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Keller et al.

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[54] **PLASMA AMPLIFIED PHOTOELECTRON PROCESS ENDPOINT DETECTION APPARATUS**

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[51] **Int. Cl.**[4] **C23C 14/00;** H01L 21/306; B44C 1/22; C23F 1/02

[52] **U.S. Cl.** **156/345;** 156/643; 156/626; 156/627; 204/192.33; 204/298; 427/10; 427/34; 118/620; 118/665

[58] **Field of Search** 204/298, 192.33, 192.32; 156/643, 646, 345, 626, 627; 118/665, 620; 427/10, 34

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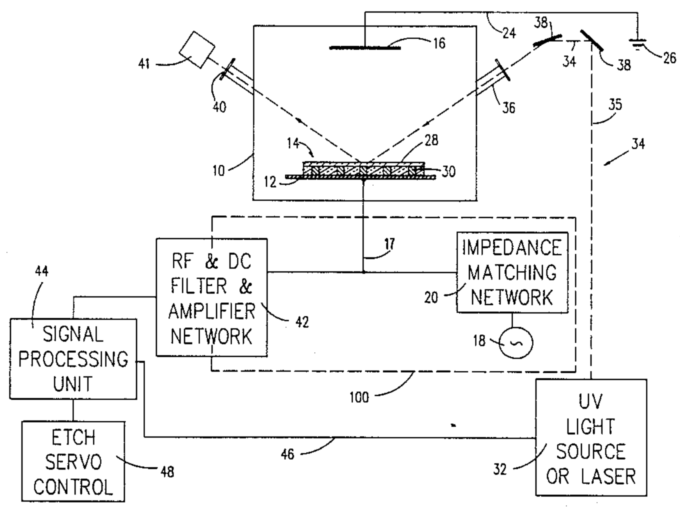
Primary Examiner—David L. Lacey
Assistant Examiner—Thi Dang
Attorney, Agent, or Firm—William T. Ellis

[57] **ABSTRACT**

A plasma processing apparatus and process endpoint detection method including a plasma chamber for processing an item that has a first portion of a first material and a second portion of a second material, with the first and second materials having different work functions, and a structure for generating a plasma in the plasma chamber, with the plasma generating structure including at least a pair of RF-power electrodes with one of them being excited by an RF excitation frequency. The apparatus further includes a structure for generating and ejecting electrons from the second material only when the second material is exposed to the plasma, and a structure for increasing the energies of these generated electrons and accelerating these electrons into the etching plasma with sufficient energy to generate secondary electrons in the plasma. The apparatus further includes a structure for receiving a plasma discharge voltage signal, a structure for filtering the discharge electrical voltage signal to remove the RF excitation frequency and any DC components therein, and a structure for amplifying the natural frequencies of excitation and decay of the plasma discharge voltage perturbation signal, to thereby detect the processing endpoint.

In a preferred embodiment, the electron energy increasing and accelerating structure includes a structure for generating an electrode voltage sheath, and a structure for generating the electrons within this voltage sheath to thereby accelerate the electrons into the plasma. The electron generating structure includes a structure for directing a beam of photons in a selected energy range onto the item to be processed, which energy range is not sufficient to eject photoelectrons from the first material, but is high enough to generate photoelectrons from areas of exposed second material.

35 Claims, 2 Drawing Sheets



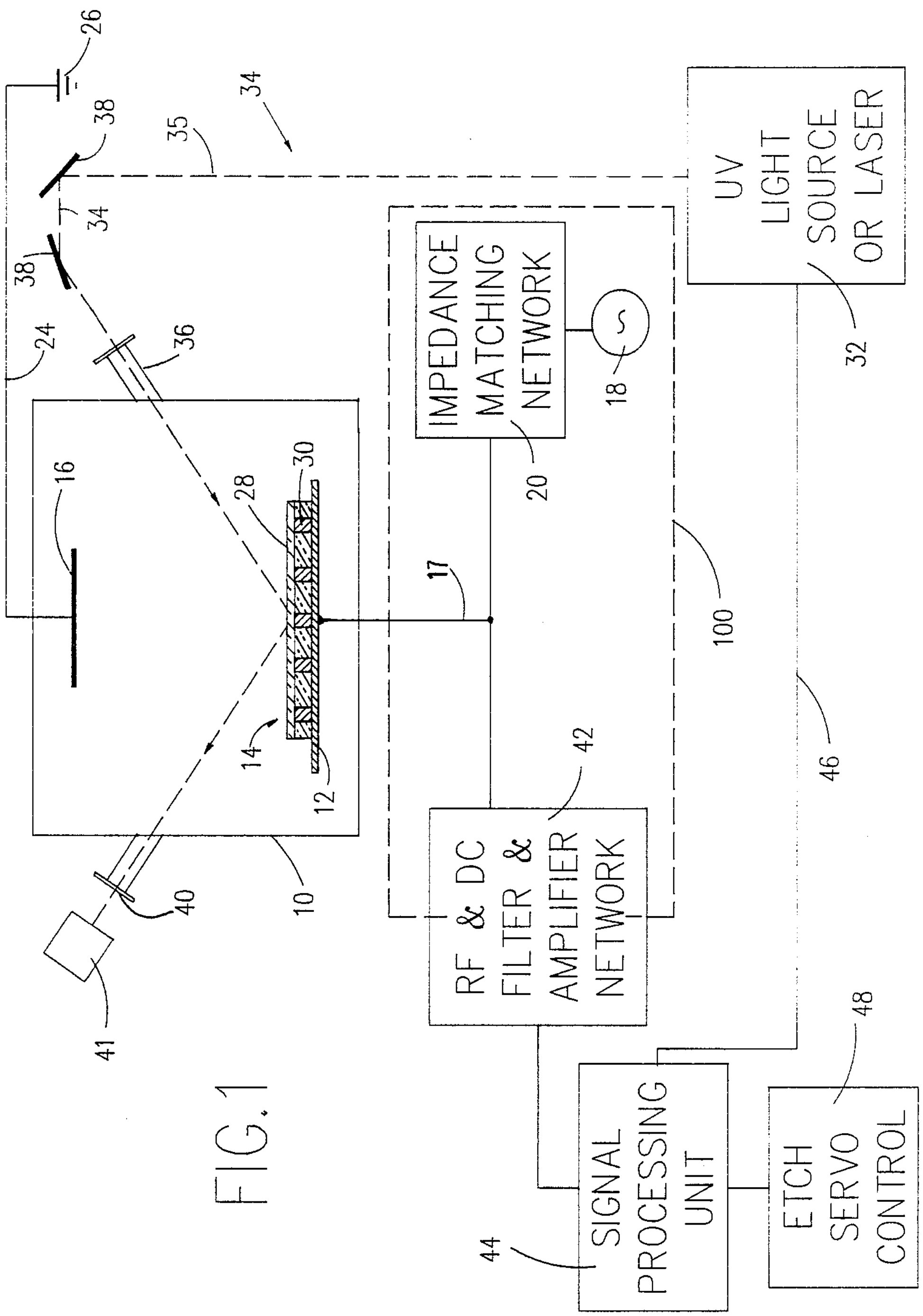

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FIG. 1

FIG. 2

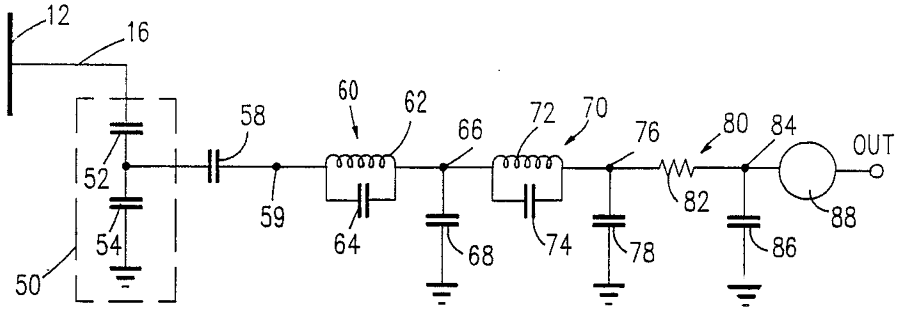
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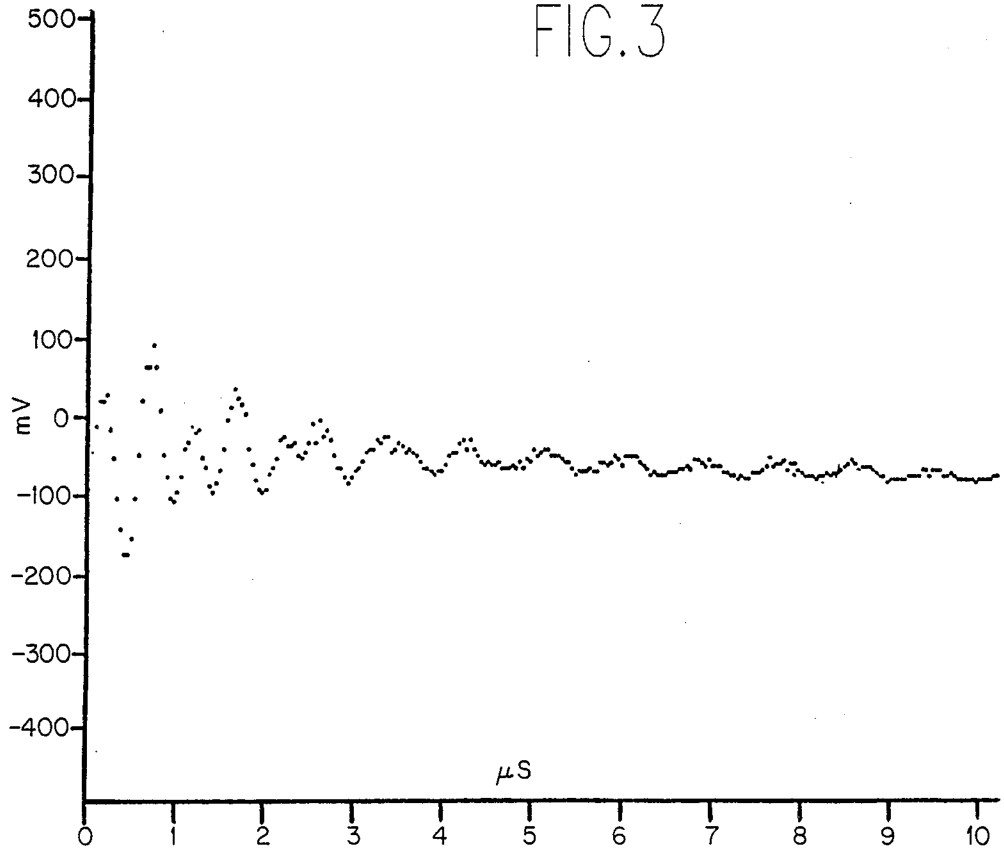
FIG. 3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PLASMA AMPLIFIED PHOTOELECTRON PROCESS ENDPOINT DETECTION APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates generally to the field of material processing, and more particularly to a plasma apparatus and a method for detecting a process endpoint.

It is desirable to have a non-intrusive, sensitive etch endpoint apparatus and method to detect the exposure of a desired sublayer in an item being etched. Several techniques have been demonstrated for etch endpoint detection, including optical emission spectroscopy, plasma impedance monitoring, and laser interferometry. However, all of these techniques fail to provide sufficient sensitivity when there is a very low pattern etch factor, i.e., a low percentage of the item's surface is exposed to the etching medium. Additionally, some of these techniques require considerable signal averaging to improve the signal-to-noise ratio. The use of these methods thus results in a slower response to etch plasma compositional changes and a slower response to endpoint indicia in the plasma.

The failure of the prior art techniques for detecting endpoint in the presence of very low pattern factors provide a significant impediment to the semiconductor industry drive for faster circuit devices. Such faster circuit devices require smaller component dimensions which often result in very low wafer pattern densities. At the same time, faster etch processes result in the need for more precise endpoint control with a fast endpoint detection response.

Alternatively, it is desirable to be able to detect with precision the coverage of a low pattern factor area in a deposition process. Similar detection problems to those noted above are encountered in this type of processing.

The invention as claimed is intended to remedy the above-described etch endpoint and deposition endpoint detection problems and limitations that arise when low pattern factors are present.

The advantages offered by the present invention are that extremely low pattern factor endpoints can be detected with high resolution and a very fast response. This endpoint detection can be utilized when etching, for example, a top layer through to another layer therebelow, when those two layers have different work functions. Likewise, this invention can be used when depositing a top layer on to another layer, where those two layers have different work functions. Accordingly, this invention can be used to detect endpoint when etching or depositing a top layer of metal, semiconductor, or insulator material through or on to another layer therebelow of metal, semiconductor or insulator material which layer has a different work function. This invention is particularly advantageous in that it is essentially independent of the plasma composition, it has a high detection signal-noise ratio, and it is not highly wavelength sensitive.

SUMMARY OF THE INVENTION

Briefly, one aspect of the invention comprises a plasma processing apparatus including

- a plasma chamber for processing an item that includes a first portion of a first material and a second portion of a second material, with the first and second materials having different work functions;

- means for generating a plasma in the plasma chamber, the plasma generating means including an RF-powered electrode excited by an RF excitation frequency;
- means for generating and ejecting electrons only when the second material is exposed to the plasma;
- means for increasing the energies of the generated electrons and accelerating the electrons into the plasma, with sufficient energy to thereby generate a secondary electrons in the plasma;
- means for receiving a plasma RF discharge voltage signal;
- means for filtering the plasma RF discharge voltage signal to remove the RF excitation frequency therefrom; and
- means for amplifying the natural frequencies of the plasma discharge in response to the electron perturbation in the plasma discharge voltage signal to thereby detect the processing endpoint or a surface condition.

In a preferred embodiment, the electron energy increasing and accelerating means comprises means for generating an electrode voltage sheath, and means for generating the electrons within this voltage sheath to thereby accelerate the electrons into the plasma.

In a further aspect of this embodiment, the electron generating means may comprise means for directing a beam of photons in a selected energy range onto the item, which energy range is not sufficient to eject photoelectrons from the first material, but is high enough to generate photoelectrons from areas of exposed second material. This photon beam directing means may comprise means for generating laser pulses.

In a further embodiment of the present invention, the filtering means may comprise a capacitor for blocking out any DC signal components, and notch filter means for removing the harmonics of the RF excitation signal.

The present apparatus may further comprise means for integrating the filtered signal. In one embodiment, this integrating means may include means for detecting the filtered signal a predetermined time period after the occurrence of each laser pulse and integrating a plurality of the detected filtered signals.

In a further aspect of the present invention, a method is disclosed and claimed for detecting the endpoint in a plasma etching or deposition process. This method comprises the steps of

- disposing an item to be processed in a plasma chamber, the item including a first portion of a first material and a second portion of a second material, with the first and second materials having different work functions;
  - generating by means of an RF electrode excited by an RF excitation frequency a plasma in the plasma chamber to process the item;
  - generating and ejecting electrons from the material only when the second material is exposed to the plasma;
  - accelerating the generated electrons into the plasma with a sufficient energy to thereby generate secondary electrons in the plasma;
  - receiving a plasma discharge voltage signal; and
  - filtering and amplifying the plasma discharge voltage signal to monitor the natural frequencies of excitation and decay of the discharge plasma, to thereby determine the process endpoint or surface condition.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram of one embodiment of the present invention.

FIG. 2 is a schematic circuit diagram of a filter and amplifier network which may be utilized to implement the filter and amplifier block 42 of FIG. 1.

FIG. 3 is a graphical representation of an integrated signal response obtained by utilizing the apparatus and method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is based on the use of the photoelectric effect, i.e., the fact that when an energy beam is directed at a material surface where the energy per quantum is greater than the work function for that material, then electrons will be ejected from that surface. It was recognized that in an etching process for etching, for example, a top layer of a first material through to a second layer therebelow of a second material, the work functions of those two materials will differ in almost every case. Likewise, in a deposition process, it was recognized that in the deposition of a top layer of a first material on to a second layer of a second material, the work functions of these two materials will differ in almost every case. The present invention utilizes the electron-ejection effect in combination with this realization of the differing work functions for these two layers of material on the item being processed to form an operable endpoint detection apparatus and method. Additionally, the invention resides in the use of means to increase the energy of electrons ejected when a given material is exposed and to accelerate those electrons into the plasma with sufficient energy to generate detectable secondary electrons. Finally, the present invention resides in the discovery that the response to these secondary electrons in the etching plasma may be detected at the natural frequencies of excitation and decay of the plasma discharge. Accordingly, the RF plasma excitation frequency and its harmonics, and the DC components in the excitation signal may be removed by appropriate filtering, while the band of frequencies containing the natural frequencies of excitation and decay of the plasma discharge is amplified to obtain a highly enhanced signal/noise ratio.

The present invention will first be described in the context of an etching system. However, the invention applies equally to deposition and other processing systems. Referring now to FIG. 1, there is shown a standard dry etching chamber 10 with an electrode 12 upon which an item 14 to be etched is disposed. This item 14 being etched may comprise, by way of example, a top or a first layer 28 of a first material disposed over a second layer 30 of a second material, with the first and second materials having different work functions. (In FIG. 1, the second layer comprises the studs 30.) In the example shown in FIG. 1, this item to be etched may be a wafer 14. By way of example, and not by way of limitation, a typical dry etching chamber that may be utilized to perform reactive ion etching is described in the reference L. M. Ephrath, "Dry Etching for VLSI—A Review", in Semiconductor Silicon 1981, (eds. H. R. Huff, Y. Takeishi and R. J. Kriegler), The Electrochemical Society, Pennington, N.J., Vol. 81-5, pp. 627 (1981). Such a chamber would have gas inlets in order to provide an appropriate etching gas mixture for the chamber 10.

The RF electrode 12 in the chamber 10 is connected by means of an electrical line 17 to a standard RF source of energy 18. The RF energy source 18 provides an excitation frequency to excite the gases in the chamber to form an etching plasma therein. The RF excitation frequency from the RF excitation signal source 18 is provided to the electrode 12 by means of an impedance matching network 20. By way of example, and not by way of limitation, this impedance matching network 20 may be implemented by a standard LC or Pi circuit of the type shown in the reference A. J. Diefenderfer, Principles of Electronic Instrumentation, W. B. Saunders Co, Philadelphia, Pa. (1979). A second electrode 22 is disposed on the opposite side of the chamber from the electrode 12 and is connected by means of a line 24 to a reference potential 26. The RIE etching plasma is generated in the volume between the electrodes 12 and 22.

The invention further comprises means for generating and ejecting electrons only when a selected material is exposed to the etching plasma. In one embodiment, the means for generating electrons comprises means for directing a beam of energy of either photons or particles in a selected energy range onto the surface of the item 14 being etched. This energy range is not sufficient to eject electrons from one of the first material layer 28 or the second material layer 30 on the item 14 being etched, but is high enough to eject electrons from the other of the first material layer 28 or the second material layer 30, to thereby eject electrons when the other material is exposed.

In the embodiment shown in FIG. 1, the energy beam directing means comprises an energy beam source 32, an energy beam 34 following a path 35, and a window 36 into the chamber 10 to permit application of the energy beam onto the surface of the item 14 being etched. In this embodiment, the energy beam source may be comprised simply of a laser or a UV light source. An ultraviolet wavelength laser such as an excimer laser, or a frequency-quadrupled Nd:VAG laser, or a frequency-doubled tunable dye laser may also be utilized, for example. Conveniently, the energy beam source should be a pulsed source or a continuous wave source that is appropriately chopped. The energy beam path 32 may include one or more mirrors 38, as required, in order to direct the energy beam through the window 36 and into the chamber 10. This energy beam may be focussed or unfocused, depending on the amount of area that is to be impinged on the item 14 being etched. It may be desirable to also include a window 40 in the chamber 10 and an energy beam stop 41 to receive the energy beam after it is reflected off of the surface of the item 14 to prevent the beam from making uncontrolled reflections within the chamber 10. It should be noted that the energy beam may be directed normal to the item 14 being etched, or it may be directed at an oblique angle to the item 14 being etched. It should also be noted that the more oblique the angle of incidence of the energy beam onto the surface of the item 14, the more generalized will be the measurement for the endpoint.

In the example of FIG. 1, when the energy beam 34 strikes a metal, semiconductor, or insulator surface, it will eject photoelectrons if the photon energy exceeds the work function, U, of the material. The ejected photoelectrons will have an energy, KE_e, equal to: $KE_e = h\nu - U$, where hν is the energy of the incident light. However, if the photon energy in the energy beam is less than the work function for the material,

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