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Holland

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(54) **PLASMA PROCESSOR WITH COIL RESPONSIVE TO VARIABLE AMPLITUDE RF ENVELOPE**

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(58) **Field of Search** ..... 156/345; 118/723 I

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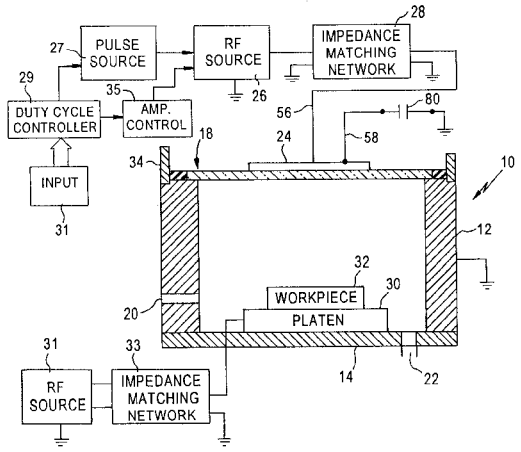
(57) **ABSTRACT**

A vacuum plasma processor includes a coil for reactively exciting a plasma so plasma incident on a workpiece has substantially uniformity. The coil and a window which reactively couples fields from the coil to the plasma have approximately the same diameter. An r.f. source supplies a pulse amplitude modulated envelope including an r.f. carrier to the coil.

39 Claims, 2 Drawing Sheets



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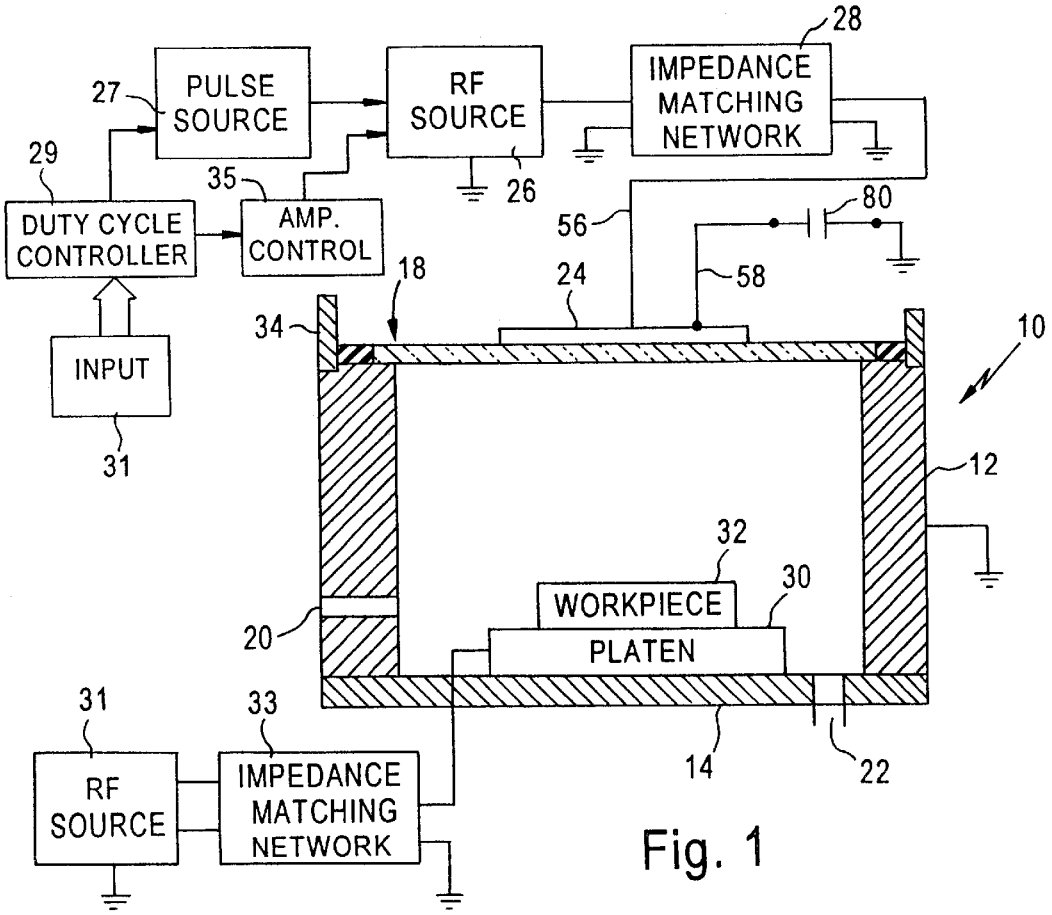

Fig. 1

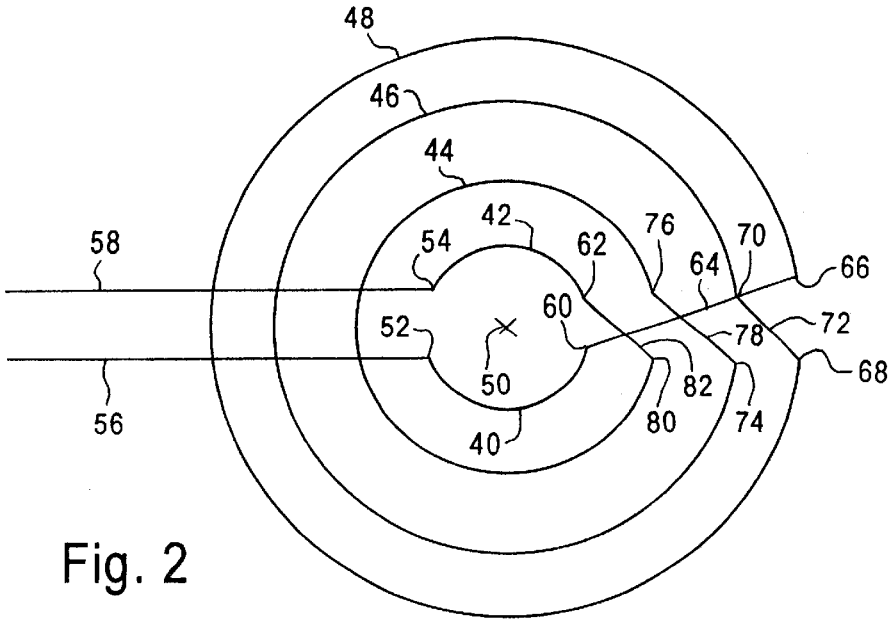

Fig. 2

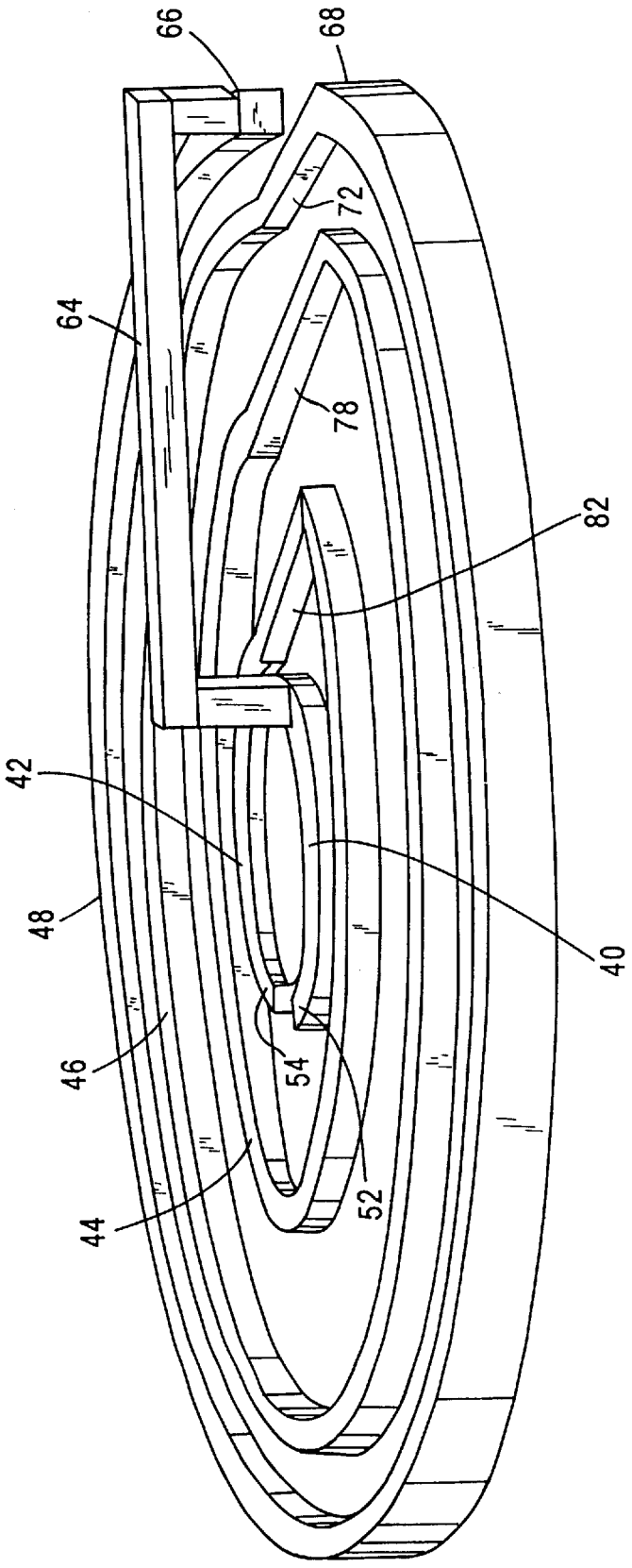

Fig. 3

PLASMA PROCESSOR WITH COIL RESPONSIVE TO VARIABLE AMPLITUDE RF ENVELOPE

FIELD OF INVENTION

The present invention relates generally to plasma processors including radio frequency (r.f.) responsive coils for exciting gases in vacuum chambers to plasmas that process workpieces in the chamber and more particularly to such a processor and to a processing method wherein plasma density on the workpiece is controlled by varying the amplitude of the envelope of the r.f. applied to the coil.

BACKGROUND ART

One type of processor for treating workpieces with an r.f. plasma in a vacuum chamber includes a coil responsive to an r.f. source. The coil responds to the r.f. source to produce magnetic and electric fields that excite ionizable gas in the chamber to a plasma. Usually the coil is on or adjacent to a dielectric window that extends in a direction generally parallel to a planar horizontally extending surface of the processed workpiece. The excited plasma interacts with the workpiece in the chamber to etch the workpiece or to deposit material on it. The workpiece is typically a semiconductor wafer having a planar circular surface or a solid dielectric plate, e.g., a rectangular glass substrate used in flat panel displays, or a metal plate.

Ogle, U.S. Pat. No. 4,948,458 discloses a multi-turn spiral coil for achieving the above results. The spiral, which is generally of the Archimedes type, extends radially and circumferentially between its interior and exterior terminals connected to the r.f. source via an impedance matching network. Coils of this general type produce oscillating r.f. fields having magnetic and capacitive field components that propagate through the dielectric window to heat electrons in the gas in a portion of the plasma in the chamber close to the window. The oscillating r.f. fields induce in the plasma currents that heat electrons in the plasma. The spatial distribution of the magnetic field in the plasma portion close to the window is a function of the sum of individual magnetic field components produced by each turn of the coil. The magnetic field component produced by each of the turns is a function of the magnitude of r.f. current in each turn which differs for different turns because of transmission line effects of the coil at the frequency of the r.f. source.

For spiral designs as disclosed by and based on the Ogle '458 patent, the r.f. currents in the spiral coil are distributed to produce a torroidal shaped magnetic field region in the portion of the plasma close to the window, which is where power is absorbed by the gas to excite the gas to a plasma. At low pressures, in the 1.0 to 10 mTorr range, diffusion of the plasma from the ring shaped region produces plasma density peaks just above the workpiece in central and peripheral portions of the chamber, so the peak densities of the ions and electrons which process the workpiece are in proximity to the workpiece center line and workpiece periphery. At intermediate pressure ranges, in the 10 to 100 mTorr range, gas phase collisions of electrons, ions, and neutrons in the plasma prevent substantial diffusion of the plasma charged particles outside of the torroidal region. As a result, there is a relatively high plasma flux in a ring like region of the workpiece but low plasma fluxes in the center and peripheral workpiece portions.

These differing operating conditions result in substantially large plasma flux (i.e., plasma density) variations between the ring and the volumes inside and outside of the ring, resulting in a substantial standard deviation, i.e., in excess of three, of the plasma flux incident on the workpiece. The substantial standard deviation of the plasma flux incident on the workpiece has a tendency to cause non-uniform workpiece processing, i.e, different portions of the workpiece are etched to different extents and/or have different amounts of molecules deposited on them.

Many coils have been designed to improve the uniformity of the plasma. The commonly assigned U.S. Pat. No. 5,759,280, Holland et al., issued Jun. 2, 1998, discloses a coil which, in the commercial embodiment, has a diameter of 12 inches and is operated in conjunction with a vacuum chamber having a 14.0 inch inner wall circular diameter. The coil applies magnetic and electric fields to the chamber interior via a quartz window having a 14.7 inch diameter and 0.8 inch uniform thickness. Circular semiconductor wafer workpieces are positioned on a workpiece holder about 4.7 inches below a bottom face of the window so the center of each workpiece is coincident with a center line of the coil.

The coil of the '280 patent produces considerably smaller plasma flux variations across the workpiece than the coil of the '458 patent. The standard deviation of the plasma flux produced by the coil of the '280 patent on a 200 mm wafer in such a chamber operating at 5 milliTorr is about 2.0, a considerable improvement over the standard deviation of approximately 3.0 for a coil of the '458 patent operating under the same conditions. The coil of the '280 patent causes the magnetic field to be such that the plasma density in the center of the workpiece is greater than in an intermediate part of the workpiece, which in turn exceeds the plasma density in the periphery of the workpiece. The plasma density variations in the different portions of the chamber for the coil of the '280 patent are much smaller than those of the coil of the '458 patent for the same operating conditions as produce the lower standard deviation.

Other arrangements directed to improving the uniformity of the plasma density incident on a workpiece have also concentrated on geometric principles, usually concerning coil geometry. See, e.g., U.S. Pat. Nos. 5,304,279, 5,277,751, 5,226,967, 5,368,710, 5,800,619, 5,401,350, and 5,847,704.

It is accordingly an object of the present invention to provide a new and improved vacuum plasma processor and method of operating same wherein the plasma density incident on the workpiece can be controlled at will.

An additional object of the present invention to provide a new and improved vacuum plasma processor and method of operating same wherein the plasma density incident on the workpiece has relatively high uniformity.

Another object of the invention is to provide a new and improved vacuum plasma processor having the same geometry as the prior art but which is operated to have controlled plasma density characteristics.

An added object of the invention is to provide a new and improved vacuum plasma processor having the same geometry as the prior art but which is operated to have greater plasma density uniformity characteristics than the prior art.

A further object of the invention is to provide a new and improved vacuum plasma processor including an r.f. excitation coil that is operated so the plasma density incident on a workpiece is substantially less than 2.0.

SUMMARY OF THE INVENTION

I have discovered that the foregoing objects are attained by varying the amplitude of the envelope of r.f. applied to a plasma excitation coil, such as the coil disclosed in the '280 patent.

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