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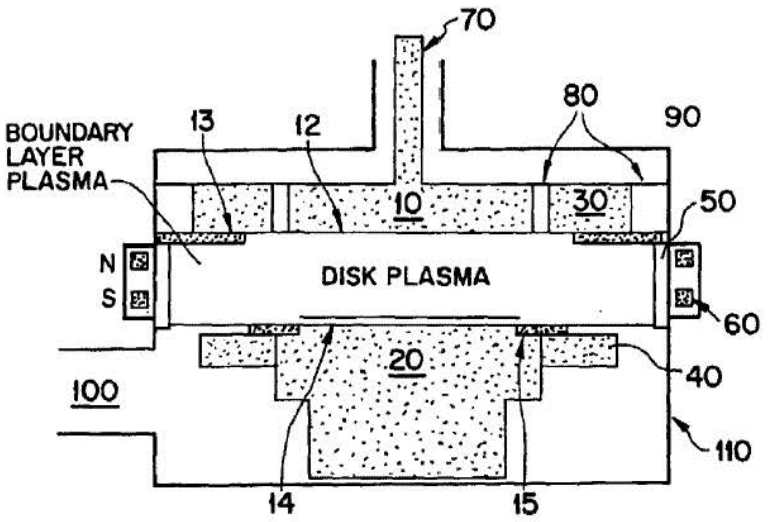
(54) Title: APPARATUS AND METHOD TO CONTROL THE UNIFORMITY OF PLASMA BY REDUCING RADIAL LOSS



(57) Abstract: A capacitively coupled plasma reactor composed of: a reactor chamber enclosing a plasma region; upper and lower main plasma generating electrodes for generating a processing plasma in a central portion of the plasma region by transmitting electrical power from a power source to the central portion while a gas is present in the plasma region; and a magnetic mirror including at least one set of magnets for maintaining a boundary layer plasma in a boundary portion of the plasma region around the processing plasma. A capacitively coupled plasma reactor composed of: a reactor chamber enclosing a plasma region; upper and lower plasma generating electrodes for generating a processing plasma in the plasma region by transmitting electrical power from a power source to the plasma region while a gas is present in the plasma region; and power supplies for applying a VHF drive voltage to the upper plasma generating electrode and RF bias voltages at a lower frequency than the VHF drive voltage to the upper and lower plasma generating electrodes.

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APPARATUS AND METHOD TO CONTROL THE UNIFORMITY OF PLASMA BY REDUCING RADIAL LOSS

This application is based on and derives priority from U.S. Provisional Patent Application No. 60/231,878, filed September 12, 2000, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to methods and apparatus for generating a plasma in a plasma chamber, the plasma being used for performing various industrial and scientific processes including etching and layer deposition on a semiconductor wafer.

Plasma generating systems are currently widely used in a number of manufacturing procedures such as etching and layer deposition on wafers as part of integrated circuit manufacturing processes. The basic components of such a system are a plasma chamber enclosing a processing region in which a plasma will be formed, a plasma electrode, usually at the top of the chamber, for delivering RF electrical power into the chamber in order to initiate and sustain the plasma, and a wafer chuck, usually at the bottom of the chamber, to hold a wafer on which integrated circuits will be formed. Such a system further necessarily includes associated devices for delivering plasma-forming gas and processing gas to the chamber and pumping gas out of the chamber in order to maintain both a desired gas pressure and a desired gas composition in the chamber. One of the key desiderata in plasma reactor design is to increase plasma density while maintaining plasma uniformity.

There are two major sources of plasma non-uniformity in parallel plate plasma reactors, or RF capacitively coupled plasma (CCP) systems, currently used in the industry: radial plasma losses; and highly localized harmonic contents.

In a CCP parallel plate plasma reactor, both the plasma electrode and the chuck, which can also be considered to be an electrode, are capacitively coupled to RF power sources, and self-bias potentials are developed on these electrodes. In existing systems, the plasma is typically associated with a halo plasma, which is a scattered plasma surrounding the discharge gap existing everywhere inside the chamber. An electric field having a large gradient in the radial direction can be developed through the halo plasma in contact with the chamber wall. Since the plasma potential is time dependent in nature and the plasma always contacts the chamber wall in these CCP reactors, there is always a time dependent radial electric field gradient in the plasma in these CCP reactors. This radial electric field gradient is associated with radial diffusion near the plasma edge. The diffusive loss generates a plasma density profile in which the plasma density is higher in the center and lower near the edge of the chamber. This diffusive radial plasma density profile is one major source of plasma non-uniformity due to radial plasma losses.

As concerns plasma non-uniformity caused by highly localized harmonic contents, if the driven frequency on the plasma electrode of a parallel plate reactor is increased, the energy contained at harmonic frequencies of the RF electric field increases rapidly. Interference among these harmonic contents always occurs inside the plasma chamber. The contribution to the total RF electric field due to the harmonic interference causes the total RF electric field on the surface of the electrodes to become non-uniform. The non-uniformity in plasma density could be much greater than the total electric field non-uniformity because high frequency power is much more efficient in creating high plasma densities. The high harmonic frequencies create additional plasma density, but they contribute even more strongly to the plasma non-uniformity. So the harmonic contents and their interference with each other is another major source of plasma non-uniformity.

For the semiconductor industry, if a system with non-uniform plasma is used for semiconductor wafer processing, the non-uniform plasma discharge will produce non-uniform deposition or etching on the surface of the semiconductor wafer. Thus, the control of the uniformity of the plasma directly affects the quality of the resulting integrated semiconductor chips.

The trend in the semiconductor equipment industry is toward reactor sources for processing ever larger wafers, current efforts being devoted to progressing from plasma reactor sources capable of processing wafers with a diameter of 200 mm to those capable of processing wafers with a diameter of 300 mm. Since local field non-uniformity increases as a substantial function of the source dimension relative to wavelength, it is expected that greater non-uniformity will be found in 300-mm systems than in equivalent 200-mm systems. Thus, control of the uniformity of the plasma becomes critical for larger systems.

In VHF CCP systems of the type currently used in the industry, both the upper electrode and the chuck are capacitively coupled to the RF power source or to respective power sources. The processing plasma in such systems makes contact with the chamber wall through the halo plasma existing in the chamber surrounding the discharge gap. Lack of control of the halo plasma makes it difficult to control the time dependent plasma potential. There is also a significant time-dependent radial electric field gradient existing near the outer edge of the processing plasma. This radial electric field gradient increases radial plasma loss, introduces charging damage near the wafer edge, and possibly causes sputtering on the chamber wall.

BRIEF SUMMARY OF THE INVENTION

The present invention provides improved plasma density uniformity in CCP systems.

The invention is implemented by a capacitively coupled plasma reactor comprising: a reactor chamber enclosing a plasma region; upper and lower main plasma generating electrodes for generating a processing plasma in a central portion of the plasma region by transmitting electrical power from a power source to the central portion while a gas is present in the plasma region; and means including at least one set of magnets for maintaining a boundary layer plasma in a boundary portion of the plasma region around the processing plasma.

The invention is further implemented by a capacitively coupled plasma reactor comprising: a reactor chamber enclosing a plasma region; upper and lower plasma generating electrodes for generating a processing plasma in a central portion

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