion bombardment to substrate

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surfaces is often undesirable. This ion bombardment, however, is known to have harmful effects on properties of material layers in devices and excessive ion bombardment flux and energy can lead to intermixing of materials in adjacent device layers, breaking down oxide and "wear out," injecting of contaminative material formed in the processing environment into substrate material layers, harmful changes in substrate morphology (e.g. amophotization), etc.

Ion assisted etching processes, however, rely upon ion bombardment to the substrate surface in defining selected films. But these ion assisted etching processes commonly have a lower selectivity relative to conventional CDE processes. Hence, CDE is often chosen when high selectivity is desired and ion bombardment to substrates are to be avoided.

One commonly used chemical dry etching technique is conventional photoresist stripping, often termed ashing or stripping. Conventional resist stripping relies upon a reaction between a neutral gas phase species and a surface material layer, typically for removal. This reaction generally forms volatile products with the surface material layer for its removal. The neutral gas phase species is formed by a plasma discharge. This plasma discharge can be sustained by a coil (e.g., helical coil, etc.) operating at a selected frequency in a conventional photoresist stripper. An example of the conventional photoresist stripper is a quarter-wave helical resonator stripper, which is described by U.S. Patent No. 4,368,092 in the name of Steinberg et al.

Referring to the above, an objective in chemical dry etching is to reduce or even eliminate ion bombardment (or ion flux) to surfaces being processed to maintain the desired etching selectivity. In practice, however, it is often difficult to achieve using conventional techniques. These conventional techniques generally attempt to control ion flux by suppressing the amount of charged species in the plasma source reaching the process chamber. A variety of techniques for suppressing these charged species have been proposed.

These techniques often rely upon shields, baffles, large separation distances between the plasma source and the chamber, or the like, placed between the plasma source and the process chamber. The conventional techniques generally attempt to directly suppress charge density downstream of the plasma source by interfering with convective and diffusive transport of charged species. They tend to promote recombination of charged species by either increasing the surface area (e.g., baffles, etc.) relative to volume, or increasing flow time, which relates to increasing the distance between the plasma source and the process chamber.

These baffles, however, cause loss of desirable neutral etchant species as well. The baffles, shields, and alike, also are often cumbersome. Baffles, shields, or the large separation distances also cause undesirable recombinative loss of active species and sometimes cause radio frequency power loss and other problems. These baffles and shields also are a potential source of particulate contamination, which is often damaging to integrated circuits.

Baffles, shields, spatial separation, and alike, when used alone also are often insufficient to substantially prevent unwanted parasitic plasma currents. These plasma currents are generated between the wafer and the plasma source, or between the plasma source and walls of the chamber. It is commonly known that when initial charged species levels are present in an electrical field, the charged species are accelerated and dissociative collisions with neutral particles can multiply the concentration of charge to higher levels. If sufficient "seed" levels of charge and rf potentials are present, the parasitic plasma in the vicinity of the process wafer can reach harmful charge density levels. In some cases, these charge densities may be similar to or even greater than plasma density within the source plasma region, thereby causing even more ion flux to the substrate.

Charge densities also create a voltage difference between the plasma source and processing chamber or substrate support, which can have an additional deleterious effect. This voltage difference enhances electric fields that can accelerate extraction of charge from the plasma source. Hence, their presence often induces increased levels of charge to be irregularly transported from the plasma source to process substrates, thereby causing non-uniform ion assisted etching.

Conventional ion assisted plasma etching, however, often requires control and maintenance of ion flux intensity and uniformity within selected process limits and within selected process energy ranges. Control and maintenance of ion flux intensity and uniformity are often difficult to achieve using conventional techniques. For instance, capacitive coupling between high voltage selections of the coil and the plasma discharge often cause high and uncontrollable plasma potentials relative to ground. It is generally understood that voltage difference between the plasma and ground can cause damaging high energy ion bombardment of articles being processed by the plasma, as illustrated by U.S. Patent No. 5,234,529 in the name of Johnson. It is further often understood that rf component of the plasma potential varies in time since it is derived from a coupling to time varying rf excitation. Hence, the energy of charged particles from plasma in conventional inductive sources is spread over a relatively wide range of energies, which undesirably tends to introduce uncontrolled variations in the processing of articles by the plasma.

The voltage difference between the region just outside of a plasma source and the processing chamber can be modified by introducing internal conductive shields or electrode elements into the processing apparatus downstream of the source. When the plasma potential is elevated with respect to these shield electrodes, however, there is a tendency to generate an undesirable capacitive discharge between the shield and plasma source. These electrode elements are often a source of contamination and the likelihood for contamination is even greater when there is capacitive discharge (ion bombardment from capacitive discharge is a potential source of sputtered material). Contamination is damaging to the manufacture of integrated circuit devices.

Another limitation is that the shield or electrode elements generally require small holes therein as structural elements. These small holes are designed to allow gas to flow therethrough. The small holes, however, tend to introduce unwanted pressure drops and neutral species recombination. If the holes are made larger, the plasma from the source tends to survive transport through the holes and unwanted downstream charge flux will often result. In addition, undesirable discharges to these holes in shields can, at times, produce an even more undesirable hollow cathode effect.

In conventional helical resonator designs, conductive external shields are interposed between the inductive power (e.g., coil, etc.) and walls of the vacuum vessel containing the plasma. A variety limitations with these external capacitive shielded plasma designs (e.g., helical resonator, inductive discharge, etc.) have been observed. In particular, the capacitively shielded design often produces plasmas that are difficult to tune and even ignite. Alternatively, the use of unshielded plasma sources (e.g., conventional quarter-wave resonator, conventional half-wave resonator, etc.) attain a substantial plasma potential from capacitive coupling to the coil, and hence are prone to create uncontrolled parasitic plasma currents to grounded surfaces. Accordingly, the use of either the shielded or the unshielded sources using conventional quarter and half-wave rf frequencies produce undesirable results.

In many conventional plasma sources a means of cooling is required to maintain the plasma source and substrates being treated below a maximum temperature limit. Power dissipation in the structure causes heating and thereby increases the difficulty and expense of implementing effective cooling means. Inductive currents may also be coupled from the excitation coil into internal or capacitive shields and these currents are an additional source of undesirable power loss and heating. Conventional capacitive shielding in helical resonator discharges utilized a shield which was substantially split along the long axis of the resonator to lessen eddy current loss. However, such a shield substantially perturbs the resonator characteristics owing to unwanted capacitive coupling and current which flows from the coil to the shield. Since there are no general design equations, nor are properties currently known for resonators which are "loaded" with a shield along the axis, sources using this design must be sized and made to work by trial and error.

In inductive discharges, it is highly desirable to be able to substantially control the plasma potential relative to ground potential, independent of input power, pressure, gas composition and other variables. In many cases, it is desired to have the plasma potential be substantially at ground potential (at least offset from ground potential by an amount insignificantly different from the floating potential or intrinsic DC plasma potential). For example, when a plasma source is utilized to generate neutral species to be transported downstream of the source for use in ashing resist on a semiconductor device substrate (a wafer or flat panel electronic display), the concentration and potential of charged plasma species in the reaction zone are desirably reduced to avoid charging damage from electron or ionic current from the plasma to the device. When there is a substantial potential difference between plasma in the source and grounded surfaces beyond the source, there is a tendency for unwanted parasitic plasma discharges to form outside of the source region.

Another undesirable effect of potential difference is the acceleration of ions toward grounded surfaces and subsequent impact of the energetic ions with surfaces. High energy ion bombardment may cause lattice damage to the device substrate being processed and may cause the chamber wall or other chamber materials to sputter and contaminate device wafers. In other plasma processing procedures, however, some ion bombardment may be necessary or desirable, as is the case particularly for anisotropic ion-induced plasma etching procedures (for a discussion of ion-enhanced plasma etching mechanisms See Flamm (Ch. 2,pp.94-183 in Plasma Etching, An Introduction, D. M. Manos and D.L. Flamm, eds., Academic Press, 1989)). Consequently, uncontrolled potential differences, such as that caused by "stray" capacitive coupling from the coil of an inductive plasma source to the plasma, are undesirable.

Referring to the above limitations, conventional plasma sources also have disadvantages when used in conventional plasma enhanced CVD techniques. These techniques commonly form a reaction of a gas composition in a plasma discharge. One conventional plasma enhanced technique relies upon ions aiding in rearranging and stabilizing the film, provided the bombardment from the plasma is not sufficiently energetic to damage the underlying substrate or the growing film. Conventional resonators and other types of inductive discharges often produce parasitic plasma currents from capacitive coupling, which often detrimentally influences film quality, e.g., an inferior film, etc. These parasitic plasma currents are often uncontrollable, and highly undesirable. These plasma sources also have disadvantages in other plasma processing techniques such as ion-assisted etching, and others. Of course, the particular disadvantage will often depend upon the application.

To clarify certain concepts used in this application, it will be

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convenient to introduce these definitions.

Ground (or ground potential): These terms are defined as a reference potential which is generally taken as the potential of a highly conductive shield or other highly conductive surface which surrounds the plasma source. To be a true ground shield in the sense of this definition, the RF conductance at the operating frequency is often substantially high so that potential differences generated by current within the shield are of negligible magnitude compared to potentials intentionally applied to the various structures and elements of the plasma source or substrate support assembly. However, some realizations of plasma sources do not incorporate a shield or surface with adequate electrical susceptance to meet this definition. In implementations where there is a surrounding conductive surface that is somewhat similar to a ground shield or ground plane, the ground potential is taken to be the fictitious potential which the imperfect grounded surface would have equilibrated to if it had zero high frequency impedance. In designs where there is no physical surface which is adequately configured or which does not have insufficient susceptance to act as a "ground" according to the above definition, ground potential is the potential of a fictitious surface which is equipotential with the shield or "ground" conductor of an unbalanced transmission line connection to the plasma source at its RF feed point. In designs where the plasma source is connected to an RF generator with a balanced transmission line RF feed, "ground" potential is the average of the driven feed line potentials at the point where the feed lines are coupled to the plasma source.

Inductively Coupled Power: This term is defined as power transferred to the plasma substantially by means of a time-varying magnetic flux which is induced within the volume containing the plasma source. A time-varying magnetic flux induces an electromotive force in accord with Maxwell's equations. This electromotive force induces motion by electrons and other charged particles in the plasma and thereby imparts energy to these particles.

RF inductive power source and bias power supply: In most conventional inductive plasma source reactors, power is supplied to an inductive coupling element (the inductive coupling element is often a multi-turn coil which abuts a dielectric wall containing a gas where the plasma is ignited at low pressure) by an rf power generator.

Conventional Helical Resonator: Conventional helical resonator can be defined as plasma applicators. These plasma applicators have been designed and operated in multiple configurations, which were described in, for example, U.S. Patent No. 4,918,031 in the names of Flamm et al., U.S. Patent No. 4,368,092 in the name of Steinberg et al., U.S Patent No. 5,304,282 in the name of Flamm, U.S. Patent No. 5,234,529 in the name of Johnson, U.S. Patent No. 5,431,968 in the name of Miller, and others. In these configurations, one end of the helical resonator applicator coil has been grounded to its outer shield. In one conventional configuration, a quarter wavelength helical resonator section is employed with one end of the applicator coil grounded and the other end floating (i.e., open circuited). A trimming capacitance is sometimes connected between the grounded outer shield and the coil to "fine tune" the quarter wave structure to a desired resonant frequency that is below the native resonant frequency without added capacitance. In another conventional configuration, a half-wavelength helical resonator section was employed in which both ends of the coil were grounded. The function of grounding the one or both ends of the coil was believed to be not essential, but advantageous to "stabilize the plasma operating characteristics" and "reduce the possibility of coupling stray current to nearby objects." See U.S. Patent No. 4,918,031.

Conventional resonators have also been constructed in other geometrical configurations. For instance, the design of helical resonators with a shield of square cross section is described in Zverev et al., IRE Transactions on Component Parts, pp. 99-110, Sept. 1961. Johnson (U.S. Patent No. 5,234,529) teaches that one end of the cylindrical spiral coil in a conventional helical resonator may be deformed into a planar spiral above the top surface of the plasma reactor tube. U.S. Patent No. 5,241,245 in the names of Barnes et al. teach the use of conventional helical resonators in which the spiral cylindrical coil is entirely deformed into a planar spiral arrangement with no helical coil component along the sidewalls of the plasma source (this geometry has often been referred to as a "transformer coupled plasma," termed a TCP).

From the above it is seen that an improved technique, including a method and apparatus, for plasma processing is often desired.

SUMMARY OF THE INVENTION

The present invention provides a technique, including a method and apparatus, for fabricating a product using a plasma discharge. The present technique relies upon the control of the instantaneous plasma AC potential to selectively control a variety of plasma characteristics. These characteristics include the amount of neutral species, the amount of charged species, overall plasma potential, the spatial extent and distribution of plasma density, the distribution of electrical current, and others. This technique can be used in applications including chemical dry etching (e.g., stripping, etc.), ion-enhanced etching, plasma immersion ion implantation, chemical vapor deposition and material growth, and others.

In one aspect of the invention, a process for fabricating a product is provided. These products include a varieties of devices (e.g., semiconductor, flat panel displays, micro-machined structures, etc.) and materials, e.g., diamonds, raw materials, plastics, etc. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages (e.g., AC plasma voltage) from the inductive coupling structure substantially balances. This process provides for a technique that is substantially free from stray or parasitic capacitive coupling from the plasma source to chamber bodies (e.g., substrate, walls, etc.) at or near ground potential.

In another aspect of the invention, another process for fabricating a product is provided. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure is selectively maintained. This process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential.

A further aspect of the invention provides yet another process for fabricating a product. This process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure is selectively maintained. A further step of selectively applying a voltage between the at least one of the entities in the plasma source and a substrate is provided. This process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential, and provide for a driving voltage between the entities and a substrate.

Another aspect of the invention provides another process for fabricating a product. The process comprises steps of subjecting a substrate to a composition of entities and using the resulting substrate for completion of the product. At least one of the entities emanates from a species generated by a gaseous discharge provided by a plasma applicator, e.g., a helical resonator, inductive coil, transmission line, etc. This plasma applicator has an integral current driven by capacitive coupling of a plasma column to elements with a selected potential greater than a surrounding shield potential substantially equal to capacitive coupling of the plasma column to substantially equal elements with a potential below shield potential.

In a further aspect, the invention provides an apparatus for fabricating a product. The apparatus has an enclosure comprising an outer surface and an inner surface. The enclosure houses a gaseous discharge. The apparatus also includes a plasma applicator (e.g., helical coil, inductive coil, transmission line, etc.) disposed adjacent to the outer surface. A high frequency power source operably coupled to the plasma applicator is included. The high frequency power source provides high frequency to excite the gaseous discharge to provide at least one entity from a high frequency field in which the vector sum of phase and anti-phase capacitive current coupled from the inductive coupling structure is selectively maintained.

In another aspect, the present invention provides an improved plasma discharge apparatus. This plasma discharge apparatus includes a plasma source, a plasma applicator (e.g., inductive coil, transmission line, etc.), and other elements. This plasma applicator provides a de-coupled plasma source. A wave adjustment circuit (e.g., RLC circuit, coil, transmission line, etc.) is operably coupled to the plasma applicator. The wave adjustment circuit can selectively adjust phase and anti-phase potentials of the plasma from an rf power supply. This rf power supply is operably coupled to the wave adjustment circuit.

The present invention achieves these benefits in the context of known process technology. However, a further understanding of the nature and advantages of the present invention may be realized by reference to the latter portions of the specification and attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified diagram of a plasma etching apparatus according to the present invention;

Figs. 2A-2E are simplified configurations using wave adjustment circuits according to the present invention;

Fig. 3 is a simplified diagram of a chemical vapor deposition apparatus according to the present invention;

Fig. 4 is a simplified diagram of a stripper according to the present invention;

Figs. 5A-5C are more detailed simplified diagrams of a helical resonator according to the present invention;

Fig. 6 is a conventional quarter-wave helical resonator plasma etching apparatus with stray plasma which results from the coupling in the conventional design;

Fig. 7 is a simplified diagram of the rf voltage distribution along the coil of the Fig. 6 apparatus;

Fig. 8 is a simplified top-view diagram of a stripping apparatus according to the present experiments; and

Fig. 9 is a simplified side-view diagram of a stripping apparatus according to the present experiments.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is a simplified diagram of a plasma etch apparatus 10 according to the present invention. This etch apparatus is provided with an inductive applicator, e.g., inductive coil. This etch apparatus depicted, however, is merely an illustration, and should not limit the scope of the claims as defined herein. One of ordinary skilled in the art may implement the present invention with other treatment chambers and the like.

The etch apparatus includes a chamber 12, a feed source 14, an exhaust 16, a pedestal 18, an inductive applicator 20, a radio frequency (rf) power source 22 to the inductive applicator 20, wave adjustment circuits 24, 29 (WACs), a radio frequency power source 35 to the pedestal 18, a controller 36, and other elements. Optionally, the etch apparatus includes a gas distributor 17.

The chamber 12 can be any suitable chamber capable of housing a product 28, such as a wafer to be etched, and for providing a plasma discharge therein. The chamber can be a domed chamber for providing a uniform plasma distribution over the product 28 to be etched, but the chamber also can be configured in other shapes or geometries, e.g., flat ceiling, truncated pyramid, cylindrical, rectangular, etc. Depending upon the application, the chamber is selected to produce a uniform entity density over the pedestal 18, providing a high density of entities (i.e., etchant species) for etching uniformity.

The present chamber includes a dome 25 having an interior surface 26 made of quartz or other suitable materials. The exterior surface of the chamber is typically a dielectric material such as a ceramic or the like. Chamber 12 also includes a process kit with a focus ring 32, a cover (not shown), and other elements. Preferably, the plasma discharge is derived from the inductively coupled plasma source that is a de-coupled plasma source (DPS) or a helical resonator, although other sources can be employed.

The de-coupled source originates from rf power derived from the inductive applicator 20. Inductively coupled power is derived from the power source 22. The rf signal frequencies ranging from 800 kHz to 80 MHz can be provided to the inductive applicator 20. Preferably, the rf signal frequencies range from 5 MHz to 60 MHz. The inductive applicator (e.g., coil, antenna, transmission line, etc.) overlying the chamber ceiling can be made using a variety of shapes and ranges of shapes. For example, the inductive applicator can be a single integral conductive film, a transmission line, or multiple coil windings. The shape of the inductive applicator and its location relative to the chamber are selected to provide a plasma overlying the pedestal to improve etch uniformity.

The plasma discharge (or plasma source) is derived from the inductive applicator 20 operating at selected phase 23 and anti-phase 27 potentials (i.e., voltages) that substantially cancel each other. The controller 36 is operably coupled to the wave adjustment circuits 24, 29. In one embodiment, wave adjustment circuits 24, 29 provide an inductive applicator operating at full-wave multiples 21. This embodiment of full-wave multiple operation provides for balanced capacitance of phase 23 and anti-phase voltages 27 along the inductive applicator (or coil adjacent to the plasma). This full-wave multiple operation reduces or substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential. Alternatively, the wave adjustment circuits 24, 29 provide an inductive applicator that is effectively made shorter or longer than a full-wave length multiple by a selected amount, thereby operating at selected phase and anti-phase voltages that are not full-wave multiples. Alternatively, more than two, one or even no wave adjustment circuits can be provided in other embodiments. But in all of these above embodiments, the phase and anti-phase potentials substantially cancel each other, thereby providing substantially no capacitively coupled power from the plasma source to the chamber bodies.

In alternative embodiments, the wave adjustment circuit can be configured to provide selected phase and anti-phase coupled voltages coupled from the inductive applicator to the plasma that do not cancel. This provides a controlled potential between the plasma and the chamber bodies, e.g., the substrate, grounded surfaces, walls, etc. In one embodiment, the wave adjustment circuits can be used to selectively reduce current (i.e., capacitively coupled current) to the plasma. This can occur when certain high potential difference regions of the inductive applicator to the plasma are positioned (or kept) away from the plasma region (or inductor-containing-the-plasma region) by making them go into the wafer adjustment circuit assemblies, which are typically configured outside of the plasma region. In this embodiment, capacitive current is reduced and a selected degree of symmetry between the phase and anti-phase of the coupled voltages is maintained, thereby providing a selected potential or even substantially ground potential. In other embodiments, the wave adjustment circuits can be used to selectively increase current (i.e., capacitively coupled current) to the plasma.

As shown, the wave adjustment circuits are attached (e.g., connected, coupled, etc.) to ends of the inductive applicator. Alternatively, each of these wave adjustment circuits can be attached at an intermediate position away from the inductive application ends. Accordingly, upper and lower tap positions for respective wave adjustment circuits can be adjustable. But both the inductive applicator portions below and above each tap position are active. That is, they both can interact with the plasma discharge.

A sensing apparatus can be used to sense plasma voltage and use automatic tuning of the wave adjustment circuits and any rf matching circuit between the rf generator and the plasma treatment chamber. This sensing apparatus can maintain the average AC potential at zero or a selected value relative to ground or any other reference value. This wave adjustment circuit provides for a selected potential difference between the plasma source and chamber bodies. These chamber bodies may be at a ground potential or a potential supplied by another bias supply, e.g., See Fig. 1 reference numeral 35. Examples of wave adjustment circuits are described by way of the Figs. below.

For instance, Figs. 2A to 2E are simplified configurations using the wave adjustment circuits according to the present invention. These simplified configurations should not limit the scope of the claims herein. In an embodiment, these wave adjustment circuits employ substantially equal circuit elements (e.g., inductors, capacitors, transmission line sections, and others) such that the electrical length of the wave adjustment circuits in series with the inductive applicator coupling power to the plasma is substantially an integral multiple of one wavelength. In other embodiments, the circuit elements provide for inductive applicators at other wavelength multiples, e.g., one-sixteenth-wave, one-eighth-wave, quarter-wave, half-wave, three-quarter wave, etc. In these embodiments (e.g., full-wave multiple, half-wave, quarter-wave, etc.), the phase and anti-phase relationship between the plasma potentials substantially cancel each other. In further embodiments, the wave adjustment circuits employ circuit elements that provide plasma applicators with phase and anti-phase potential relationships that do not cancel each other out using a variety of wave length portions.

Fig. 2A is a simplified illustration of an embodiment 50 using wave adjustment circuits according to the present invention. This embodiment 50 includes a discharge tube 52, an inductive applicator 55, an exterior shield 54, an upper wave adjustment circuit 57, a lower wave adjustment circuit 59, an rf power supply 61, and other elements. The upper wave adjustment circuit 57 is a helical coil transmission line portion 69, outside of the plasma source region 60. Lower wave adjustment circuit 59 also is a helical coil transmission line portion 67 outside of the plasma source region 60. The power supply 61 is attached 65 to this lower helical coil portion 67, and is grounded 63. Each of the wave adjustment circuits also are shielded 66, 68.

In this embodiment, the wave adjustment circuits are adjusted to provide substantially zero AC voltage at one point on the inductive coil (refer to point 00 in Fig. 2A). This embodiment also provides substantially equal phase 70 and anti-phase 71 voltage distributions in directions about this point (refer to 00-A and 00-C in Fig. 2A) and provides substantially equal capacitance coupling to the plasma from physical inductor elements (00-C) and (00-A), carrying the phase and anti-phase potentials. Voltage distributions 00-A and 00-C are combined with C-D and A-B (shown by the phantom lines) would substantially comprise a full-wave voltage distribution in this embodiment where the desired configuration is a selected phase/antiphase portion of a full-wave inductor (or helical resonator) surrounding the plasma source discharge tube.

In this embodiment, it is desirable to reduce or minimize capacitive coupling current from the inductive element to the plasma discharge in the plasma source. Since the capacitive current increases monotonically with the magnitude of the difference of peak phase and anti-phase voltages, which occur at points A and C in Fig. 2A, this coupling can be lessened by reducing this voltage difference. In Fig. 2A, for example, it is achieved by way of two wave adjustment circuits 57, 59. Coil 55 (or discharge source) is a helical resonator and the wave adjustment circuits 57, 59 are helical resonators.

The discharge source helical resonator 53 can be constructed using conventional design formulae. Generally, this helical resonator includes an electrical length which is a selected phase portion "x" (A to 00 to C) of a full-wave helical resonator. The helical resonator wave adjustment circuits are each selected to comprise a portion (2 -x) of full-wave helical resonators. Physical parameters for the wave adjustment helical resonators can be selected to realize practical physical dimensions and appropriate Q, Z_o, etc values. In particular, some or even all of the transmission line parameters (Q, Z_o, etc.) of the wave adjustment circuit sections may be selected to be substantially the same as the transmission line parameters of the inductive applicator. The portion of the inductive plasma applicator helical resonator, on the other hand, is designed and sized to provide selected uniformity values over substrate dimensions within an economical equipment size and reduced Q.

The wave adjustment circuit provides for external rf power coupling, which can be used to control and match power to the plasma source, as compared to conventional techniques used in helical resonators and the like. In particular, conventional techniques often match to, couple power to, or match to the impedance of the power supply to the helical resonator by varying a tap position along the coil above the grounded position, or selecting a fixed tap position relative to a grounded coil end and matching to the impedance at this position using a conventional matching network, e.g., LC network,   network, etc. Varying this tap position along the coil within a plasma source is often cumbersome and generally imposes a difficult mechanical design problems. Using the fixed tap and external matching network also is cumbersome and can cause unanticipated changes in the discharge Q, and therefore influences its operating mode and stability. In the present embodiments, the wave adjustment circuits can be positioned outside of the plasma source (or constrained in space containing the inductive coil, e.g., See Fig. 2A. Accordingly, the mechanical design (e.g., means for varying tap position, change in the effective rf power coupling point by electrical means, etc.) of the tap position are simplified relative to those conventional techniques.

In the present embodiment, rf power is fed into the lower wave adjustment circuit 59. Alternatively, rf power can be fed into the upper wave adjustment circuit (not shown). The rf power also can be coupled directly into the inductive plasma coupling applicator (e.g., coil, etc.) in the wave adjustment circuit design, as illustrated by Fig. 2B. Alternatively, other application will use a single wave adjustment circuit, as illustrated by Fig. 2C. Power can be coupled into this wave adjustment circuit or by conventional techniques such as a tap in the coil phase. In some embodiments, this tap in the coil phase is positioned above the grounded end. An external impedance matching network may then be operably coupled to the power for satisfactory power transfer efficiency from, for example, a conventional coaxial cable to impedances (current to voltage rations) existing between the wave adjustment circuit terminated end of the applicator.

A further embodiment using multiple inductive plasma applicators also is provided, as shown in Fig. 2D. This embodiment includes multiple plasma applicators (PA1, PA2...PAn). These plasma applicators respectively provide selected combinations of inductively coupled power and capacitively coupled power from respective voltage potentials (V1, V2...Vn). Each of these plasma applicators derives power from its power source (PS1, PS2...PSn) either directly through an appropriate matching or coupling network or by coupling to a wave adjustment circuit as described. Alternatively, a single power supply using power splitters and impedance matching networks can be coupled to each (or more than two) of the plasma applicators. Alternatively, more than one power supply can be used where at least one power supply is shared among more than one plasma applicator. Each power source is coupled to its respective wave adjustment circuits (WAC1, WAC2...WACn).

Generally, each plasma applicator has an upper wave adjustment circuit (e.g., WAC 1a, WAC 2a...WACna) and a lower wave adjustment circuit (e.g., WAC1b, WAC 2b...WACnb). The combination of upper and lower wave adjustment circuits are used to adjust the plasma source potential for each plasma source zone. Alternatively, a single wave adjustment circuit can be used for each plasma applicator. Each wave adjustment circuit can provide substantially the same impedance characteristics, or substantially distinct impedance characteristics. Of course, the particular configuration used will depend upon the application.

For instance, multiple plasma applicators can be used to employ distinct excitation frequencies for selected zones in a variety of applications. These applications include film deposition using plasma enhanced chemical deposition, etching by way of ion enhanced etching or chemical dry etching and others. Plasma cleaning also can be performed by way of the multiple plasma applicators. Specifically, at least one of the plasma applicators will define a cleaning plasma used for cleaning purposes. In one embodiment, this cleaning plasma can have an oxygen containing species. This cleaning plasma is defined by using an oxygen discharge, which is sustained by microwave power to a cavity or resonant microwave chamber abutting or surrounding a conventional dielectric vessel. Of course, a variety of other processes also can be performed by way of this multiple plasma applicator embodiment.

This present application using multiple plasma applicators can provide a multi-zone (or multi-chamber) plasma source without the use of conventional mechanical separation means (e.g., baffles, separate process chambers, etc.). Alternatively, the degree of interaction between adjacent zones or chambers can be relaxed owing to the use of voltage potential control via wave adjustment circuits. This plasma source provides for multiple plasma source chambers, each with its own control via its own plasma applicator. Accordingly, each plasma applicator provides a physical zone region (i.e., plasma source) with selected plasma characteristics (e.g., capacitively coupled current, inductively coupled current, etc.). These zones can be used alone or can be combined with other zones. Of course, the particular configuration will depend upon the application.

In the present embodiments, the wave adjustment circuit can be made from any suitable combination of element(s) such as various types of transmission lines, circuits, etc. These transmission lines include conventional solid or air dielectric coaxial cable, or ordinary, repeating inductor/capacitor discrete approximations to transmission lines, and others. These types of transmission lines are co-axial transmission lines, balanced parallel transmission lines, so called slow wave transmission lines with a spiral inner conductor (e.g., selected portions of a helical resonator, etc.), and others. Individual lumped, fixed, or adjustable combinations of resistors, capacitors, and inductors (e.g., matching networks, etc.) also can be used in place of transmission line sections for the wave adjustment circuit. These general types of wave adjustment circuits are frequency dependent, and can be termed frequency dependent wave adjustment circuits (or FDWACs).

Frequency independent elements also can be used as the wave adjustment circuits. These wave adjustment circuits can be termed frequency independent WACs (or FIWACs). Frequency independent wave adjustment circuits include degenerate cases such as short-circuit connections to ground or an infinite impedance (i.e., open circuit), and others. Frequency independent wave adjustment circuits can be used alone, or in combination with the frequency dependent wave adjustment circuits. Alternatively, the frequency dependent wave adjustment circuits can be used alone or in combination with other wave adjustment circuits. Other variations, alternative constructions, and modifications also may be possible depending upon the application.

With regard to operation of the wave adjustment circuits, various embodiments can be used, as illustrated by Fig. 2E. The wave adjustment circuits are used to select a wave length portion to be applied in the plasma applicator. In some embodiments, the average rf plasma potential is maintained close to ground potential by providing substantially equal phase 90, 81 and anti-phase 91, 82 capacitively coupled portions of the inductive applicator. This can occur in multi-wave embodiments 92, full-wave embodiments 93, half-wave multiple embodiments, quarter-wave multiple embodiments, or any other embodiments 94.

In alternative embodiments, it is desirable to maintain an elevated source plasma voltage relative to ground potential to induce a controlled ion plasma flux (or ion bombardment) to the product substrate (or any other chamber bodies). These embodiments are provided by selecting distinct electrical lengths for each of the wave adjustment circuit sections such that the capacitive coupled current from a phase section of the inductive plasma applicator is in excess of capacitive coupled current from its anti-phase portion. In these embodiments, the wave adjustment circuit provides a deliberate imbalance between the phase and anti-phase of the coupled voltages. In some embodiments 97, this occurs by shifting the zero voltage nodes along the process chamber axially, thereby achieving a bias relative to the plasma discharge. As shown, the phase 95 is imbalanced relative to its anti-phase 96.

In other embodiments 99, one phase portion 84 is imbalanced by way of a different period relative to its complementary phase portion 85. Other embodiments are provided where the source plasma voltage is lower relative to ground potential. In the embodiments were imbalance is desirable, the potential difference between the phase and anti-phase potential portions is reduced (or minimized) when the amount of sputtering (e.g., wall sputtering, etc.) is reduced. The amount of sputtering, however, can be increased (or maximized) by increasing the potential difference between the phase and anti-phase potential portions. Sputtering is desirable in, for example, sputtering a quartz target, cleaning applications, and others. Of course, the type of operation used will depend upon the application.

Current maxima on an inductive applicator with distributed capacitance (e.g., helical resonator transmission line, etc.) occur at voltage minima. In particular, conventional quarter-wave helical resonator current is substantially at a relative maximum at its grounded end of the coil, and to a lesser extend in the nearby coil elements. Therefore, partial inductive coupling of power, if it occurs, will tend to be at this grounded end. In conventional half-wave helical resonators, inductive coupling tends to occur at each of the two grounded ends.

In the present invention, substantially anti-symmetric phase and anti-phase inductive half-wave and other fractional wave applicator sections support substantially more inductive coupling at a selected rf voltage node, e.g., Fig. 2A reference numeral 00. This effect is caused by high current flow in the inductor applicator zones (or sections) both directly above and below the node (corresponding to inductor elements in the phase and anti-phase sections at and immediately adjacent to the rf voltage zero point). It should be noted that conventional quarter and half-wave inductively coupled inductive applicators have inductive coupling which abruptly declines below the grounded coil locations because the coil terminates and voltage extrema are present at these locations. This generally produces conventional quarter and half-wave helical resonators that tend to operate in a capacitive mode, or with a substantial fraction of power which is capacitively coupled to the plasma, unless the plasma is shielded from coil voltages, as noted above.

In a specific embodiment, the power system includes selected circuit elements for effective operation. The power system includes an rf power source. This rf power source can be any suitable rf generator capable of providing a selected or continuously variable frequency in a range from about 800 kHz to about 80 MHz. Many generators are useful. Preferably, generators capable of operating into short and open-circuit loads without damage are used for industrial applications. One example of a suitable generator is a fixed frequency rf generator 28.12 MHz - 3 kW CX-3000 power supply made by Comdel, Inc. of Beverly, Massachusetts. A suitable variable frequency power supply arrangement capable of the 3 kW output over an 800 kHz to 50 MHz range can be made by driving an IFI Model TCCX3500 High Power Wide Band Amplifier with a Hewlett Packard HP116A, 0-50 MHz Pulse/Function Generator. Other generators including those capable of higher or lower power also can be used depending upon the application.

Power from the generator can be transmitted to the plasma source by conventional coaxial cable transmission line. An example of this transmission line is RG8/U and other higher temperature rated cable (e.g., RG1151U, etc.) with a coaxial TEFLON dielectric. In some embodiments, power is fed to conventional end-grounded half-wave helical resonators by positioning a movable tap on the helical coil and connecting a power source between the tap and the ground. In other embodiments, matching networks can be introduced between the coaxial cable power feed and the helical coil tap for flexibility. The matching network will depend on the selected wave configuration and wave adjustment circuits. In a balanced half-wave helical resonator embodiment, for example, the ends of the resonator coil can be terminated with wave adjustment circuits which substantially have zero susceptance. In particular, the wave adjustment circuit is designed as an open circuit by making no electrical connections to the ends of the coil, or establishing an electrical equivalence thereof. Alternatively, the ends of the coil are isolated by chokes series resistance, thereby DC coupled to a fixed reference potential. These types of wave adjustment circuits are frequency independent and are "degenerate" cases. In these embodiments, the rf power is provided such that the phase and anti-phase current flows above and below the electrical midpoint of the coil. This provides for substantially balanced phase and anti-phase current flow from the power source stabilizing desired operation in coil voltages above the midpoint of the coil, and also provides substantially equal phase and anti-phase voltages.

The embodiments described above also can be applied to other plasma processing applications, e.g., PECVD, plasma immersion ion implantation (PIII), stripping, sputtering, etc. For instance, Fig. 3 is a simplified CVD apparatus 100 according to the present invention. The present CVD apparatus includes a chamber 112, a feed source 114, an exhaust 116, a pedestal 118, a power source 122, a ground 124, a helical resonator 126, and other elements. The helical resonator 126 has a coil 132, an outer shield 133, and other elements. The chamber can be any suitable chamber capable of housing a product 119 such as a wafer for deposition, and for providing a plasma discharge therein. Preferably, the chamber is a right circular cylinder chamber for providing an uniform plasma species distribution over the product. But the chamber can also be configured in the form of rectangular right cylinder, a truncated cone, and the like. The chamber and fixtures are constructed from aluminum and quartz, and other suitable materials. The plasma discharge is derived from a plasma source which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phase-anti-phase potentials. The present CVD apparatus provides for deposition of a dielectric material, e.g., silicon dioxide or the like.

The product 119 having an upper surface 130 is placed into the present CVD apparatus for deposition, e.g., plasma enhanced chemical vapor deposition (PECVD), and others. Examples of deposition materials include a dielectric material such as a silicon dioxide (SiO_2), a phosphosilicate glass (PSG), a borophosphosilicate glass (BPSG), a silicon nitride (Si_3N_4), among others.

In one embodiment, the deposition occurs by introducing a mixture comprising organic silane, oxygen, and an inert gas such as helium or argon according to the present invention. The organic silane can be any suitable organic silicate material such TEOS, HMDS, OMCTS, and the like. Deposition is also conformal in selected instances. As for the oxygen, it includes a flow rate of about 1 liter/per minute and less. A relative flow rate between the organic silane such as TEOS and oxygen ranges from about 1:40 to about 2:1, and is preferably less than about 1:2 in certain applications. A deposition temperature of the organic silane-oxygen layer ranges from about 300 to about 500 C, and can also be at other temperatures. Pressures in the range of 1 to 7 Torr are generally used. Of course, other concentrations, temperatures, materials, and flow rates can be used depending upon the particular application.

This chamber also includes a wave adjustment circuit 127. The wave adjustment circuit 127 is used to provide a helical coil operating with capacitive coupling to selected phase and anti-phase voltages. This portion 127 of the wave adjustment circuit coil also is shielded 140 to prevent rf from interfering with the plasma discharge or external elements, e.g., equipment, power, etc. The coil shield 140 is made of a conductive material such as copper, aluminum, or the like. In one embodiment, an operating frequency is selected and the wave adjustment circuit is adjusted to short circuit the upper end of the helical applicator coil to ground 124. This provides a helical coil operating at approximately a full-wave multiple and has substantially equal phase and anti-phase sections. This full-wave multiple operation provides for balanced capacitance of phase 151 and anti-phase 153 voltages along the coil 132 adjacent to the plasma source. Full-wave multiple operation reduces or even substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential.

In the present embodiment, the wave adjustment circuit 127 is a variable coil portion 128 of a spiral transmission line, which is selectively placed outside the outer shield 133. Accordingly, when the wave adjustment circuit is adjusted to become a short circuit, the plasma source "sees" only a selected full-wave multiple comprising substantially equal phase 151 and anti-phase 153 of the entire instantaneous AC voltages 134, 135. In this embodiment, stress of the deposited oxide film is often tensile, which can be undesirable.

Alternatively, the wave adjustment circuit 127 provides a helical resonator operating at selected phase and anti-phase voltages that are not full-wave multiples. This wave adjustment circuit provides for a selected amount of capacitive coupling from the plasma source to the chamber bodies. Stress of the deposited oxide film in this embodiment can be made to be zero or slightly compressive. In some embodiments, the oxide films can be deposed with an rf plasma potential of several hundred volts between the plasma source and the substrate to decrease the tendency of the oxide film to absorb moisture. This can occur by adjusting the wave adjustment circuit to add in a small section of transmission line outside of the source and correspondingly shortening the applicator coil (by moving the lower point at which the applicator coil is short-circuited and thereby decreasing the inductance of the applicator coil and electrical length of the helical resonator 126 (e.g., spiral transmission line, etc.)). Of course, the selected amount of capacitive coupling will depend upon the application.

Fig. 4 is a simplified diagram of a resist stripper according to the present invention. The present stripping apparatus includes similar elements as the previous described CVD apparatus. The present stripping apparatus includes a chamber 112, a feed source 114, an exhaust 116, a pedestal 118, an rf power source 122, a ground 124, a helical resonator 126, and other elements. The helical resonator 126 includes a coil 132, an outer shield 133, a wave adjustment circuit 400, and other elements. The chamber can be any suitable chamber capable of housing a product 119 such as a photoresist coated wafer for stripping, and for providing a plasma discharge therein. The plasma discharge is derived from a plasma source, which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phase\anti-phase potentials. The present stripping apparatus provides for stripping or ashing photoresist, e.g., implant hardened, etc. Further examples of such a stripping apparatus are described in the experiments section below.

In this embodiment, the wave adjustment circuits rely upon open circuits (i.e., zero susceptance). Power transfer can be occurred with a balanced feed such as an inductively-coupled push-pull arrangement such as coupled inductors. Techniques for constructing these coupled inductors are described in, for example, "The ARRL Antenna Book," R.D. Straw, Editor, The American Radio Delay League, Newington, CT (1994) and "The Radio Handbook," W.I. Orr, Editor, Engineering Ltd, Indiana (1962), which are both hereby incorporated by reference for all purposes. In one embodiment, a ferrite or powdered iron core "balun" (balanced-unbalanced) toroidal transformer (i.e., broadband transmission transformer, broadband transformer, etc.) 401 can be used to provide balanced matching from a conventional unbalanced coaxial transmission line. Techniques for constructing toroidal baluns are described in, for example, "Transmission Line Transformers," J. Sevick, 2nd Edition, American Radio Relay League, Newington, CT (1990). The toroidal transformer is coupled between the rf power source 122 and the coil 132. The midpoint 406 between the phase 405 and anti-phase voltage on the coil is effectively rf grounded, hence it may be convenient to directly ground this midpoint of the inductive application in some embodiments for stability. This permits alternate operation in which power may be coupled into the inductive applicator (e.g., coil, etc.) with a conventional unbalanced feed line tapped on one side of the center. Push-pull balanced coupling ignites the plasma more easily than conventional unbalanced coil tap matching and generally is easier to adjust in selected applications.

Referring to the helical resonator embodiments operating at substantially equal phase and anti-phase potentials, Fig. 5A is a simplified diagram 200 of an equivalent circuit diagram of some of them. The diagram is merely an illustration and should not limit the scope of the claims herein. The equivalent circuit diagram includes a plurality of rf power supplies (V_1, V_2, $V_3 \ldots V_n$) 203, representing for example, a single rf power source. These power supplies are connected in parallel to each other. One end of the power supply is operably coupled to a ground connection 201. The other end of the power supplies can be represented as being connected to a respective capacitor (C_1, C_2, $C_3 \ldots C_n$). Each of these capacitors are connected in parallel to each other. During this mode of operation, substantially no voltage difference exists between any of these capacitors, as they are all connected to each other in parallel.

Fig. 5B is a simplified diagram of instantaneous AC voltage and current along a helical resonator coil of Fig. 5A where each end of the inductive applicator is short circuited. The diagram is merely an illustration and should not limit the scope of the claims herein. This diagram includes the discharge tube 213 and an inductive plasma discharge (or plasma source) 501 therein. As shown, the plasma discharge includes an intensified "donut-shaped" glow region 501 that occupies a limited range (R) of the discharge tube 213. The plasma discharge has an average voltage potential (V_{ave}) of substantially zero volt between the ground potential (V_G) and the high voltage potential (V_H). As can be seen, the plasma discharge 501 has capacitively coupling elements to V_H and V_G. But the average voltage potential of this plasma discharge is zero. This operation provides for balanced capacitance of phase 503 and anti-phase 505 voltages along the coil adjacent to the plasma, thereby substantially preventing capacitively coupling from the plasma source to chamber bodies. As also shown, a current maxima 507 exists at V_{ave}, which corresponds to an inflection point between the phase 503 and the anti-phase 505.

In an alternative operating mode, dim rings of plasma caused by inductively coupled plasma current are visible near top and bottom extremes of the inductive application, as illustrated by Fig. 5C. This operating mode is generally for a full-wave 517 inductive coupling coil operated at a very high power, e.g., maximum power input to the inductive applicator is often limited by thermal considerations and breakdown. The rings 513, 515 of current in the plasma discharge are simulated by maximum coil current areas corresponding to voltage minima at the top and bottom shorted ends of the coil. Under these high power conditions, subordinate current rings are detectable and some excitation is often visible in the intermediate regions. This excitation is partially caused by capacitively driven currents within the discharge coupled to the voltage maximum and voltage minimum positions along the inductive applicator.

Alternatively, subordinate inductive plasma current rings at the top and bottom ends 513 of the resonator do not appear with limited input power. The coil current and inductive flux fall beyond the ends of the inductive applicator so that a single inductive ring 515 in the center portion is more stable, provided that the conductivity of the plasma is large enough to support a single current ring at a specified input power.

In alternative applications using high power operation, no secondary plasma current rings may be desirable. These applications often have substantially minimum internal capacitive coupling. In these applications, the inductive applicator (e.g., coil) abutting the vacuum vessel may be shortened from a full wave to an appropriate length such that only the central current maxima exists on the coil abutting the plasma source and the potential difference between maximum and minimum voltage on the applicator is substantially reduced. The present application is achieved by stabilizing the desired waveform along the applicator by appropriate impedance wave adjustment circuits.

Referring to the above embodiments, the present invention provides for processing with an inductively coupled plasma in which the plasma potential from coupling to a phase portion of the inductive applicator is substantially not offset by capacitive coupling to anti-phase voltages on selective portions to the inductive coupling element. Conventional inductive sources (e.g., conventional helical resonators, etc.), however, have hitherto been operated in quarter-wave or half-wave modes. These modes provide only phase capacitive coupling to the plasma, which raises the plasma potential toward the coil without compensation anti-phase coupling. Conventional inductive sources that are longer than a half-wave have been generally considered cumbersome and impractical for plasma reactors. In particular, these inductive sources are large in size, and have nodes along the helical coil, which have been believed to create a non-uniform plasma. In order to operate a substantially inductive plasma in a helical resonator, conventional inductive sources relied upon shielding the plasma tube from electrical fields originating on the coil. Shielding occurred, for example, by inserting a longitudinally split shield between the coil and plasma tube.

The present invention provides for a substantially pure inductively coupled power source. A benefit of this inductively coupled power as a primary means to sustain plasma excitation is that electric field lines produced by inductive coupling are solenoidal (e.g. they close on themselves). Since solenoidal electric field lines have zero divergence, they do not create or support a scalar potential field (e.g. a voltage difference) within the plasma volume. Thus, in an ideal case, inductively coupled power can be transferred into a plasma without no direct relationship between the plasma potential and the voltages on coupling elements (e.g.

the voltage on the coil in a helical resonator) or voltages on rf matching networks, if such are used. Furthermore, when transferring power to the plasma by purely inductive means, power transfer does not require any significant potential difference to be maintained between elements of the plasma and ground potential (e.g. the potential difference between the plasma and ground can be fixed by factors which are substantially independent of inductive excitation power).

Although in theory, inductive power transfer does not require raising the AC or DC potential of the plasma with respect to ground, in practice there has been substantial shift and harmful alteration in the plasma potential found in unshielded current art inductive sources.

As previously noted, and further emphasized herein, the most effective conventional method employed to avoid plasma potential shift in conventional commercially available inductive sources is to shield the plasma from the electrical fields on the inductive coupling element (commonly a multi-turn coil) by inserting a grounded conductive member between the inductive driving element and the plasma discharge tube. Shielding is, however, cumbersome and inconvenient and has serious disadvantages in practice. Shields couple to inductive applicator elements and can cause wide excursions in the natural resonance frequency, which are not predicted by conventional design formulae. This often results in laborious trail and error and iterative mechanical designs to achieve a desired resonance. Another disadvantage of shielding is that shields often make it difficult to achieve initial ignition of the plasma since shields generally exclude capacitive electric fields in the plasma discharge tube. In particular, ignition (known as plasma breakdown) of inductive breakdown generally begins with a capacitive electric field discharge, which is stable at lower currents and powers (See, for example, J. Amorim, H.S. Maciel and J.P. Sudana, J. Vac. Sci. Technol. B9, pp. 362-365, 1991). Accordingly, shields tend to block capacitive electric fields, which induce plasma ignition.

Insertion of the shield close to high voltage RF point in a network (such as the voltage maximum points in a helical resonator or the high potential driven side of a TCP coil) also causes large displacement currents to flow through the capacitance between the shield and coil. This high potential difference is also a potential cause of damaging rf breakdown across the air gap, hence the gap may require protection by inconvenient solid or liquid dielectric insulation. The displacement current flow causes power loss and requires that higher power RF generating equipment be used to compensate for the power loss. Coupling loss in the plasma source structure is also undesirable from the standpoint of thermal control. These limitations are overcome by the present invention using the wave adjustment circuits, an inductive applicator of selected phase length, and other elements.

Experiments

To prove the principle and demonstrate the operation of the present invention, a helical resonator plasma source was used in a photoresist stripper. Conventional helical resonators also were evaluated in these experiments. These experiments are merely examples, and should not limit the scope of the claims herein. One of ordinary skill in the art would easily recognize other experiments, uses, variations, and modifications of the inventions defined by these claims.

I. Conventional Photoresist Stripper

In this experiment, the conventional resist stripper was a prototype made by MC Electronics, present assignee. Of course, other stripper platforms also can be used depending upon the application. A conventional quarter-wave helical resonator resist stripper 600 was constructed with a quarter-wave helical resonator source 602 upstream of a processing chamber 604, shown in Fig. 6. This quarter-wave helical resonator 602 included a coil 608 and other elements.

Coil 608 consisted of 5.15 turns of 0.4 inch diameter copper tubing would with a pitch of 0.5 turns per inch with a mean radius of 6.4 inches and centered radially and vertically inside an outer copper shield 610. Coil 608 is operably coupled to a power source 612 and operated at about 13 MHz radio frequency. A 17 inch long, 9.25 inch diameter quartz tube 606 was centered inside of the copper coil 608. The shield 610 was 16 inches inside diameter, approximately 0.08 inches thick and 18 inches long. This shield 610 also was connected to a ground (V_G) connection on the aluminum process chamber body (except when making the current measurements described below).

The process chamber 604 was for a conventional resist stripper. This resist stripper included a wafer support 616 (or pedestal) and other elements. Process chamber 604 is operably coupled at an outer location 620 to ground via shield 610. Wafer support 616 has a wafer 618 disposed thereon.

The wafer 618 is a 6-inch (250mm) <100> type wafer with approximately 1.25 microns of spin-coated Mitsubishi Kasei positive photoresist MPR-4000. This wafer was ashed on the grounded 10 inch diameter wafer support 616. This support was resistivity heated and the temperature of the substrate support was sensed with a thermocouple.

After the helical resonator plasma was ignited, visible plasma filled the quartz plasma tube under all of the conditions used for processing. In addition, a strong plasma glow was always visible above the wafer in the downstream processing chamber which was indicative of secondary plasma discharge to the substrate support. This secondary plasma discharge was also accompanied by current flow from the resonator shield to the chamber of approximately 5-10 Amperes rms (and sometimes even more) which could be measured by elevating the shield on insulating blocks and monitoring the current flow through a 2 inch long 1.5 inch wide strip of copper braid which was passed through a Pearson Current probe used to monitor the current.

Fig. 7 is a simplified diagram 700 of the rf voltage distribution along the coil for the quarter-wave helical resonator of Fig. 6. This diagram includes the quartz tube 606 and a plasma discharge (or source) 701 therein. As shown, the plasma discharge includes a glow region that 701 occupies a large range (R) of the quartz tube 606. The plasma discharge has an average voltage potential (V_{ave}) between the ground potential (V_G) and the high voltage potential (V_H). As can be seen, the plasma discharge 701 has capacitively coupling elements to V_H and V_G due to its average voltage potential V_{ave}. In fact, as previously noted, the current flow from the resonator shield to the chamber was at least 5-10 Amperes rms. In high power applications, intense sparking was observed in the chamber from the capacitively coupled plasma source.

II. Present Photoresist Stripper

To prove the principle and operation of the present inventions, experiments were performed. These experiments used a photoresist stripper apparatus. This resist stripper apparatus in a cluster tool arrangement used a helical resonator according to the present inventions. One of ordinary skill in the art, however, would recognize that other implementations, modifications, and variations may be used. Accordingly, the experiments performed herein are not intended to limit the scope of the claims below.

The photoresist stripper apparatus was configured with multiple process chambers in a cluster tool arrangement, as illustrated by Figs. 8 and 9. Figs. 8 and 9 illustrate a simplified top-view diagram 800 and a simplified side-view diagram, respectively. Two process chambers, e.g., chamber 1 901 and chamber 2 903, were used. Chamber 1 901 was used for stripping implant hardened resist crust (or skin). Chamber 2 903 was used for stripping the remaining photoresist. Alternatively, the chambers can be both used for stripping implant hardened resist crust and stripping remaining photoresist. Of course, the particular use depends upon the application. These chambers also were made of aluminum with ceramic inserts, which is highly resistant to chemical attack.

The apparatus also used a microprocessor based controller to oversee process operations. This microprocessor based controller can be accessed through a control panel 921. The present apparatus used a controller made from a 486DX processor PC made by EPSON, with a color LCD touch panel display. This controller also is shielded and highly resistant to chemical attack.

An automatic wafer handling system 910 was also provided. The automatic wafer handling system used standard cassettes 912 for transferring the photoresist coated wafers to and from the process chambers 901, 903. The automatic wafer handling system included a robot 917, cassette chamber 1 905, cassette chamber 2 907, cassette stage 1 909, cassette stage 2 911, and other elements. The wafer handling system 910 used a conventional interlock system for providing the cassettes 912 from the cleanroom into the process chambers 901, 903. A main shuttle chamber 913 housed the robot 917 in the cluster tool arrangement. The controller oversees the automatic wafer handling system operations. The present wafer handing system is made by JEL Co., LTD of Japan.

A cooling plate 915 was included in the main chamber 913 housing the robot 917. The cooling plate 915 was of conventional design, and was capable of cooling the wafer after being stripped, which often occurs at elevated temperatures. Alternatively, the cooling plate can be used to thermally adjust the wafer temperature either before, after, or even between selected process operations.

The process chambers 901, 903 were disposed downstream from respective plasma sources 923, 925. Each helical resonator included a coil 927 disposed around a quartz tube 929. The coil consisted of 11.5 turns of 0.4 inch copper tubing wound with a pitch of 0.9 turns per inch with a mean radius of 9.4 inches and centered radially and vertically inside an outer copper shield 931. The coil is operably coupled to a power source (not shown). A 17 inch long, 9.25 inch diameter quartz tube was centered inside of the copper coil. The shield was 16 inches inside diameter, approximately 0.08 inches thick and 18 inches long. The shield is operably coupled to a lower portion of the coil.

In one experiment, processes were used for stripping photoresist from wafers, e.g., <u>See</u> Fig. 9 reference numeral 933. The processes involved the use of a multi-step stripping operation to remove implanted photoresist from semiconductor wafers. Samples were prepared using eight-inch wafers. These wafers were spin coated with Mitsubishi Kasei positive photoresist MPR-4000. Spin coating occurred at 1,200 rpm and 120 C for 90 seconds. The resulting photoresist was about 1.2 microns in thickness in the sample wafers. These sample wafers were implanted to form a implanted hardened resist layer near the top of the photoresist.

An implant resist stripping process was performed to remove the top implant hardened resist. This occurred by stripping using an "un-balanced" phase and anti-phase coupling relationship in a half-wave helical resonator. The half-wave helical resonator was configured in one of the process chambers. In this chamber, the pedestal had a temperature of about 40 C to maintain a low wafer temperature. This low wafer temperature was maintained to reduce the possibility of "popping." Popping occurs when vapor in the underlying photoresist explodes through the implant hardened resist.

After the top hardened layer was removed. The wafer was transferred into a chamber operating at a full-wave multiple. This chamber operated at a frequency of about 27.12 MHz at a full-wave multiple. The pedestal of this chamber was at 150 to 200 C. The full wave structure provided for balanced phase and anti-phase coupled currents, thereby reducing the amount of capacitively coupled plasma, which can be detrimental to the underlying substrate. In this step, overashing was performed to substantially remove all photoresist material from the wafer. No damage occurred to the underlying substrate during this overashing step.

Once the photoresist has been stripped, the wafer is cooled. In particular, the wafer is removed from the full-wave multiple process chamber, and placed on the cooling station. This cooling station reduces the temperature of the wafer (which was heated). This wafer is then reloaded back into its wafer cassette. Once all wafers have been processed in the cassette, the cassette comprising the stripped wafers is removed from the cluster tool apparatus. Characteristics of this half-wave helical resonator were described in detail above. In the present experiments, the following tests also were performed.

Test 1: 6-inch wafers were ashed at a total pressure of 0.13 Torr using a gas flow of 0.2 standard liter per minute of pure oxygen, forward rf power of 2200 watts and a reflected power of 150 watts at an excitation frequency of 13.4 Mhz. The substrate was held at 60 C and wafers were ashed and then the discharge was extinguished). The ashing rate across the wafer was determined to vary between approximately 3411 Å/min and 3139 Å/min with the rates approximately symmetric about the center of each wafer and the maximum ashing rate at the center. The average etching rate was 3228 Å/min and etching uniformity was approximately 4 percent.

Test 2: 6-inch wafers were ashed at a total pressure of 1 Torr using a gas flow of 1 standard liter per minute, forward rf power of 2200 watts and a reflected power of 160 watts at an excitation frequency of 13.0 MHz. The substrate was held at 60 C and the ashing rate was determined to very between approximately 3144 Å/min and 3748 Å/min depending on position on a wafer. The etching uniformity was approximately 9 percent.

Test 3: Resist coated wafers were implanted with a selected dose of 5 x 10^{15} atoms/cm^2 at 40 kev arsenic (As). The wafers were cleaved into samples approximately 3 centimeters square.

Two samples were then ashed on the substrate support simultaneously, under the various conditions listed in Table 1.

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TABLE 1: Experimental Results for Ashing

Run	Time(s) (sec.)	Pressure (Torr.)	O_2 Flow (slm)*	Fwd Pwr (W)	Refl. Pwr (W)	rf freq. (MHz)	Temp (C)
A	180	0.23	0.5	2,000	180	13.2	68
B	132	0.06	0.2	2,150	180	13.3	90
C	180	0.13	0.2	2,200	150	13.3	60
D	300	0.13	0.2	2,200	150	13.3	40
E(I)	90	0.09	0.1	2,200	80	13.4	40
F(II)	150	0.09	0.1	2,200	80	13.4	40

*slm=standard liters per minute (or 1000 sccm)

(I) Unimplanted resist was used in this test and ashing was terminated before endpoint was reached to test uniformity. The average ashing rate was 5259 Å/min and uniformity was 7.5%.

(II) Implanted resist was etched for 150 sec, but endpoint was visible at 100 seconds.

Under conditions used for Run D, it was determined that resist was cleared from the entire wafer after 3 minute and 15 seconds. Consequently, the ashing time in the table included approximately 100 sec. overetching. Under conditions where practical ashing rates were attained, a visible plasma discharge and sheath could be observed over the wafer.

Diagnostic measurements of current similar to those performed in the conventional stripping apparatus were performed. In these measurements, currents from the shield of the resonator to the processing chamber gave values of at about 0.1 to 0.5 Amperes rms and less. These measurements were limited by error using available instrumentation. Accordingly, these currents were at least an order of magnitude below those currents measured above in the conventional stripping apparatus.

A visual inspection of the stripped wafers shows extremely good results. That is, the wafers were stripped at a sufficient rate for production operation and no substantial damaged occurred to the wafers. This provides for effective wafer turn-around-time and substantially no damage caused by the plasma. In addition, current measured from the shield to the chamber by elevating the shield on insulating blocks was less than about 0.5 Amperes rms and, in some instances, at or below measured error using available instrumentation. This current was substantially less than those measured in the conventional stripping apparatus.

While the invention has been described with reference to specific embodiments, various alternatives, modifications, and equivalents may be used. In fact, the invention also can be applied to almost any type of plasma discharge apparatus. This discharge apparatus can include an apparatus for plasma immersion ion implantation or growing diamonds, TCPs, and others. This discharge apparatus can be used for the manufacture of flat panel displays, disks, integrated circuits, diamonds, semiconductor materials, bearings, raw materials, and the like. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

WHAT IS CLAIMED IS:

a1

~~1. A process for fabricating a product, said process comprising the steps of subjecting a substrate to entities, at least one of said entities emanating from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase portion and anti-phase portion of capacitive current coupled from the inductive coupling structure is selectively balanced;~~

~~wherein said inductive coupling structure is selectively balanced using a wave adjustment circuit.~~

add a2

08/660470

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

ABSTRACT OF THE DISCLOSURE

A process for fabricating a product 28, 119 . The process comprises the steps of subjecting a substrate to a composition of entities, at least one of the entities emanating from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase and anti-phase capacitive coupled voltages from the inductive coupling structure substantially balances.

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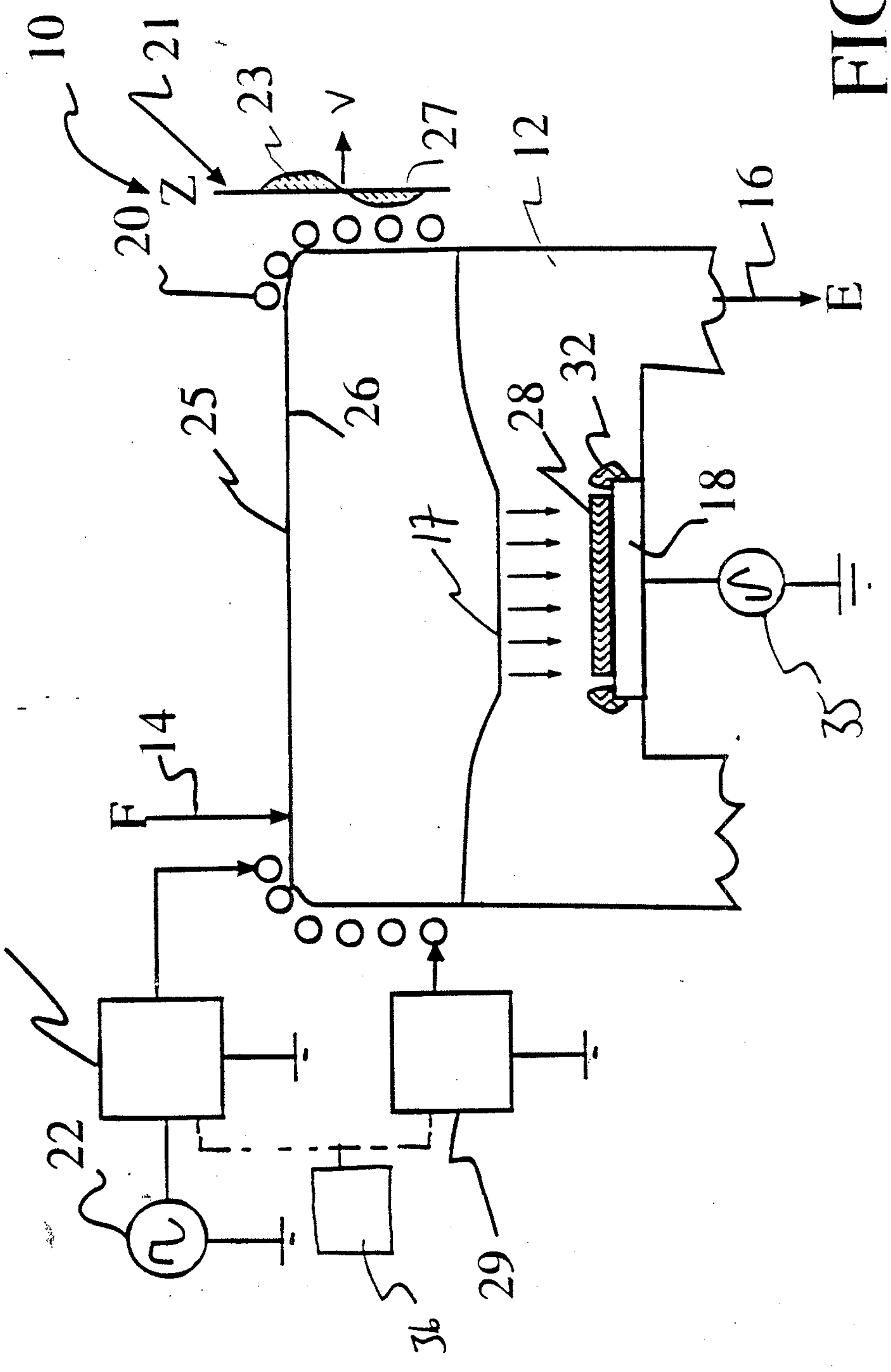

FIG. 1

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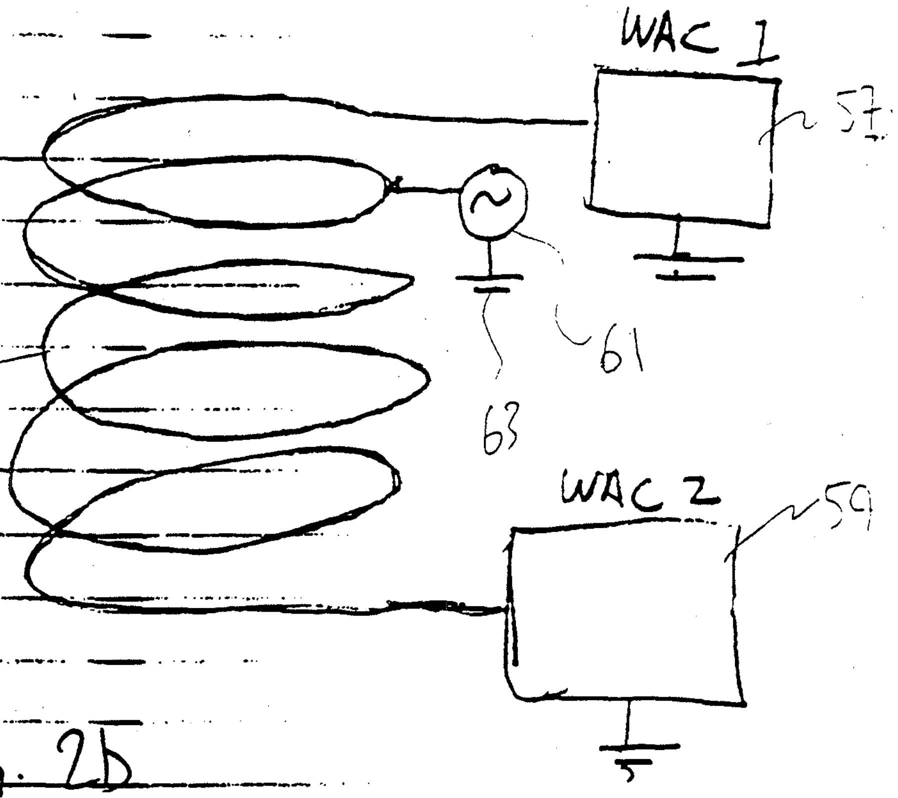

FIG. 2D

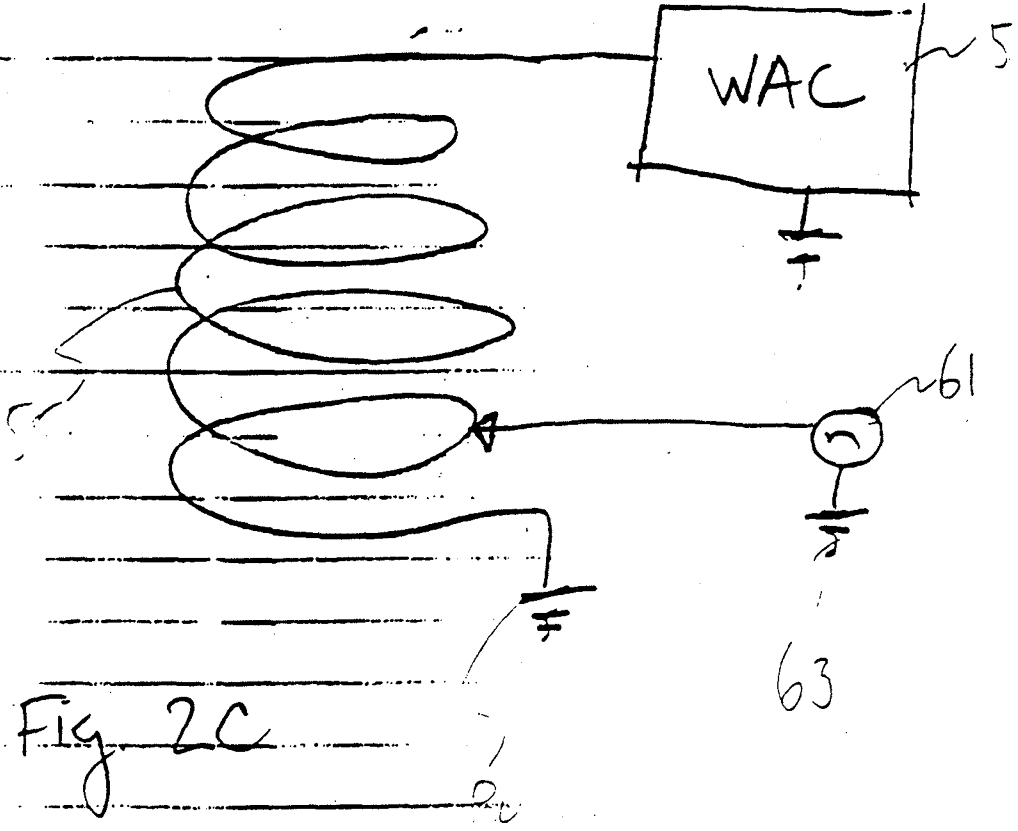

Fig. 2C

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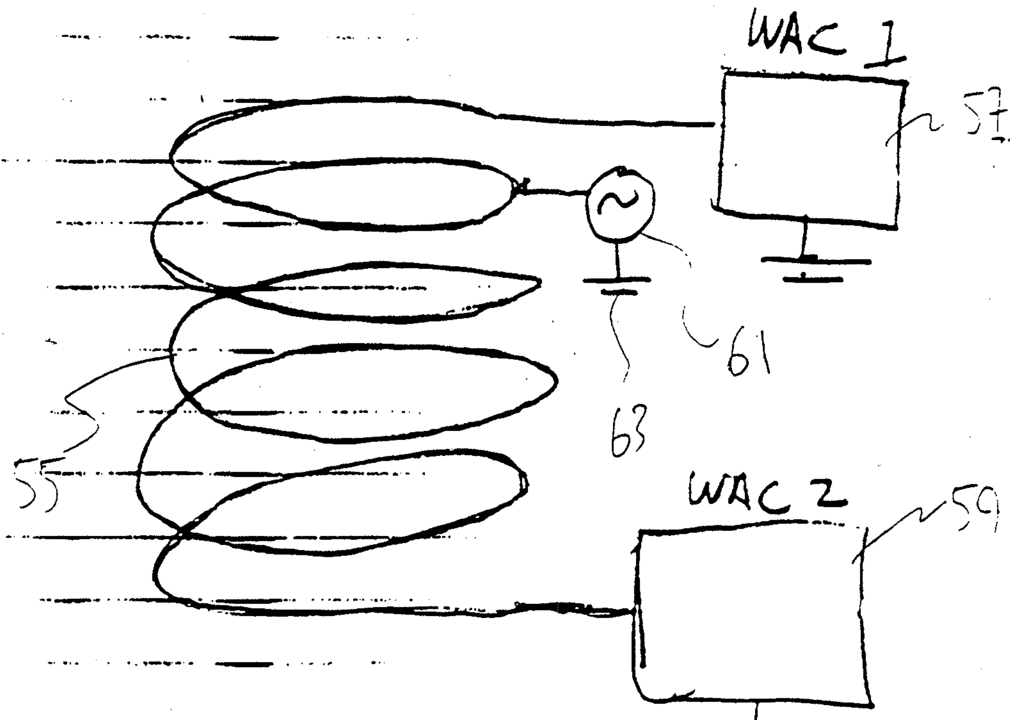

FIG. 2D

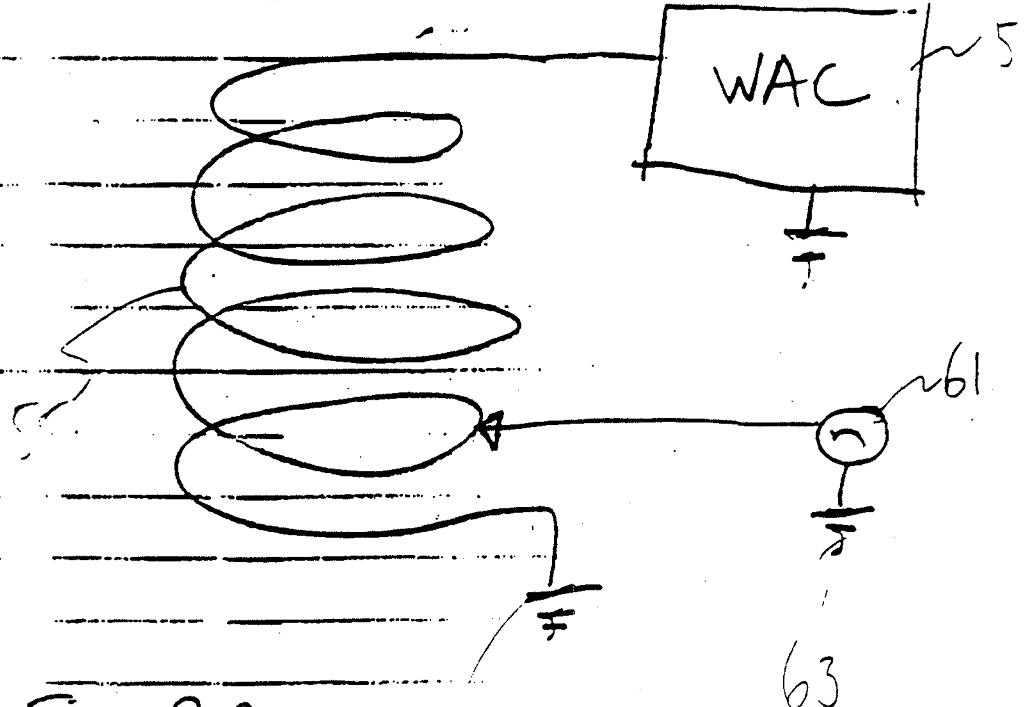

Fig 2C

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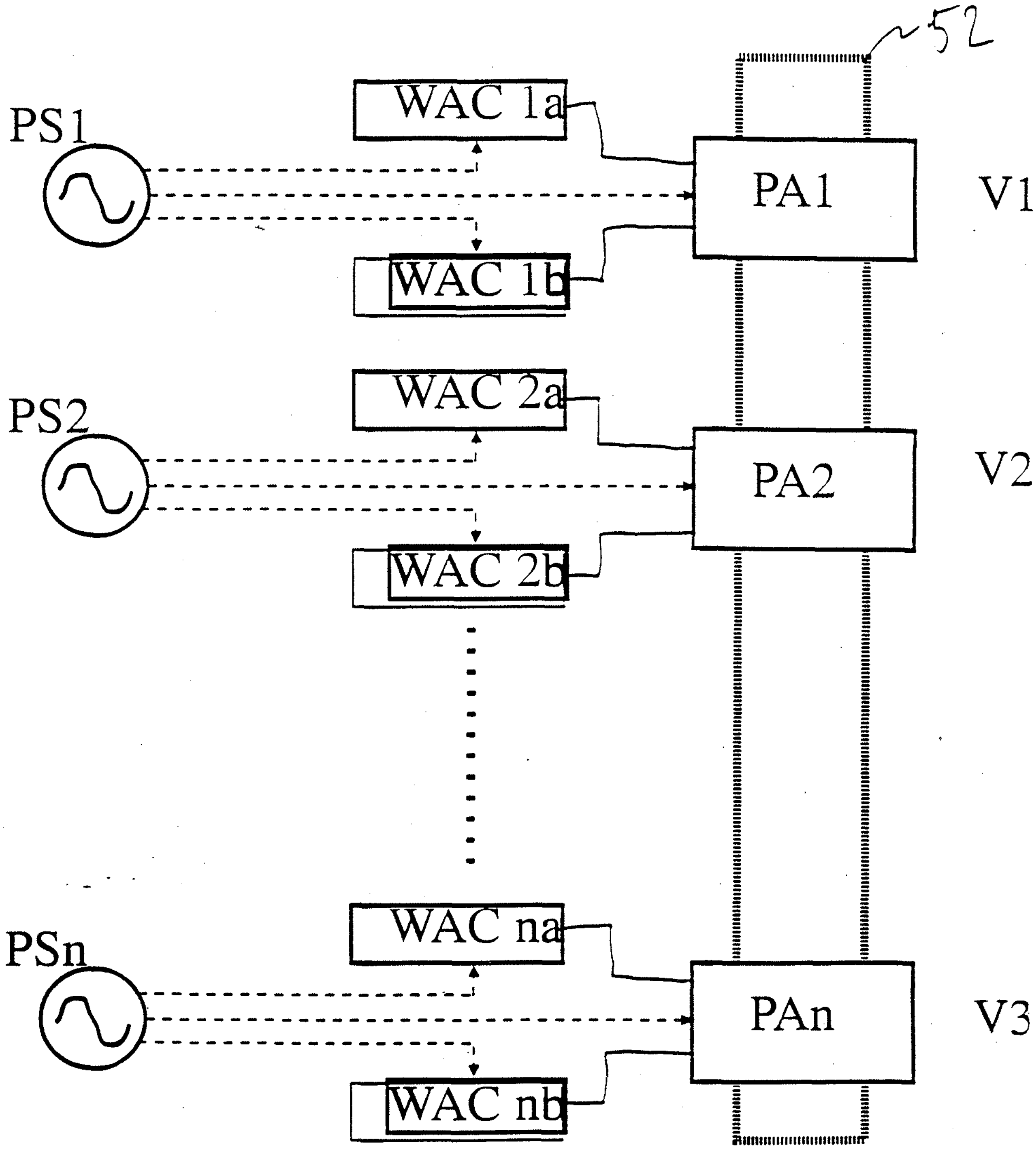

FIG. 2d

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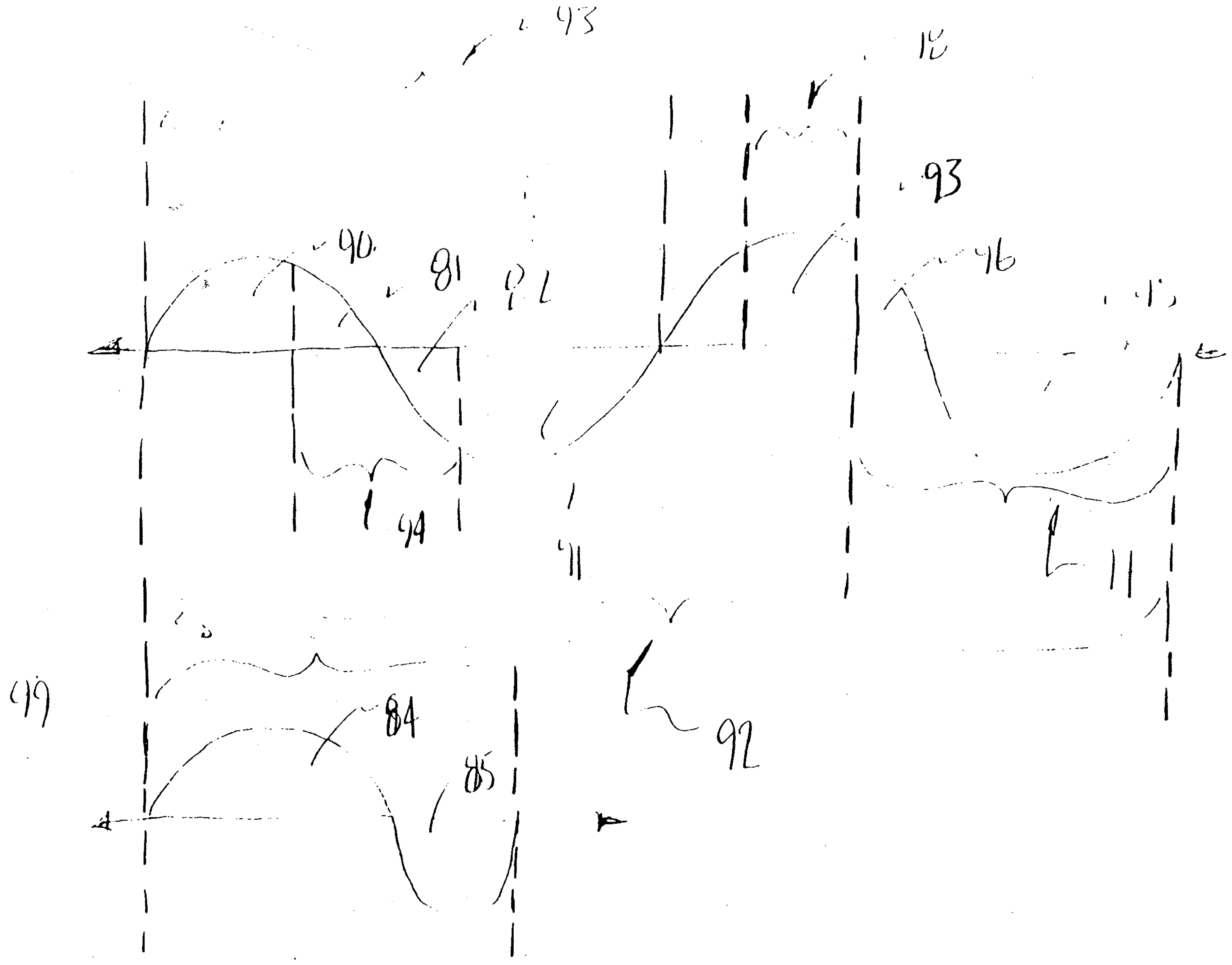
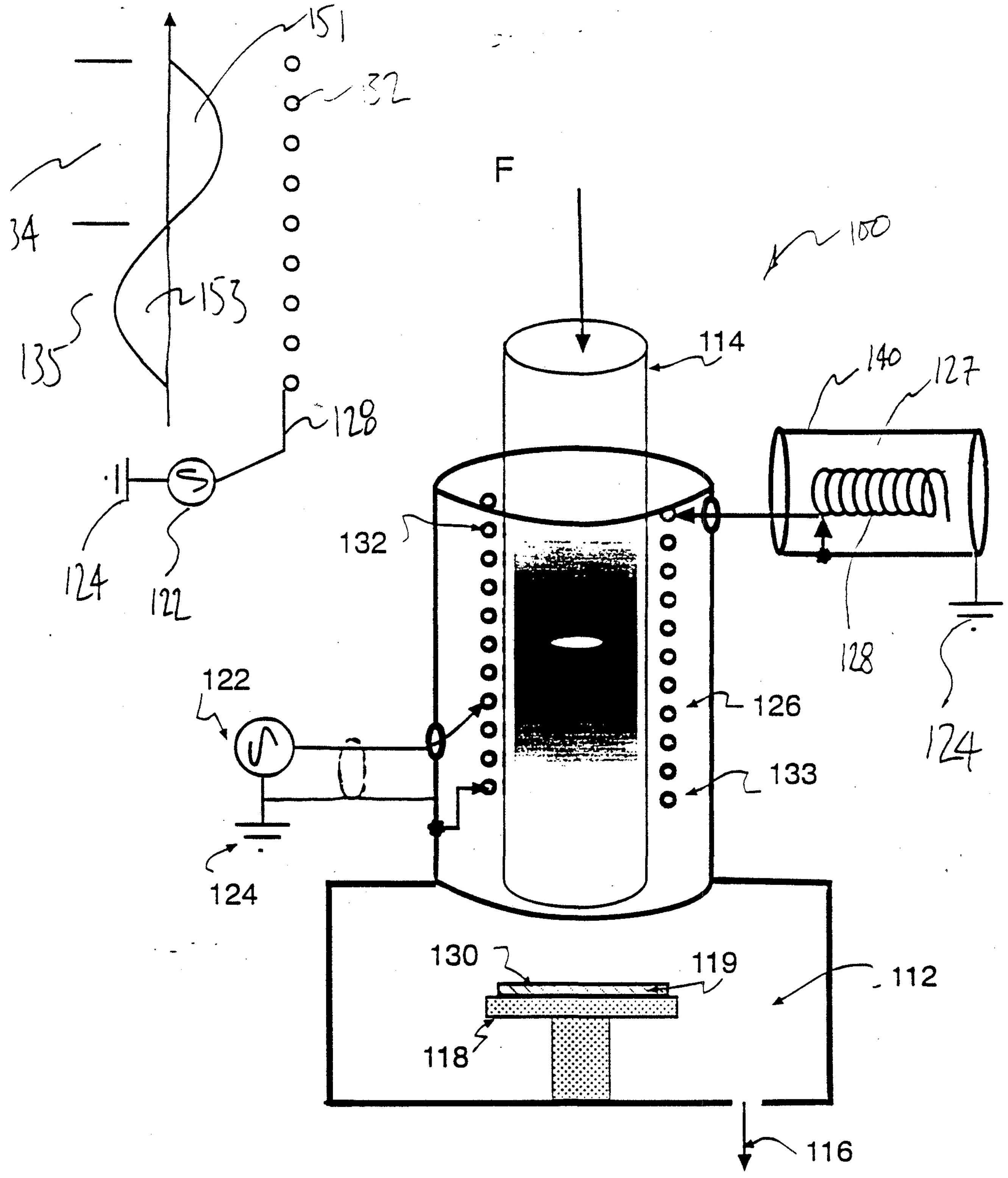


FIG. 2E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118
116

Fig 3

PRINT OF DRAWINGS
AS ORIGINALL LED

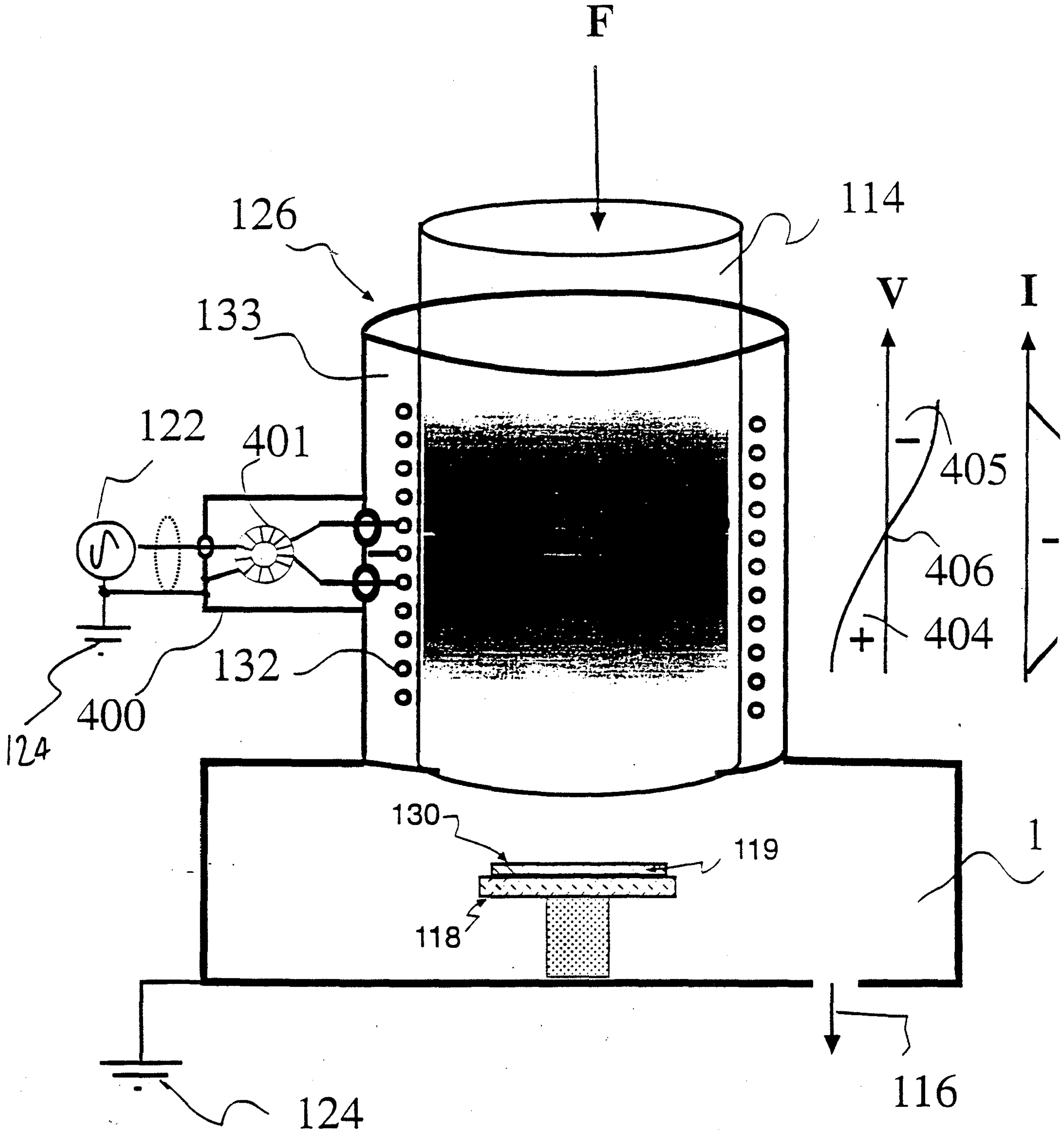

Fig. 4

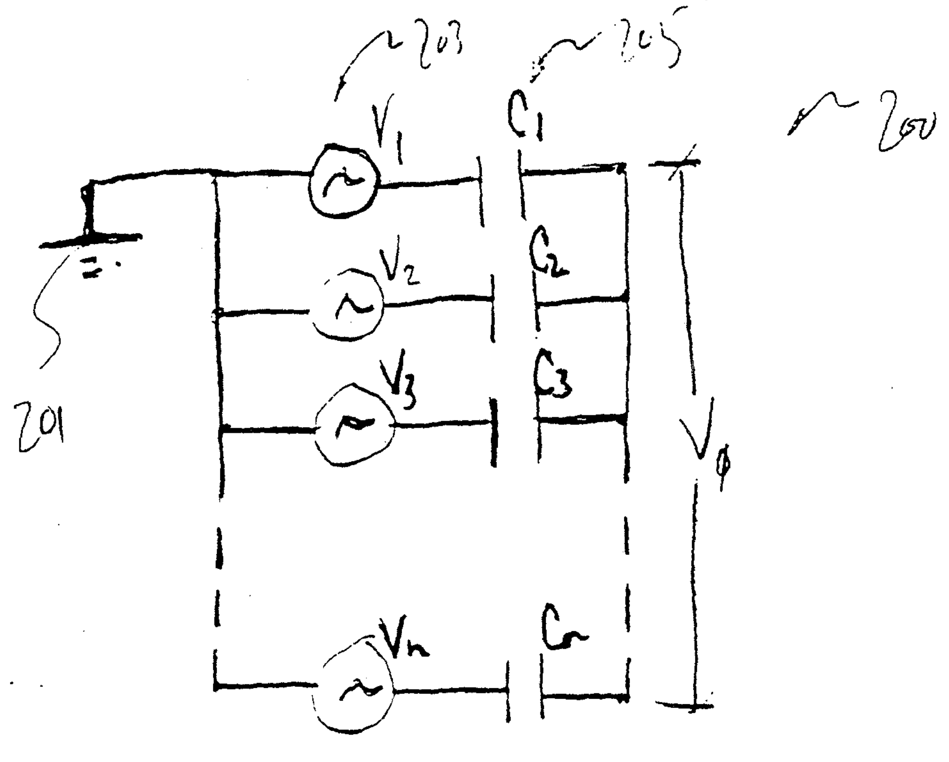

FIG. 5A

PRINT OF DRAWINGS
AS ORIGINALL FILED

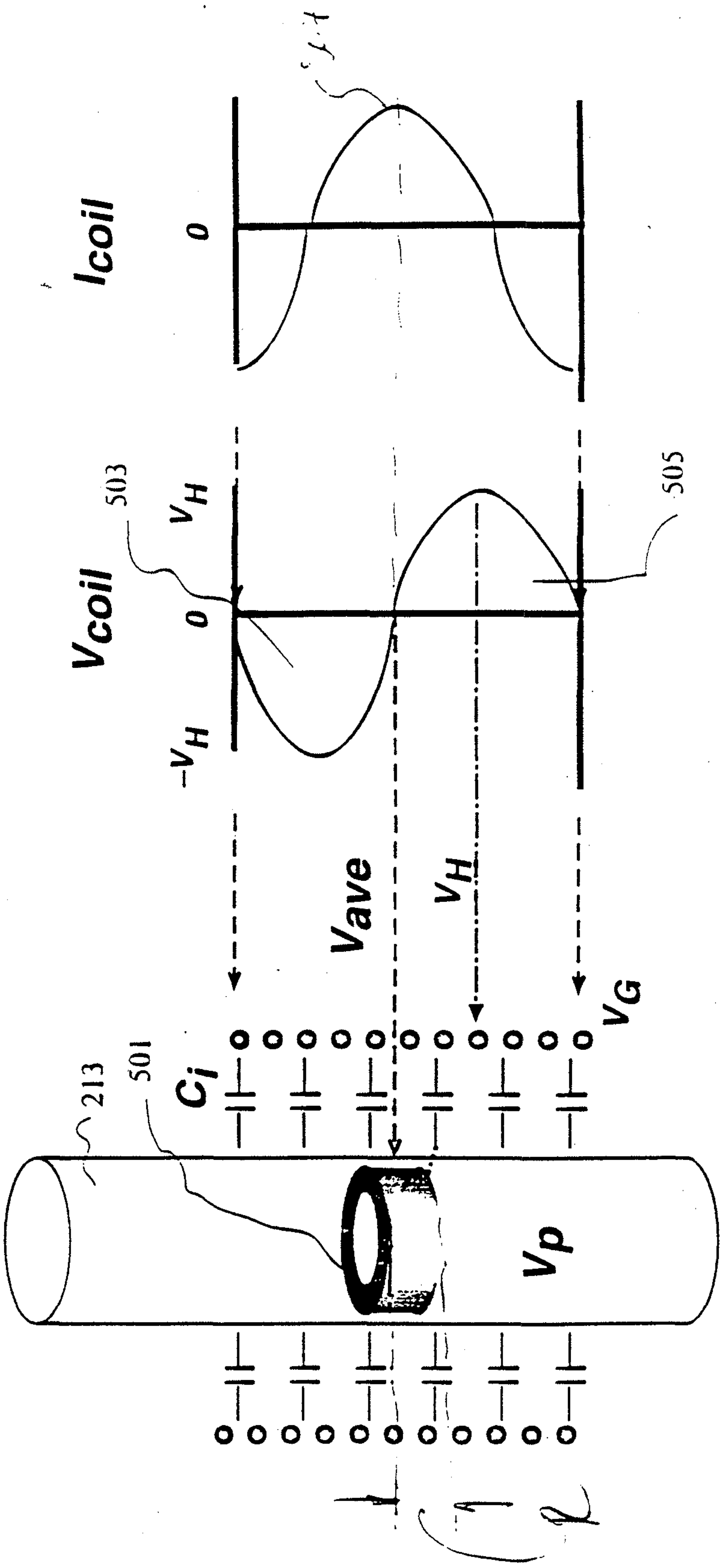

FIG. 5B

PRINT OF DRAWINGS
AS ORIGINALLY ED

FUNDAMENTAL STRUCTURE
OF FULL LAMBDA HELICAL RESONATOR DISCHARGE

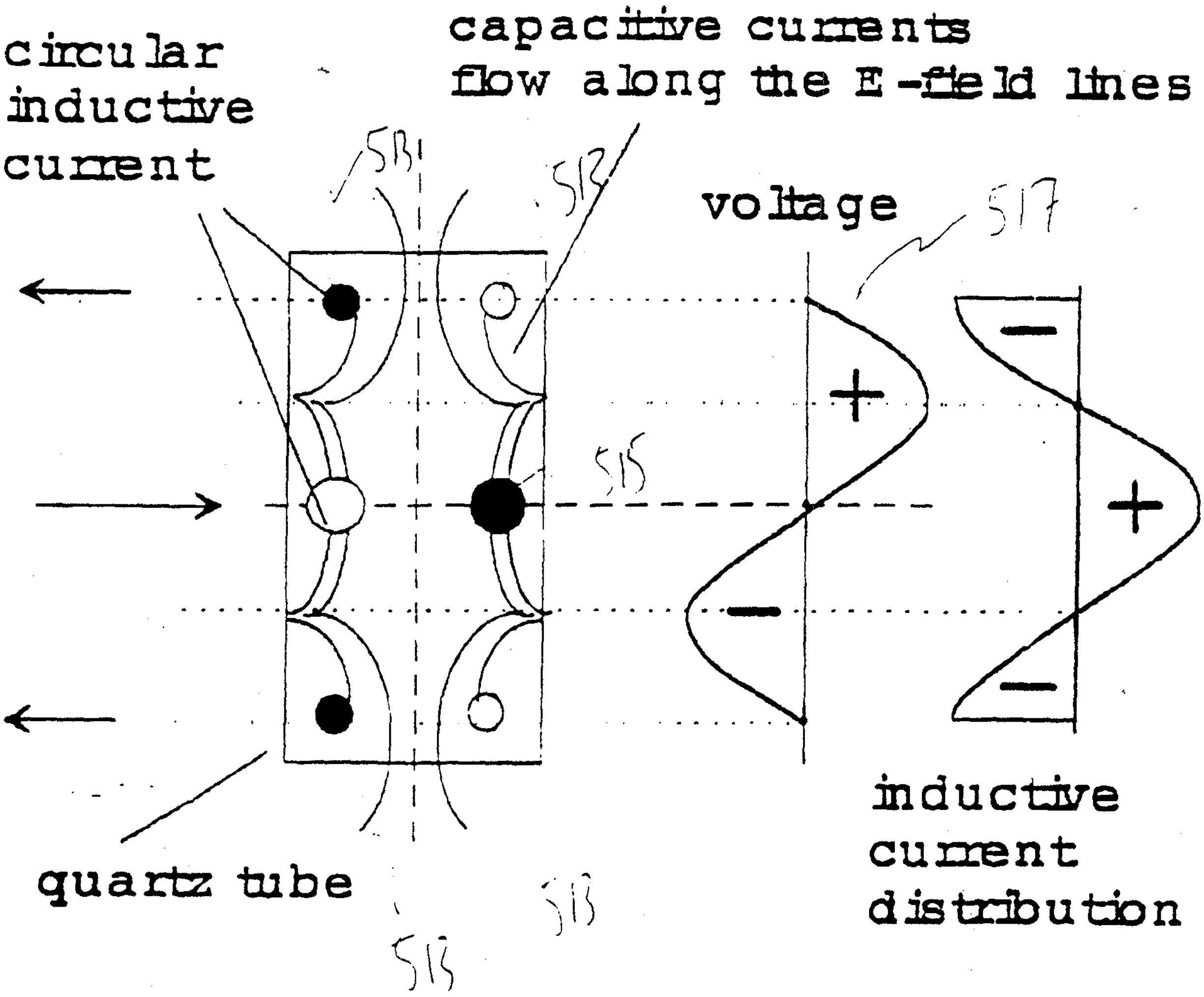

FIG. 5C

PRINT OF DRAWINGS
AS ORIGINALLY FILED

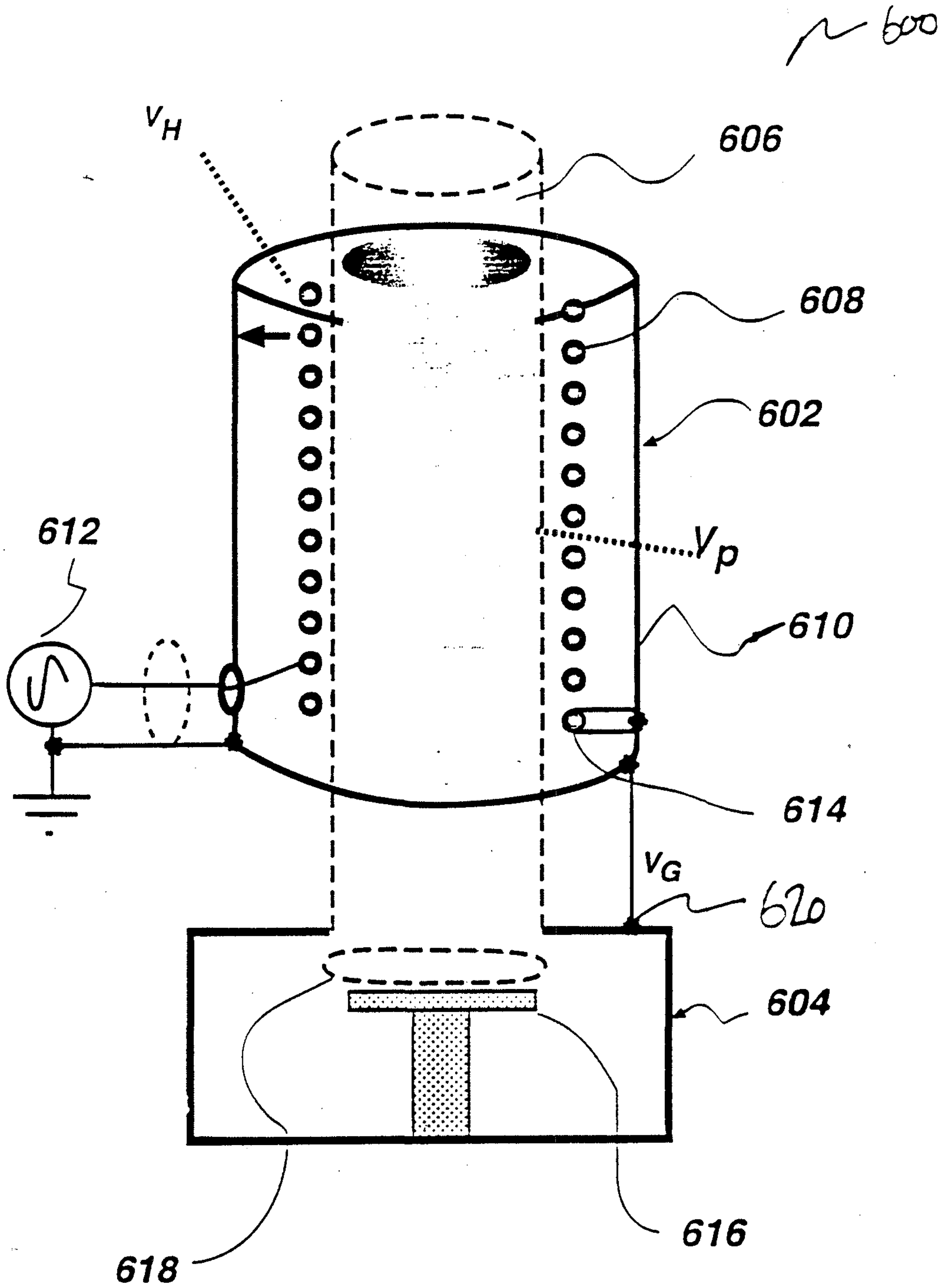

Fig. 6

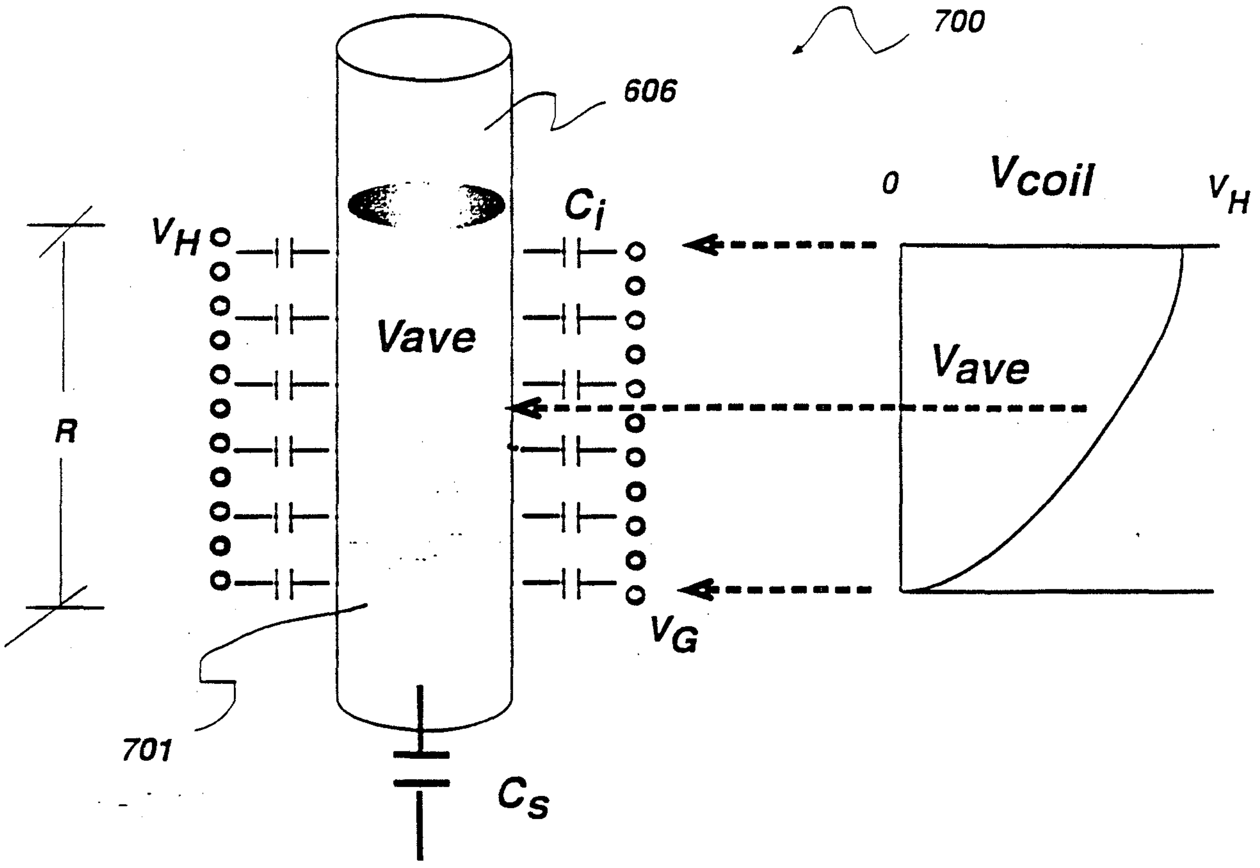

Fig. 7

PRINT OF DRAWINGS
AS ORIGINALJ ILED

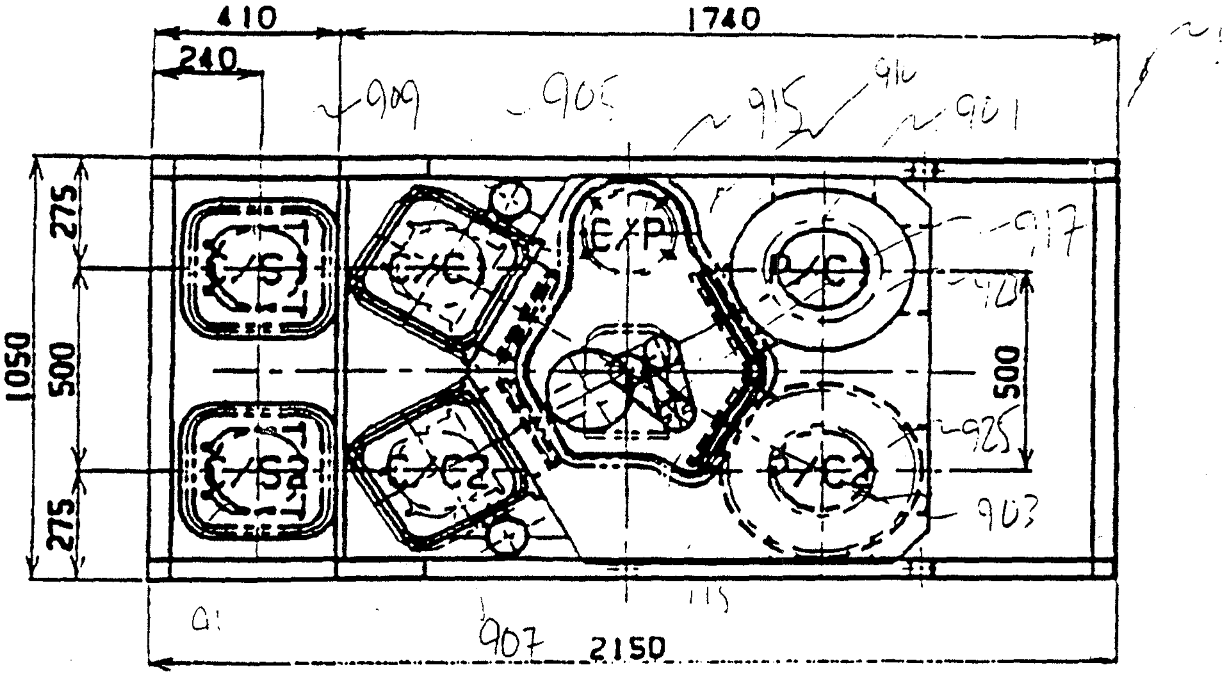

FIG. 8

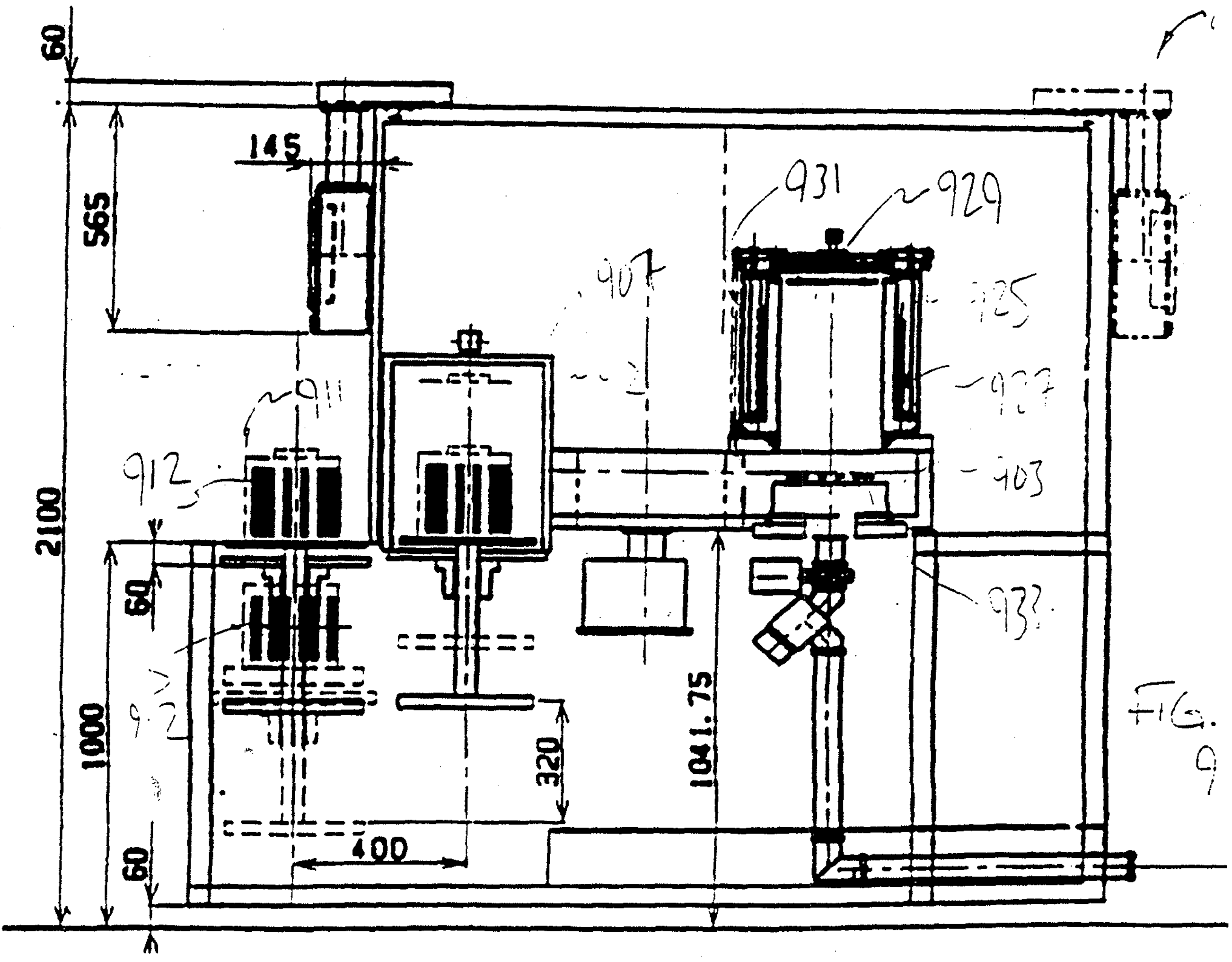

FIG. 9

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO./TITLE
08/866,040	05/30/97	FLAMM D	16655-000311

0292/1014

TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO CA 94111-3834

NOT ASSIGNED

1104

DATE MAILED: 10/14/97

NOTICE TO FILE MISSING PARTS OF APPLICATION
Filing Date Granted

An Application Number and Filing Date have been assigned to this application. However, the items indicated below are missing. The required items and fees identified below must be timely submitted ALONG WITH THE PAYMENT OF A SURCHARGE for items 1 and 3-6 only of $ 130 for a ☑ large entity ☐ small entity in compliance with 37 CFR 1.27. The surcharge is set forth in 37 CFR 1.16(e). Applicant is given TWO MONTHS FROM THE DATE OF THIS NOTICE within which to file all required items and pay any fees required above to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

If all required items on this form are filed within the period set above, the total amount owed by applicant as a ☑ large entity ☐ small entity (verified statement filed), is $ 920.

☑ 1. The statutory basic filing fee is:
  ☑ missing.
  ☐ insufficient.
  Applicant must submit $ 790 to complete the basic filing fee and/or file a verified small entity statement claiming such status (37 CFR 1.27).

☐ 2. Additional claim fees of $ __________, including any multiple dependent claim fees, are required.
  Applicant must either submit the additional claim fees or cancel additional claims for which fees are due.

☑ 3. The oath or declaration:
  ☑ is missing.
  ☐ does not cover the newly submitted items.
  ☐ does not identify the application to which it applies.
  ☐ does not include the city and state or foreign country of applicant's residence.
  An oath or declaration in compliance with 37 CFR 1.63, including residence information and identifying the application by the above Application Number and Filing Date is required.

☐ 4. The signature(s) to the oath or declaration is/are:
  ☐ missing.
  ☐ by a person other than inventor or person qualified under 37 CFR 1.42, 1.43, or 1.47.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.

☐ 5. The signature of the following joint inventor(s) is missing from the oath or declaration:
  ____
  An oath or declaration listing the names of all inventors and signed by the omitted inventor(s), identifying this application by the above Application Number and Filing Date, is required.

☐ 6. A $ __________ processing fee is required since your check was returned without payment (37 CFR 1.21(m)).

☐ 7. Your filing receipt was mailed in error because your check was returned without payment.

☐ 8. The application does not comply with the Sequence Rules.
  See attached "Notice to Comply with Sequence Rules 37 CFR 1.821-1.825."

☐ 9. OTHER:

Direct the response and any questions about this notice to "Attention: Box Missing Parts."

A copy of this notice MUST be returned with the response.

D. Durham
Customer Service Center
Initial Patent Examination Division (703) 308-1202

FORM PTO-1533 (REV.7-96)

PART 3 - OFFICE COPY

*U.S. GPO: 1996-404-496/40515

SECTOR

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Assistant Commissioner for Patents, Attn: Box Missing Parts, Washington, D.C. 20231, on December 12, 1997

TOWNSEND and TOWNSEND and CREW LLP

By Diane Elzinga

PATENT

Attorney Docket No. 16655-000311

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:	
Daniel L. Flamm, et al.	Examiner: Unassigned
Serial No.: 08/866,040	Art Unit: Unassigned
Filed: May 30, 1997	TRANSMITTAL LETTER - RESPONSE TO NOTICE OF MISSING PARTS
For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING	

Attn: Box Missing Parts
Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Pursuant to the Notice to File Missing Parts of Application - Filing Date Granted dated October 14, 1997, enclosed are the following to be made of record in the above-identified application:

1) Executed Declaration and Power of Attorney;
2) Executed Verified Statement Claiming Small Entity;
3) Copy of Notice of Missing Parts;
4) Postcard.

Please charge Deposit Account No. 20-1430 for the following fees:

a)	Filing Fee (§1.16(a))(Small Entity)	$ 395.00
b)	Excess Claims Fee (§1.16(b), (c):	
	1 - 20 = 0 x 11.00 =	$ 0.00
	1 - 3 = 0 x 42.00 =	$ 0.00
c)	Missing Parts Surcharge (§1.16(e))	$ 65.00
	TOTAL FEES TO BE CHARGED:	**$ 460.00**

The Commissioner is hereby authorized to charge any additional fees associated with this paper or during the pendency of this application, or credit any overpayment to Deposit Account

No. 20-1430 for this paper and during the prosecution of this application. This Transmittal Letter is submitted in triplicate.

Respectfully submitted,

Dated: 12/12/97

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400
Fax (650) 326-2422
RTO:de

rto\work\16655\3-1-1mp.res

Atty. Docket No. 16655-000311

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) and 1.27(b)) - INDEPENDENT INVENTOR

cant or Patentee: Daniel L. Flamm
cation or Patent No.: 08/866,040
or Issued: May 30, 1997
ROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

As a below named inventor, I hereby declare that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office regarding the invention entitled PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING described in:

☐ the specification filed herewith.
☒ Application No. 08/866,040, filed May 30, 1997.
☐ Patent No. ______, issued ______.

I have not assigned, granted, conveyed or licensed and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey or license any rights in the invention is listed below:*

☐ No such person, concern, or organization
☐ Persons, concerns or organizations listed below*

*NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

Name ______________________________
Address ______________________________
____
☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

Name ______________________________
Address ______________________________
____
☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Name of Inventor: Daniel L. Flamm	Name of Inventor:	Name of Inventor:
Daniel L. Flamm Signature of Inventor	Signature of Inventor	Signature of Inventor
Date 11/8/97	Date:	Date:

33.MRG 8/96
16655\3-1-1se.dec

Attorney Docket No. 16655-000311

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I declare that:
My residence, post office address and citizenship are as stated below next to my name; I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: **PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING** the specification of which ___ is attached hereto or _X_ was filed on _May 30, 1997_ as Application Serial No. _08/866,040_ and was amended on ___________ (if applicable).

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56. I claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign applications(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Country	Application No.	Date of Filing	Priority Claimed Under 35 USC 119
			Yes ___ No ___
			Yes ___ No ___

I claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Date of Filing	Status
08/567,224	December 4, 1995	___ Patented _X_ Pending ___ Abandoned
08/736,315	October 23, 1996	___ Patented ___ Pending _X_ Abandoned

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

Richard T. Ogawa, Reg. No. **37,692**
William J. Bohler, Reg. No. **31,487**
Kenneth R. Allen, Reg. No. **27,301**

Send Correspondence to: **Richard T. Ogawa** **TOWNSEND and TOWNSEND AND CREW LLP** **Two Embarcadero Center, 8th Floor** **San Francisco, CA 94111**	Direct Telephone Calls to: (Name, Reg. No., Telephone No.) **Name: Richard T. Ogawa** **Reg. No. 37,692** **Telephone: 650 326-2400**

Full Name of Inventor 1	Last Name **Flamm**	First Name **Daniel**	Middle Name or Initial **L.**	
Residence & Citizenship	City **Walnut Creek**	State/Foreign Country **California**	Country of Citizenship **U.S.A.**	
Post Office Address	Post Office Address **476 Green View Drive**	City **Walnut Creek**	State/Country **California**	Zip Code **94596**
Full Name of Inventor 2	Last Name	First Name	Middle Name or Initial	
Residence & Citizenship	City	State/Foreign Country	Country of Citizenship	
Post Office Address	Post Office Address	City	State/Country	Zip Code
Full Name of Inventor 3	Last Name	First Name	Middle Name or Initial	
Residence & Citizenship	City	State/Foreign Country	Country of Citizenship	
Post Office Address	Post Office Address	City	State/Country	Zip Code

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signature of Inventor 1 Daniel L. Flamm	Signature of Inventor 2	Signature of Inventor 3
Date 11/8/97	Date	Date

16655-000311

UNITED ATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

PTO

12/15/97
JC526 U.S. PTO

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO./TITLE
/866,040	05/30/97	FLAMM	D 16655-000311

0292/1014

TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO CA 94111-3834

NOT ASSIGNED

1104
DATE MAILED:
10/14/97

NOTICE TO FILE MISSING PARTS OF APPLICATION
Filing Date Granted

An Application Number and Filing Date have been assigned to this application. However, the items indicated below are missing. The required items and fees identified below must be timely submitted ALONG WITH THE PAYMENT OF A SURCHARGE for items 1 and 3-6 only of $ 130 for a ☑ large entity ☐ small entity in compliance with 37 CFR 1.27. The surcharge is set forth in 37 CFR 1.16(e). Applicant is given TWO MONTHS FROM THE DATE OF THIS NOTICE within which to file all required items and pay any fees required above to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

If all required items on this form are filed within the period set above, the total amount owed by applicant as a ☑ large entity ☐ small entity (verified statement filed), is $ 920 .

☑ 1. The statutory basic filing fee is:
  ☑ missing.
  ☐ insufficient.
  Applicant must submit $ 790 to complete the basic filing fee and/or file a verified small entity statement claiming such status (37 CFR 1.27).

☐ 2. Additional claim fees of $________, including any multiple dependent claim fees, are required.
  Applicant must either submit the additional claim fees or cancel additional claims for which fees are due.

☑ 3. The oath or declaration:
  ☑ is missing.
  ☐ does not cover the newly submitted items.
  ☐ does not identify the application to which it applies.
  ☐ does not include the city and state or foreign country of applicant's residence.
  An oath or declaration in compliance with 37 CFR 1.63, including residence information and identifying the application by the above Application Number and Filing Date is required.

☐ 4. The signature(s) to the oath or declaration is/are:
  ☐ missing.
  ☐ by a person other than inventor or person qualified under 37 CFR 1.42, 1.43, or 1.47.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.

☐ 5. The signature of the following joint inventor(s) is missing from the oath or declaration:
  ____
  An oath or declaration listing the names of all inventors and signed by the omitted inventor(s), identifying this application by the above Application Number and Filing Date, is required.

☐ 6. A $________ processing fee is required since your check was returned without payment (37 CFR 1.21(m)).

☐ 7. Your filing receipt was mailed in error because your check was returned without payment.

☐ 8. The application does not comply with the Sequence Rules.
  See attached "Notice to Comply with Sequence Rules 37 CFR 1.821-1.825."

☐ 9. OTHER:

Direct the response and any questions about this notice to "Attention: Box Missing Parts."

A copy of this notice MUST be returned with the response.

D. Durham
Customer Service Center
Initial Patent Examination Division (703) 308-1202

01/15/1998 JTIPPETT 00000088 DAH:201430 08866040
01 C:201 395.00 CH
02 C:205 65.00 CH

FORM PTO-1533 (REV.7-96)

PART 2-COPY TO BE RETURNED WITH RESPONSE

*U.S. GPO: 1996-404-496/40515

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
08/866,040	05/30/97	FLAMM	D 16655-000311

HM21/1002
TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO CA 94111-3834

EXAMINER	
SCHEINER, L	
ART UNIT	PAPER NUMBER
1648	4

DATE MAILED: 10/02/98

This is a communication from the examiner in charge of your application.
COMMISSIONER OF PATENTS AND TRADEMARKS

OFFICE ACTION SUMMARY

☑ Responsive to communication(s) filed on 12/15/97.

☐ This action is **FINAL**.

☐ Since this application is in condition for allowance except for formal matters, **prosecution as to the merits is closed** in accordance with the practice under *Ex parte Quayle*, 1935 D.C. 11; 453 O.G. 213.

A shortened statutory period for response to this action is set to expire 3 month(s), or thirty days, whichever is longer, from the mailing date of this communication. Failure to respond within the period for response will cause the application to become abandoned. (35 U.S.C. § 133). Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

Disposition of Claims

☑ Claim(~~s~~) 1 is/~~are~~ pending in the application.

Of the above, claim(s) ______ is/are withdrawn from consideration.

☐ Claim(s) ______ is/are allowed.

☑ Claim(s) 1 is/~~are~~ rejected.

☐ Claim(s) ______ is/are objected to.

☐ Claims ______ are subject to restriction or election requirement.

Application Papers

☐ See the attached Notice of Draftsperson's Patent Drawing Review, PTO-948.

☐ The drawing(s) filed on ______ is/are objected to by the Examiner.

☐ The proposed drawing correction, filed on ______ is ☐ approved ☐ disapproved.

☐ The specification is objected to by the Examiner.

☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

☐ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been

☐ received.

☐ received in Application No. (Series Code/Serial Number) ______.

☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: ______.

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

Attachment(s)

☑ Notice of Reference Cited, PTO-892

☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). ______

☐ Interview Summary, PTO-413

☐ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Notice of Informal Patent Application, PTO-152

-- SEE OFFICE ACTION ON THE FOLLOWING PAGES --

PTOL-326 (Rev. 10/95)

Claim 1 is rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

Claim 1 is vague and indefinite. That is, the term "entities may encompass virtually any compound or composition providing that it may be discharged in a gaseous state. Moreover, the phrase "selectively balanced" may refer to any ratio and therefore fails to further define or limit the claim. That is, applicant's fail to particularly point out their invention in claim 1.

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless --
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

Claim 1 is rejected under 35 U.S.C. 102(b) as being anticipated by Asmussen et al. (U.S. Patent No. 4,943,345).

Asmussen et al. teach that which is claimed (please see the claims). Please see claim 26 wherein the wave generating means can be adjusted in input power to the coupler means and the inlet means can be adjusted as to flow rate of the gas so as to vary the excited species which impinge on the substrate.

Claim 1 rejected under 35 U.S.C. 102(b) as being anticipated by Ohkawa et al (U.S. Patent No. 5,361,016).

Ohkawa et al. teach a method for producing high density plasma which does not appear to differ from that which is instantly claimed.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Laurie Scheiner, whose telephone number is (703) 308-1122. Any inquiry of a general nature or relating to the status of this application should be directed to the Group 1600 receptionist whose telephone number is (703) 308-0196.

Correspondence related to this application may be submitted to Group 1600 by facsimile transmission. The faxing of such papers must conform with the notice published in the Official Gazette, 1096 OG 30 (November 15, 1989). Official communications should be directed toward one of the following Group 1600 fax numbers: (703) 308-4242 or (703) 305-3014. Informal communications may be submitted directly to the Examiner through the following fax number: (703) 308-4426. Applicants are encouraged to notify the Examiner prior to the submission of such documents to facilitate their expeditious processing and entry.

LS
Laurie Scheiner/LAS
September 29, 1998

LAURIE SCHEINER
PRIMARY EXAMINER

Notice of References Cited	Application No. 08/866,040	Applicant(s)	
	Examiner	Group Art Unit 1648	Page 1 of 1

U.S. PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS
	A	4,943,345	7/90	ASmussen et al.	156	643
	B	5,361,016	11/94	OHKawa et al.	315	111.41
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	COUNTRY	NAME	CLASS	SUBCLASS
	N						
	O						
	P						
	Q						
	R						
	S						
	T						

NON-PATENT DOCUMENTS

*		DOCUMENT (Including Author, Title, Source, and Pertinent Pages)	DATE
	U		
	V		
	W		
	X		

* A copy of this reference is not being funished with this Office action.
(See Manual of Patent Examining Procedure, Section 707.05(a).)

U.S. Patent and Trademark Office
PTO-892 (Rev. 9-96)

Part of Paper No. 4

*U.S. GPO: 1996-420-311/40176

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Assistant Commissioner for Patents Washington, D.C. 20231

On April 2, 1999

By: Diane Elzingre

OIPE
APR 05 1999
PATENT & TRADEMARK OFFICE

PATENT
Attorney Docket No.: 016655-000311

#5

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

For: **PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING**

Examiner: ~~L. Alejandro~~ Scheiner

Art Unit: 1648

PETITION TO EXTEND TIME

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicant petitions the Assistant Commissioner of Patents to extend the time for response to the Office Action, dated October 2, 1998 for 3 months, from January 2, 1999 to April 2, 1999. An appropriate response in the form of an Amendment is enclosed herewith.

Please charge the fee of $435.00 to the undersigned's Deposit Account No. 20-1430. Please charge any additional fees or credit overpayment to the above deposit account. This petition is submitted in duplicate.

04/08/1999 CHOANG 00000062 201430 08866040
03 FC:217 435.00 CH

Respectfully submitted,

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
Tel: (650) 326-2400
Fax: (650) 326-2422
RTO:de

PA 184239 v1

99 APR -9 PM 12:59
GROUP 180

GP1648 #5

Amendment Transmittal

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400

Attorney Docket No. 16655-000311

O I P E
APR 05 1999
PATENT & TRADEMARK OFFICE

In re application of: Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

Group Art Unit: 1648

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Date: April 2, 1999

I hereby certify that this is being deposited with the United States Postal Service as first class mail in an envelope addressed to:

Assistant Commissioner for Patents
Washington, D.C. 20231

Signed: ____________

THE ASSISTANT COMMISSIONER FOR PATENTS
Washington, D.C. 20231

Sir:

Transmitted herewith is an amendment in the above-identified application.

[X] Enclosed is a petition to extend time to respond.
[X] Small entity status of this application under 37 CFR 1.9 and 1.27 has been established by a verified statement previously submitted.
[ ] A verified statement to establish small entity status under 37 CFR 1.9 and 1.27 is enclosed.
[X] Postcard

If any extension of time is needed, then this response should be considered a petition therefor.
The filing fee has been calculated as shown below:

	(Col. 1) CLAIMS REMAINING AFTER AMENDMENT		(Col. 2) HIGHEST NO. PREVIOUSLY PAID FOR	(Col. 3) PRESENT EXTRA
TOTAL	* 32	MINUS	** 20	= 12
INDEP.	* 6	MINUS	*** 3	= 3
[ ] FIRST PRESENTATION OF MULTIPLE DEP. CLAIM				

SMALL ENTITY RATE	SMALL ENTITY ADDIT. FEE		OTHER THAN SMALL ENTITY RATE	OTHER THAN SMALL ENTITY ADDIT. FEE
12x $9.00 =	$108.00		x $18.00 =	
3x $39.00 =	$117.00		x $78.00 =	
+ $130.00 =			+ $260.00 =	
TOTAL ADDIT. FEE	$225.00	OR	TOTAL	

* If the entry in Col. 1 is less than the entry in Col. 2, write "0" in Col. 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, write "20" in this space.
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, then write "3" in this space. The "Highest Number Previously Paid For" (Total or Independent) is the highest number found from the equivalent box in Col. 1 of a prior amendment or the number of claims originally filed.

[ ] No fee is due.

Please charge Deposit Account No. 20-1430 as follows:

[X] Claims fee $ 225.00
[X] Any additional fees associated with this paper or during the pendency of this application.

2 extra copies of this sheet are enclosed.

TOWNSEND and TOWNSEND and CREW LLP

Richard T. Ogawa, Reg. No.: 37,692
Attorneys for Applicant

I hereby certify that this correspondence is being
deposited with the United States Postal Service as
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Assistant Commissioner for Patents,
Washington, D.C. 20231,
on April 2, 1999

TOWNSEND and TOWNSEND and CREW LLP

By Diane Elzingre

#6

PATENT

Attorney Docket No. 16655-000311

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:	
Daniel L. Flamm	Examiner: Scheiner, L.
Application No.: 08/866,040	Art Unit: 1648
Filed: May 30, 1997	<u>AMENDMENT UNDER 37 CFR §1.115</u>
For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING	

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sirs:

In response to the Office Action mailed October 2, 1998, the period for response being extended as a result of the enclosed Petition to Extend Time and requisite fee, please amend the above-cited application as follows.

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02 FC:203 108.00 CH

A

IN THE CLAIMS:

Please amend claim 1 and add claims 2-32 as follows. For the convenience of the Examiner, all claims subject to examination are shown, even if not being amended.

A1

1. (Amended) A process for fabricating a product, said process comprising the steps of subjecting a substrate to entities, at least one of said entities emanating from **[a species generated by]** a gaseous discharge excited by a high frequency field from an inductive coupling structure in which **[the vector sum of]** a phase portion and an anti-phase portion of capacitive currents coupled from the inductive coupling structure **[is]** are selectively balanced;

wherein said inductive coupling structure is adjusted **[selectively balanced]** using a wave adjustment circuit, said wave adjustment circuit adjusting the phase portion and the anti-phase portion of the capacitively coupled currents.

A2

2. (New) The process of claim 1 wherein the wave adjustment circuit selectively adjusts a frequency of an rf power supply.

3. (New) The process of claim 1 wherein the high frequency field is adjusted using a variable frequency power supply.

4. (New) The process of claim 1 wherein the wave adjustment circuit comprises a transmission line.

5. (New) The process of claim 1 wherein said process is provided in a chamber.

6. (New) The process of claim 5 wherein the chamber is provided for a process selected from etching, deposition, sputtering, or implantation.

7. (New) A process for manufacturing a product, said process comprising subjecting a substrate to at least one entity emanating from a gaseous discharge powered at least by a high frequency inductive field applied from a coupling structure, characterized in that at least one first capacitively coupled AC current flows from a first portion of said

~~coupling structure to a volume element of said gaseous discharge and at least a second capacitively coupled AC current flows from the gaseous discharge to a second portion of the coupling structure, said second capacitively coupled current having a predetermined phase relationship to said first capacitively coupled current wherein said first capacitively coupled AC current and the second capacitively coupled AC current to the plasma substantially cancel.~~

~~8. (New) The process of claim 7 wherein the coupling structure comprises an inductive coupling structure, said inductive coupling structure comprising a portion of said first capacitively AC current and a portion coupling the second capacitively coupled AC current.~~

a2

~~9. (New) The process of claim 7 wherein the inductively coupled powered is at least 15 percent of a net power input to the gaseous discharge.~~

~~10. (New) The process of claim 7 wherein the phase relationship is selected by a wave adjustment circuit.~~

~~11. (New) The process of claim 9 wherein the phase relationship is selected by means of a wave adjustment circuit.~~

~~12. (New) A process for manufacturing a product, said process comprising at least one step of subjecting a substrate to an entity emanating from a gaseous plasma discharge powered at least in part by a high frequency inductive field applied from a coupling structure, wherein said gaseous plasma discharge is coupled to a first portion of said coupling structure by a capacitance, said first coupling structure portion has a voltage distribution relative to a ground potential, said gaseous plasma discharge is capacitively coupled to at least a second portion of a coupling structure, characterized in that said second portion has a selected phase and capacitance relative to a phase and said capacitance of said first portion.~~

~~13. (New) The process of claim 12 wherein the capacitance of the second portion is adjusted during the process.~~

14. (New) The process of claim 12 wherein the selected phase is adjusted during the process.

15. (New) The process of claim 14 wherein the selected phase is adjusted by a wave adjustment circuit.

16. (New) The process of claim 12 wherein the process is controlled using a controller, the controller including a computer code.

a2

17. (New) The process of claim 12 wherein the process is controlled by a process sensing means.

18. (New) The process of claim 12 wherein the second coupling structure portion is a portion of said first coupling structure.

19. (New) The process of claim 12 wherein said coupling capacitance of the first portion and the coupling capacitance of the second portion are substantially equal.

20. (New) The process of claim 12 wherein said gaseous plasma discharge comprises a plasma potential that is controlled during said process.

21. (New) The process of claim 20 wherein said plasma potential is adjusted by means of a wave adjustment circuit.

22. (New) A process for manufacturing a product, said process comprising at least one step of subjecting a substrate to at least one entity emanating from a gaseous plasma discharge powered at least in part by a high frequency inductive field applied from an inductive coupling structure, said gaseous plasma discharge also powered by capacitive coupling, said capacitive coupling comprising a first element and a second element, the first element comprising a first capacitance and a first phase, the second element comprising a second capacitance and a second phase, wherein the first capacitance and the first phase are selected relative to the second capacitance and the second phase.

23. (New) The process of claim 22 wherein the inductive coupling structure comprises the first element.

24. (New) The process of claim 22 wherein the inductive coupling structure comprises the second element.

25. (New) The process of claim 22 wherein the process comprises a voltage distribution along said inductive coupling structure.

26. (New) The process of claim 25 wherein the voltage distribution is provided by a wave adjustment circuit.

a2

27. (New) A process for manufacturing a product, said process comprising at least one step of subjecting a substrate to at least one entity emanating from a gaseous discharge powered at least in part by a high frequency inductive field applied from a coupling structure, characterized in that least one first capacitively coupled AC current flows from a portion of said coupling structure to a volume element of said gaseous plasma discharge and at least a second capacitively coupled AC current flows from the gaseous plasma discharge to a distinct portion of the coupling structure, the second capacitively coupled AC current having a predetermined phase relationship to said first capacitively coupled AC current wherein said first capacitively coupled AC current and the second capacitively coupled AC current to the gaseous plasma discharge selectively cancel.

28. (New) A process for manufacturing a product, said process comprising subjecting a substrate to at least one entity emanating from a gaseous plasma discharge powered at least in part by a high frequency inductive field applied from a coupling structure, said gaseous plasma discharge being coupled to a first portion of said coupling structure by a coupling capacitance, said first coupling structure portion having a voltage distribution relative to a ground potential, and said gaseous plasma discharge being capacitively coupled to at least a second distinct portion of the coupling structure, characterized in that said second distinct portion has a selected phase and capacitance relative to a phase and capacitance of said first coupling structure portion.

a2

29. (New) The process of claim 28 wherein the gaseous plasma discharge comprises an average potential that is provided by a wave adjustment circuit.

30. (New) The process of claim 29 wherein the average potential is a selected potential relative to a ground potential.

31. (New) The process of claim 28 wherein said substrate is supported by a selected coupling structure.

32. (New) The process of claim 31 wherein the coupling structure is driven by a first power source and the selected coupling structure is powered by a second power source.

REMARKS

Claims 1-32 are now pending in this application.

35 U.S.C. §112

Claim 1 stands rejected under 35 U.S.C. §112, second paragraph. The Examiner has indicated that the term "entities may encompass virtually any compound or composition providing that it may be discharged in a gaseous state." Additionally, the phrase "selectively balanced" may refer to any ratio and therefore fails to further define or limit the claim. Applicant has carefully reviewed this rejection. Using claim 1, for example, Applicant would like to indicate that the present invention provides a claimed combination of elements for forming a novel plasma discharge, which can be adjusted by way of a wave adjustment circuit for selectively adjusting a phase and antiphase of capacitively coupled currents. These currents are coupled from an inductive coupling structure. The present invention teaches, for example, that selected portions of a standing wave on an inductive coupling structure can be in resonance with external wave adjustment circuits. Additionally, the invention can be applied to a variety of entities from the gaseous discharge. For easier reading, Applicant has amended claim 1 for the Examiner. Accordingly, Applicant believes the claim has been clarified which should traverse the rejection.

35 U.S.C. §102

The Examiner has rejected claim 1 under 35 U.S.C. §102(b) as being anticipated by Asmussen, et al. The Examiner has indicated that Asmussen, et al. supposedly taught a wave generating means and a coupling means. Applicant, however, asserts that Asmussen, et al. fails to show or suggest the invention of claim 1.

Specifically, Asmussen, et al. fails to show or suggest the claimed combination of elements including an inductive coupling structure and entities emanating from a gaseous discharge excited by a high frequency field in which a phase portion and an anti-phase portion of capacitive current coupled from the inductive coupling structure are selectively balanced. Here, Asmussen, et al. fails to show or suggest any inductive coupling structure, but taught a resonant cavity plasma generating means. The inductive coupling structure can be made by way of, for example, an rf inductive source or the like. This inductive coupling structure is selectively balanced using a wave adjustment circuit. The wave adjustment circuit adjusts the phase portion and the anti-phase portion of the capacitive current coupled to the inductive coupling structure so they are selectively balanced. At best, Asmussen, et al. taught a "sliding short" which is <u>not</u> a wave adjustment circuit for adjusting a phase and antiphase of capacitively coupled currents in the manner claimed. See, Col. 3, lines 1-10 of Asmussen, et al. Accordingly, claim 1 is clearly patentable over Asmussen, et al.

Ohkawa, et al. suffers from similar limitations. For example, Ohkawa, et al. also fails to show or suggest the claimed combination of elements including an inductive coupling structure and entities emanating from a gaseous discharge excited by a high frequency field in which a phase portion and an anti-phase portion of capacitive current coupled from the inductive coupling structure are selectively balanced. Here, Ohkawa et al. fails to show or suggest any inductive coupling structure. The inductive coupling structure can be made by way of, for example, an rf inductive source or the like. This inductive coupling structure is selectively balanced using a wave adjustment circuit. The wave adjustment circuit adjusts the phase portion and the anti-phase portion of the capacitive current coupled to the inductive coupling structure so that they are selectively balanced. At best, Ohkawa, et al. taught a "plunger" which is not a wave adjustment circuit in the manner claimed. Additionally, Ohkawa, et al., at best, discloses a <u>microwave cavity</u> for forming a plasma, rather than <u>inductive coupling</u> in the manner claimed. Accordingly, claim 1 is clearly patentable over Ohkawa, et al.

Applicant has also added new claims 2-32. No new matter has been introduced thereby.

CONCLUSION

Therefore, in view of the remarks above, Applicant respectfully requests that the rejection be removed, that claims 1-32 be allowed, and the case passed to issue. The issuance of a formal Notice of Allowance at an early date is respectfully requested.

If the Examiner believes a telephone conference would expedite prosecution of this application, please telephone the undersigned at (650) 326-2400.

Respectfully submitted,

Date: 4/12/99

RTO

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400
Fax (650) 326-2422

RTO:dhe

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PATENT
Attorney Docket No.: 16655-000311US

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Assistant Commissioner for Patents
Washington, D.C. 20231

On June 2, 1999

TOWNSEND and TOWNSEND and CREW LLP

By:

OIPE
JUN 04 1999
JC52
PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Examiner: L. Scheiner

Art Unit: 1648

INFORMATION DISCLOSURE STATEMENT UNDER 37 CFR §1.97 and §1.98

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

The references cited on attached form PTO-1449 are being called to the attention of the Examiner. Copies of the references are enclosed. It is respectfully requested that the cited information be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR 1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and

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no representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This IDS is being filed after the mailing date of the first Office Action and more than three months after the filing date, but prior to the Notice of Allowance or Final Office Action.

Please deduct $240.00, pursuant to 37 CFR §1.17(p), from the undersigned's Deposit Account No. 20-1430. Please deduct any additional fees from, or credit any overpayment to, the above-noted Deposit Account.

This Petition is submitted in triplicate.

Respectfully submitted,

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
Tel: 650-326-2400
Fax: 650-326-2422
RTO:crf

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attach

Attorney Docket No. 16655-000500

OIPE JC52
JUN 04 1999
PATENT & TRADEMARK OFFICE

PATENT APPLICATION

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Inventors:

Daniel L. Flamm, a citizen of the United States,
residing at 476 Green View Drive, Walnut Creek, California 94596.

Entity Status:

Small

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 9411-3834
(415) 326-2400

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of Application Serial No. 08/567,224 filed December 4, 1995.

BACKGROUND OF THE INVENTION

This invention relates generally to plasma processing. More particularly, the invention is for plasma processing of devices using an inductive discharge. This invention is illustrated in an example with regard to plasma etching or stripping used in the manufacture of semiconductor devices. The invention also is illustrated with regard to chemical vapor deposition (CVD) of semiconductor devices. But it will be recognized that the invention has a wider range of applicability. Merely by way of example, the invention also can be applied in other plasma etching applications, and deposition of materials such as silicon, silicon dioxide, silicon nitride, polysilicon, among others.

Plasma processing techniques can occur in a variety of semiconductor manufacturing processes. Examples of plasma processing techniques occur in chemical dry etching (CDE), ion-assisted etching (IAE), and plasma enhanced chemical vapor deposition (PECVD), including remote plasma deposition (RPCVD) and ion-assisted plasma enhanced chemical vapor deposition (IAPECVD). These plasma processing techniques often rely upon radio frequency power (rf) supplied to an inductive coil for providing power to gas phase species in forming a plasma.

Plasmas can be used to form neutral species (i.e., uncharged) for purposes of removing or forming films in the manufacture of integrated circuit devices. For instance, chemical dry etching generally depends on gas-surface reactions involving these neutral species without substantial ion bombardment.

Ion assisted etching processes, however, rely upon ion bombardment to the substrate surface in defining selected films. Ion bombardment can accelerate gas-surface reaction processes and by doing so can produce highly directional (anisotropic) profiles. But these ion assisted etching processes commonly have a lower selectivity relative to conventional CDE processes. Hence, CDE is often chosen when high selectivity is desired, directionality is not essential and ion bombardment to substrates are to be avoided.

In other manufacturing processes, ion bombardment to substrate surfaces is often undesirable. This ion bombardment, however, is known to have harmful effects on properties of material layers in devices and excessive ion bombardment flux and energy can lead to intermixing of materials in adjacent device layers, breaking down oxide and "wear out," injecting of contaminative material formed in the processing environment into substrate material layers, harmful changes in substrate morphology (e.g. amophotization), etc.

One commonly used chemical dry etching technique is conventional photoresist stripping, often termed ashing or stripping. Conventional resist stripping relies upon a reaction between a neutral gas phase species and a surface material layer, typically for removal. This reaction generally forms volatile products with the surface material layer for its removal. The neutral gas phase species is formed by a plasma discharge. This plasma discharge can be sustained by a coil (e.g., helical coil, etc.) operating at a selected frequency in a conventional photoresist stripper. An example of the conventional photoresist stripper is a quarter-wave helical resonator stripper, which is described by U.S. Patent No. 4,368,092 in the name of Steinberg et al.

Referring to the above, an objective in chemical dry etching is to reduce or even eliminate ion bombardment (or ion flux) to surfaces being processed to maintain the desired etching selectivity. In practice, however, it is often difficult to achieve using conventional techniques. These conventional techniques generally attempt to control ion flux by suppressing the amount of charged species in the plasma source reaching the process chamber. A variety of techniques for suppressing these charged species have been proposed.

These techniques often rely upon shields, baffles, large separation distances between the plasma source and the chamber, or the like, placed between the plasma source and the process chamber. The conventional techniques generally attempt to directly suppress charge density downstream of the plasma source by interfering with convective and diffusive transport of charged species. They tend to promote recombination of charged species by either increasing the surface area (e.g., baffles, etc.) relative to volume, or increasing flow time, which relates to increasing the distance between the plasma source and the process chamber.

These baffles, however, cause loss of desirable neutral etchant species as well. The baffles, shields, and alike, also are often cumbersome. Baffles, shields, or the large separation distances also cause undesirable recombinative loss of active species and sometimes cause radio frequency power loss and other problems. These baffles and shields also are a potential source of particulate contamination, which is often damaging to integrated circuits.

Baffles, shields, spatial separation, and alike, when used alone also are often insufficient to substantially prevent unwanted parasitic plasma currents. These plasma currents are generated between the wafer and the plasma source, or between the plasma source and walls of the chamber. It is commonly known that when initial charged species levels are present in an electrical field, the charged species are accelerated and dissociative collisions with neutral particles can multiply the concentration of charge to higher levels. If sufficient "seed" levels of charge and rf potentials are present, the parasitic plasma in the vicinity of the process wafer can reach harmful charge density levels. In some cases, these charge densities may be similar to or even greater than plasma density within the source plasma region, thereby causing even more ion flux to the substrate.

Charge densities also create a voltage difference between the plasma source and processing chamber or substrate support, which can have an additional deleterious effect. This voltage difference enhances electric fields that can accelerate extraction of charge from the plasma source. Hence, their presence often induces increased levels of charge to be irregularly transported from the plasma source to process substrates, thereby causing non-uniform ion assisted etching.

Conventional ion assisted plasma etching, however, often requires control and maintenance of ion flux intensity and uniformity within selected process limits and within selected process energy ranges. Control and maintenance of ion flux intensity and uniformity are often difficult to achieve using conventional techniques. For instance, capacitive coupling between high voltage selections of the coil and the plasma discharge often cause relatively high and uncontrollable plasma potentials relative to ground. It is generally understood that a voltage difference between the plasma and ground can cause damaging high energy ion bombardment of articles being processed by the plasma, as illustrated by U.S. Patent No. 5,234,529 in the name of Johnson. It is further often understood that the rf component of the plasma potential varies in time since it is derived from a coupling to time varying rf excitation. Hence, the energy of charged particles from plasma in conventional inductive sources is spread over a relatively wide range of energies, which undesirably tends to introduce uncontrolled variations in the processing of articles by the plasma.

The voltage difference between the region just outside of a plasma source and the processing chamber can be modified by introducing internal conductive shields or electrode elements into the processing apparatus downstream of the source. When the plasma potential is elevated with respect to these shield electrodes, however, there is a tendency to generate an undesirable capacitive discharge between the shield and plasma source. These electrode elements are often a source of contamination and the likelihood for contamination is even greater when there is capacitive discharge (ion bombardment from capacitive discharge is a potential source of sputtered material). Contamination is damaging to the manufacture of integrated circuit devices.

Another limitation is that shields, baffles or electrode elements generally require small holes therein as structural elements. These small holes are designed to allow gas to flow therethrough. The small holes, however, tend to introduce unwanted pressure drops and neutral species recombination. If the holes are made larger, the plasma from the source tends to survive transport through the holes and unwanted downstream charge flux will often result. In addition, undesirable discharges to these holes in conductive shields can, at times, produce an even more undesirable hollow cathode effect.

In conventional helical resonator designs, conductive external shields are interposed between the inductive power applicator (e.g., coil, etc.) and walls of the vacuum vessel containing the plasma. A variety of limitations with these external capacitive shielded plasma designs (e.g., helical resonator, inductive discharge, etc.) have been observed. In particular, the capacitively shielded design often produces plasmas that are difficult to tune and even ignite. Alternatively, the use of unshielded plasma sources (e.g., conventional quarter-wave resonator, conventional half-wave resonator, etc.) attain a substantial plasma potential from capacitive coupling to the coil, and hence are prone to create uncontrolled parasitic plasma currents to grounded surfaces. Accordingly, the use of either the shielded or the unshielded sources using conventional quarter and half-wave rf configurations produce undesirable results.

In many conventional plasma sources a means of cooling is required to maintain the plasma source and substrates being treated below a maximum temperature limit. Power dissipation in the structure causes heating and thereby increases the difficulty and expense of implementing effective cooling means. Inductive currents may also be coupled from the excitation coil into internal or capacitive shields and these currents are an additional source of undesirable power loss and heating. Conventional capacitive shielding in helical resonator discharges utilized a shield which was substantially split along the long axis of the resonator to lessen eddy current loss. However, such a shield substantially perturbs the resonator characteristics owing to unwanted capacitive coupling and current which flows from the coil to the shield. Since there are no general design equations, nor are properties currently known for resonators which are "loaded" with a shield along the axis, sources using this design must be sized and made to work by trial and error.

In inductive discharges, it is highly desirable to be able to substantially control the plasma potential relative to ground potential, independent of input power, pressure, gas composition and other variables. In many cases, it is desired to have the plasma potential be substantially at ground potential (or at least offset from ground potential by an amount insignificantly different from the floating potential or intrinsic DC plasma potential). For example, when a plasma source is utilized to generate neutral species to be transported downstream of the source for use in ashing resist on a semiconductor device substrate (a wafer or flat panel electronic display), the concentration and potential of charged plasma species in the reaction zone are desirably reduced to avoid charging damage from electron or ionic current from the plasma to the device. When there is a substantial potential difference between plasma in the source and grounded surfaces beyond the source, there is a tendency for unwanted parasitic plasma discharges to form outside of the source region.

Another undesirable effect of potential difference is the acceleration of ions toward grounded surfaces and subsequent impact of the energetic ions with surfaces. High energy ion bombardment may cause lattice damage to the device substrate being processed and may cause the chamber wall or other chamber materials to sputter and contaminate device wafers. In other plasma processing procedures, however, some ion bombardment may be necessary or desirable, as is the case particularly for anisotropic ion-induced plasma etching procedures (for a discussion of ion-enhanced plasma etching mechanisms See Flamm (Ch. 2,pp.94-183 in Plasma Etching, An Introduction, D. M. Manos and D.L. Flamm, eds., Academic Press, 1989)). Consequently, uncontrolled potential differences, such as that caused by "stray" capacitive coupling from the coil of an inductive plasma source to the plasma, are undesirable.

Referring to the above limitations, conventional plasma sources also have disadvantages when used in conventional plasma enhanced CVD techniques. These techniques commonly form a reaction of a gas composition in a plasma discharge. One conventional plasma enhanced technique relies upon ions aiding in rearranging and stabilizing the film, provided the bombardment from the plasma is not sufficiently energetic to damage the underlying substrate or the growing film. Conventional resonators and other types of inductive discharges often produce parasitic plasma currents from capacitive coupling, which often detrimentally influence film quality, e.g., an inferior film, etc. These parasitic plasma currents are often uncontrollable, and highly undesirable. These plasma sources also have disadvantages in other plasma processing techniques such as ion-assisted etching, and others. Of course, the particular disadvantage will often depend upon the application.

To clarify certain concepts used in this application, it will be convenient to introduce these definitions.

Ground (or ground potential): These terms are defined as a reference potential which is generally taken as the potential of a highly conductive shield or other highly conductive surface which surrounds the plasma source. To be a true ground shield in the sense of this definition, the RF conductance at the operating frequency is often substantially high so that potential differences generated by current within the shield are of negligible magnitude compared to potentials intentionally applied to the various structures and elements of the plasma source or substrate support assembly. However, some realizations of plasma sources do not incorporate a shield or surface with adequate electrical susceptance to meet this definition. In implementations where there is a surrounding conductive surface that is somewhat similar to a ground shield or ground plane, the ground potential is taken to be the fictitious potential which the imperfect grounded surface would have equilibrated to if it had zero high frequency impedance. In designs where there is no physical surface which is adequately configured or which does not have insufficient susceptance to act as a "ground" according to the above definition, ground potential is the potential of a fictitious surface which is equi-potential with the shield or "ground" conductor of an unbalanced transmission line connection to the plasma source at its RF feed point. In designs where the plasma source is connected to an RF generator with a balanced transmission line RF feed, "ground" potential is the average of the driven feed line potentials at the point where the feed lines are coupled to the plasma source.

Inductively Coupled Power: This term is defined as power transferred to the plasma substantially by means of a time-varying magnetic flux which is induced within the volume containing the plasma source. A time-varying magnetic flux induces an electromotive force in accord with Maxwell's equations. This electromotive force induces motion by electrons and other charged particles in the plasma and thereby imparts energy to these particles.

RF inductive power source and bias power supply: In most conventional inductive plasma source reactors, power is supplied to an inductive coupling element (the inductive coupling element is often a multi-turn coil which abuts a dielectric wall containing a gas where the plasma is ignited at low pressure) by an rf power generator. The chuck or workpiece support is often isolated from ground by a capacitance and powered by a second rf power generator which is termed a bias power supply. Rf power delivered to the chuck may cause the chuck to develop a negative DC bias voltage relative to plasma potential (for a discussion of bias, See Flamm (Ch. 1,pp.28-35, in Plasma Etching, An Introduction, D. M. Manos and D.L. Flamm, eds., Academic Press, 1989)). A bias power source is often selected to operate at the same frequency as the inductive power source, however it can also operate at a distinct frequency since the bias frequency can be adjusted to control ion bombardment energy,flux and other etching properties such as uniformity.

Vector sum voltage or current: Those skilled in the art will recognize that alternating currents and voltages are often represented as complex numbers which are sometimes termed phasors (for a explanation of phasors see Ch. 10 in Electric Circuits, 2nd Ed., by J. W. Nilsson, Addison Wesley, 1986 ISBN 0-201-12695-8. Complex voltages and currents are explained in Chapt. 8 of Electricity and Magnetism by E. M. Purcell, Berkeley Physics Course-Volume 2, McGraw-Hill, 1985, ISBN 0-07-004908-4). The vector sum of two currents I_1 and I_2 or voltages V_1 and V_2 is understood to be defined as the sum of these quantities expressed as complex numbers (phasors) which contain both magnitude and phase information. At any particular time t, actual physical current is given by the real part of this complex sum.

Inverse voltage or current: Those skilled in the art will recognize that two electrical quantities are said to be the inverse of each other when they have the same magnitude, but opposite sign. Hence if a voltage V_1 is given by $V_0e^{j\omega t}$ its inverse is equal to $-V_0e^{j\omega t}$ (or equivalently $V_0e^{j\omega t\pm\pi)}$. Correspondingly the vector sum of any current summed with its inverse is zero.

Inverse phase or antiphase: Two electrical quantities are defined to have an inverse phase relationship when the phase difference between them is 180° (π) or equivalently, $(2n\pm1)\pi$, where n is an integer number. It will be understood that two voltages or currents are in an inverse relationship when they have the same absolute magnitude and a phase difference of $(2n\pm1)\pi$. However the sum of a first current added to a second current characterized as having an inverse phase relation to the first (or equivalently "antiphase") may not be zero, since the sum of these currents will balance to zero (the currents "compensate") only when both have the same magnitude.

Conventional Helical Resonator: Conventional helical resonator can be defined as plasma applicators. These plasma applicators have been designed and operated in multiple configurations, which were described in, for example, U.S. Patent No. 4,918,031 in the names of Flamm et al., U.S. Patent No. 4,368,092 in the name of Steinberg et al., U.S Patent No. 5,304,282 in the name of Flamm, U.S. Patent No. 5,234,529 in the name of Johnson, U.S. Patent No. 5,431,968 in the name of Miller, and others. In these configurations, one end of the helical resonator applicator coil has been grounded to its outer shield. In one conventional configuration, a quarter wavelength helical resonator section is employed with one end of the applicator coil grounded and the other end floating (i.e., open circuited). A trimming capacitance is sometimes connected between the grounded outer shield and the coil to "fine tune" the quarter wave structure to a desired resonant frequency that is below the native resonant frequency without added capacitance. In another conventional configuration, a half-wavelength helical resonator section was employed in which both ends of the coil were grounded. The function of grounding the one or both ends of the coil was believed to be not essential, but advantageous to "stabilize the plasma operating characteristics" and "reduce the possibility of coupling stray current to nearby objects." See U.S. Patent No. 4,918,031.

Conventional resonators have also been constructed in other geometrical configurations. For instance, the design of helical resonators with a shield of square cross section is described in Zverev et al., IRE Transactions on Component Parts, pp. 99-110, Sept. 1961. Johnson (U.S. Patent No. 5,234,529) teaches that one end of the cylindrical spiral coil in a conventional helical resonator may be deformed into a planar spiral above the top surface of the plasma reactor tube. U.S. Patent No. 5,241,245 in the names of Barnes et al. teach the use of conventional helical resonators in which the spiral cylindrical coil is entirely deformed into a planar spiral arrangement with no helical coil component along the sidewalls of the plasma source (this geometry has often been referred to as a "transformer coupled plasma," termed a TCP).

From the above it is seen that an improved technique, including a method and apparatus, for plasma processing is often desired.

SUMMARY OF THE INVENTION

The present invention provides a technique, including a method and apparatus. for fabricating a product using a plasma discharge. The present technique relies upon the control of the instantaneous plasma AC potential to selectively control a variety of plasma characteristics. These characteristics include the amount of reactive neutral species, the amount of charged species, time and spatially averaged plasma potentials, the spatial extent and distribution of plasma density, the distribution of electrical current, and others. This technique can be used in applications including chemical dry etching, ion-enhanced etching, plasma immersion ion implantation, chemical vapor deposition and material growth, and others.

In one aspect of the invention, a device is made using a process for fabricating a product. These products include a varieties of devices (e.g., semiconductor, flat panel displays, micro-machined structures, etc.) and materials, e.g., diamonds, raw materials, plastics, etc. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge which is powered by high frequency fields coupled from an inductive coupling structure, in which the vector sum of phase and inverse-phase capacitively coupled currents between the inductive coupling structure and the gaseous plasma discharge can be selectively produced or substantially balanced. The capacitively coupled currents are driven by the AC voltage differences between the potential along the inductive coupling structure and the plasma potential. This process provides for a technique that is substantially free from stray or parasitic capacitive coupling from the plasma source to chamber bodies (e.g., substrate, walls, etc.) at or near ground potential.

In another aspect of the invention, another method for fabricating a product is provided. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge which is powered by high frequency fields coupled from an inductive coupling structure, in which the vector sum of phase and inverse-phase capacitive coupled current from the inductive coupling structure is selectively maintained. In one embodiment of this method, a process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential. In a second embodiment, the process provides for a technique that can selectively control the potential difference between the plasma and a product being processed. It will be evident to those skilled in the art that there is a relationship between the plasma potential and current. Therefore selective control of the potential difference may advantageously be used to control the amount of charge flowing to a product being processed. Merely by way of example, one such product might be a device wafer which can be damaged by excessive charge or ion bombardment energy.

In another aspect of the invention, a further method for fabricating a product is provided. The process includes steps of subjecting a substrate to a composition of entities. At least one of the entities emanates from a species generated by a gaseous discharge which is powered by high frequency fields coupled from an inductive coupling structure, in which the vector sum of phase and inverse-phase capacitive coupled current from the inductive coupling structure is selectively maintained. In one aspect of this method, a process provides for a technique that can selectively control the amount of capacitive coupling to chamber bodies at or near ground potential. In a second aspect, a process provides for a technique that can selectively control the potential difference between the plasma and a product being processed. It will be evident to those skilled in the art that there is a direct relationship between current flow to the product and the difference between plasma potential and the product potential. Therefore selective control of the potential difference may advantageously be used to control the amount of charge flowing to a product being processed. Merely by way of example, one such product might be a device wafer which can be damaged by excessive charge or ion bombardment energy.

An additional aspect of the invention, provides a further process for fabricating a product. This process includes the steps of subjecting a substrate to a composition of entities wherein at least one of the entities emanates from a species generated by a gaseous discharge. The gaseous discharge is powered by high frequency fields coupled from a coupling structure, in which the vector sum of phase and inverse-phase capacitive coupled currents from the inductive coupling structure are selectively maintained. A further step of selectively applying a voltage between the at least one of the entities in the plasma source and a substrate is provided. Yet a further step provides for sensing the current flow to a substrate and using selectively maintained voltage differences between the substrate and at least one of the entities in the plasma source to control the current flow.

Another aspect of the invention provides another process for fabricating a product. The process comprises steps of subjecting a substrate to a composition of entities and using the resulting substrate for completion of the product. At least one of the entities emanates from a species generated by a gaseous discharge provided by a plasma applicator, e.g., a helical resonator, inductive coil, transmission line, etc. This plasma applicator has an integral current flow to the plasma driven by capacitive coupling of a plasma column to elements with a selected potential greater than a surrounding shield potential substantially equal to capacitive coupling of the plasma column to substantially equal elements with a potential below shield potential.

In a further aspect, the invention provides an apparatus for fabricating a product. The apparatus has an enclosure comprising an outer surface and an inner surface. The enclosure houses a gaseous discharge. The apparatus also includes a plasma applicator (e.g., helical coil, inductive coil, transmission line, etc.) disposed adjacent to the outer surface. A high frequency power source operably coupled to the plasma applicator is included. The high frequency power source provides power to excite the gaseous discharge to provide at least one entity from a high frequency field in which the vector sum of phase and inverse-phase capacitive currents coupled from the inductive coupling structure is selectively maintained.

In another aspect, the present invention provides an improved plasma discharge apparatus. This plasma discharge apparatus includes a plasma source, a plasma applicator (e.g., inductive coil, transmission line, etc.), and other elements. This plasma applicator provides a de-coupled plasma source. A wave adjustment circuit (e.g., RLC circuit, coil, transmission line, etc.) is operably coupled to the plasma applicator structure. The wave adjustment circuit can selectively adjust phase and inverse-phase potentials between the plasma and applicator elements, produced by at least one rf power supply. The rf power supply (or supplies) are operably coupled to the wave adjustment circuit.

The present invention achieves these benefits in the context of known process technology. However, a further understanding of the nature and advantages of the present invention may be realized by reference to the latter portions of the specification and attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified diagram of a plasma etching apparatus according to the present invention;

Figs. 2A-2E are simplified configurations using wave adjustment circuits according to the present invention;

Fig. 3 is a simplified diagram of a chemical vapor deposition apparatus according to the present invention;

Fig. 4 is a simplified diagram of a stripper according to the present invention;

Figs. 5A-5C are more detailed simplified diagrams of a helical resonator according to the present invention;

Fig. 6 is a conventional quarter-wave helical resonator plasma etching apparatus with stray plasma which results from the coupling in the conventional design;

Fig. 7 is a simplified diagram of the rf voltage distribution along the coil of the Fig. 6 apparatus;

Fig. 8 is a simplified top-view diagram of an apparatus suitable for CDE or resist ashing apparatus according to the present examples; and

Fig. 9 is a simplified side-view diagram of a chamber suitable for CDE or resist ashing chamber according to the present examples.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is a simplified diagram of a plasma etch apparatus 10 according to the present invention. This etch apparatus is provided with an inductive applicator, e.g., inductive coil. This etch apparatus depicted, however, is merely an illustration, and should not limit the scope of the claims as defined herein. One of ordinary skilled in the art may implement the present invention with other treatment chambers and the like.

The etch apparatus includes a chamber 12, a feed source 14, an exhaust 16, a pedestal 18, an inductive applicator 20, a radio frequency (rf) power source 22 to the inductive applicator 20, wave adjustment circuits 24, 29 (WACs), a radio frequency power source 35 to the pedestal 18, a controller 36, and other elements. Optionally, the etch apparatus includes a gas distributor 17.

The chamber 12 can be any suitable chamber capable of housing a product 28, such as a wafer to be etched, and for providing a plasma discharge therein. The chamber can be a domed chamber for providing a uniform plasma distribution over the product 28 to be etched, but the chamber also can be configured in other shapes or geometries, e.g., flat ceiling, truncated pyramid, cylindrical, rectangular, etc. Depending upon the application, the chamber is selected to produce a uniform entity density over the pedestal 18, providing a high density of entities (i.e., etchant species) for etching uniformity.

The present chamber includes a dome 25 having an interior surface 26 made of quartz or other suitable materials. The exterior surface of the chamber is typically a dielectric material such as a ceramic or the like. Chamber 12 also includes a process kit with a focus ring 32, a cover (not shown), and other elements. Preferably, the plasma discharge is derived from the inductively coupled plasma source that is a de-coupled plasma source (DPS) or a helical resonator, although other sources can be employed.

The de-coupled source originates from rf power derived from the inductive applicator 20. Inductively coupled power is derived from the power source 22. The rf signal frequencies ranging from 800 KHz to 80 MHz can be provided to the inductive applicator 20. Preferably, the rf signal frequencies range from 5 MHz to 60 MHz. The inductive applicator (e.g., coil, antenna, transmission line, etc.) overlying the chamber ceiling can be made using a variety of shapes and ranges of shapes. For example, the inductive applicator can be a single integral conductive film, a transmission line, or multiple coil windings. The shape of the inductive applicator and its location relative to the chamber are selected to provide a plasma overlying the pedestal to improve etch uniformity.

The plasma discharge (or plasma source) is derived from the inductive applicator 20 operating at selected phase 23 and inverse-phase 27 potentials (i.e., voltages) that substantially cancel each other. The controller 36 is operably coupled to the wave adjustment circuits 24, 29. In one embodiment, wave adjustment circuits 24, 29 provide an inductive applicator operating at full-wave multiples 21. This embodiment of full-wave multiple operation provides for balanced capacitive coupling to of the plasma to phase 23 and inverse-phase voltages 27 along the inductive applicator (or coil adjacent to the plasma). This full-wave multiple operation reduces or substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential. Alternatively, the wave adjustment circuits 24, 29 provide an inductive applicator that is effectively made shorter or longer than a full-wave length multiple by a selected amount, thereby operating with coupling to selected phase and inverse-phase voltages which do not comprise full-wave multiples. Alternatively, more than two, one or even no wave adjustment circuits can be provided in other embodiments. But in all of these above embodiments, the coupling to phase and inverse-phase potentials substantially cancel each other, thereby providing substantially no capacitively coupled power from the plasma source to the chamber bodies.

In alternative embodiments, the wave adjustment circuit can be configured to provide selected phase and inverse-phase voltages coupled from the inductive applicator to the plasma that do not cancel. This provides a controlled potential between the plasma and the chamber bodies, e.g., the substrate, grounded surfaces, walls, etc. In one embodiment, the wave adjustment circuits can be used to selectively reduce current (i.e., capacitively coupled current) to the plasma. This can occur when certain high potential difference regions of the inductive applicator to the plasma are positioned (or kept) away from the plasma region (or inductor-containing-the-plasma region) by making them go into the wafer adjustment circuit assemblies, which are typically configured outside of the plasma region. In this embodiment, capacitive current is reduced and a selected degree of symmetry between the phase and inverse-phase of the coupled voltages is maintained, thereby providing a selected potential or even substantially ground potential. In other embodiments, the wave adjustment circuits can be used to selectively increase current (i.e., capacitively coupled current) to the plasma.

As shown, the wave adjustment circuits are attached (e.g., connected, coupled, etc.) to ends of the inductive applicator. Alternatively, each of these wave adjustment circuits can be attached at an intermediate position away from the inductive application ends. Accordingly, upper and lower tap positions for respective wave adjustment circuits can be adjustable. But both the inductive applicator portions below and above each tap position are active. That is, they both can interact with the plasma discharge.

A sensing apparatus can be used to sense plasma voltage and use automatic tuning of the wave adjustment circuits and any rf matching circuit between the rf generator and the plasma treatment chamber. This sensing apparatus can maintain the average AC potential at zero or a selected value relative to ground or any other reference value. This wave adjustment circuit provides for a selected potential difference between the plasma source and chamber bodies. These chamber bodies may be at a ground potential or a potential supplied by another bias supply, e.g., See Fig. 1 reference numeral 35. Examples of wave adjustment circuits are described by way of the Figs. below.

For instance, Figs. 2A to 2E are simplified configurations using the wave adjustment circuits according to the present invention. These simplified configurations should not limit the scope of the claims herein. In an embodiment, these wave adjustment circuits employ substantially equal circuit elements (e.g., inductors, capacitors, transmission line sections, and others) such that the electrical length of the wave adjustment circuits in series with the inductive applicator coupling power to the plasma is substantially an integral multiple of one wavelength. In other embodiments, the circuit elements provide for inductive applicators at other wavelength multiples, e.g., one-sixteenth-wave, one-eighth-wave, quarter-wave, half-wave, three-quarter wave, etc. In these embodiments (e.g., full-wave multiple, half-wave, quarter-wave, etc.), the phase and inverse-phase relationship between the potentials coupled to the plasma substantially cancel each other. In further embodiments, the wave adjustment circuits employ circuit elements that provide plasma applicators with phase and inverse-phase potential relationships that do not cancel each other out using a variety of wave length portions.

Fig. 2A is a simplified illustration of an embodiment 50 using wave adjustment circuits according to the present invention. This embodiment 50 includes a discharge tube 52, an inductive applicator 55, an exterior shield 54, an upper wave adjustment circuit 57, a lower wave adjustment circuit 59, an rf power supply 61, and other elements. The upper wave adjustment circuit 57 is a helical coil transmission line portion 69, outside of the plasma source region 60. Lower wave adjustment circuit 59 also is a helical coil transmission line portion 67 outside of the plasma source region 60. The power supply 61 is attached 65 to this lower helical coil portion 67, and is grounded 63. Each of the wave adjustment circuits also are shielded 66, 68.

In this embodiment, the wave adjustment circuits are adjusted to provide substantially zero AC voltage at one point on the inductive coil (refer to point 00 in Fig. 2A). This embodiment also provides substantially equal phase 70 and inverse-phase 71 voltage distributions in directions about this point (refer to 00-A and 00-C in Fig. 2A) and provides substantially equal capacitance coupling to the plasma from physical inductor elements (00-C) and (00-A), carrying the phase and inverse-phase potentials. Voltage distributions 00-A and 00-C are combined with C-D and A-B (shown by the phantom lines) would substantially comprise a full-wave voltage distribution in this embodiment where the desired configuration is a selected phase/inverse-phase portion of a full-wave inductor (or helical resonator) surrounding the plasma source discharge tube.

In this embodiment, it is desirable to reduce or minimize capacitive coupling current from the inductive element to the plasma discharge in the plasma source. Since the capacitive current increases monotonically with the magnitude of the difference of peak phase and inverse-phase voltages, which occur at points A and C in Fig. 2A, this coupling can be lessened by reducing this voltage difference. In Fig. 2A, for example, it is achieved by way of two wave adjustment circuits 57, 59. Coil 55 (or discharge source) is a helical resonator and the wave adjustment circuits 57, 59 are helical resonators.

The discharge source helical resonator 53 can be constructed using conventional design formulae. Generally, this helical resonator includes an electrical length which is a selected phase portion "x" (A to 00 to C) of a full-wave helical resonator. The helical resonator wave adjustment circuits are each selected to comprise a portion (2π-x) of full-wave helical resonators. Physical parameters for the wave adjustment helical resonators can be selected to realize practical physical dimensions and appropriate Q, Z_o, etc. values. In particular, some or even all of the transmission line parameters (Q, Z_o, etc.) of the wave adjustment circuit sections may be selected to be substantially the same as the transmission line parameters of the inductive applicator. The portion of the inductive plasma applicator helical resonator, on the other hand, is designed and sized to provide selected uniformity values over substrate dimensions within an economical equipment size and reduced Q.

The wave adjustment circuit provides for external rf power coupling, which can be used to control and match power to the plasma source, as compared to conventional techniques used in helical resonators and the like. In particular, conventional techniques often match to, couple power to, or match to the impedance of the power supply to the helical resonator by varying a tap position along the coil above the grounded position, or selecting a fixed tap position relative to a grounded coil end and matching to the impedance at this position using a conventional matching network, e.g., LC network, π-network, etc. Varying this tap position along the coil within a plasma source is often cumbersome and generally imposes difficult mechanical design problems. Using the fixed tap and external matching network also is cumbersome and can cause unanticipated changes in the discharge Q, and therefore influences its operating mode and stability. In the present embodiments, the wave adjustment circuits can be positioned outside of the plasma source (or constrained in space containing the inductive coil, e.g., <u>See</u> Fig. 2A. Accordingly, the mechanical design (e.g., means for varying tap position, change in the effective rf power coupling point by electrical means, etc.) of the tap position are simplified relative to those conventional techniques.

In the present embodiment, rf power is fed into the lower wave adjustment circuit 59. Alternatively, rf power can be fed into the upper wave adjustment circuit (not shown). The rf power also can be coupled directly into the inductive plasma coupling applicator (e.g., coil, etc.) in the wave adjustment circuit design, as illustrated by Fig. 2B. Alternatively, other application will use a single wave adjustment circuit, as illustrated by Fig. 2C. Power can be coupled into this wave adjustment circuit or by conventional techniques such as a tap in the coil phase. In some embodiments, this tap in the coil phase is positioned above the grounded end. An external impedance matching network may then be operably coupled to the power for satisfactory power transfer efficiency from, for example, a conventional coaxial cable to impedances (current to voltage rations) existing between the wave adjustment circuit terminated end of the applicator.

A further embodiment using multiple inductive plasma applicators also is provided, as shown in Fig. 2D. This embodiment includes multiple plasma applicators (PA1, PA2...Pan). These plasma applicators respectively provide selected combinations of inductively coupled power and capacitively coupled power from respective voltage potentials (V1, V2...Vn). Each of these plasma applicators derives power from its power source (PS1, PS2...PSn) either directly through an appropriate matching or coupling network or by coupling to a wave adjustment circuit as described. Alternatively, a single power supply using power splitters and impedance matching networks can be coupled to each (or more than two) of the plasma applicators. Alternatively, more than one power supply can be used where at least one power supply is shared among more than one plasma applicator. Each power source is coupled to its respective wave adjustment circuits (WAC1, WAC2...WACn).

Generally, each plasma applicator has an upper wave adjustment circuit (e.g., WAC 1a, WAC 2a...WACna) and a lower wave adjustment circuit (e.g., WAC1b, WAC 2b...WACnb). The combination of upper and lower wave adjustment circuits are used to adjust the plasma source potential for each plasma source zone. Alternatively, a single wave adjustment circuit can be used for each plasma applicator. Each wave adjustment circuit can provide substantially the same impedance characteristics, or substantially distinct impedance characteristics. Of course, the particular configuration used will depend upon the application.

For instance, multiple plasma applicators can be used to employ distinct excitation frequencies for selected zones in a variety of applications. These applications include film deposition using plasma enhanced chemical deposition, etching by way of ion enhanced etching or chemical dry etching and others. Plasma cleaning also can be performed by way of the multiple plasma applicators. Specifically, at least one of the plasma applicators will define a cleaning plasma used for cleaning purposes. In one embodiment, this cleaning plasma can have an oxygen containing species. This cleaning plasma is defined by using an oxygen discharge, which is sustained by microwave power to a cavity or resonant microwave chamber abutting or surrounding a conventional dielectric vessel. Of course, a variety of other processes also can be performed by way of this multiple plasma applicator embodiment.

This present application using multiple plasma applicators can provide a multi-zone (or multi-chamber) plasma source without the use of conventional mechanical separation means (e.g., baffles, separate process chambers, etc.). Alternatively, the degree of interaction between adjacent zones or chambers can be relaxed owing to the use of voltage potential control via wave adjustment circuits. This plasma source provides for multiple plasma source chambers, each with its own control via its own plasma applicator. Accordingly, each plasma applicator provides a physical zone region (i.e., plasma source) with selected plasma characteristics (e.g., capacitively coupled current, inductively coupled current, etc.). These zones can be used alone or can be combined with other zones. Of course, the particular configuration will depend upon the application.

In the present embodiments, the wave adjustment circuit can be made from any suitable combination of element(s) such as various types of transmission lines, circuits, etc. These transmission lines include conventional solid or air dielectric coaxial cable, or ordinary, repeating inductor/capacitor discrete approximations to transmission lines, and others. These types of transmission lines are coaxial transmission lines, balanced parallel transmission lines, so called slow wave transmission lines with a spiral inner conductor (e.g., selected portions of a helical resonator, etc.), and others. Individual lumped, fixed, or adjustable combinations of resistors, capacitors, and inductors (e.g., matching networks, etc.) also can be used in place of transmission line sections for the wave adjustment circuit. These general types of wave adjustment circuits are frequency dependent, and can be termed frequency dependent wave adjustment circuits (or FDWACs).

Frequency independent elements also can be used as the wave adjustment circuits. These wave adjustment circuits can be termed frequency independent WACs (or FIWACs). Frequency independent wave adjustment circuits include degenerate cases such as short-circuit connections to ground or an infinite impedance (i.e., open circuit), and others. Frequency independent wave adjustment circuits can be used alone, or in combination with the frequency dependent wave adjustment circuits. Alternatively, the frequency dependent wave adjustment circuits can be used alone or in combination with other wave adjustment circuits. Other variations, alternative constructions, and modifications also may be possible depending upon the application.

With regard to operation of the wave adjustment circuits, various embodiments can be used, as illustrated by Fig. 2E. The wave adjustment circuits are used to select a wave length portion to be applied in the plasma applicator. In some embodiments, the average rf plasma potential is maintained close to ground potential by providing substantially equal phase 90, 81 and inverse-phase 91, 82 capacitively coupled portions of the inductive applicator. This can occur in multi-wave embodiments 92, full-wave embodiments 93, half-wave multiple embodiments, quarter-wave multiple embodiments, or any other embodiments 94.

In alternative embodiments, it is desirable to maintain an elevated source plasma voltage relative to ground potential to induce a controlled ion plasma flux (or ion bombardment) to the product substrate (or any other chamber bodies). These embodiments are provided by selecting distinct electrical lengths for each of the wave adjustment circuit sections such that the capacitive coupled current from a phase section of the inductive plasma applicator is in excess of capacitive coupled current from its inverse-phase portion. In these embodiments, the wave adjustment circuit provides a deliberate imbalance between coupling to phase and inverse-phase voltages. In some embodiments 97, this occurs by shifting the zero voltage nodes along the process chamber axially, thereby achieving a bias relative to the plasma discharge. As shown, the phase 95 is imbalanced relative to its inverse-phase 96. In other embodiments 99, one phase portion 84 is imbalanced by way of a different period relative to its complementary phase portion 85. Other embodiments are provided where the source plasma voltage is lower relative to ground potential. In the embodiments were imbalance is desirable, the potential difference between the phase and inverse-phase potential portions is reduced (or minimized) when the amount of sputtering (e.g., wall sputtering, etc.) is reduced. The amount of sputtering, however, can be increased (or maximized) by increasing the potential difference between the phase and inverse-phase potential portions. Sputtering is desirable in, for example, sputtering a quartz target, cleaning applications, and others. Of course, the type of operation used will depend upon the application.

Current maxima on an inductive applicator with distributed capacitance (e.g., helical resonator transmission line, etc.) occur at voltage minima. In particular, conventional quarter-wave helical resonator current is substantially at a relative maximum at its grounded end of the coil, and to a lesser extend in the nearby coil elements. Therefore, partial inductive coupling of power, if it occurs, will tend to be at this grounded end. In conventional half-wave helical resonators, inductive coupling tends to occur at each of the two grounded ends.

In the present invention, substantially equal coupling to voltage elements and inverse-voltage elements along half-wave and other fractional wave inductive applicator structure sections support substantially more inductive coupling at a selected rf voltage node, e.g., Fig. 2A reference numeral 00. This effect is caused by high current flow in the inductor applicator zones (or sections) both directly above and below the node (corresponding to inductor elements in the phase and inverse-phase sections at and immediately adjacent to the rf voltage zero point). It should be noted that conventional quarter and half-wave inductively coupled inductive applicators have inductive coupling which abruptly declines below the grounded coil locations because the coil terminates and voltage extrema are present at these locations. This generally produces conventional quarter and half-wave helical resonators that tend to operate in a capacitive mode, or with a substantial fraction of power which is capacitively coupled to the plasma, unless the plasma is shielded from coil voltages, as noted above.

In a specific embodiment, the power system includes selected circuit elements for effective operation. The power system includes an rf power source. This rf power source can be any suitable rf generator capable of providing a selected or continuously variable frequency in a range from about 800 kHz to about 80 MHz. Many generators are useful. Preferably, generators capable of operating into short and open-circuit loads without damage are used for industrial applications. One example of a suitable generator is a fixed frequency rf generator 28.12 MHz - 3 kW CX-3000 power supply made by Comdel, Inc. of Beverly, Massachusetts. A suitable variable frequency power supply arrangement capable of the 3 kW output over an 800 kHz to 50 MHz range can be made by driving an IFI Model TCCX3500 High Power Wide Band Amplifier with a Hewlett Packard HP116A, 0-50 Mhz Pulse/Function Generator. Other generators including those capable of higher or lower power also can be used depending upon the application.

Power from the generator can be transmitted to the plasma source by conventional coaxial cable transmission line. An example of this transmission line is RG8/U and other higher temperature rated cable (e.g., RG1151U, etc.) with a coaxial TEFLON™ dielectric. In some embodiments, power is fed to conventional end-grounded half-wave helical resonators by positioning a movable tap on the helical coil and connecting a power source between the tap and the ground. In other embodiments, matching networks can be introduced between the coaxial cable power feed and the helical coil tap for flexibility. The matching network will balanced half-wave helical resonator embodiment, for example, the ends of the resonator coil can be terminated with wave adjustment circuits which substantially have zero susceptance. In particular, the wave adjustment circuit is designed as an open circuit by making no electrical connections to the ends of the coil, or establishing an electrical equivalence thereof. Alternatively, the ends of the coil are isolated by high series impedance chokes, thereby maintaining DC coupling to a fixed reference potential. These types of wave adjustment circuits are frequency independent and are "degenerate" cases. In these embodiments, the rf power is provided such that the phase and inverse-phase current flows above and below the electrical midpoint (i.e., zero voltage node, etc.) of the coil. This provides for substantially balanced phase and inverse-phase current flow from the power source stabilizing desired operation in coil voltages above the midpoint of the coil, and also provides substantially equal phase and inverse-phase voltages.

The embodiments described above also can be applied to other plasma processing applications, e.g., PECVD, plasma immersion ion implantation (PIII), stripping, sputtering, etc. For instance, Fig. 3 is a simplified CVD apparatus 100 according to the present invention. The present CVD apparatus includes a chamber 112, a feed source 114, an exhaust 116, a pedestal 118, a power source 122, a ground 124, a helical resonator 126, and other elements. The helical resonator 126 has a coil 132, an outer shield 133, and other elements. The chamber can be any suitable chamber capable of housing a product 119 such as a wafer for deposition, and for providing a plasma discharge therein. Preferably, the chamber is a right circular cylinder chamber for providing an uniform plasma species distribution over the product. But the chamber can also be configured in the form of rectangular right cylinder, a truncated cone, and the like. The chamber and fixtures are constructed from aluminum and quartz, and other suitable materials. The plasma discharge is derived from a plasma source which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phase/inverse-phase potentials. The present CVD apparatus provides for deposition of a dielectric material, e.g., silicon dioxide or the like.

The product 119 having an upper surface 130 is placed into the present CVD apparatus for deposition, e.g., plasma enhanced chemical vapor deposition (PECVD), and others. Examples of deposition materials include a dielectric borophosphosilicate glass (BPSG), a silicon nitride (Si_3N_4), among others.

In one embodiment, the deposition occurs by introducing a mixture comprising organic silane, oxygen, and an inert gas such as helium or argon according to the present invention. The organic silane can be any suitable organic silicate material such TEOS, HMDS, OMCTS, and the like. Deposition is also conformal in selected instances. As for the oxygen, it includes a flow rate of about 1 liter/per minute and less. A relative flow rate between the organic silane such as TEOS and oxygen ranges from about 1:40 to about 2:1, and is preferably less than about 1:2 in certain applications. A deposition temperature of the organic silane-oxygen layer ranges from about 300 to about 500°C, and can also be at other temperatures. Pressures in the range of 1 to 7 Torr are generally used. Of course, other concentrations, temperatures, materials, and flow rates can be used depending upon the particular application.

This chamber also includes a wave adjustment circuit 127. The wave adjustment circuit 127 is used to provide a helical coil operating with capacitive coupling to selected phase and inverse-phase voltages. This portion 127 of the wave adjustment circuit coil also is shielded 140 to prevent rf from interfering with the plasma discharge or external elements, e.g., equipment, power, etc. The coil shield 140 is made of a conductive material such as copper, aluminum, or the like. In one embodiment, an operating frequency is selected and the wave adjustment circuit is adjusted to short circuit the upper end of the helical applicator coil to ground 124. This provides a helical coil operating at approximately a full-wave multiple and has substantially equal phase and inverse-phase sections. This full-wave multiple operation provides for balanced capacitance of phase 151 and anti-phase 153 voltages along the coil 132 adjacent to the plasma source. Full-wave multiple operation reduces or even substantially eliminates the amount of capacitively coupled power from the plasma source to chamber bodies (e.g., pedestal, walls, wafer, etc.) at or close to ground potential.

In the present embodiment, the wave adjustment circuit 127 is a variable coil portion 128 of a spiral transmission line, which is selectively placed outside the outer shield 133. Accordingly, when the wave adjustment circuit is adjusted to become a short circuit, the plasma source "sees" only a selected full-wave multiple comprising substantially equal phase 151 and anti-phase 153 of the entire instantaneous AC voltages 134, 135. In this embodiment, stress of the

Alternatively, the wave adjustment circuit 127 provides a helical resonator operating at selected phase and anti-phase voltages that are not full-wave multiples. This wave adjustment circuit provides for a selected amount of capacitive coupling from the plasma source to the chamber bodies. Stress of the deposited oxide film in this embodiment can be made to be zero or slightly compressive. In some embodiments, the oxide films can be deposed with an rf plasma potential of several hundred volts between the plasma source and the substrate to decrease the tendency of the oxide film to absorb moisture. This can occur by adjusting the wave adjustment circuit to add in a small section of transmission line outside of the source and correspondingly shortening the applicator coil (by moving the lower point at which the applicator coil is short-circuited and thereby decreasing the inductance of the applicator coil and electrical length of the helical resonator 126 (e.g., spiral transmission line, etc.)). Of course, the selected amount of capacitive coupling will depend upon the application.

Fig. 4 is a simplified diagram of a resist stripper according to the present invention. The present stripping apparatus includes similar elements as the previous described CVD apparatus. The present stripping apparatus includes a chamber 112, a feed source 114, an exhaust 116, a pedestal 118, an rf power source 122, a ground 124, a helical resonator 126, and other elements. The helical resonator 126 includes a coil 132, an outer shield 133, a wave adjustment circuit 400, and other elements. The chamber can be any suitable chamber capable of housing a product 119 such as a photoresist coated wafer for stripping, and for providing a plasma discharge therein. The plasma discharge is derived from a plasma source, which is preferably a helical resonator discharge or other inductive discharge using a wave adjustment circuit or other techniques to selectively adjust phase/anti-phase potentials. The present stripping apparatus provides for stripping or ashing photoresist, e.g., implant hardened, etc. Further examples of such a stripping apparatus are described in the experiments section below.

In this embodiment, the wave adjustment circuits rely upon open circuits (i.e., zero susceptance). Power transfer can be effected with a balanced feed such as an inductively-coupled push-pull arrangement with means such as coupled inductors. Techniques for constructing these coupled inductors are described in, for example, "The ARRL Antenna Book," R.D. Straw, Editor, The American Radio Relay League, Newington, CT (1994) and "The Radio Handbook," [illegible] incorporated by reference for all purposes. In one embodiment, a ferrite or powdered iron core "balun" (balanced-unbalanced) toroidal transformer (i.e., broadband transmission transformer, broadband transformer, etc.) 401 can be used to provide balanced matching from a conventional unbalanced coaxial transmission line. Techniques for constructing toroidal baluns are described in, for example, "Transmission Line Transformers," J. Sevick, 2nd Edition, American Radio Relay League, Newington, CT (1990). The toroidal transformer is coupled between the rf power source 122 and the coil 132. The midpoint 406 between the phase 405 and anti-phase voltage on the coil is effectively rf grounded, hence it may be convenient to directly ground this midpoint of the inductive application in some embodiments for stability. This permits alternate operation in which power may be coupled into the inductive applicator (e.g., coil, etc.) with a conventional unbalanced feed line tapped on one side of the center. Push-pull balanced coupling ignites the plasma more easily than conventional unbalanced coil tap matching and generally is easier to adjust in selected applications.

Referring to the helical resonator embodiments operating at substantially equal phase and anti-phase potentials, Fig. 5A is a simplified diagram 200 of an equivalent circuit diagram of some of them. The diagram is merely an illustration and should not limit the scope of the claims herein. The equivalent circuit diagram includes a plurality of rf power supplies (V_1, V_2, V_3...V_n) 203, representing for example, a single rf power source. These power supplies are connected in parallel to each other. One end of the power supply is operably coupled to a ground connection 201. The other end of the power supplies can be represented as being connected to a respective capacitor (C_1, C_2, C_3...C_n). Each of these capacitors are connected in parallel to each other. During this mode of operation, no significant voltage difference exists between any of the common side of the capacitors, as they are all connected to each other in parallel.

Fig. 5B is a simplified diagram of instantaneous AC voltage and current along a helical resonator coil of Fig. 5A where each end of the inductive applicator is short circuited. The diagram is merely an illustration and should not limit the scope of the claims herein. This diagram includes the discharge tube 213 and an inductive plasma discharge (or plasma source) 501 therein. As shown, the plasma discharge includes an intensified "donut-shaped" glow region 501 that occupies a limited range (R) of the discharge tube 213. The plasma discharge has zero volts (i.e., the ground potential). As can be seen, the plasma discharge 501 has capacitively coupling elements to V_H and V_G. But the average voltage potential of this plasma discharge is substantially zero. This operation provides for balanced capacitance of phase 503 and anti-phase 505 voltages along the coil adjacent to the plasma, thereby substantially preventing capacitively coupling from the plasma source to chamber bodies. As also shown, a current maxima 507 exists at V_{ave}, which corresponds to an inflection point between the phase 503 and the anti-phase 505.

In an alternative operating mode, dim rings of plasma caused by inductively coupled plasma current are visible near top and bottom extremes of the inductive application, as illustrated by Fig. 5C. This operating mode is generally for a full-wave 517 inductive coupling coil with a voltage distribution 518 and current distribution 519 operated at a very high power, e.g., maximum power input to the inductive applicator is often limited by thermal considerations and breakdown. A full wave helical resonator applicator 523 and rf feed 524 are shown in phantom along the outside of a dielectric tube 532 enclosing the plasma. The rings 513, 515 of current in the plasma discharge are simulated by maximum coil current areas corresponding to voltage minima at the center of the coil as well as the top and bottom shorted ends of the coil. Under high power conditions, these subordinate current rings are detectable and some excitation is often visible in the intermediate regions. This excitation is partially caused by capacitively driven currents within the discharge coupled to the voltage maximum and voltage minimum positions along the inductive applicator.

Alternatively, subordinate inductive plasma current rings at the top and bottom ends 513 of the resonator do not appear with limited input power. The coil current and inductive flux fall beyond the ends of the inductive applicator so that a single inductive ring 515 in the center portion is more stable, provided that the conductivity of the plasma is large enough to support a single current ring at a specified input power.

In alternative applications using high power operation, no secondary plasma current rings may be desirable. These applications often have substantially minimum internal capacitive coupling. In these applications, the inductive applicator (e.g., coil) abutting the vacuum vessel may be shortened from a full wave to an appropriate length such that only the central current maxima exists on the coil abutting the plasma source and the [illegible] minimum voltage on the applicator is substantially reduced. The present application is achieved by stabilizing the desired waveform along the applicator by appropriate impedance wave adjustment circuits.

Referring to the above embodiments, the present invention provides for processing with an inductively coupled plasma in which the plasma potential from coupling to a phase portion of the inductive applicator is substantially not offset by capacitive coupling to complementary anti-phase voltages on selective portions of the inductive coupling element. Conventional inductive sources (e.g., conventional helical resonators, etc.), however, have hitherto been operated in quarter-wave or half-wave modes. These modes substantially provide only phase capacitive coupling to the plasma, which raises the plasma potential toward the coil in the absence of substantial anti-phase compensation. Conventional inductive sources that are longer than a half-wave have been generally considered cumbersome and impractical for plasma reactors. In particular, these inductive sources are large in size, and have voltage nodes along the helical coil, which have been believed to create a non-uniform plasma. In order to operate a substantially inductive plasma in a helical resonator, conventional inductive sources relied upon shielding the plasma tube from electrical fields originating on the coil. Shielding occurred, for example, by inserting a longitudinally split shield between the coil and plasma tube.

The present invention provides for a substantially pure inductively coupled power source. A benefit of this inductively coupled power as a primary means to sustain plasma excitation is that electric field lines produced by inductive coupling are purely rotational (e.g. they close on themselves). Hence they do not create or support a scalar potential field (e.g. a voltage difference) within the plasma volume. Thus, in an ideal case, inductively coupled power can be transferred into a plasma without no direct relationship between the plasma potential and the voltages on coupling elements (e.g. the voltage on the coil in a helical resonator) or voltages on rf matching networks, if such are used. Furthermore, when transferring power to the plasma by purely inductive means, power transfer does not require any significant potential difference to be maintained between elements of the plasma and ground potential (e.g. the potential difference between the plasma and ground can be fixed by factors which are substantially independent of inductive excitation power). Although in theory, inductive power transfer does practice there has been substantial potential shifts and harmful alteration in the plasma potential found in unshielded current art inductive sources.

As previously noted, and further emphasized herein, the most effective conventional method employed to avoid plasma potential shift in conventional commercially available inductive sources is to shield the plasma from the electrical fields on the inductive coupling element (commonly a multi-turn coil) by inserting a grounded conductive member between the inductive driving element and the plasma discharge tube. Shielding is, however, cumbersome and inconvenient and has serious disadvantages in practice. Shields couple to inductive applicator elements and can cause wide excursions in the natural resonance frequency, which are not predicted by conventional analytical design formulae. This often results in laborious trail and error and iterative mechanical designs to achieve a desired resonance. Another disadvantage of shielding is that shields often make it difficult to achieve initial ignition of the plasma since shields generally exclude capacitive electric fields in the plasma discharge tube. In particular, ignition (known as plasma breakdown) of inductive breakdown generally begins with a capacitive electric field discharge, which is stable at lower currents and powers (See, for example, J. Amorim, H.S. Maciel and J.P. Sudana, J. Vac. Sci. Technol. B9, pp. 362-365, 1991). Accordingly, shields tend to block capacitive electric fields, which induce plasma ignition.

Insertion of the shield close to high voltage RF point in a network (such as the voltage maximum points in a helical resonator or the high potential driven side of a TCP coil) also causes large displacement currents to flow through the capacitance between the shield and coil. This high potential difference is also a potential cause of damaging rf breakdown across the air gap, hence the gap may require protection by inconvenient solid or liquid dielectric insulation. The displacement current flow causes power loss and requires that higher power RF generating equipment be used to compensate for the power loss. Coupling loss in the plasma source structure is also undesirable from the standpoint of thermal control. These limitations are overcome by the present invention using the wave adjustment circuits, an inductive applicator of selected phase length, and other elements.

Examples

invention, a helical resonator plasma source can be used in a photoresist stripper for ashing with a pure O_2 plasma. A substantially similar configuration is useful for chemical dry etching (CDE), as exemplified by the selective removal of silicon nitride over silicon oxide layers with a plasma sustained in feed gas mixtures containing suitable mixtures of $CF_4/O_2/N_2$. Conventional helical resonators can also be evaluated. These are merely examples, and should not limit the scope of the claims herein. One of ordinary skill in the art would easily recognize other examples, uses, variations, and modifications of the inventions defined by the claims.

I. Conventional Photoresist Stripper

In this example, a conventional quarter-wave helical resonator resist stripper 600 can be constructed with a quarter-wave helical resonator source 602 upstream of a processing chamber 604, shown in Fig. 6. This quarter-wave helical resonator 602 included a coil 608 and other elements.

Coil 608 consisted of 5.15 turns of 0.4 inch diameter copper tubing wound with a pitch of 0.5 turns per inch with a mean radius of 6.4 inches and centered radially and vertically inside an outer copper shield 610. Coil 608 is operably coupled to a power source 612 and operated at about 13 MHz radio frequency. A 17 inch long, 9.25 inch diameter quartz tube 606 is centered inside of the copper coil 608. The shield 610 is 16 inches inside diameter, approximately 0.08 inches thick and 18 inches long. This shield 610 also can be connected to a ground (V_G) connection on the aluminum process chamber body (except when making the current measurements described below).

The process chamber 604 can be for a conventional resist stripper. This resist stripper included a wafer support 616 (or pedestal) and other elements. Process chamber 604 is operably coupled at an outer location 620 to ground via shield 610. Wafer support 616 has a wafer 618 disposed thereon.

The wafer 618 is a 6-inch (250mm) <100> type wafer with approximately 1.25 microns of spin-coated positive photoresist. This wafer can be ashed on the grounded 10 inch diameter wafer support 616. This support can be resistivity heated and the temperature of the substrate support can be sensed with a thermocouple.

After the helical resonator plasma is ignited, visible plasma filled the strong plasma glow can always be visible above the wafer in the downstream processing chamber which was indicative of secondary plasma discharge to the substrate support. This secondary plasma discharge cab also be accompanied by current flow from the resonator shield to the chamber of approximately 5-10 Amperes rms (and sometimes even more) which could be measured by elevating the shield on insulating blocks and monitoring the current flow through a 2 inch long 1.5 inch wide strip of copper braid which is passed through a Pearson Current probe used to monitor the current.

Fig. 7 is a simplified diagram 700 of the rf voltage distribution along the coil for the quarter-wave helical resonator of Fig. 6. This diagram includes the quartz tube 606 and a plasma discharge (or source) 701 therein. As shown, the plasma discharge includes a glow region that 701 occupies a large range (R) of the quartz tube 606. The plasma discharge has an average voltage (V_{ave}) between the ground potential (V_G) and the high voltage potential (V_H). As can be seen, the plasma discharge 701 has current flow through capacitively coupling elements to V_H and V_G and elements of elevated potential on the coil due to its average voltage potential V_{ave}. In fact, as previously noted, the current flow from the resonator shield to the chamber is at least 5-10 Amperes rms. In high power applications, intense sparking is observed in the chamber from the capacitively coupled plasma source.

II. New Photoresist Stripper

A resist stripper apparatus in a cluster tool arrangement using a helical resonator according to the present inventions is shown in Figure 8 with a side view diagram of one of the two chambers, 901, shown in figure 9. One of ordinary skill in the art, however, will recognize that other implementations, modifications, and variations may be used. Accordingly, the experiments performed herein are not intended to limit the scope of the claims below.

The photoresist stripper apparatus is configured with multiple process chambers in a cluster tool arrangement, as illustrated by simplified top-view diagram Fig. 8 and simplified side-view diagram of one chamber 901 in Fig. 9. Two process chambers, e.g., chamber 1 901 and chamber 2 903, are used. Chamber 1 901 is used for stripping to upper layer of implant hardened resist (crust or skin). Chamber 2 903 is used for stripping the remaining underlayer of hardened resist crust and stripping remaining photoresist in parallel using sequential process operations. Of course, the particular use and recipe depends upon the application. These chambers can also be made of aluminum with inserts, which are resistant to chemical attack.

The apparatus uses a microcontroller based controller to oversee process operations. This microprocessor based controller can be accessed through a control panel 921. A suitable controller can be made using a 486 or Pentium processor in a conventional PCI bus-based personal computer. Operator access to the control recipes and process parameters can be made using a conventional LCD touch panel display.

An automatic wafer handling system 910 is also provided. The automatic wafer handling system uses standard cassettes 912 for transferring photoresist-coated wafers to and from the process chambers 901, 903. The automatic wafer handling system includes a robot 917, cassette chamber 1 905, cassette chamber 2 907, cassette stage 1 909, cassette stage 2 911, and other elements. The wafer handling system 910 uses a conventional interlock system for providing the cassettes 912 from the cleanroom into the process chambers 901, 903. A main shuttle chamber 913 houses the robot 917 in the cluster tool arrangement. The controller oversees the automatic wafer handling system operations.

Cooling plates 915 and 910 are optionally included in the main chamber 913 housing the robot 917. The cooling plates 915 and 910 are of conventional design, and are capable of cooling the wafer after being stripped, which often occurs at elevated temperatures. Alternatively, the cooling plates can be used to thermally adjust the wafer temperature either before, after, or even between selected process operations.

The process chambers 901, 903 are disposed downstream from respective plasma sources 923, 925. Each helical resonator includes a coil 927 disposed around a quartz tube 929. A suitable coil consists of 11.5 turns of 0.4 inch copper tubing wound with a pitch of 0.9 turns per inch with a mean radius of 9.4 inches and centered radially and vertically inside an outer copper shield 931. The coil is operably coupled to a power source by coaxial cable 941 which is connected to a suitable matching tap point 951 on the helical coil. A 17 inch long, 9.25 inch diameter quartz tube is centered inside of the copper coil. The shield is 16 inches inside diameter, approximately 0.1 inches thick and 18 inches long. The

Although the helical resonator delivers rf power to the discharge with very high efficiency, the plasma source and applicator structures are often strongly heated by the energy released from within the plasma discharge chamber. Hence it is desirable to control the temperature of the plasma source and rf applicator structure. This is conveniently done by means of a liquid heat transfer agent (e.g. deionized water or a suitable heat exchange fluid) which is maintained at a constant temperature and circulated through the tubular helical coil by way of fluid connections 987 and 988. Additional means for cooling the shield 931 (not shown in figure 9) are provided for use in certain high power applications. It will be obvious to those skilled in the art that heat transfer utilizing a gaseous coolant (e.g. air or nitrogen) or external conductive or convective heat transfer means can also be used in many applications.

Processes in this equipment may be used for stripping photoresist from wafers, e.g., <u>See</u> Fig. 9 reference numeral 933, or selected CDE operations such as the selective removal of silicon nitride films which have been deposited over silicon oxide. Particular processes may involve a multi-step stripping operation to remove implanted photoresist from semiconductor wafers. For example, Photoresist 1.5 microns in thickness on device wafers may be implanted. This implant operation causes the formation of an implant hardened stratum over the top of an underlying layer of normal photoresist.

A clean implant resist stripping process can be conveniently be performed by stripping the top implant hardened resist layer by ion-assisted ashing using an "un-balanced" coupling relationship in a half-wave helical resonator. A suitable half-wave helical resonator is configured in one of the process chambers. The half wave helical resonator plasma chamber can be conveniently operated at a frequency of about 13.56 MHz corresponding to a full-wave multiple. In this chamber, the pedestal can conveniently be maintained at a low wafer temperature in the range of 50C-80C to reduce the possibility of "popping." Popping occurs when the pressure of low molecular weight monomer, oligimer or solvent in the underlying photoresist bursts the relatively impermeable implant hardened surface layer of the resist.

After the uppermost hardened layer of the resist is removed, the wafer is transferred into a chamber operating in a suitable balanced configuration such as a full-wave multiple. Plasma confinement afforded by use of the present it as exposed as the resist is "cleared" just before and after "endpoint." The full wave helical resonator plasma chamber can be conveniently operated at a frequency of about 27.12 MHz corresponding to a full-wave multiple. The pedestal of this chamber is generally maintained at a selected temperature in the range of 150 to 220 °C. It is advantageous to operate at as high a temperature as is permissible because the ashing chemical reaction rate increases with temperature and therefore the machine productivity (throughput) will be greater. However the maximum usable temperature is often limited by the vulnerability of device layers to harmful thermal effects. For example, some silicon antireflection coatings require that temperature be limited to below about 170-180°C. Another limitation on temperature is related to uniformity. Temperature uniformity in some heater configurations deteriorates with increasing temperature owing to a shift from dominantly conductive and convective heat transfer to an energy balance in which radiative heat transfer processes have a greater role. In general, there are proportionately greater amounts of heating and cooling by radiation at higher temperatures, since radiative energy transfer depends on the temperatures of surfaces which "view" each other raised to the fourth power, whereas conductive and convective heat transfer often depend linearally on localized temperature differences. It is desirable that etching and ashing processes be highly uniform in order that the overetch period during which all or portions of device layers are exposed to reactive plasma species can be minimized. Plasma induced damage, if it occurs, is known to take place after some or all parts of device layers are exposed. (A discussion of damage and temperature effects in resist stripping is given in "Dry Plasma Resist Stripping" by D. L. Flamm in Solid State Technology, pps. 37-39, August 1992 (Part I),pps. 43-48, September 1992 (Part II) and pps. 43-48, October 1992 (Part III)).

A balanced structure which provides for substantially equal capacitive coupling to applicator elements with rf voltages inverse to each other, in particular a balanced full wave structure such as that described in this example provides for balanced phase and inverse-phase coupled currents, thereby reducing the amount of capacitively coupled plasma, which can be detrimental to the underlying substrate. In this step, overashing is performed to substantially remove all photoresist material from the wafer. No damage occurs to the underlying substrate during this overashing step.

Once the photoresist has been stripped, the wafer is cooled. In placed on the cooling station. This cooling station reduces the temperature of the wafer (which was heated). This wafer is then reloaded back into its wafer cassette. Once all wafers have been processed in the cassette, the cassette comprising the stripped wafers is removed from the cluster tool apparatus. Characteristics of this half-wave helical resonator were described in detail above.

Useful processing conditions for ashing 6-inch wafers with normal (not ion-implanted) photoresist are pressures in the range of 0.1 to 10 Torr using a gas flow in the range of 0.1 to 10 standard liters per min. and input power to the plasma of approximately 1.5 to 2.5kW (For this purpose power is defined to be the net power transferred to the helical resonator structure, e.g. forward-reflected power in the transmission feed line, since the helical resonator is extremely efficient e.g. more than 90% of transferred power is absorbed by the plasma). Under these conditions an ashing rate above 3kÅ/min are readily achieved when ashing a lower temperature (e.g. c.a. 60C) and rates of 1μ/min and higher can be achieved when the temperature is elevated (in the range of 170-210°C). When feed the feed gas flow profile is sufficiently uniform (A wide residence time distribution of gas flow in the plasma source is undesirable. In the example the residence time is made more homogeneous by the imposition of a baffle plate 975 below the feed gas inlet 976. Ashing uniformity in a chamber geometry exemplified by figure 9 is mainly determined by temperature uniformity across the wafer. When the resist asher is equipped with a suitably designed wafer heating means such as a multizone resistive heater 981 with multiple electrical connections 983-986 as shown in Fig. 9, an average etching uniformity better than 5% is readily achieved.

A visual inspection of wafers stripped in this type of apparatus can show extremely good results. That is, the wafers are stripped at a sufficient rate for production operation and no substantial damage occurs to the wafers. This provides for effective wafer turn-around-time and substantially no damage caused by the plasma. In addition, current measured from the shield to the chamber by elevating the shield on insulating blocks is substantially less than current(s) measured in a conventional (unbalanced) helical resonator stripping apparatus.

While the invention has been described with reference to specific embodiments, various alternatives, modifications, and equivalents may be used. In fact, the invention also can be applied to almost any type of plasma discharge apparatus. This discharge apparatus can include an apparatus for plasma immersion can be used for the manufacture of flat panel displays, disks, integrated circuits, diamonds, semiconductor materials, bearings, raw materials, and the like. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

WHAT IS CLAIMED IS:

1. A device made using a process for fabricating a product, said process comprising the steps of subjecting a substrate to entities, at least one of said entities emanating from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of phase portions and inverse-phase portions of capacitive current coupled from the inductive coupling structure are selectively maintained.

2. The device of claim 1 wherein said product comprises a semiconductor device.

3. The device of claim 1 wherein said gaseous discharge is provided by a helical resonator.

4. The device of claim 1 wherein said gaseous discharge is provided by a helical resonator having an electrical length which is substantially a whole number multiple of one wavelength.

5. The device of claim 1 wherein said gaseous discharge is provided by a helical resonator structure, said helical resonator structure having an electrical length which is substantially free from any whole number multiple of one quarter wavelength.

6. The device of claim 1 wherein said one of said entities is provided in chemical vapor deposition.

7. The device of claim 1 wherein said one of said entities is provided in plasma etching.

8. The device of claim 1 wherein said inductive coupling structure is selectively balanced using a wave adjustment circuit.

9. Apparatus for fabricating a product, said apparatus comprising:

an enclosure comprising an outer surface and an inner surface, said enclosure housing a gaseous discharge.

a plasma applicator disposed adjacent to said outer surface;

a high frequency power source operably coupled to said plasma applicator, said high frequency power source exciting said gaseous discharge to provide at least one entity from a high frequency field in which the vector sum of phase and inverse-phase capacitive currents coupled from the inductive coupling structure are selectively maintained; and

a wave adjustment circuit, said wave adjustment circuit operably coupled to said plasma applicator to selectively maintain said inductive coupling structure.

10. Apparatus of claim 9 wherein said enclosure is a chamber.

11. Apparatus of claim 9 wherein said enclosure is a tube.

12. Apparatus of claim 11 wherein said tube is made of one or more materials selected from quartz, glass, diamond, polymer, sapphire, ceramic and alumina.

13. Apparatus of claim 9 wherein said apparatus is provided for chemical vapor deposition.

14. Apparatus of claim 9 wherein said apparatus is provided for plasma etching.

15. Apparatus for fabricating a product, said apparatus comprising:

a high frequency power source operably coupled to an inductive plasma applicator, said high frequency power source exciting a gaseous discharge to provide at least one entity from a high frequency field in which a vector sum of coupling to phase and inverse phase voltage elements from the inductive coupling structure are selectively maintained; and

a wave adjustment circuit, said wave adjustment circuit operably coupled to a plasma applicator to selectively adjust said inductive coupling structure.

PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

ABSTRACT OF THE DISCLOSURE

A process for fabricating a product 28, 119. The process comprises the steps of subjecting a substrate to a composition of entities, at least one of the entities emanating from a species generated by a gaseous discharge excited by a high frequency field in which the vector sum of currents to phase and inverse-phase capacitive coupled voltages from the inductive coupling structure can be selectively maintained.

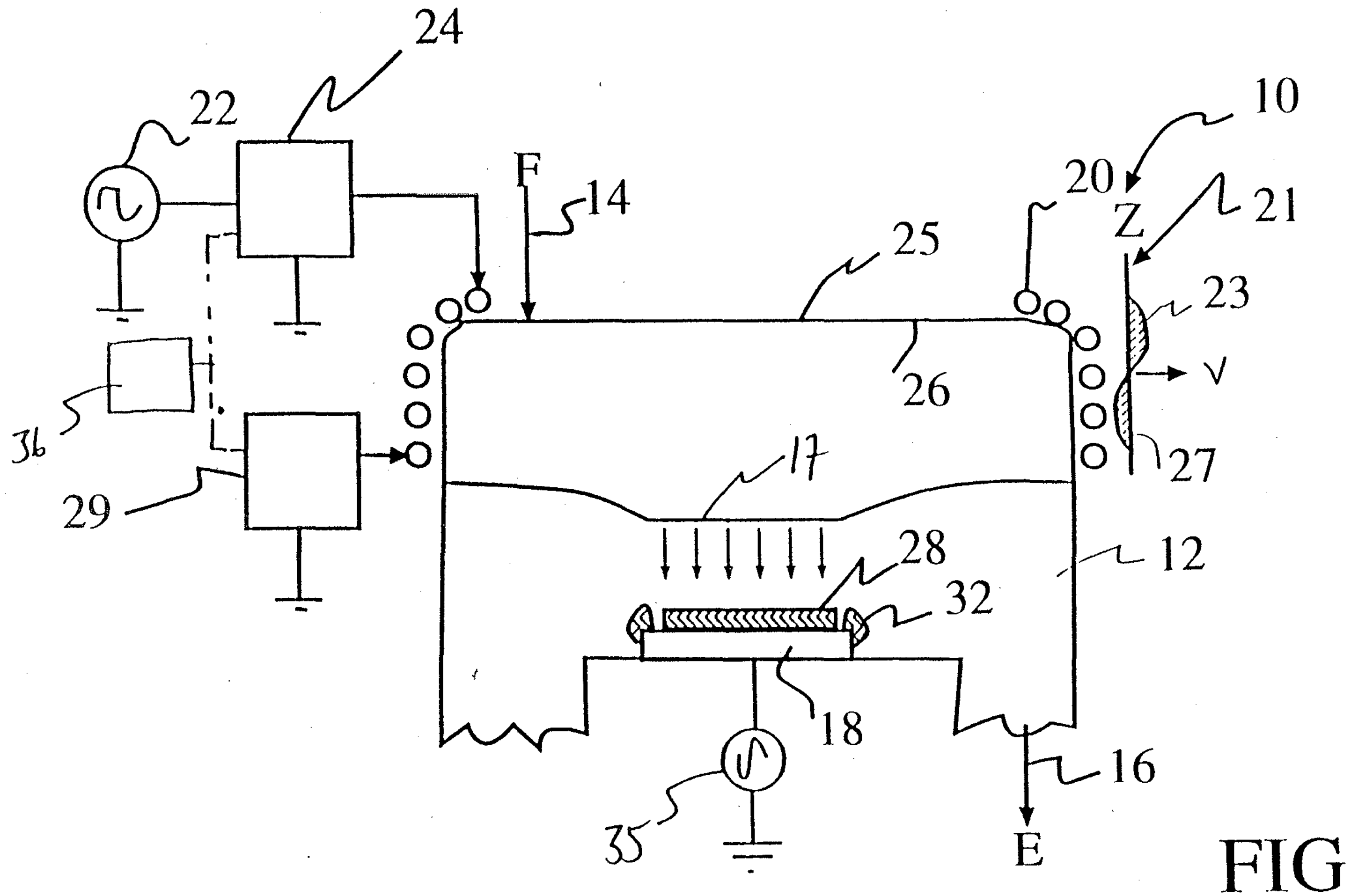

FIG. 1

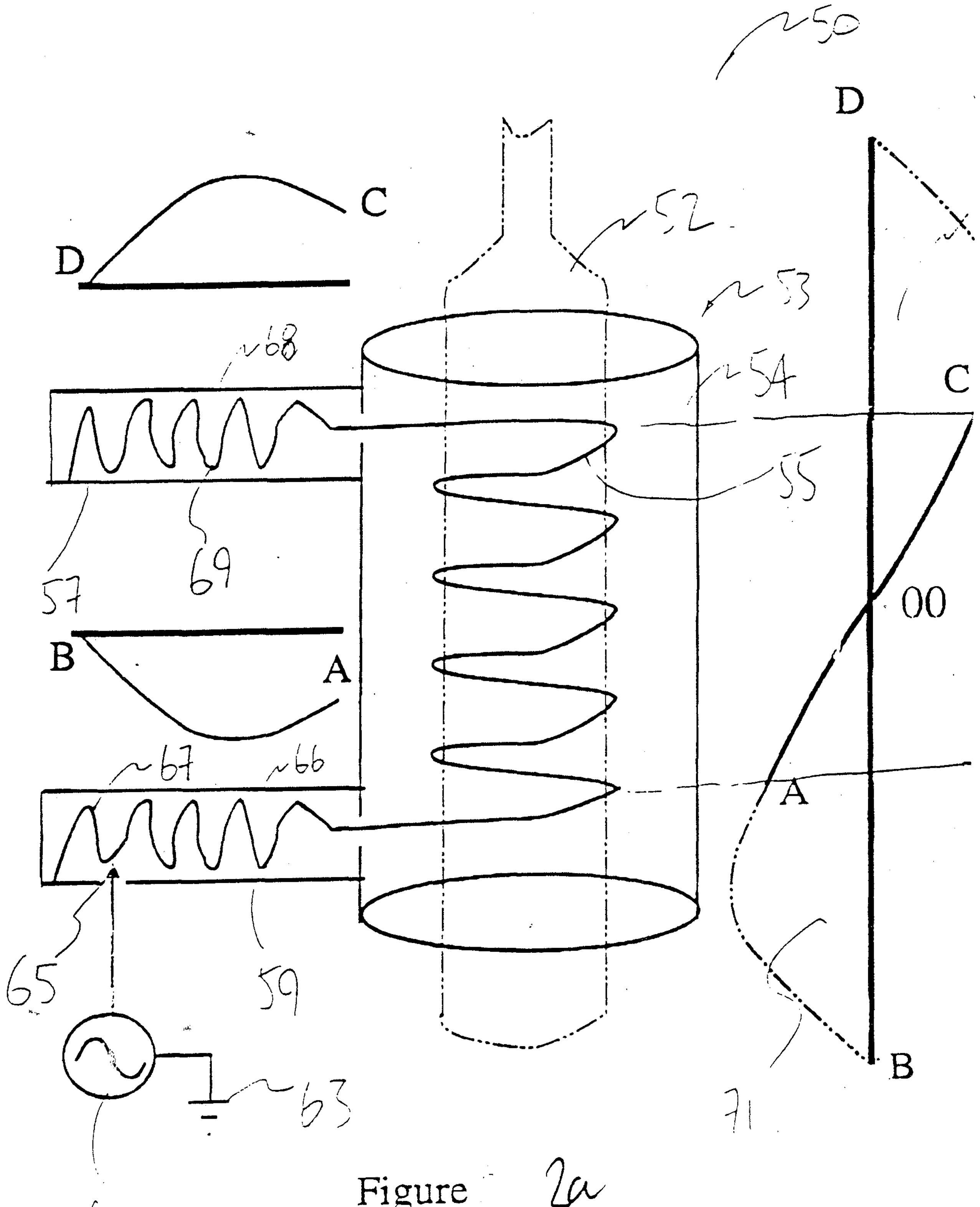

Figure 2a

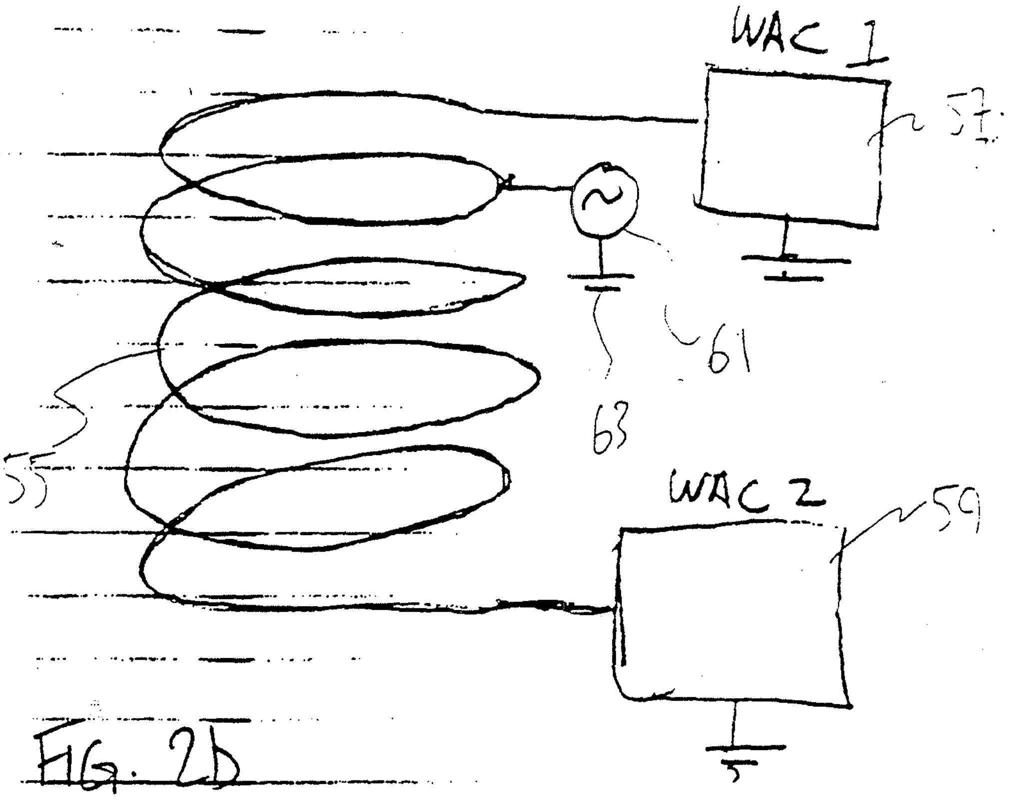

FIG. 2b

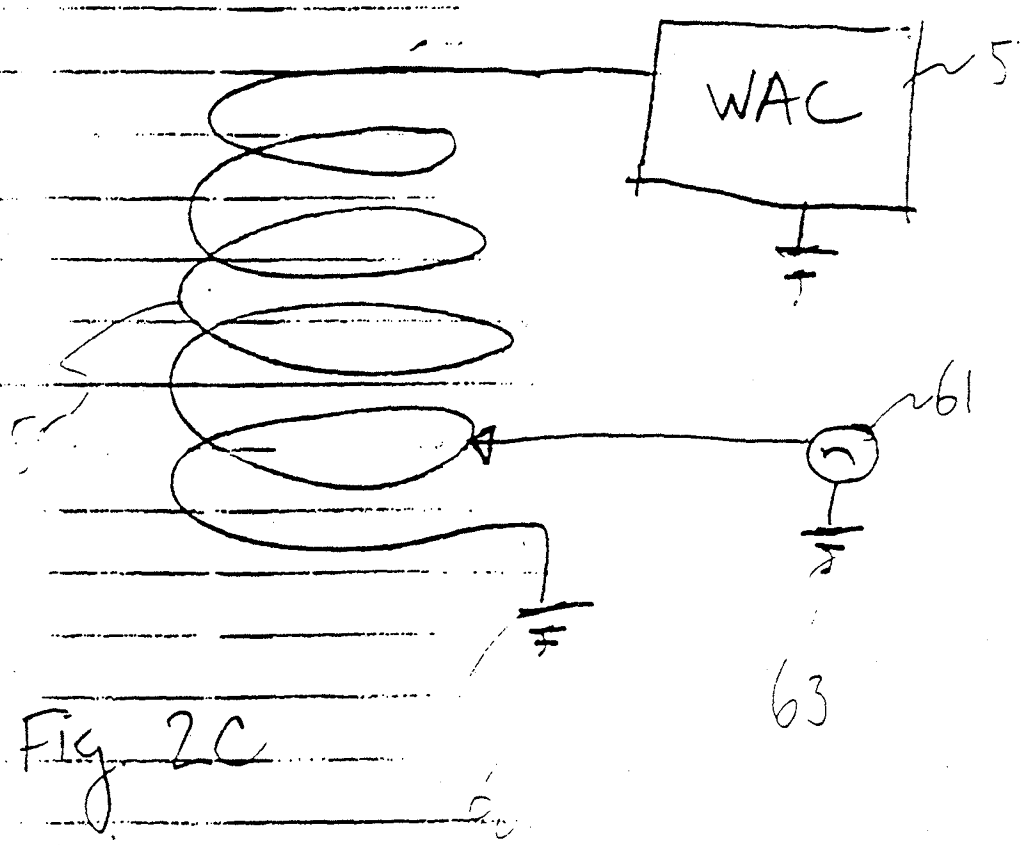

Fig 2C

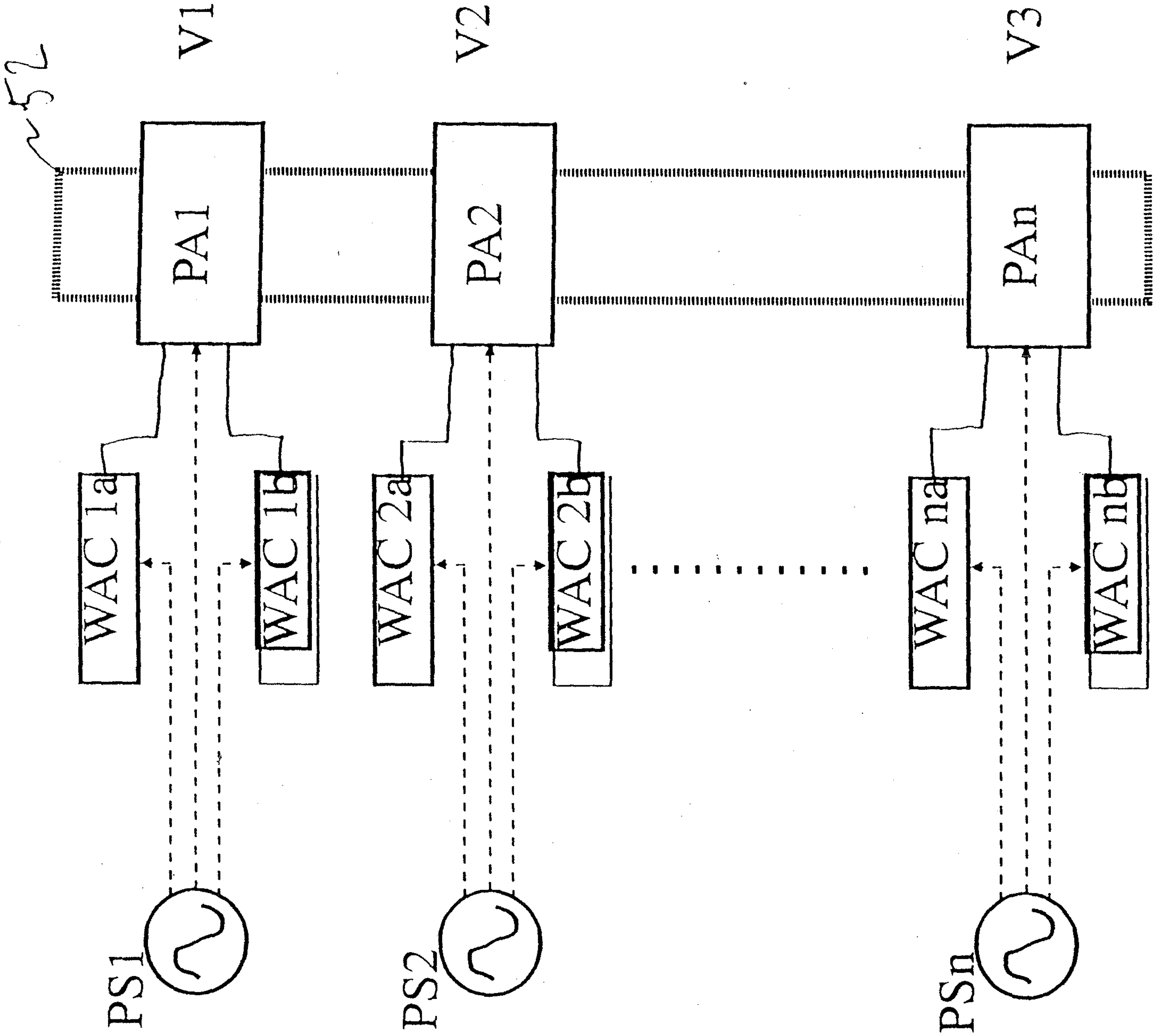
52
V1
V2
V3
PA1
PA2
PAn
WAC 1a
WAC 1b
WAC 2a
WAC 2b
WAC na
WAC nb
PS1
PS2
PSn

Fig. 2d

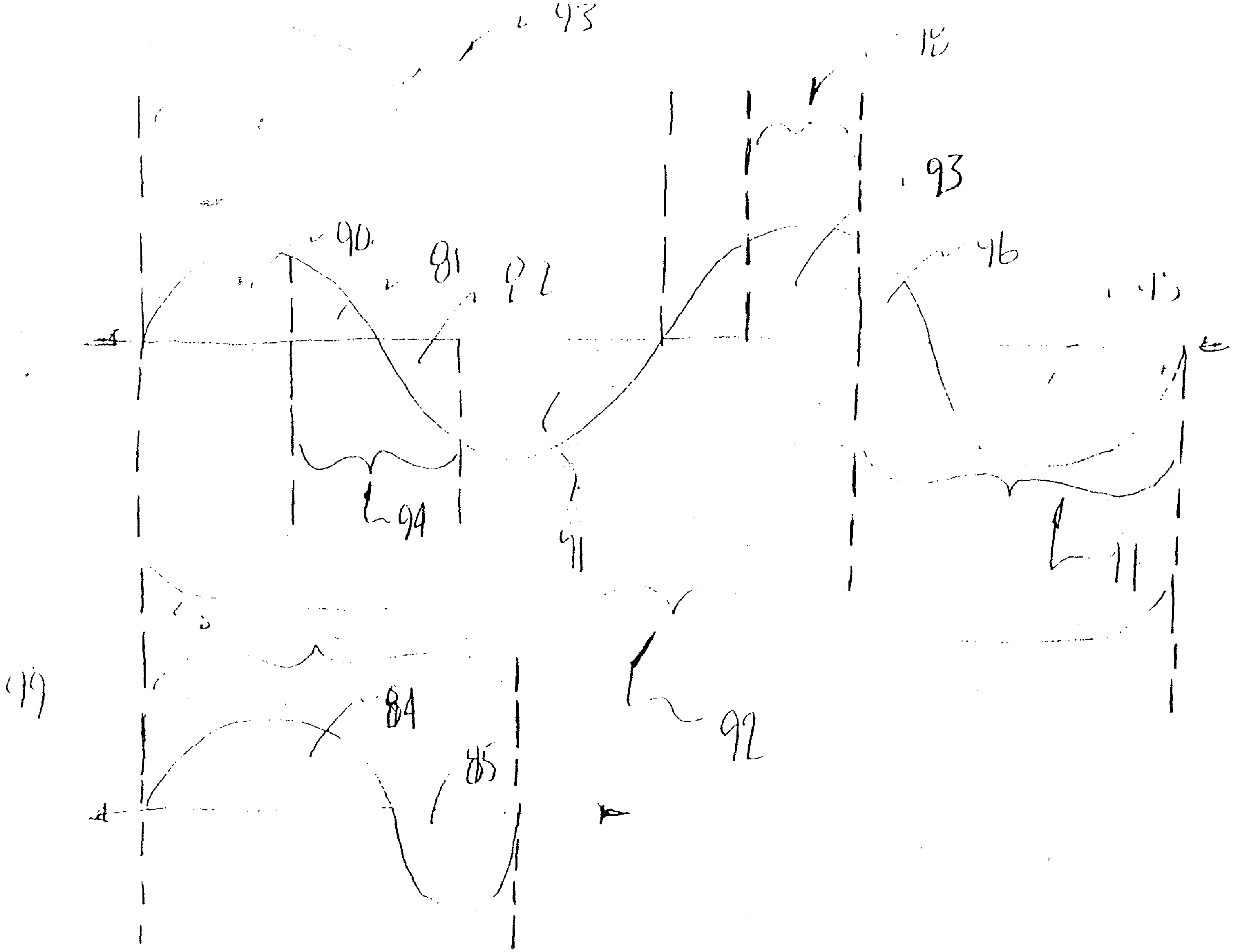

FIG. 2E

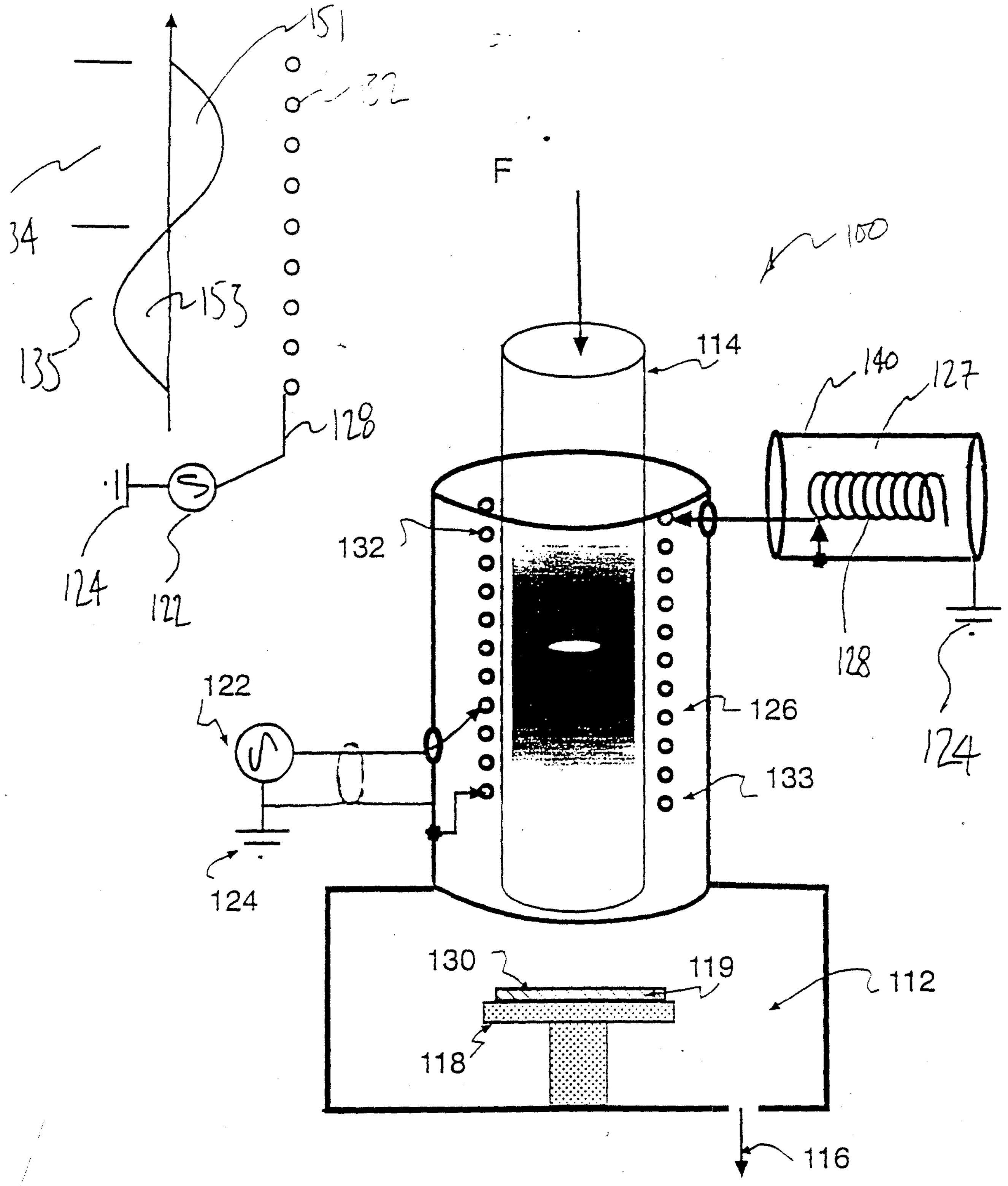
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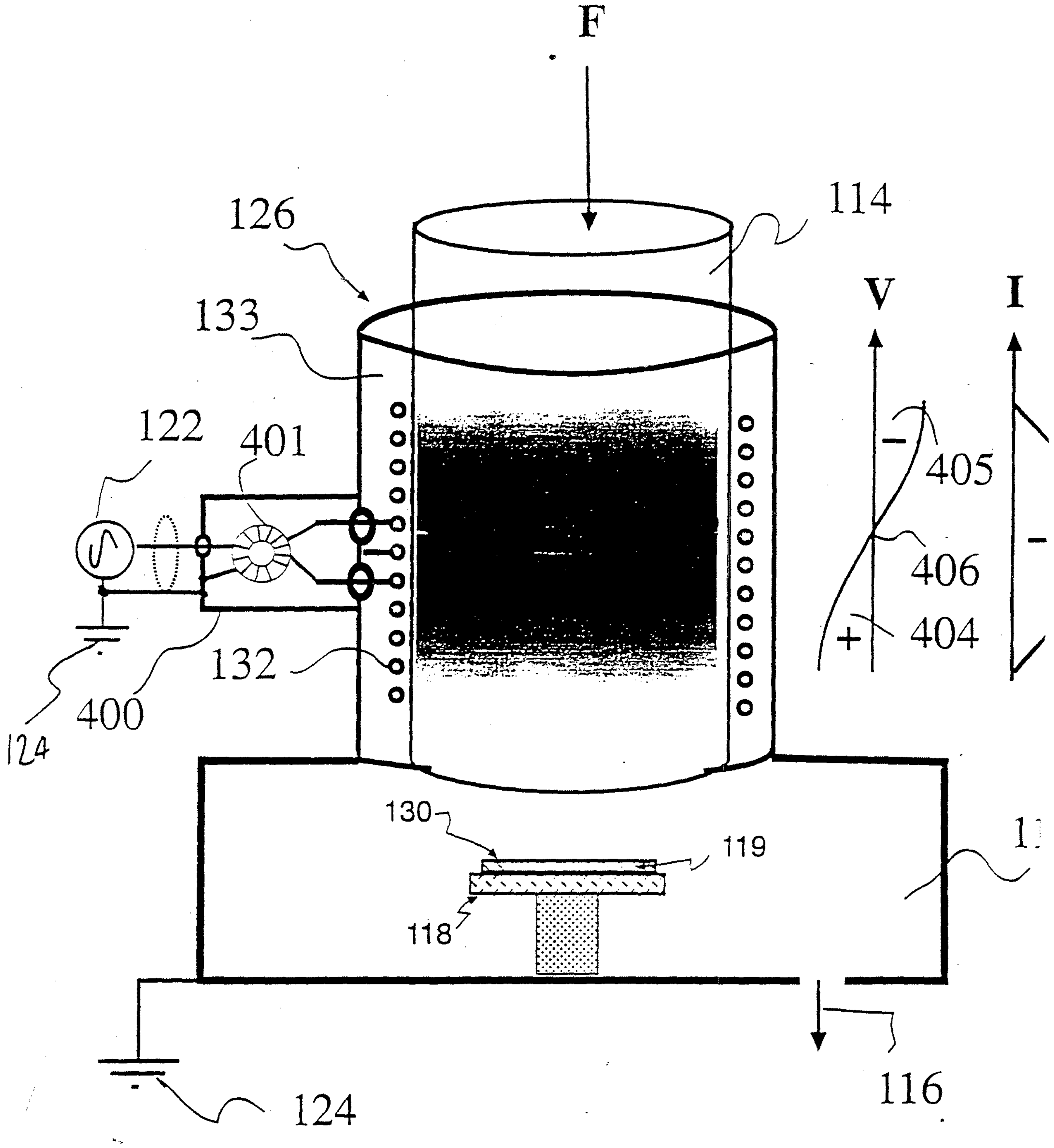
Fig 3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401
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130
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124

Fig. 4

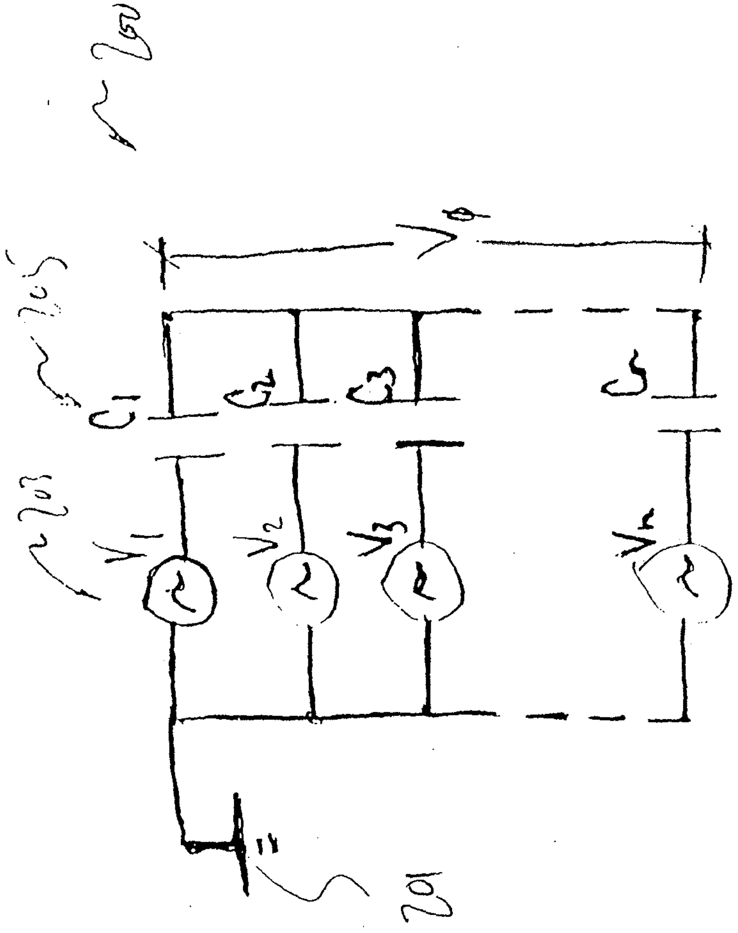

FIG. 5A

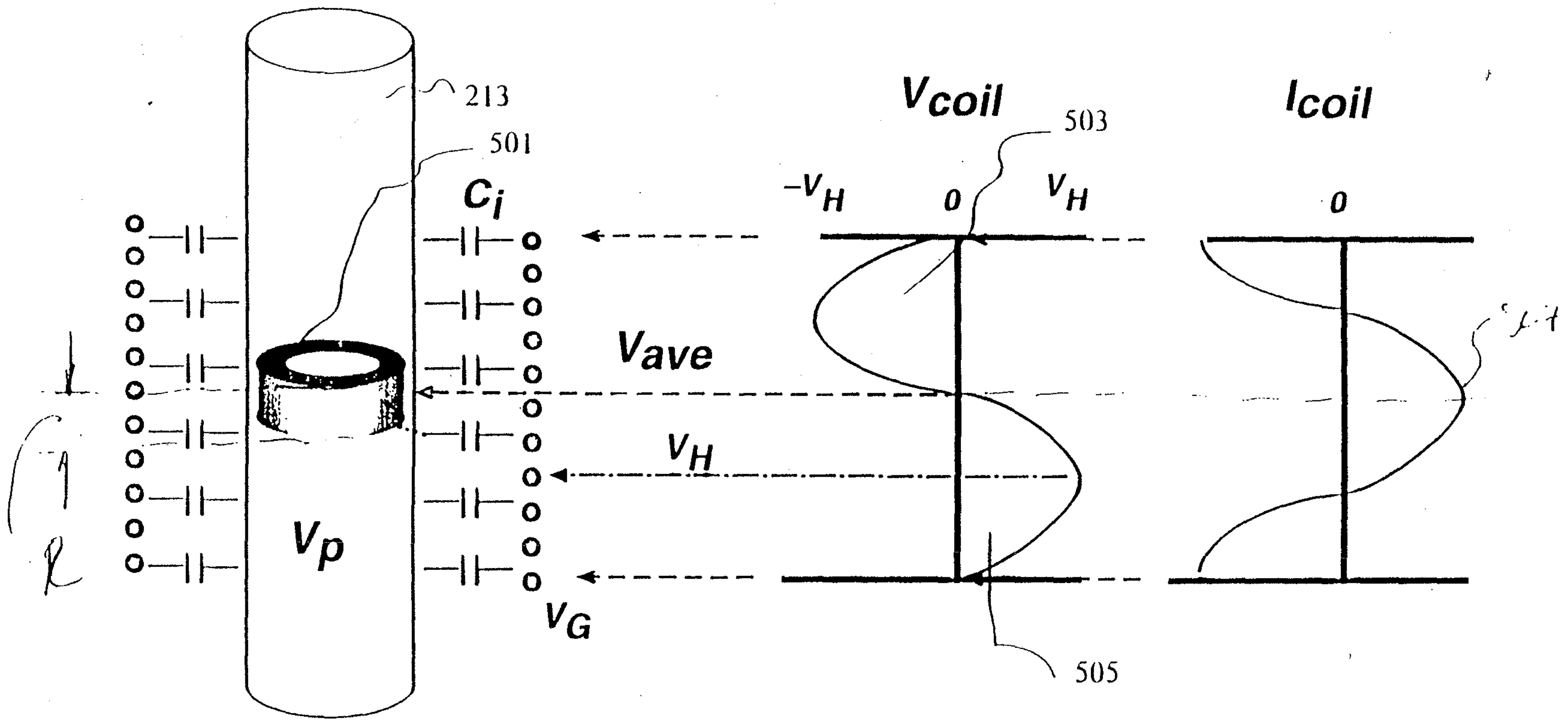

FIG. 5B

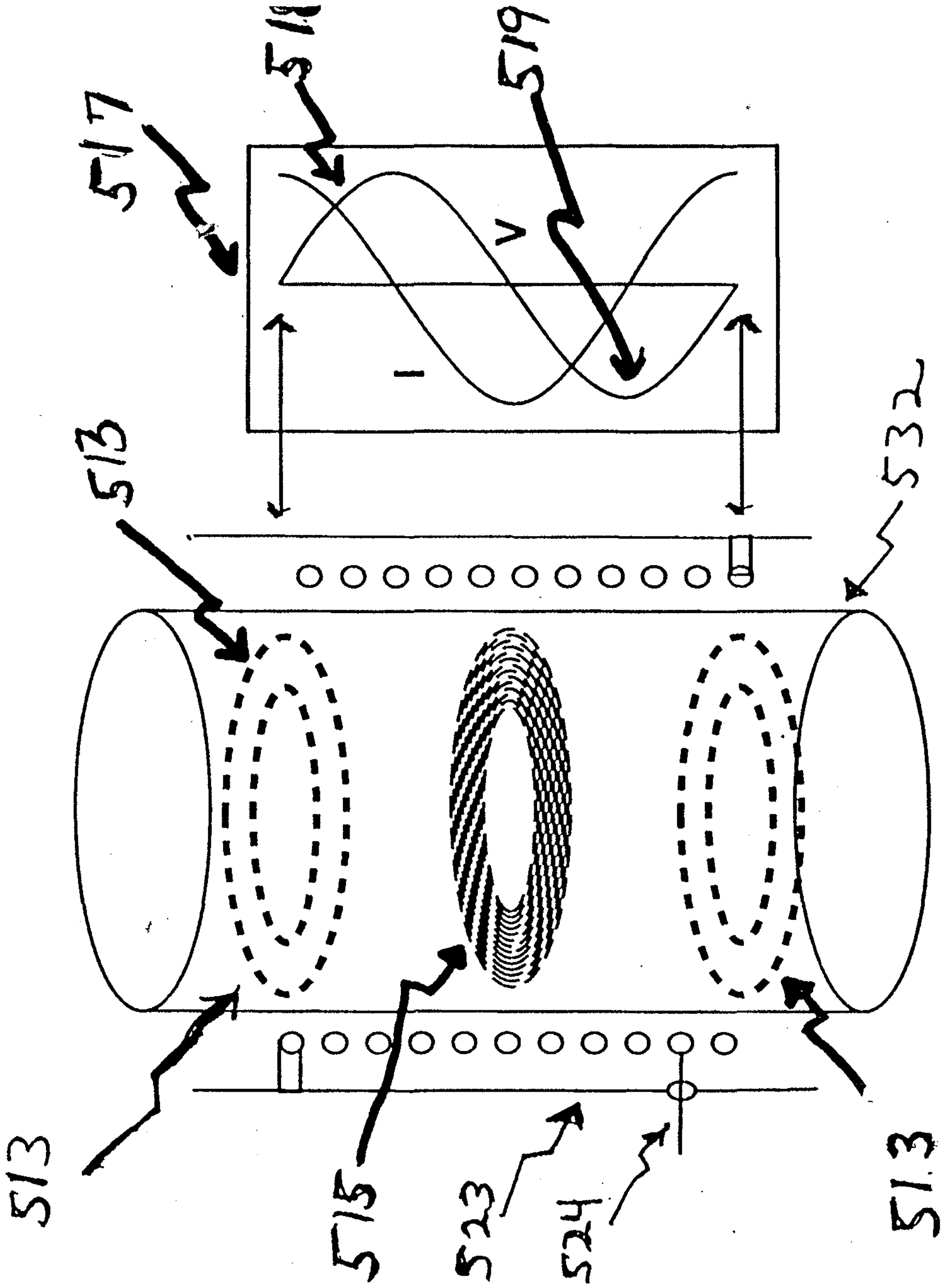

Fig. 5C

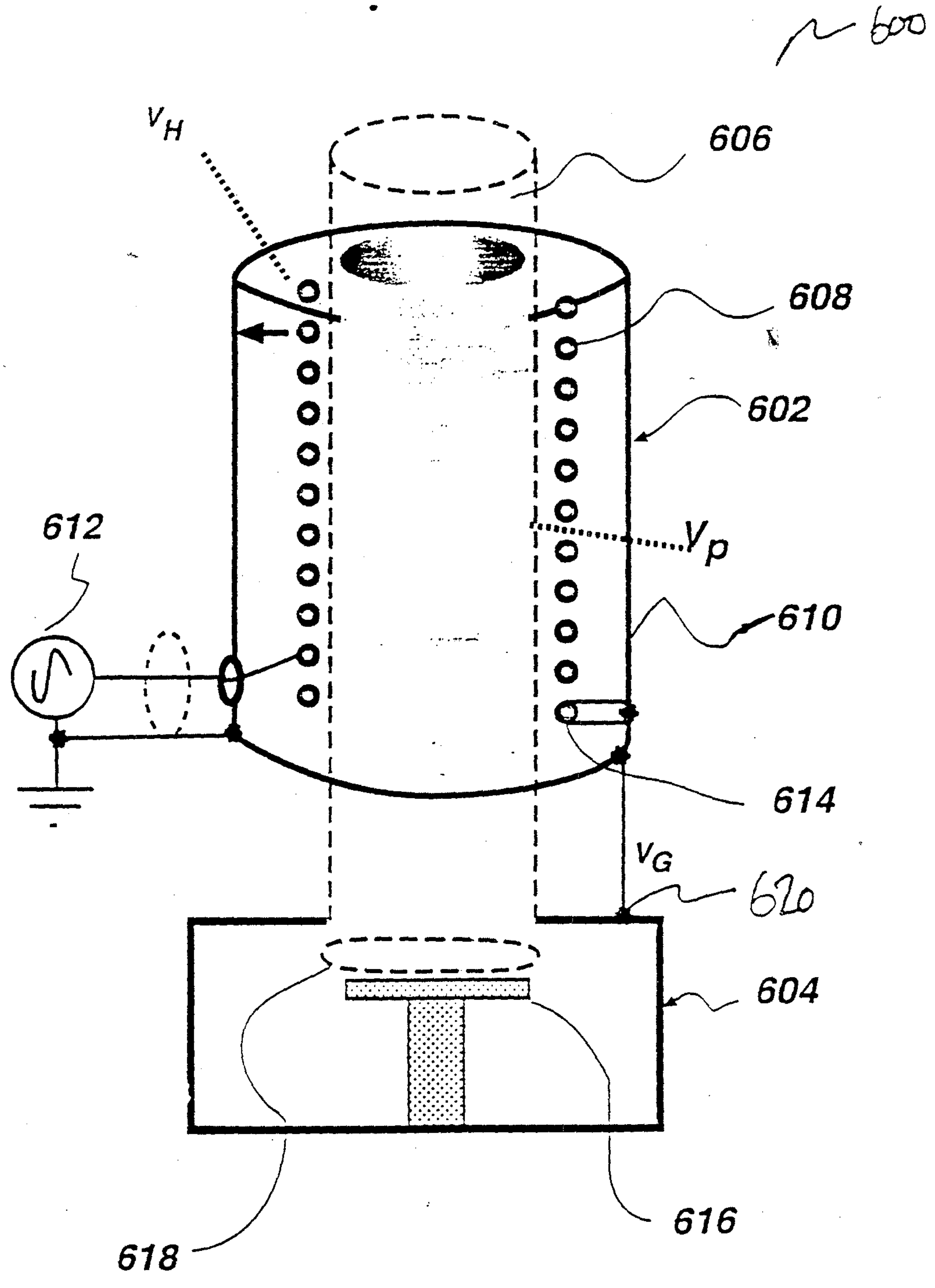

Fig. 6

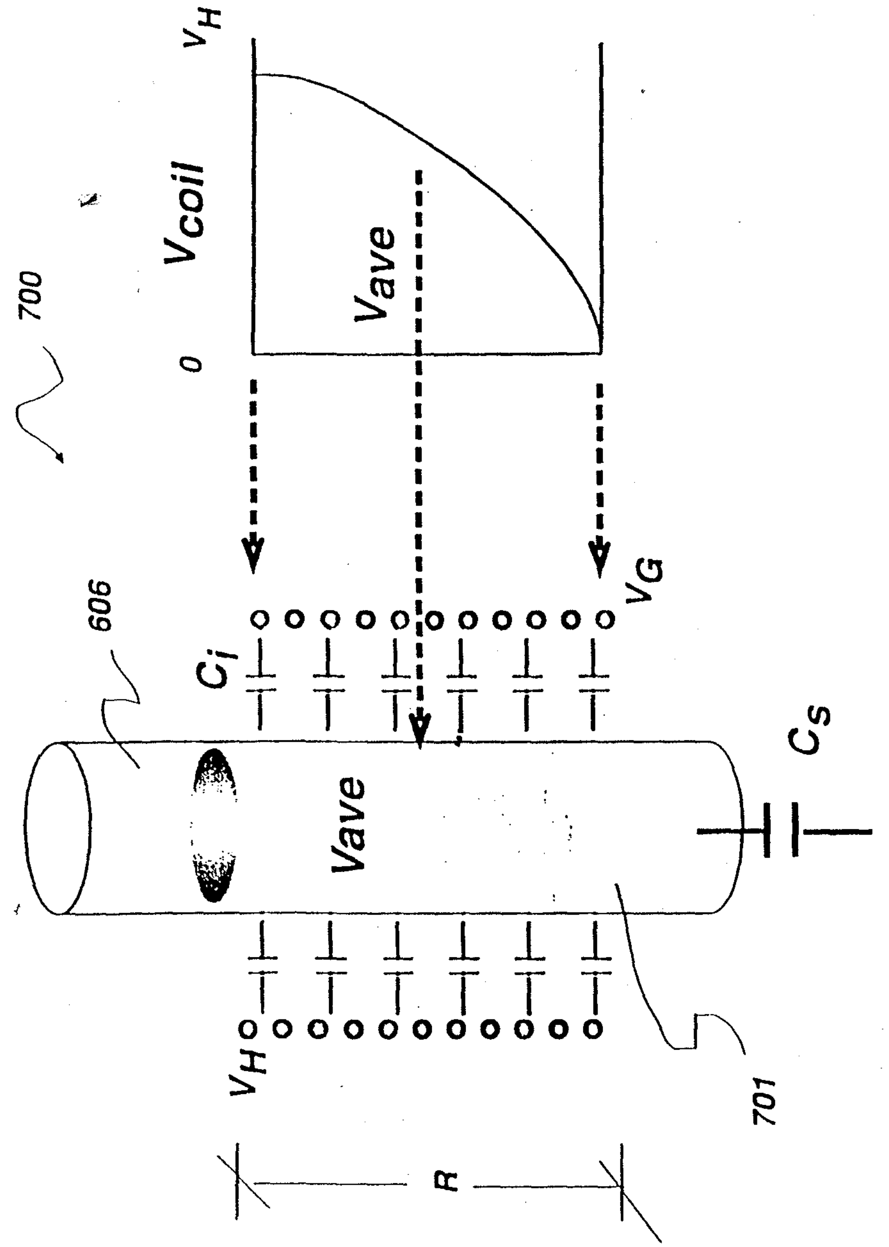

Fig. 7

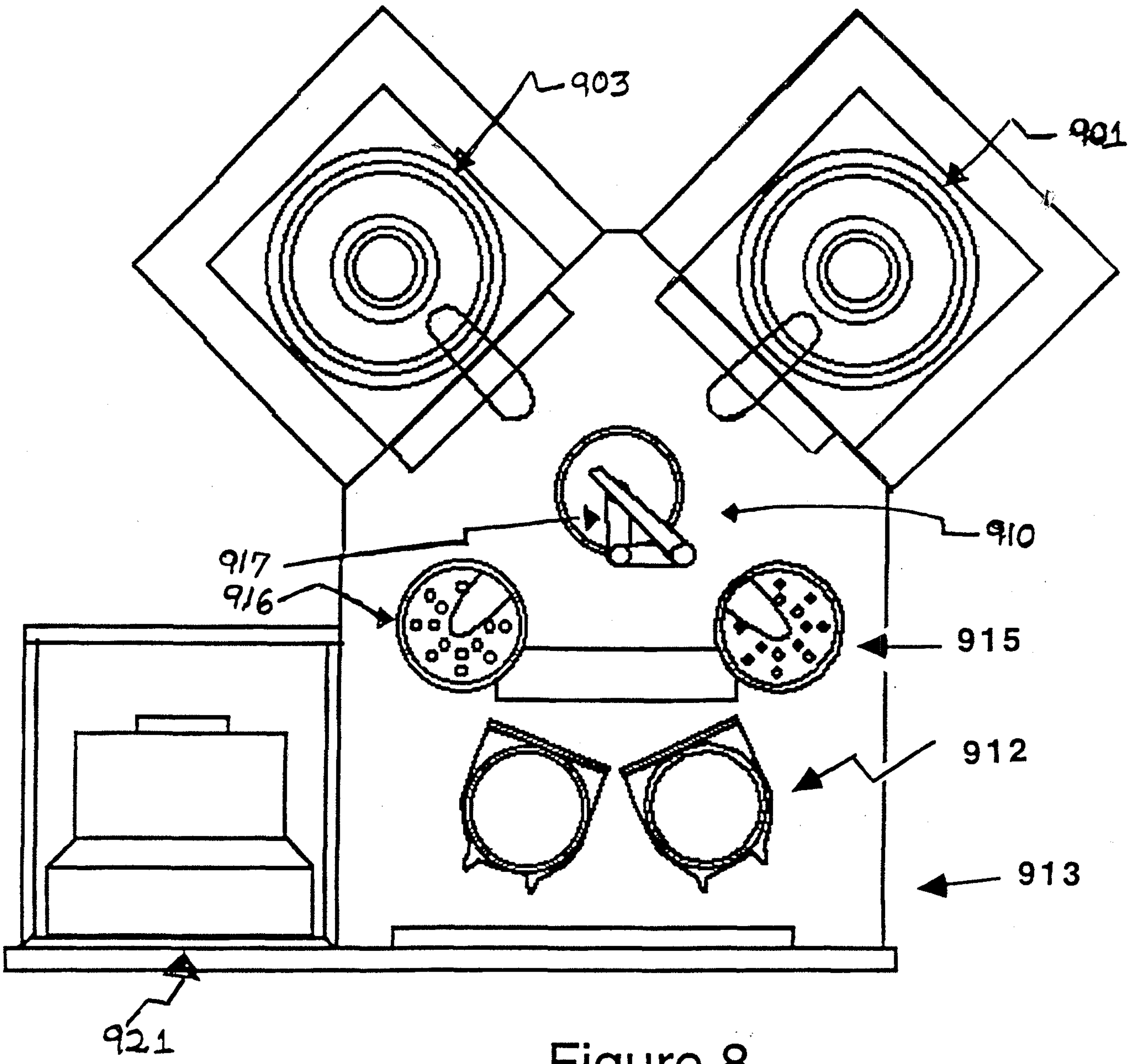

Figure 8

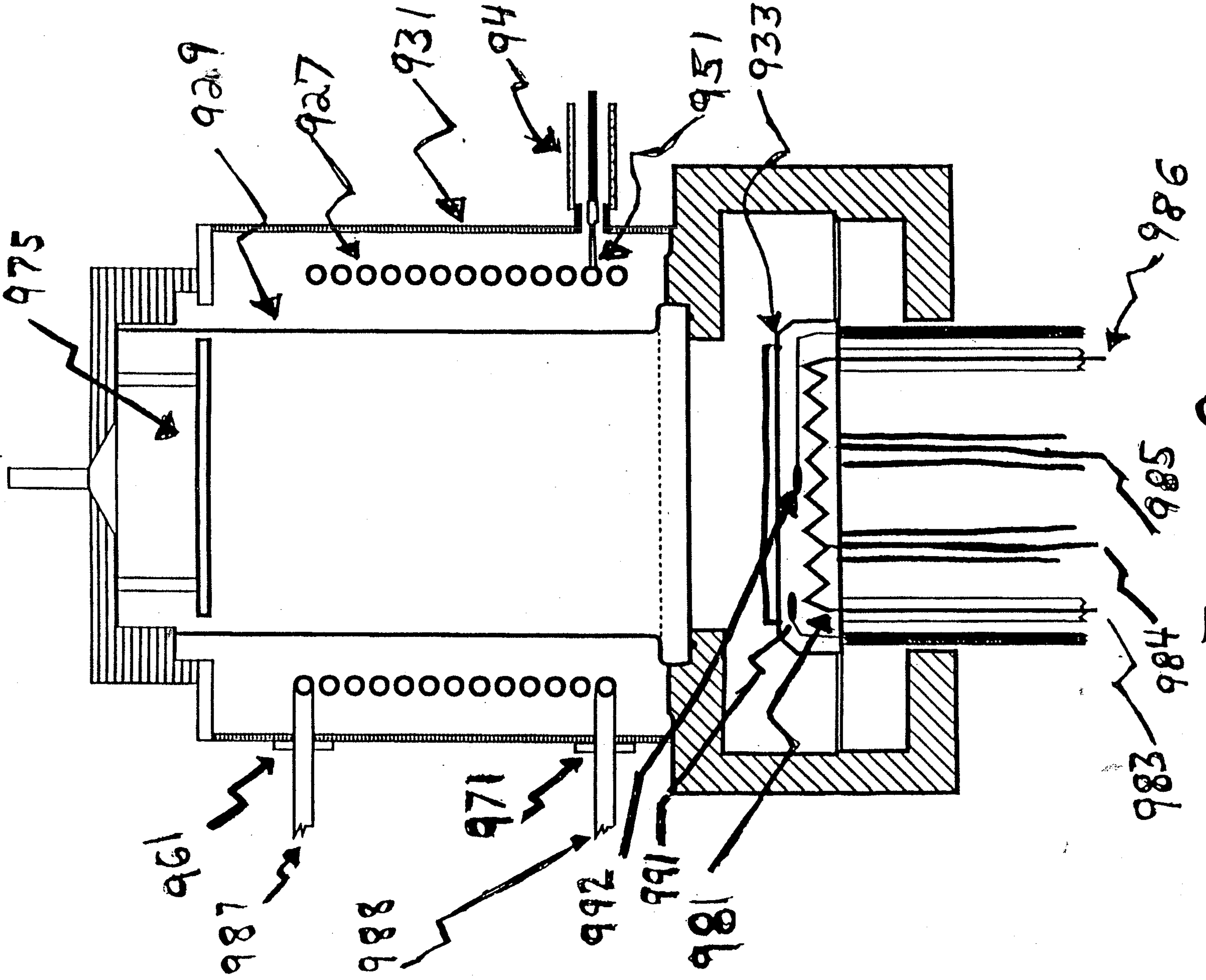
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Figure 9

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
08/866,040	05/30/97	FLAMM	D 16655-000311

HM12/0622
TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO CA 94111-3834

EXAMINER	
SCHEINER,L	
ART UNIT	**PAPER NUMBER**
1648	8

DATE MAILED: 06/22/99

This is a communication from the examiner in charge of your application.
COMMISSIONER OF PATENTS AND TRADEMARKS

OFFICE ACTION SUMMARY

☑ Responsive to communication(s) filed on 4/5/99.

☑ This action is **FINAL.**

☐ Since this application is in condition for allowance except for formal matters, **prosecution as to the merits is closed** in accordance with the practice under *Ex parte Quayle*, 1935 D.C. 11; 453 O.G. 213.

A shortened statutory period for response to this action is set to expire 3 month(s), or thirty days, whichever is longer, from the mailing date of this communication. Failure to respond within the period for response will cause the application to become abandoned. (35 U.S.C. § 133). Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

Disposition of Claims

- ☑ Claim(s) 1-32 is/are pending in the application.
  - Of the above, claim(s) 7-32 is/are withdrawn from consideration.
- ☐ Claim(s) ______ is/are allowed.
- ☑ Claim(s) 1-6 is/are rejected.
- ☐ Claim(s) ______ is/are objected to.
- ☐ Claims ______ are subject to restriction or election requirement.

Application Papers

- ☐ See the attached Notice of Draftsperson's Patent Drawing Review, PTO-948.
- ☐ The drawing(s) filed on ______ is/are objected to by the Examiner.
- ☐ The proposed drawing correction, filed on ______ is ☐ approved ☐ disapproved.
- ☐ The specification is objected to by the Examiner.
- ☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

- ☐ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been
  - ☐ received.
  - ☐ received in Application No. (Series Code/Serial Number) ______.
  - ☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: ______.

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

Attachment(s)

- ☐ Notice of Reference Cited, PTO-892
- ☑ Information Disclosure Statement(s), PTO-1449, Paper No(s). 7
- ☐ Interview Summary, PTO-413
- ☐ Notice of Draftsperson's Patent Drawing Review, PTO-948
- ☐ Notice of Informal Patent Application, PTO-152

-- SEE OFFICE ACTION ON THE FOLLOWING PAGES --

PTOL-326 (Rev. 10/95)

Claims 1-32 are pending in this application. Newly submitted claims 7-32 are directed to an invention that is independent or distinct from the invention originally claimed since they are drawn to methods having various different process limitations.

Since applicant has received an action on the merits for the originally presented invention, this invention has been constructively elected by original presentation for prosecution on the merits. Accordingly, claims 7-32 are withdrawn from consideration as being directed to a non-elected invention. See 37 CFR 1.142(b) and MPEP § 821.03.

The following is a quotation of the first paragraph of 35 U.S.C. 112:

> The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same and shall set forth the best mode contemplated by the inventor of carrying out his invention.

Claims 1-6 are rejected under 35 U.S.C. 112, first paragraph, as containing subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor(s), at the time the application was filed, had possession of the claimed invention. The newly recited "inductive coupling structure" appears to be new matter. Moreover, the concept that the phase portion and the anti-phase portion of the capacitively coupled currents is adjusted by the wave adjustment circuit appears to be new matter.

Applicant's amendment necessitated the new ground(s) of rejection presented in this Office action. Accordingly, **THIS ACTION IS MADE FINAL**. See MPEP § 706.07(a). Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the

THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the date of this final action.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Laurie Scheiner, whose telephone number is (703) 308-1122. Any inquiry of a general nature or relating to the status of this application should be directed to the Group 1600 receptionist whose telephone number is (703) 308-0196.

Correspondence related to this application may be submitted to Group 1600 by facsimile transmission. The faxing of such papers must conform with the notice published in the Official Gazette, 1096 OG 30 (November 15, 1989). Official communications should be directed toward one of the following Group 1600 fax numbers: (703) 308-4242 or (703) 305-3014. Informal communications may be submitted directly to the Examiner through the following fax number: (703) 308-4426. Applicants are encouraged to notify the Examiner prior to the submission of such documents to facilitate their expeditious processing and entry.

Laurie Scheiner/LAS
June 18, 1999

LAURIE SCHEINER
PRIMARY EXAMINER

FORM PTO-1449 (Modified) LIST OF PATENTS AND PUBLICATIONS FOR APPLICANT'S INFORMATION DISCLOSURE STATEMENT (Use several sheets if necessary)	Attorney Docket No.: 16655-000311US	Application No.: 08/866,040
	Applicant: Daniel L. Flamm	
	Filing Date: May 30, 1997	Group: 1648

Reference Designation **U.S. PATENT DOCUMENTS** Page 1

Examiner Initial	Document No.	Date	Name	Class	Sub-class	Filing Date (If Appropriate)
AA	5,591,493	1/7/97	Paranjpe et al.			
AB	5,573,595	11/12/96	Dible			
AC	5,571,366	11/5/96	Ishii et al.			
AD	5,405,480	4/11/95	Benzing et al.			
AE	08/748,746	11/18/96	Daniel L. Flamm			

FOREIGN PATENT DOCUMENTS

	Document No.	Date	Country	Class	Sub-class	Translation (Yes/No)

OTHER ART (Including Author, Title, Date, Pertinent Pages, Etc.)

EXAMINER DATE CONSIDERED 6/18/99

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

GP 1648/#

PATENT
Attorney Docket No.: 16655-000311US

#9/JR
07/01/99

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to:

Assistant Commissioner for Patents
Washington, D.C. 20231

On June 21, 1999

TOWNSEND and TOWNSEND and CREW LLP

By:

OIPE JC61
JUN 23 1999
PATENT & TRADEMARK OFFICE

RECEIVED
JUN 30 1999
TECH CENTER 1600/2900

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Examiner: L. Scheiner

Art Unit: 1648

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT UNDER 37 CFR §1.97 and §1.98

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

The references cited on attached form PTO-1449 are being called to the attention of the Examiner. Copies of the references are enclosed. It is respectfully requested that the cited information be expressly considered during the prosecution of this application, and the references be made of record therein and appear among the "references cited" on any patent to issue therefrom.

As provided for by 37 CFR 1.97(g) and (h), no inference should be made that the information and references cited are prior art merely because they are in this statement and

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no representation is being made that a search has been conducted or that this statement encompasses all the possible relevant information.

This IDS is being filed after the mailing date of the first Office Action and more than three months after the filing date, but prior to the Notice of Allowance or Final Office Action.

Please deduct $240.00, pursuant to 37 CFR §1.17(p), from the undersigned's Deposit Account No. 20-1430. Please deduct any additional fees from, or credit any overpayment to, the above-noted Deposit Account.

This Petition is submitted in triplicate.

Respectfully submitted,

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
Tel: 650-326-2400
Fax: 650-326-2422
RTO:crf

PA 3004051 v1

FORM PTO-1449 (Modified) LIST OF PATENTS AND PUBLICATIONS FOR APPLICANT'S INFORMATION DISCLOSURE STATEMENT (Use several sheets if necessary)	Attorney Docket No.: 16655-000311US Applicant: Daniel L. Flamm Filing Date: May 30, 1997	Application No.: 08/866,040 Group: 1648

OIPE
JUN 23 1999
PATENT & TRADEMARK OFFICE

Reference Designation **U.S. PATENT DOCUMENTS** Page 1

Examiner Initial	Document No.	Date	Name	Class	Sub-class	Filing Date (If Appropriate)
AA	5,637,961	6/10/97	Ishii et al.			
AB	5,534,231	7/9/96	Savas			
AC	5,431,968	7/11/95	Miller et al.			
AD	5,361,016	11/1/94	Ohkawa et al.			
AE	5,304,282	4/19/94	Flamm			
AF	5,241,245	8/31/93	Barnes et al.			
AG	5,234,529	8/10/93	Johnson			
AH	4,943,345	7/24/90	Asmussen et al.			
AI	4,918,031	4/17/90	Flamm et al.			
AJ	4,368,092	1/11/83	Steinberg et al.			
AK	3,873,884	3/25/75	Gabriel			

FOREIGN PATENT DOCUMENTS

	Document No.	Date	Country	Class	Sub-class	Translation (Yes/No)

OTHER ART (Including Author, Title, Date, Pertinent Pages, Etc.)

AL	Asmussen et al., "The Design of a Microwave Plasma Cavity," Proc. of IEEE, 62(1):109-117 (January 1974).
AM	Eckert, "The Hundred Year History of Induction Discharges," 2^{nd} Ann. Int'l Conf. Plasma Chem. Tech., (1984).
AN	Fossheim et al., "Broadband tguning of helical resonant cavities," J. Phys. E. Sci Instrum., 11:892-893 (1978).
AO	Niazi et al. "Operation of a helical resonator plasma source," Plasma Sources Sci. Technol., 3:482-495 (1994).
AP	Roppel et al., "Low temperature oxidation of silicon using a microwave plasma disk source," J. Vac. sci. Technol., B4(1):295-298 (Jan./Feb. 1986).
AQ	Zverev et al., "Realization of a Filter with Helical Components," IRE Trans. on Component Parts, pp. 99-110, (September 1961).
EXAMINER	DATE CONSIDERED 9/1/99

EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

Amendment Transmittal

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400

Attorney Docket No. 16655-000311

RECEIVED
AUG 31 1999
GROUP 1800

In re application of: Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

Group Art Unit: 1648

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

I hereby certify that this correspondence is being sent by facsimile transmission to:

Examiner L Scheiner
Facsimile No.: (703) 308-4426

On August 31, 1999

TOWNSEND and TOWNSEND and CREW LLP

By:

THE ASSISTANT COMMISSIONER FOR PATENTS
Washington, D.C. 20231

Sir:

Transmitted herewith is an amendment in the above-identified application.

[ ] Enclosed is a petition to extend time to respond.
[X] Small entity status of this application under 37 CFR 1.9 and 1.27 has been established by a verified statement previously submitted.
[ ] A verified statement to establish small entity status under 37 CFR 1.9 and 1.27 is enclosed.
[X] Postcard

If any extension of time is needed, then this response should be considered a petition therefor.
The filing fee has been calculated as shown below:

	(Col. 1) CLAIMS REMAINING AFTER AMENDMENT		(Col. 2) HIGHEST NO. PREVIOUSLY PAID FOR	(Col. 3) PRESENT EXTRA
TOTAL	* 7	MINUS	** 32	- 0
INDEP.	* 1	MINUS	*** 6	- 0
[ ] FIRST PRESENTATION OF MULTIPLE DEP. CLAIM				

SMALL ENTITY			OTHER THAN SMALL ENTITY	
RATE	ADDIT. FEE	OR	RATE	ADDIT. FEE
0x $9.00 =	$0.00		x $18.00 =	
0x $39.00 =	$0.00		x $78.00 =	
+ $130.00 =			+ $260.00 =	
TOTAL ADDIT. FEE	$0.00	OR	TOTAL	

* If the entry in Col. 1 is less than the entry in Col. 2, write "0" in Col. 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, write "20" in this space.
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, then write "3" in this space. The "Highest Number Previously Paid For" (Total or Independent) is the highest number found from the equivalent box in Col. 1 of a prior amendment or the number of claims originally filed.

[X] No fee is due.

Please charge Deposit Account No. 20-1430 as follows:

[ ] Claims fee $ $0.00
[X] Any additional fees associated with this paper or during the pendency of this application.

2 extra copies of this sheet are enclosed.

TOWNSEND and TOWNSEND and CREW LLP

Richard T. Ogawa, Reg. No. 37,692
Attorneys for Applicant

PA 184139 v1

Page 1 of 1

Atty Docket No. 16655-000311

PTO FAX NO.: (703) 308-4426

ATTENTION: Examiner L. Scheiner
Group Art Unit 1648

Official

OFFICIAL COMMUNICATION

FOR THE PERSONAL ATTENTION OF

EXAMINER L. SCHEINER

CERTIFICATION OF FACSIMILE TRANSMISSION

I hereby certify that the following Amendment Transmittal and Amendment, in re Application of Daniel L. Flamm, Serial No. 08/866,040, filed May 30, 1997, for PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING is being facsimile transmitted to the Patent and Trademark Office on the date shown below.

Number of pages being transmitted, including this page: 6

Dated: August 31, 1999

Diane Elzingre
Diane Elzingre

PLEASE CONFIRM RECEIPT OF THIS PAPER BY RETURN FACSIMILE AT (650) 326-2400

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 94111-3834
Telephone: (650) 326-2400
Fax: (650) 326-2422

PA 3018723 v1

Richard T. Ogawa, Reg. No. 37,692
Attorneys for Applicant

PA 184139 v1

Page 1 of 1

I hereby certify that this correspondence is being sent via facsimile to:

Examiner L. Scheiner
Facsimile No.: (703) 308-4426
on August 31, 1999
TOWNSEND and TOWNSEND and CREW LLP
By

OFFICIAL

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PATENT
Attorney Docket No. 16655-000311 NB

RECEIVED
AUG 31 1999
GROUP 1800

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

O.K. to enter LS 8/31/99

In re application of:

Daniel L. Flamm

Application No.: 08/866,040

Filed: May 30, 1997

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Examiner: Scheiner, L.

Art Unit: 1648

AMENDMENT UNDER 37 CFR §1.116

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sirs:

In response to the Final Office Action mailed June 22, 1999, please amend the above-cited application as follows.

IN THE CLAIMS:

Please amend claim 1, add claim 33, and cancel claims 7-32 as follows. For the convenience of the Examiner, all claims subject to examination are shown, even if not being amended.

6

1. (Twice Amended) A process for fabricating a product using a plasma source, said process comprising the steps of subjecting a substrate to entities, at least one of said entities emanating from a gaseous discharge excited by a high frequency field from an inductive coupling structure in which a phase portion and an anti-phase portion of capacitive currents coupled from the inductive coupling structure are selectively balanced;

wherein said inductive coupling structure is adjusted using a wave adjustment circuit, said wave adjustment circuit adjusting the phase portion and the anti-phase portion of the capacitively coupled currents.

duplicate claims

~~2. The process of claim 1 wherein the wave adjustment circuit selectively adjusts a frequency of an rf power supply.~~

~~3. The process of claim 1 wherein the high frequency field is adjusted using a variable frequency power supply.~~

~~4. The process of claim 1 wherein the wave adjustment circuit comprises a transmission line.~~

~~5. The process of claim 1 wherein said process is provided in a chamber.~~

~~6. The process of claim 5 wherein the chamber is provided for a process selected from etching, deposition, sputtering, or implantation.~~

7-~~32.~~ (Cancelled)

P2

7 ~~33.~~ (New) The process of claim 1 wherein said inductive coupling structure provides a wave multiple selected from a one-sixteenth wave, a one-eighth-wave, a quarter-wave, a half-wave, a three-quarter wave, and a full-wave.

REMARKS

Applicant would like to thank Examiner Scheiner for the time for reviewing the present application.

Claims 1-6 and 33 are now pending in this application, where claims 7-32 have been cancelled and claim 33 has been added.

Claims 7-32 were indicated as being directed to an invention that is independent or distinct from the invention originally claimed. Accordingly, Applicant has also cancelled claims 7-32 without prejudice for renewal in a continuation and/or related application.

Claims 1-6 were rejected under 35 U.S.C. §112, first paragraph, as containing subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor, at the time the application was filed, had possession of the claimed invention. In particular, the Examiner indicated that the "inductive coupling structure" terms appeared to be new matter. Applicant has carefully reviewed the present specification and would like to point out that support for the inductive coupling structure is found throughout the specification, and more particularly at page 9 lines 17-20. Further support for the inductive coupling structure can be found in the inductive applicator, which has been described in, for example, Fig. 1 and related description. The Examiner has also noted that the terms "phase portion and anti-phase portion" appeared to be new matter. These terms are described throughout the specification in relation to voltages, since electrical current is fundamentally related to voltage by an impedance. More particularly, support can be found at, for example, V_{coil} at Fig. 5B, which illustrates a phase and anti-phase relationship of a waveform. Accordingly, claims 1-6 are patentable under 35 U.S.C. §112, first paragraph.

Applicant has also amended claim 1 with the term "plasma" for clarification purposes, as suggested by the Examiner. This amendment is not intended to unduly limit such claim in any manner. Furthermore, Applicant has added claim 33 also for clarification purposes, as suggested by the Examiner. Support can be found for claim 33 throughout the specification and more particularly at page 14 lines 16-30. Accordingly, all pending claims are believed allowable in view of the cited references.

CONCLUSION

Therefore, in view of the remarks above, Applicant respectfully requests that the rejection be removed, that claims 1-6 and 33 be allowed, and the case passed to issue. The issuance of a formal Notice of Allowance at an early date is respectfully requested.

If the Examiner believes a telephone conference would expedite prosecution of this application, please telephone the undersigned at (650) 326-2400.

Respectfully submitted,

Date: 8/31/99

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400
Fax (650) 326-2422

RTO:de

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FAX COVER SHEET

Wed, Sep 1, 1999 1:21 AM

Fax #: 1-703-308-4426

Fax: 1 page and a cover page.

B

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKETT NO.

EXAMINER

ART UNIT	PAPER NUMBER
	10

DATE MAILED:

EXAMINER INTERVIEW SUMMARY RECORD

All participants (applicant, applicant's representative, PTO personnel):

(1) Laurie Scheiner
(3)
(2) Richard Ogawa
(4)

Date of interview 8/31/99

Type: ☒ Telephonic ☐ Personal (copy is given to ☐ applicant ☐ applicant's representative).

Exhibit shown or demonstration conducted: ☐ Yes ☒ No. If yes, brief description:

Agreement ☒ was reached with respect to some or all of the claims in question. ☐ was not reached.

Claims discussed: all pending

Identification of prior art discussed: N/A

Description of the general nature of what was agreed to if an agreement was reached, or any other comments: applicant's representative agreed to cancel non-elected claims. Also minor claim language changes were discussed — which would place application in condition for allowance. Applicants will fax amendment.

(A fuller description, if necessary, and a copy of the amendments, if available, which the examiner agreed would render the claims allowable must be attached. Also, where no copy of the amendments which would render the claims allowable is available, a summary thereof must be attached.)

☒ 1. It is not necessary for applicant to provide a separate record of the substance of the interview.

Unless the paragraph below has been checked to indicate to the contrary, A FORMAL WRITTEN RESPONSE TO THE LAST OFFICE ACTION IS NOT WAIVED AND MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW (e.g., items 1-7 on the reverse side of this form). If a response to the last Office action has already been filed, then applicant is given one month from this interview date to provide a statement of the substance of the interview.

☐ 2. Since the examiner's interview summary above (including any attachments) reflects a complete response to each of the objections, rejections and requirements that may be present in the last Office action, and since the claims are now allowable, this completed form is considered to fulfill the response requirements of the last Office action. Applicant is not relieved from providing a separate record of the substance of the interview unless box 1 above is also checked.

Examiner's Signature

PTOL-413 (REV. 2 -93)

ORIGINAL FOR INSERTION IN RIGHT HAND FLAP OF FILE WRAPPER

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.

EXAMINER

ART UNIT	PAPER NUMBER
	11

DATE MAILED:

This is a communication from the examiner in charge of your application.
COMMISSIONER OF PATENTS AND TRADEMARKS

NOTICE OF ALLOWABILITY

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance and Issue Fee Due or other appropriate communication will be mailed in due course.

☒ This communication is responsive to Amendment filed August 31, 1999 (Paper No. 10)

☒ The allowed claim(s) is/are 1-6 & 33 Renumbered as 1-7.

☐ The drawings filed on ______ are acceptable.

☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

☐ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been

- ☐ received.
- ☐ received in Application No. (Series Code/Serial Number) ______.
- ☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: ______.

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

A SHORTENED STATUTORY PERIOD FOR RESPONSE to comply with the requirements noted below is set to EXPIRE **THREE MONTHS** FROM THE "DATE MAILED" of this Office action. Failure to timely comply will result in ABANDONMENT of this application. Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

☐ Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL APPLICATION, PTO-152, which discloses that the oath or declaration is deficient. A SUBSTITUTE OATH OR DECLARATION IS REQUIRED.

☒ Applicant MUST submit NEW FORMAL DRAWINGS

- ☒ because the originally filed drawings were declared by applicant to be informal.
- ☐ including changes required by the Notice of Draftperson's Patent Drawing Review, PTO-948, attached hereto or to Paper No. ______.
- ☐ including changes required by the proposed drawing correction filed on ______, which has been approved by the examiner.
- ☐ including changes required by the attached Examiner's Amendment/Comment.

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the reverse side of the drawings. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftperson.

☐ Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Any response to this letter should include, in the upper right hand corner, the APPLICATION NUMBER (SERIES CODE/SERIAL NUMBER). If applicant has received a Notice of Allowance and Issue Fee Due, the ISSUE BATCH NUMBER and DATE of the NOTICE OF ALLOWANCE should also be included.

Attachment(s)

- ☐ Notice of References Cited, PTO-892
- ☒ Information Disclosure Statement(s), PTO-1449, Paper No(~~s~~). 9
- ☐ Notice of Draftsperson's Patent Drawing Review, PTO-948
- ☐ Notice of Informal Patent Application, PTO-152
- ☒ Interview Summary, PTO-413
- ☐ Examiner's Amendment/Comment
- ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
- ☐ Examiner's Statement of Reasons for Allowance

LAURIE SCHEINER
PRIMARY EXAMINER

PTOL-37 (Rev. 10/95)

U.S. GPO: 1997-417-381/62707

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

NOTICE OF ALLOWANCE AND ISSUE FEE DUE

HM32/0927
TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO CA 94111-3834

APPLICATION NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT		DATE MAILED
08/866,040	05/30/97	007	SCHEINER, L	1648	09/27/99

First Named Applicant FLAMM, 35 USC 154(b) term ext. = 0 Days.

TITLE OF INVENTION PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
1 16655-000311	432-225.000	C07	UTILITY	YES	$605.00	12/27/99

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED.

THE ISSUE FEE MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED.

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#12 AA

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TRANSMITTAL LETTER

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 94105
(650) 326-2400

Atty. Docket No. 16655-000311

Date November 12, 1999

OIPE JC65
NOV 17 1999
PATENT & TRADEMARK OFFICE

In re application of: Daniel L. Flamm
Serial No.: 08/866,040
Filed: May 30, 1997
Group Art Unit: 2813
For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

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I hereby certify that this is being deposited with the United States Postal Service as first class mail in an envelope addressed to:
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Assistant Commissioner for Patents
Washington, D.C. 20231
Date: November 12, 1999
By:

Sir:

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2) Issue Fee Transmittal (Part B);
3) Letter to Official Draftsperson;
4) Formal Drawings (13 sheets);
5) Postcard.

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TOWNSEND and TOWNSEND and CREW LLP

Richard T. Ogawa
Reg. No.: 37,692
Attorneys for Applicant

3033104v1

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Washington, D.C. 20231

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NOV 17 1999
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Diane Elzingre (Depositor's name)
Diane Elzingre (Signature)
November 12, 1999 (Date)

APPLICATION NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT		DATE MAILED
08/866,040	05/30/97	007	SCHEINER, L	1648	09/27/99

First Named Applicant FLAMM, 35 USC 154(b) term ext. = 0 Days.

TITLE OF INVENTION PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
1 16655-000311	432-225.000	C07	UTILITY	YES	$605.00	12/27/99

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363). Use of PTO form(s) and Customer Number are recommended, but not required.

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47) attached.

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Townsend and Townsend and Crew LLP
2 ____________
3 ____________

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)
PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropiate when an assignment has been previously submitted to the PTO or is being submitted under separate cover. Completion of this form is NOT a subsititue for filing an assignment.

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(B) RESIDENCE: (CITY & STATE OR COUNTRY)

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Richard T. Ogawa, Reg. No. 37,692

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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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Two Embarcadero Center, 8th Floor
San Francisco, CA 94105
(650) 326-2400

OIPE JC65
NOV 17 1999
PATENT & TRADEMARK OFFICE

In re application of: Daniel L. Flamm
Serial No.: 08/866,040
Filed: May 30, 1997
Group Art Unit: 2813
For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Atty. Docket No. 16655-000311

Date November 12, 1999

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By: Diane Elizinga

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1) Transmittal Letter (in trip.);
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2 copies of this sheet are enclosed.

TOWNSEND and TOWNSEND and CREW LLP

Richard T. Ogawa
Reg. No.: 37,692
Attorneys for Applicant

3033104v1

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Assistant Commissioner of Patents and Trademarks,
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By

OIPE
NOV 17 1999
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PATENT

Attorney Docket No. 16655-000311US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Daniel L. Flamm

Serial No.: 08/866,040

Filed: May 30, 1997

For: PROCESS DEPENDING ON PLASMA DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Examiner: L. Scheiner

Art Unit: 1648

Batch No.: C07

LETTER TO OFFICIAL DRAFTSPERSON

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Assistant Commissioner of Patents
Washington, D.C. 20231

Sir:

Pursuant to the Notice of Allowability dated September 27, 1999, applicant submits thirteen sheets of formal drawings to be made of record in the above-identified case.

Respectfully submitted,

Richard T. Ogawa
Reg. No. 37,692

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, California 94111-3834
(650) 326-2400
RTO:de

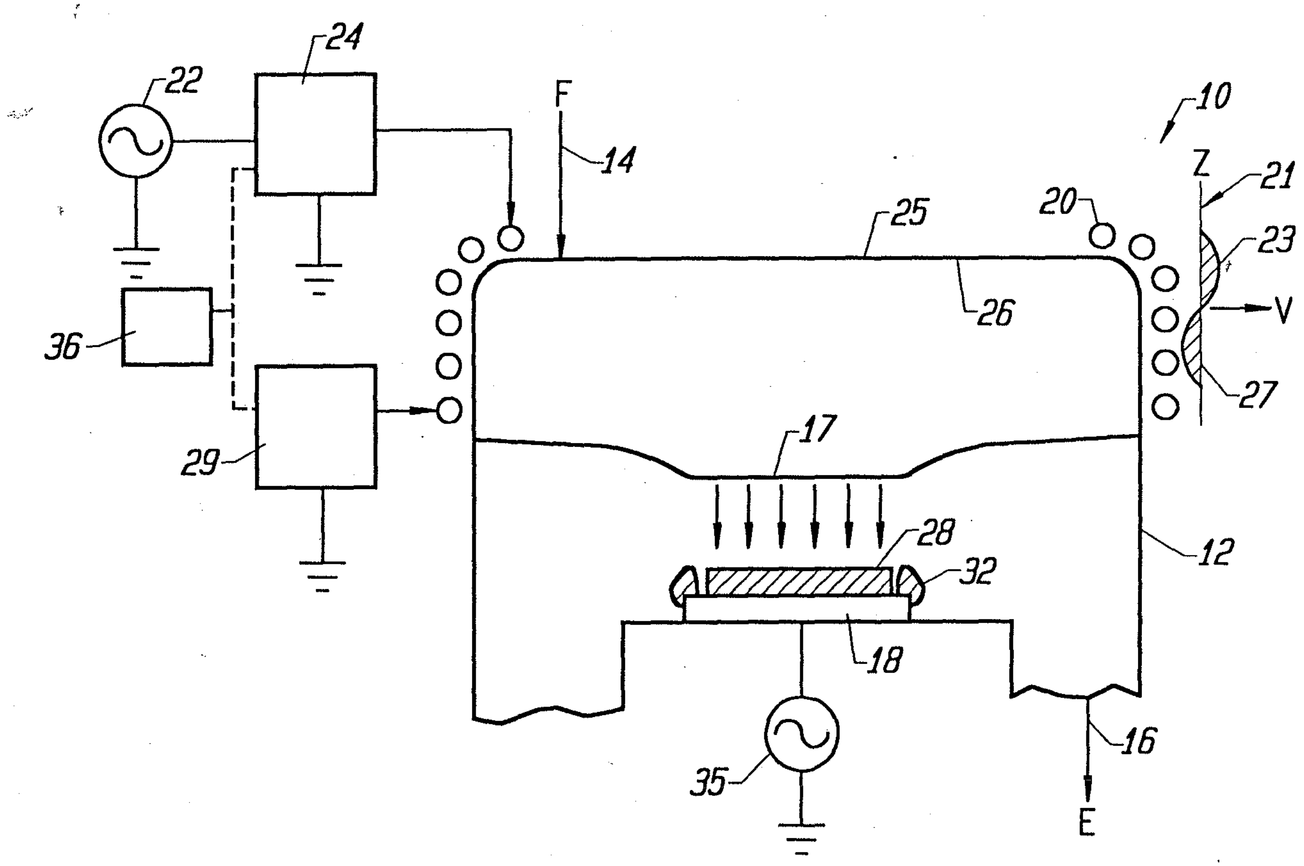

FIG. 1

6017221

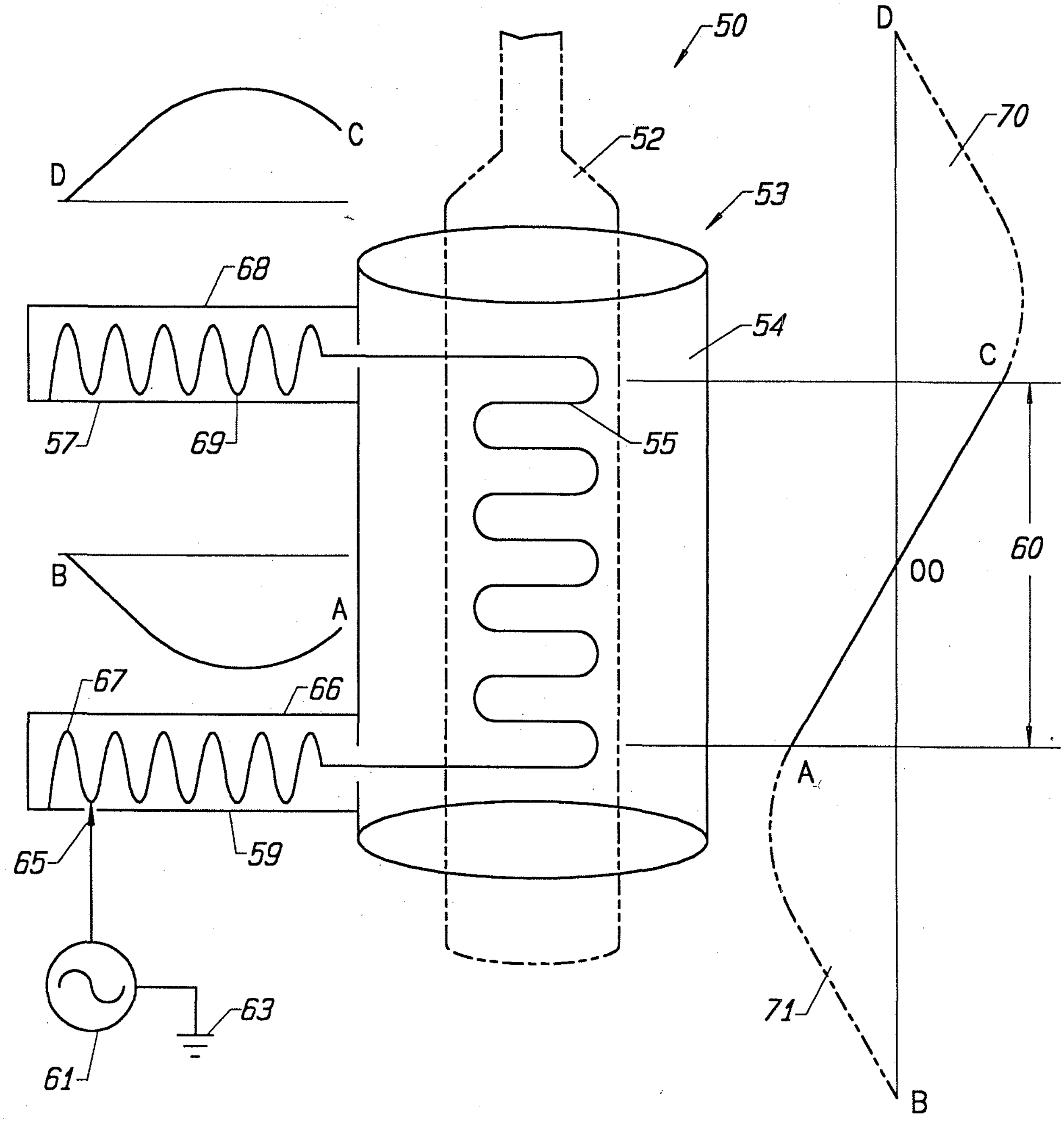

FIG. 2A

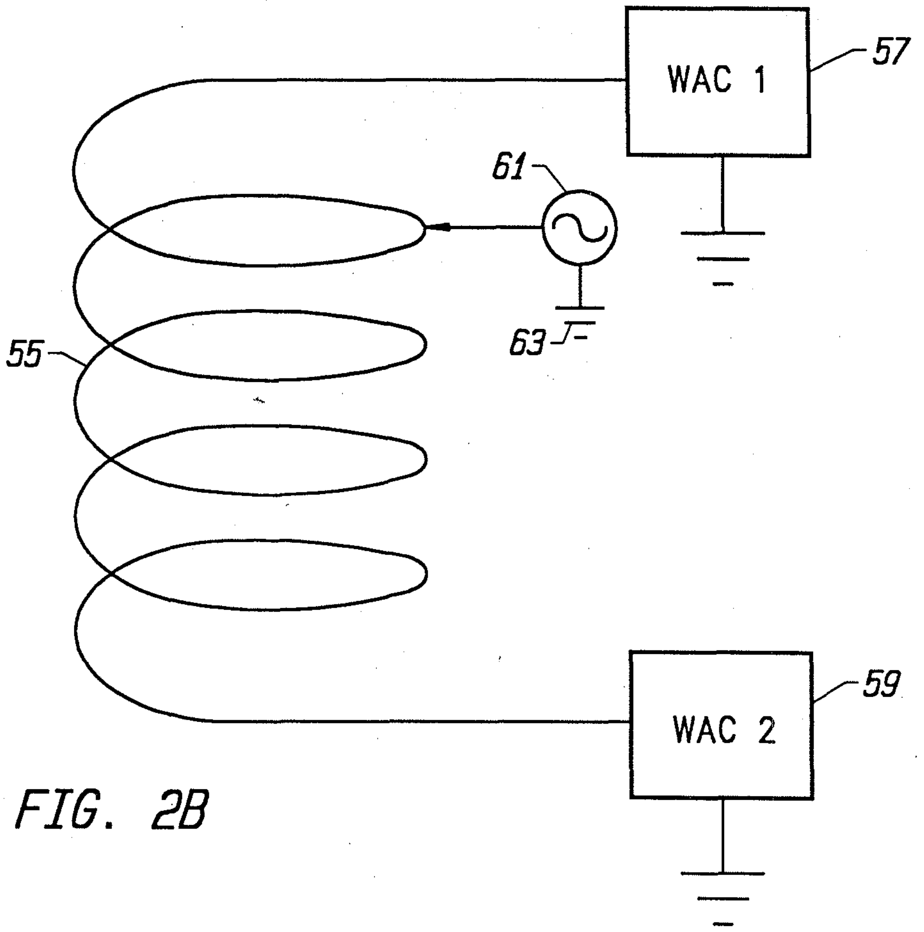

FIG. 2B

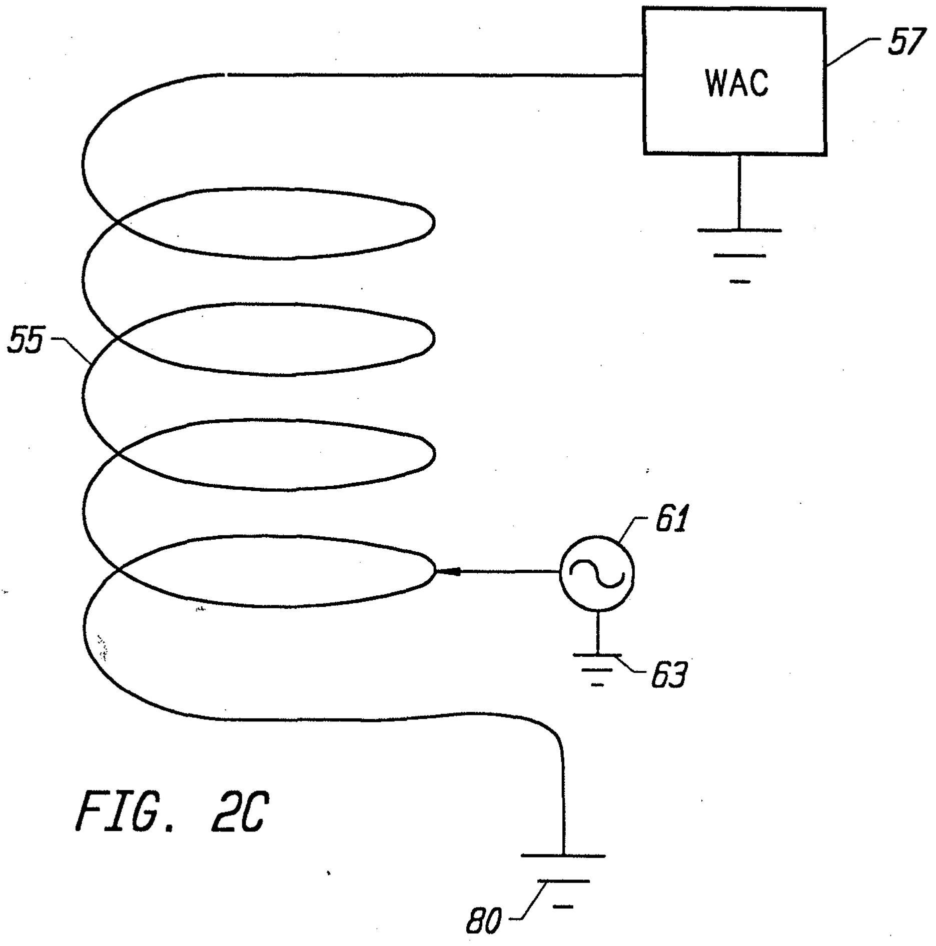

FIG. 2C

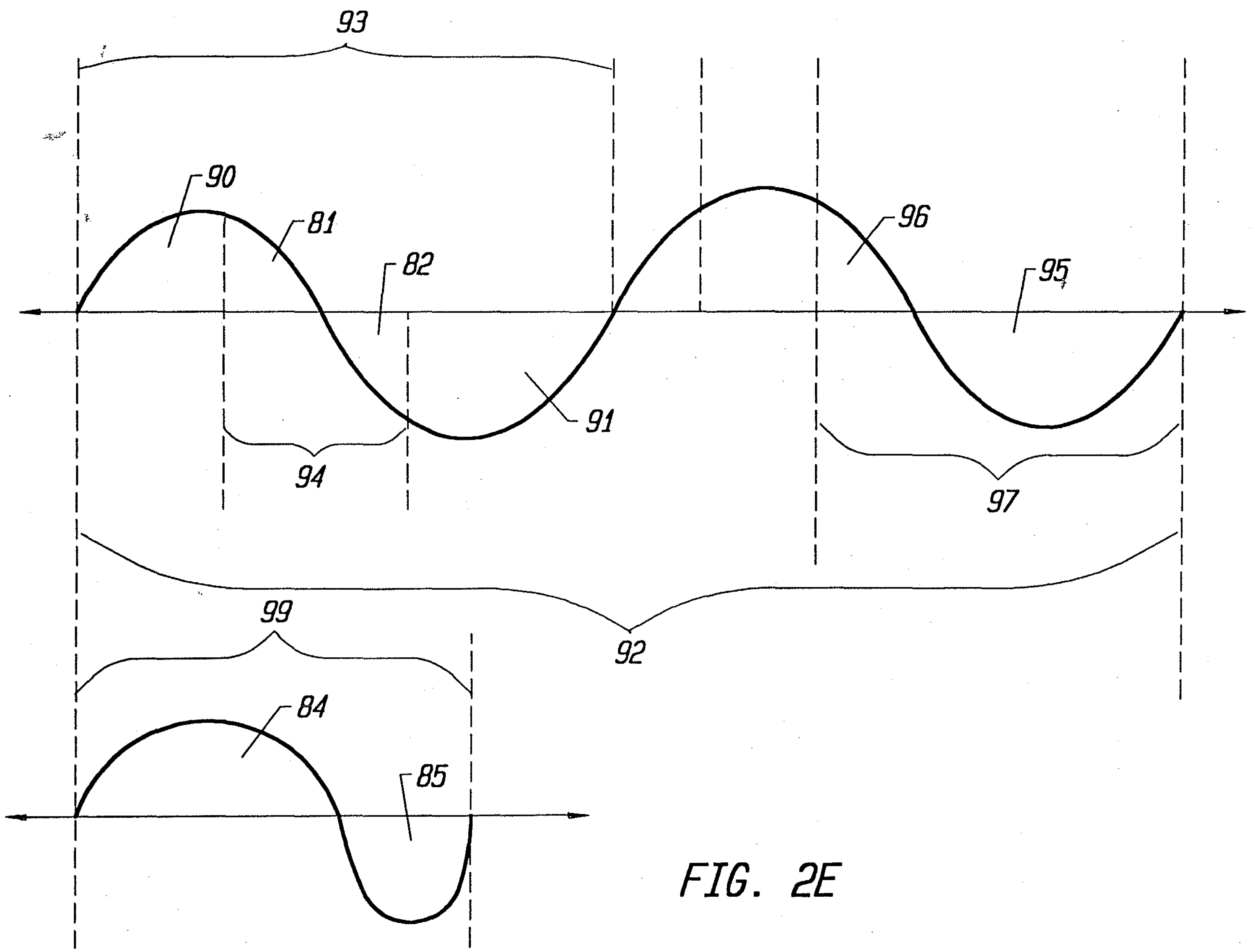

FIG. 2E

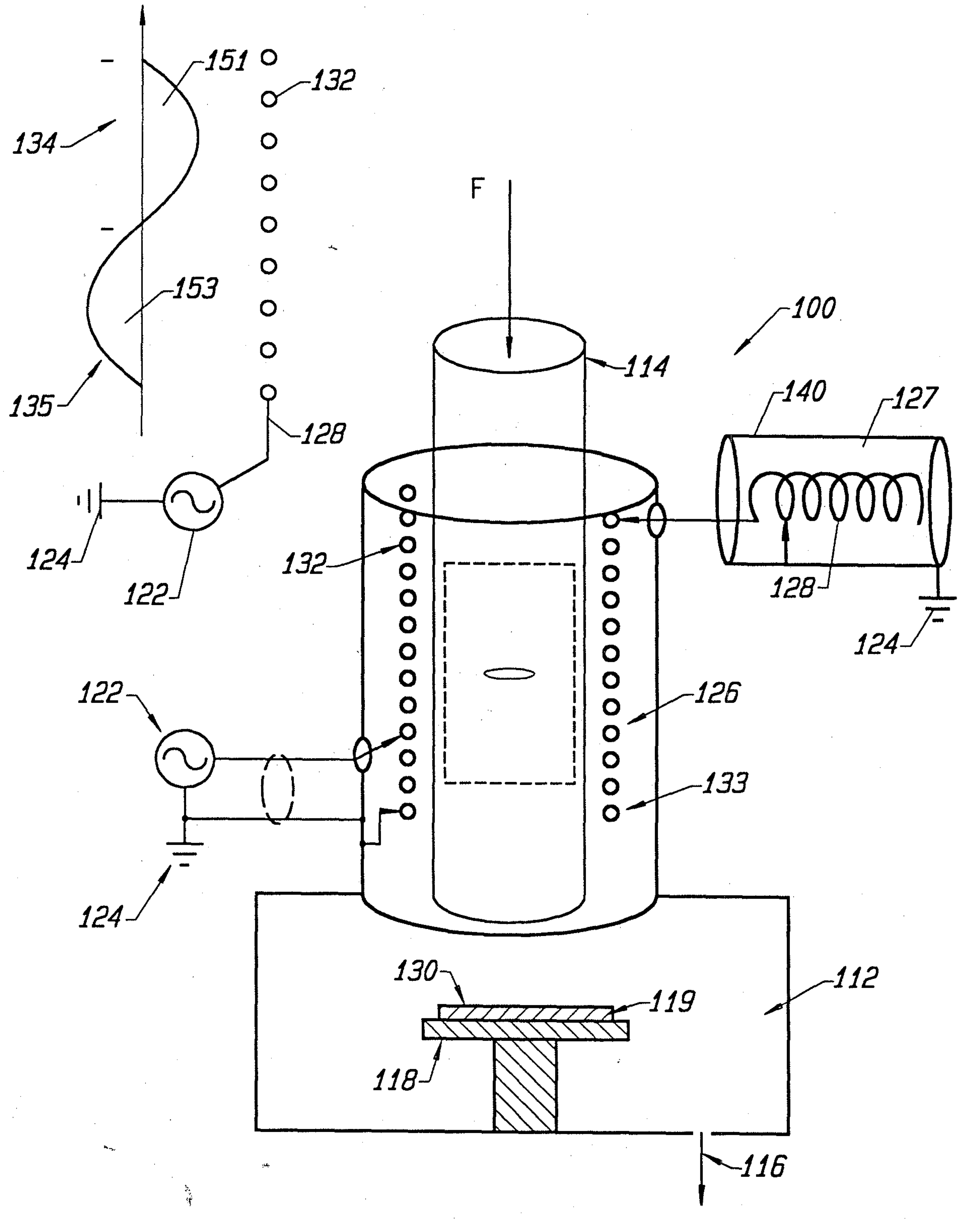

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FIG. 3

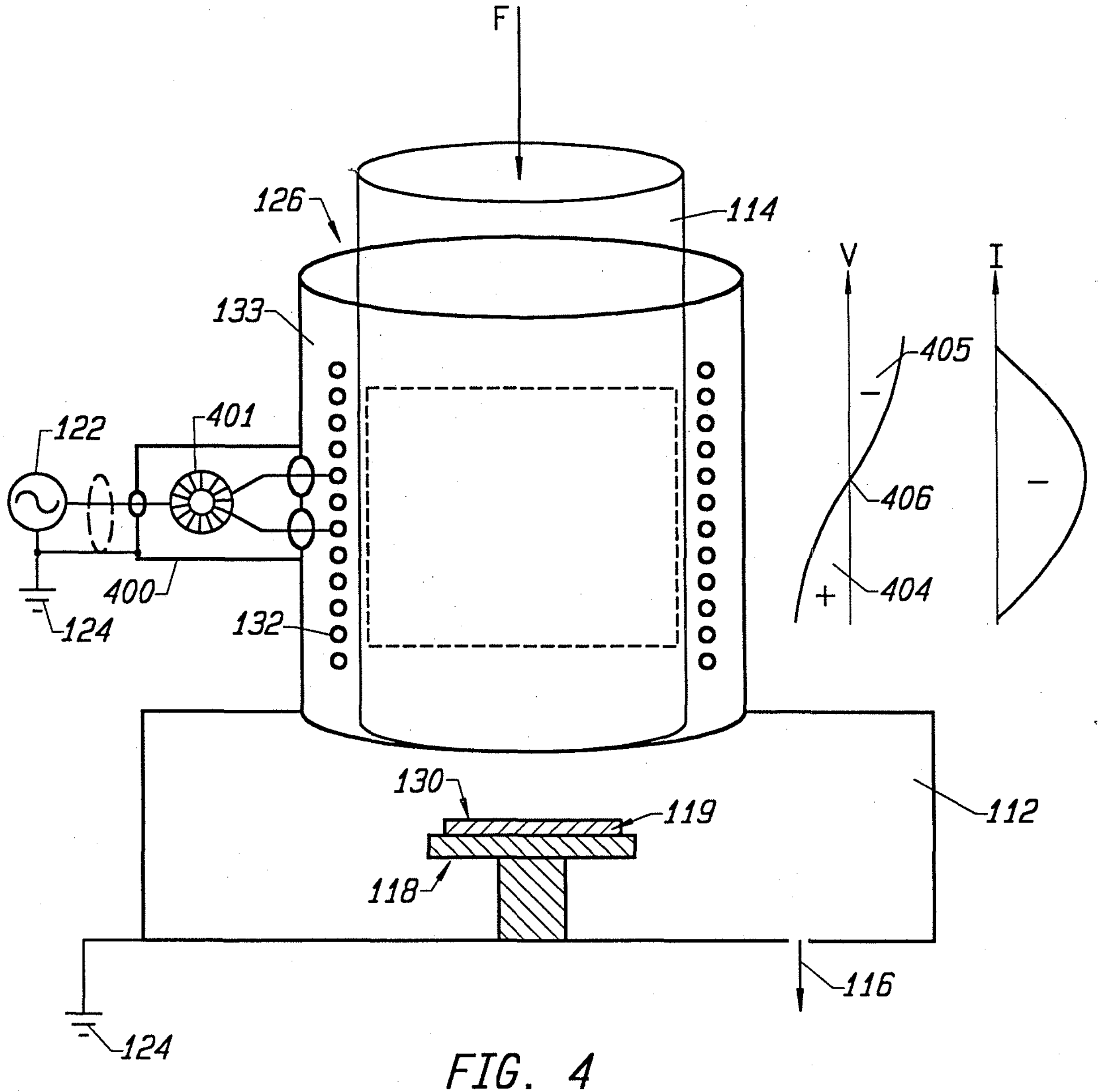
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FIG. 4

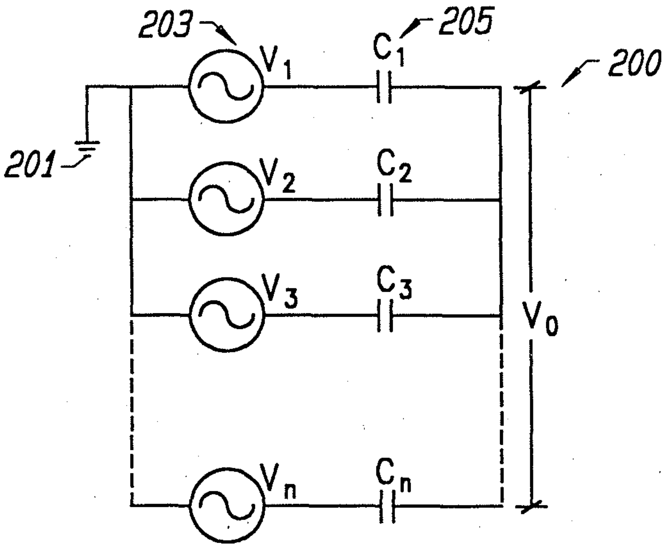

FIG. 5A

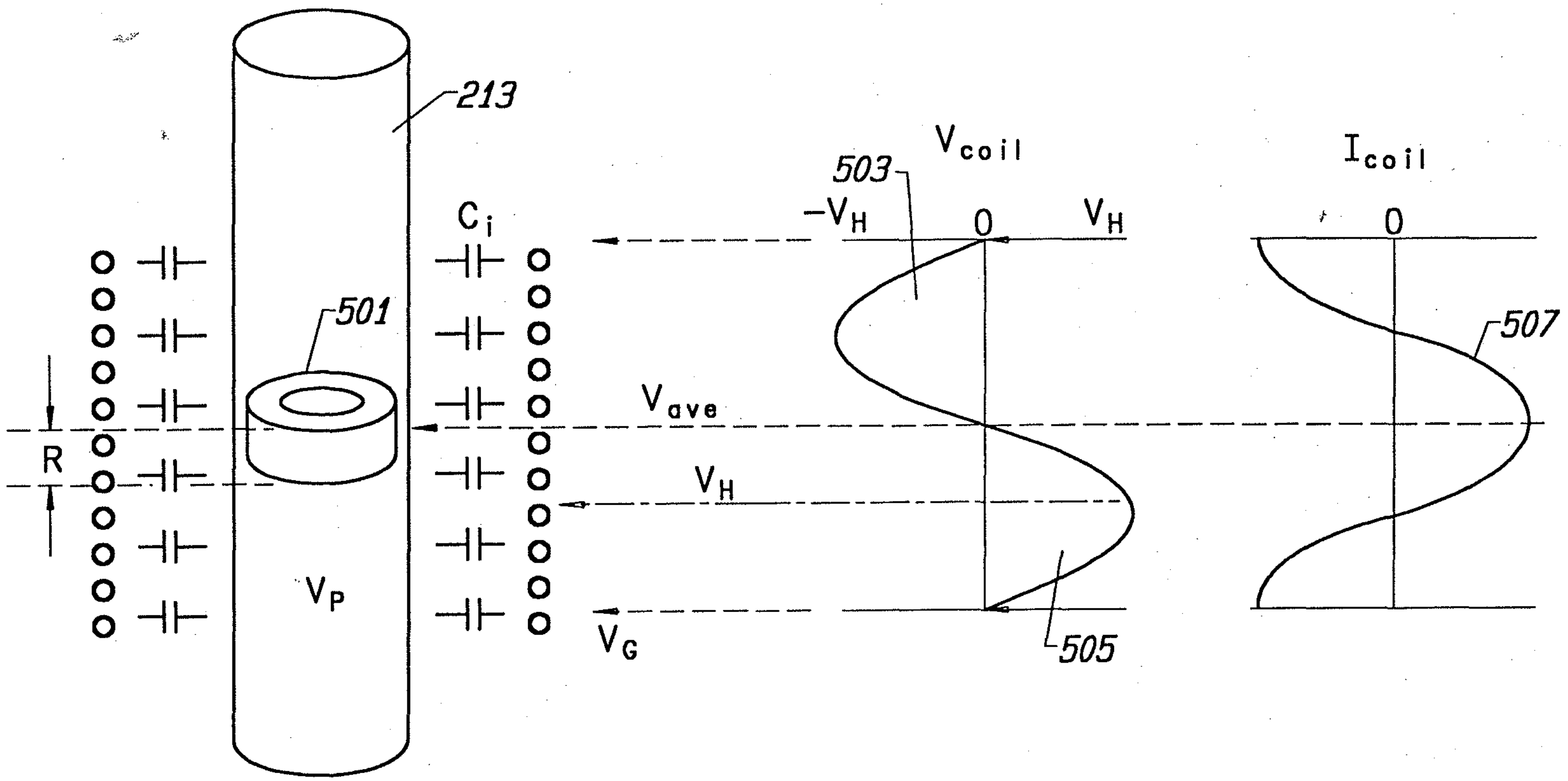

FIG. 5B

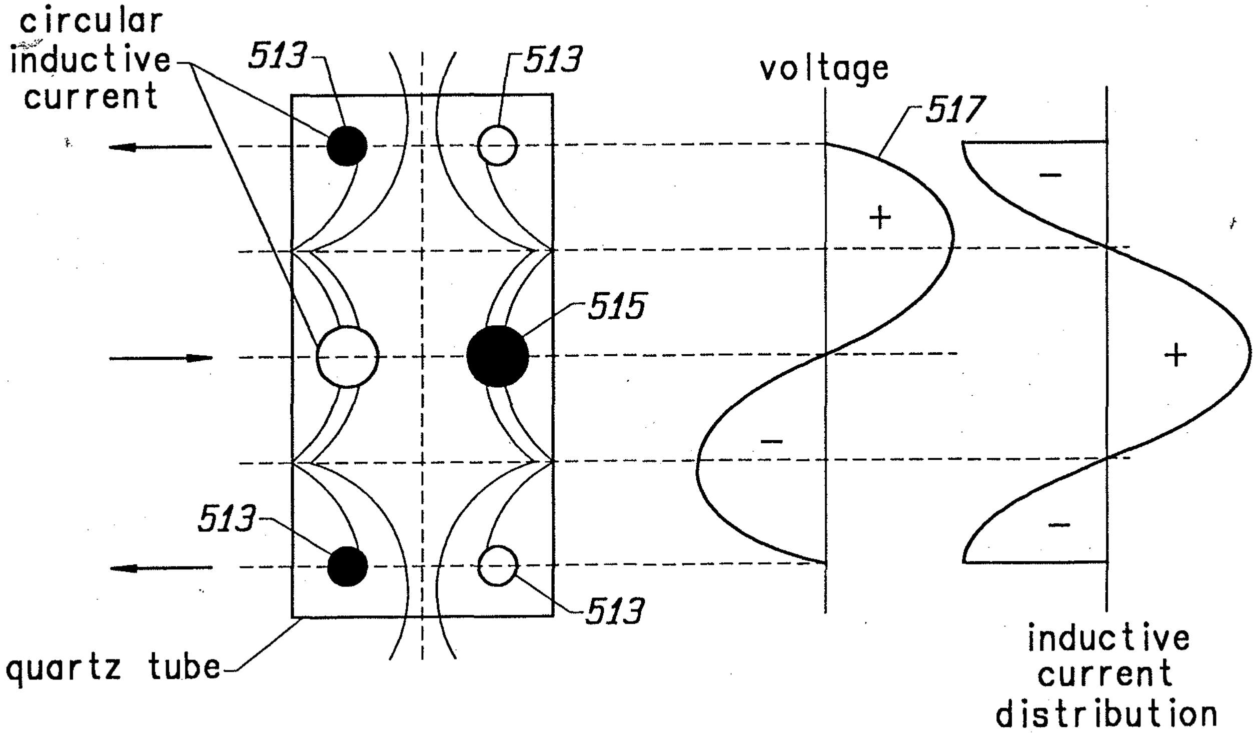
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FIG. 5C

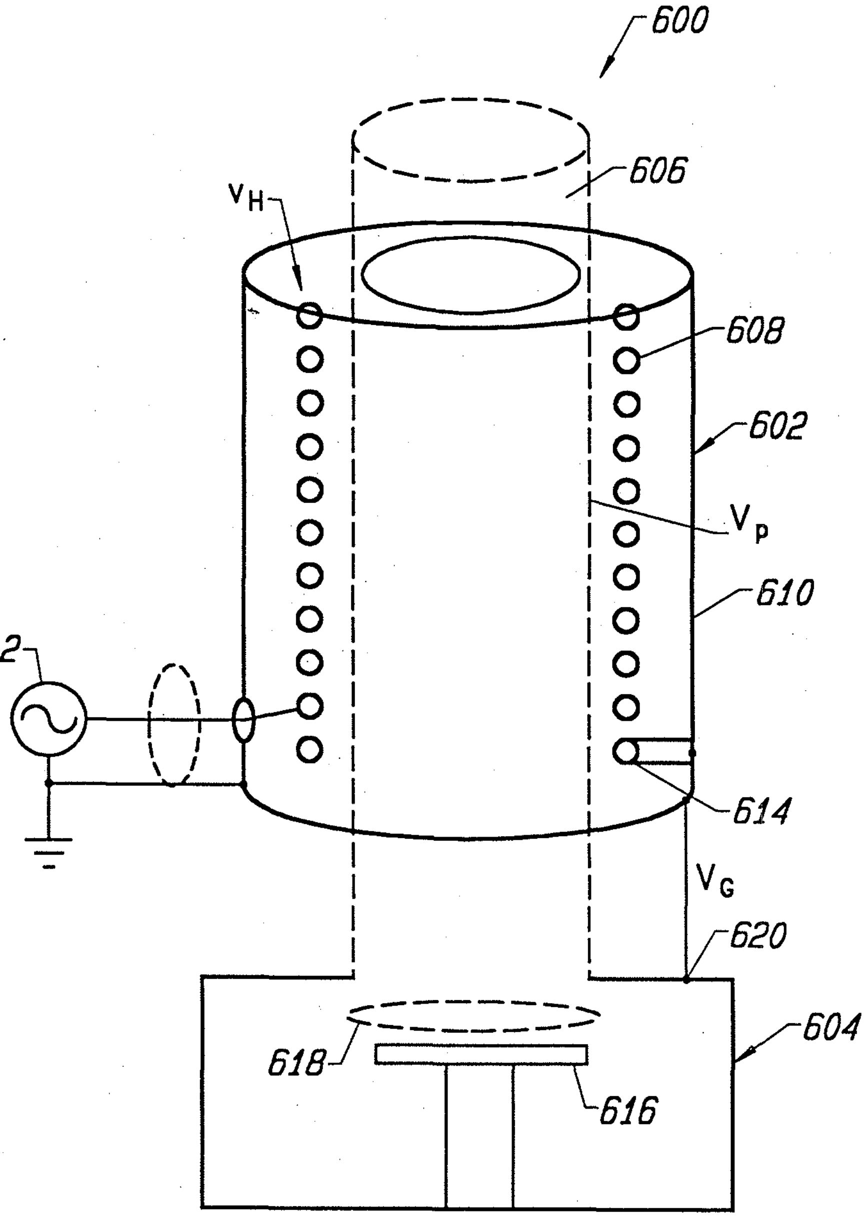

FIG. 6

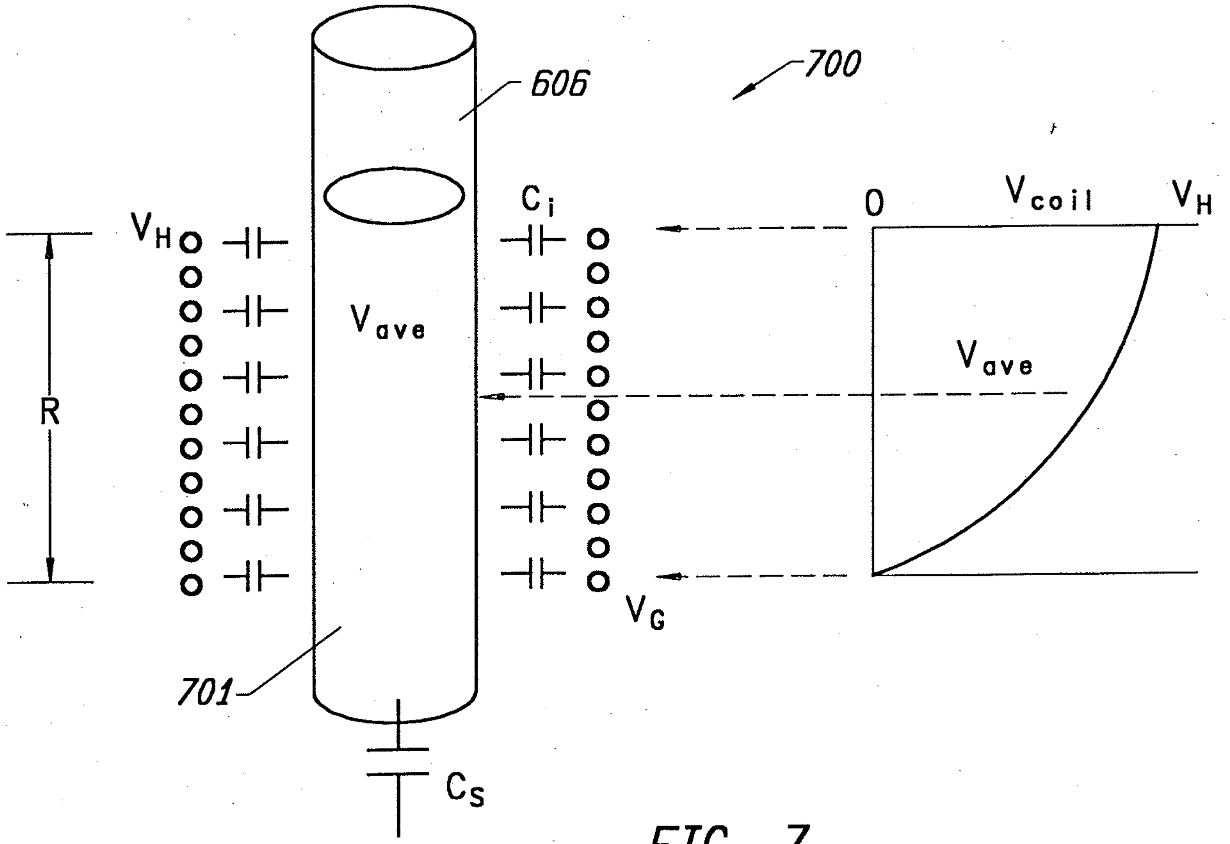

FIG. 7

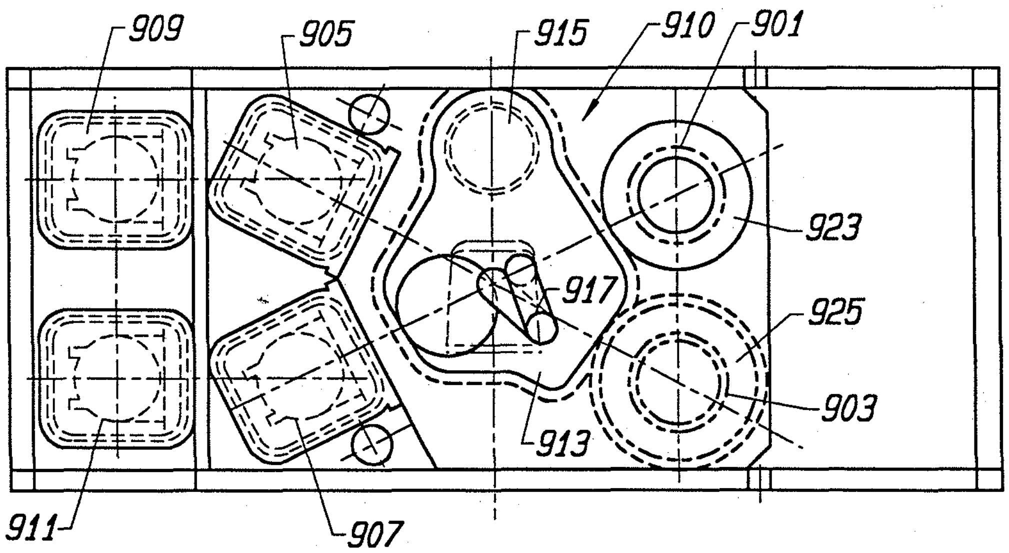
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FIG. 8

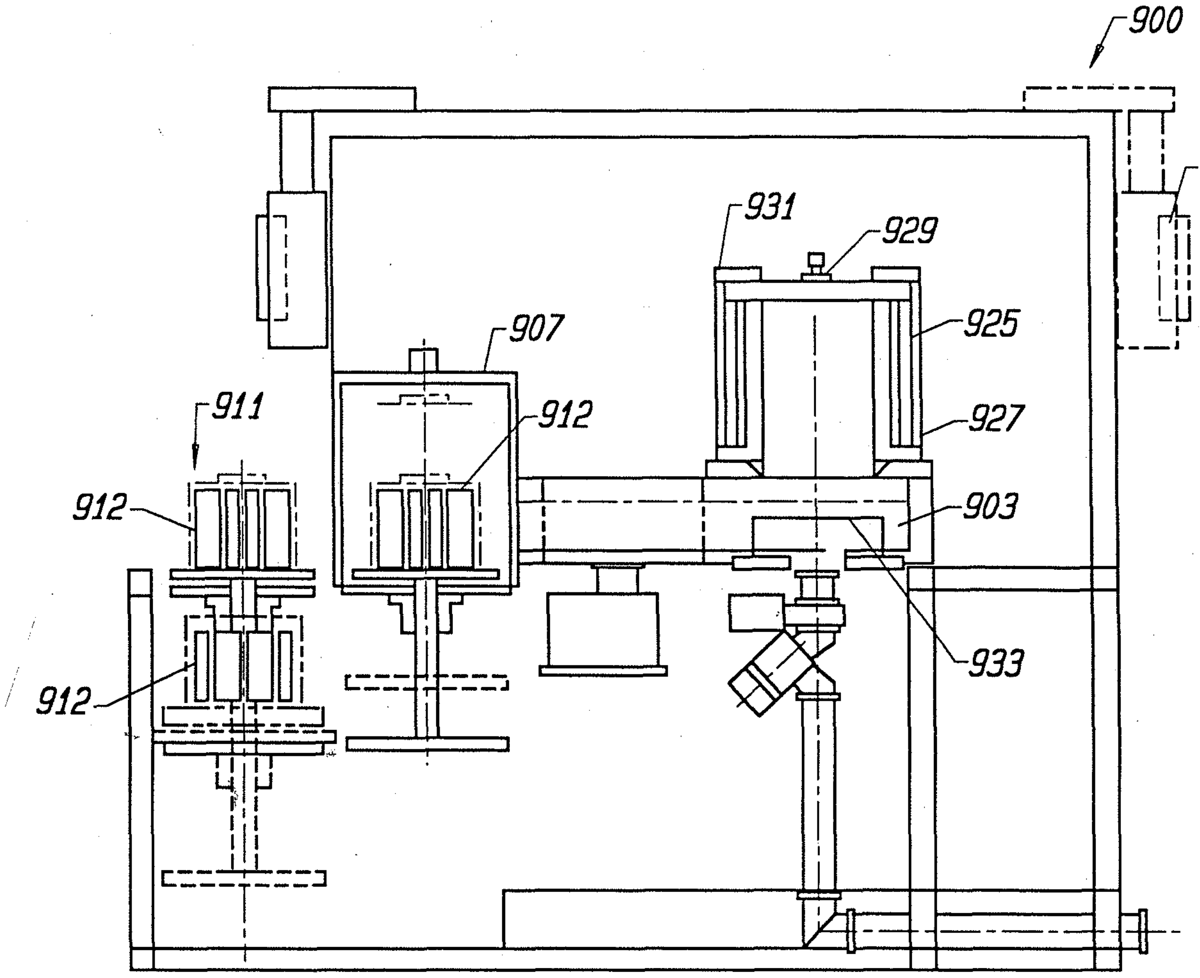
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FIG. 9

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PATENT
Attorney Docket No.: 016655-000311US

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Washington, D.C. 20231

on May 9, 2001

TOWNSEND and TOWNSEND and CREW LLP

By

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:

Daniel L. Flamm et al.

Application No.: 08/866,040
U.S. Patent No.: 6,017,221

Filed: May 30, 1997

For: PROCESS DEPENDING ON PLASM DISCHARGES SUSTAINED BY INDUCTIVE COUPLING

Examiner:

Art Unit:

WITHDRAWAL OF ATTORNEY OR AGENT UNDER 37 CFR § 1.36

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Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Pursuant to 37 CFR § 1.36, Townsend and Townsend and Crew LLP, attorneys for applicant hereby withdraws from representation relative to the above-identified patent. Please direct all future correspondence regarding the subject patent to applicant at:

Dr. Daniel J. Flamm
476 Green View Drive
Walnut Creek, California 94596

By: William J. Bohl
William J. Bohler
Reg. No. 31,487

TOWNSEND and TOWNSEND and CREW LLP
Two Embarcadero Center, 8th Floor
San Francisco, CA 94111-3834
Tel (415) 576-0200
Fax (415) 576-0300
PA 3135626 v1

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Pat#6017221

APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
08/866,040	05/30/1997	DANIEL L. FLAMM	16655-000311

CONFIRMATION NO. 9212

OC000000006131854

TOWNSEND TOWNSEND AND CREW
TWO EMBARCADERO CENTER 8TH FLOOR
SAN FRANCISCO, CA 941113834

Date Mailed: 05/31/2001

NOTICE REGARDING POWER OF ATTORNEY

This is in response to the Power of Attorney filed 05/14/2001.

- The withdrawal as attorney in this application has been accepted. Future correspondence will be mailed to the new address of record. 37 CFR 1.33.

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APPLICATION NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
08/866,040	05/30/1997	DANIEL L. FLAMM	16655-000311

CONFIRMATION NO. 9212

OC000000006131865

DR. DANIEL J. FLAMM
476 GREEN VIEW DRIVE
WALNUT CREEK, CA 94596

Date Mailed: 05/31/2001

NOTICE REGARDING POWER OF ATTORNEY

This is in response to the Power of Attorney filed 05/14/2001.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

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Initial Patent Examination Division (703) 308-1202

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DR. DANIEL J. FLAMM
476 GREEN VIEW DRIVE
WALNUT CREEK CA 94596

DATE PRINTED

08/06/07

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PATENT NUMBER	FEE AMT	MAINT. SURCHG	U.S. APPL NUMBER	PATENT ISSUE DATE	APPL. FILING DATE	PAY-MENT YEAR	SMALL ENTITY?	TOTAL PYMT DUE	ATTORNEY DOCKET NUMBER
6017221	1150	65	08866040	01/25/00	05/30/97	8	YES	1215	16655-000311

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MF440H (3/2006)

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08/29/11

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The total payment due is the amount required on the date the fee is paid (and not necessarily the amount indicated below). All USPTO fees (including maintenance fees) are subject to change. Customers should refer to the USPTO Web site (www.uspto.gov) or call the Maintenance Fee Branch at 571-272-6500 for the most current fee amounts for the correct entity status before submitting payment. The total payment due indicated below is based on the entity status according to current Office records (shown below).

Timely payment of the total payment due is required in order to avoid expiration of the patent. A maintenance fee payment can be timely made using the certificate of mailing or transmission procedure set forth in 37 CFR 1.8.

			U.S.	PATENT	APPL.	PAY-		TOTAL	ATTORNEY
PATENT	FEE	MAINT.	APPL	ISSUE	FILING	MENT	SMALL	PYMT	DOCKET
NUMBER	AMT	SURCHG	NUMBER	DATE	DATE	YEAR	ENTITY?	DUE	NUMBER
6017221	2055	65	08866040	01/25/00	05/30/97	12	YES	2120	16655-000311

The maintenance fee and the applicable surcharge can be paid quickly and easily over the Internet at www.uspto.gov by electronic funds transfer (EFT), credit card, or USPTO deposit account payment methods. The mailing address for all maintenance fee payments not electronically submitted over the Internet is: U.S. Patent and Trademark Office, P.O. Box 979070, St. Louis, MO 63197-9000.

Direct any questions about this notice to: Mail Stop M Correspondence, Director of the United States Patent and Trademark Office, P.O. Box 1450, Alexandria, VA 22313-1450.

NOTE: This notice was automatically generated based on the amount of time that elapsed since the date a patent was granted. It is possible that the patent term may have ended or been shortened due to a terminal disclaimer that was filed in the application. Also, for any patent that issued from an application filed on or after June 8, 1995 containing a specific reference to an earlier filed application or applications under 35 U.S.C. 120, 121, or 365(c), the patent term ends 20 years from the date on which the earliest such application was filed, unless the term was adjusted or extended under 35 U.S.C. 154 or 156. Patentee should determine the relevant patent term for a patent before paying the maintenance fee.

66474 U.S. PTO
08/866040
05/30/97

PATENT APPLICATION SERIAL NO.__________

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

PTO-1556
(5/87)

PATENT APPLICATION FEE DETERMINATION RECORD

Effective October 1, 1996

Application or Docket Number
866040

CLAIMS AS FILED - PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY RATE	SMALL ENTITY FEE	OR	OTHER THAN SMALL ENTITY RATE	OTHER THAN SMALL ENTITY FEE
BASIC FEE	▨	▨	▨	395 ~~385.00~~	OR	▨	770.00
TOTAL CLAIMS	1 minus 20 =	*	x$11=		OR	x$22=	
INDEPENDENT CLAIMS	1 minus 3 =	*	x40=		OR	x80=	
MULTIPLE DEPENDENT CLAIM PRESENT			+130=		OR	+260=	
			TOTAL	395	OR	TOTAL	770

* If the difference in column 1 is less than zero, enter "0" in column 2

460

CLAIMS AS AMENDED - PART II

AMENDMENT A

	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE	SMALL ENTITY ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	OTHER THAN SMALL ENTITY ADDITIONAL FEE
Total	* 32	Minus	** 20	= 12	x$~~11~~9=	108	OR	x$22=	
Independent	* 6	Minus	*** 3	= 3	~~x40=~~ 39	117	OR	x80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					+130=		OR	+260=	
					TOTAL ADDIT. FEE	225 00	OR	TOTAL ADDIT. FEE	

AMENDMENT B

	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE	SMALL ENTITY ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	OTHER THAN SMALL ENTITY ADDITIONAL FEE
Total	*	Minus	**	=	x$11=		OR	x$22=	
Independent	*	Minus	***	=	x40=		OR	x80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					+130=		OR	+260=	
					TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT C

	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE	SMALL ENTITY ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	OTHER THAN SMALL ENTITY ADDITIONAL FEE
Total	*	Minus	**	=	x$11=		OR	x$22=	
Independent	*	Minus	***	=	x40=		OR	x80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM					+130=		OR	+260=	
					TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

Staple Issue Slip Here

POSITION		ID NO.	DATE
CLASSIFIER		5	8-29-97
EXAMINER		32	10/10/97
TYPIST			
VERIFIER			
CORPS CORR.			
SPEC. HAND		412	2-25
FILE MAINT.		32	10/10/97
DRAFTING			

INDEX OF CLAIMS

Claim		Date							
Final	Original	9/29/98	6/18/99	9/23/99					
1	1		✓	=					
2	2								
3	3								
4	4								
5	5								
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SYMBOLS

✓ .... Rejected
= .... Allowed
- (Through numberal) Canceled
\+ .... Restricted
N .... Non-elected
I .... Interference
A .... Appeal
O .... Objected

Claim		Date							
Final	Original								
	51								
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(LEFT INSIDE)

[redacted]

SEARCHED

Class	Sub.	Date	Exmr.
118	50.1	9/9/98	
156	643 345 646 659.1	..	..
219	121.41 121.44	..	..
204	192.1 192.12	..	..
427	192.25 12	..	..
216	2		
437	225,228 233		
UPDATED above	"	9/18/99	
UPDATED above	"	9/23/99	

INTERFERENCE SEARCHED

Class	Sub.	Date	Exmr.
437	225 228 233	9/23/99	
156	643 659.1	..	..
204	192.25	"	"

SEARCH NOTES

	Date	Exmr.
Searched APS	12/9/97	
APS	9/12/98	
APS	9/23/99	

(RIGHT OUTSIDE)