(12) UK Patent Application (19) GB (11) 2 231 197 (13) A

(43) Date of A publication 07.11.1990

(21) Application No 9004980.0

(22) Date of filing 06.03.1990

(30) Priority data
(31) 8905075 (32) 06.03.1989 (33) GB

(51) INT CL⁵
H01J 37/32, H05H 1/46

(52) UK CL (Edition K)
H1D DGQ D10 D11X D11Y D12B4 D12B47Y D12B5 D12B6 D12B8 D12B9 D12C D38 D8TY D8T1 D8X D9CX D9CY D9C1A D9C1Y D9D D9L D9Y
U1S S1632 S1655 S1664

(56) Documents cited
GB 2170350 A **GB 1230982 A** **EP 0261922 A2**
EP 0184812 A2 **EP 0073963 A2**

(58) Field of search
UK CL (Edition J) **H1D DG**
INT CL⁴ **H01J**

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(54) Plasma apparatus electrode assembly

(57) An electrode assembly for use in a plasma processing apparatus, e.g. for reactive dry etching or plasma deposition, comprises a primary electrode 13 with a conductive wall defining a plasma chamber 5 which is open at both ends and has an inlet 9 for gas, an insulator at one end of the plasma chamber for insulating the primary electrode when it is mounted on the body 2 of a vacuum chamber, r.f. generator 29, 10 associated with a dielectric member 8 extending across the other end of the chamber 5 for inductively generating a plasma in the gas in the plasma chamber 5 and a primary magnet arrangement 14, see also Figs 3-5 (not shown), which produces lines of magnetic flux within the plasma chamber which extend in a curve from the plasma chamber wall and return thereto so as to form an arch over a respective one of a plurality of wall regions which extend substantially longitudinally of the wall of the plasma chamber in a zone which is, in use, above and spaced from the substrate table 6, so as to trap electrons from the plasma adjacent the chamber wall.

The r.f. generator coil 10 may be in the form of a substantially flat spiral which is adjacent to or embedded in the dielectric member 8 and additional secondary magnets 11, 12 provide a dipole field that penetrates the energising coil 10.

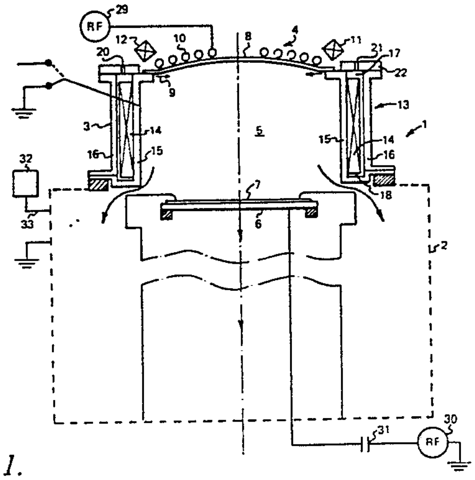

Fig. 1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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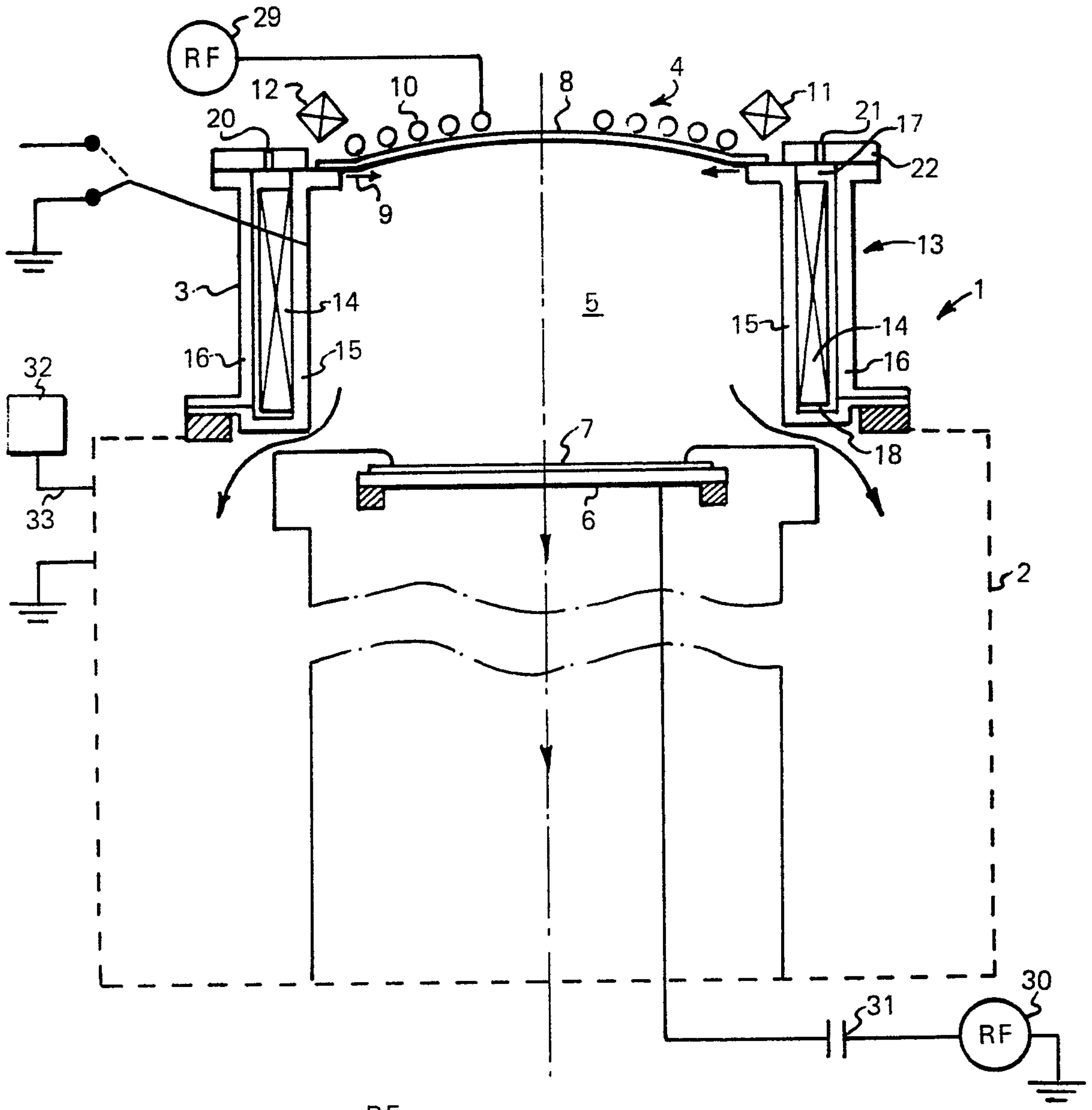
Fig. 1.


RF
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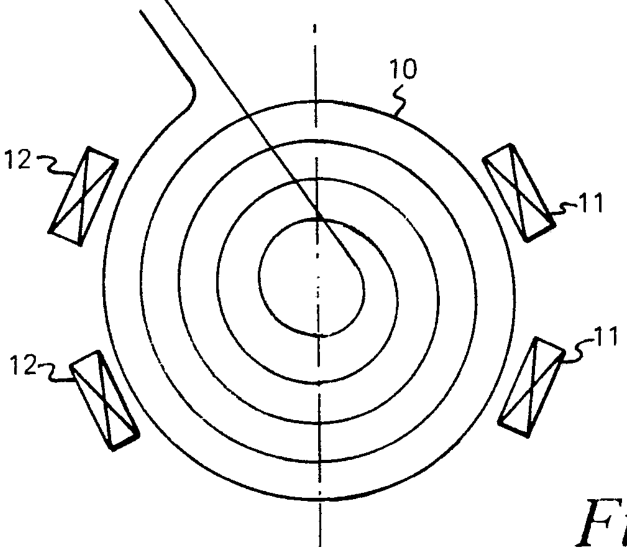
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Fig. 2.

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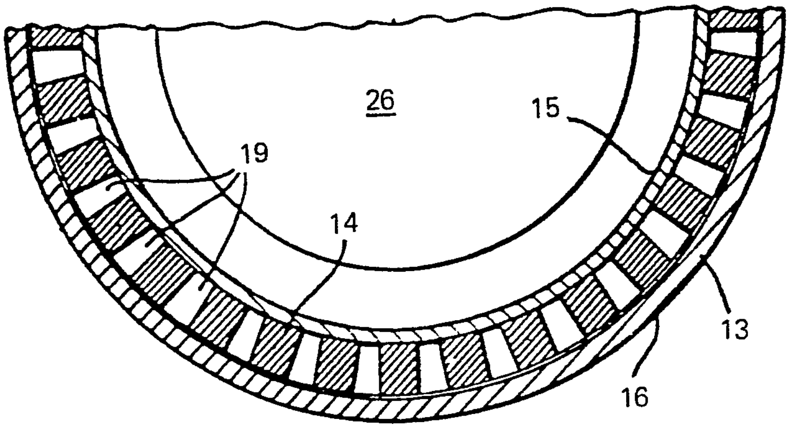

Fig. 3.

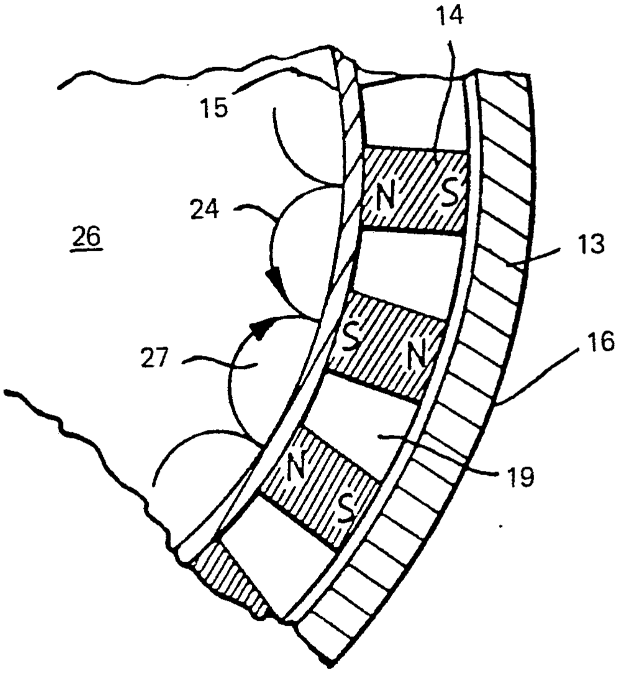

Fig. 4.

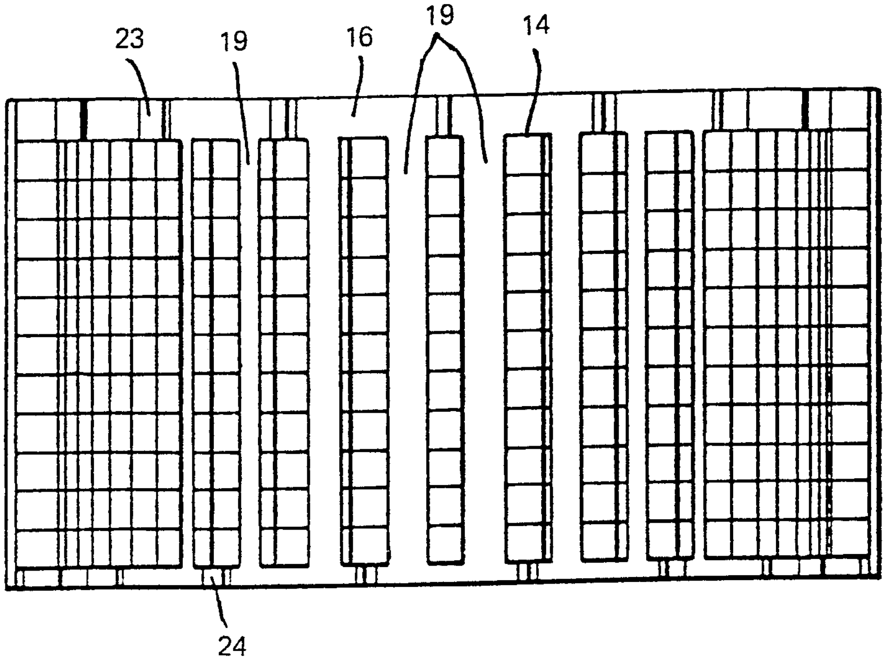

Fig. 5.

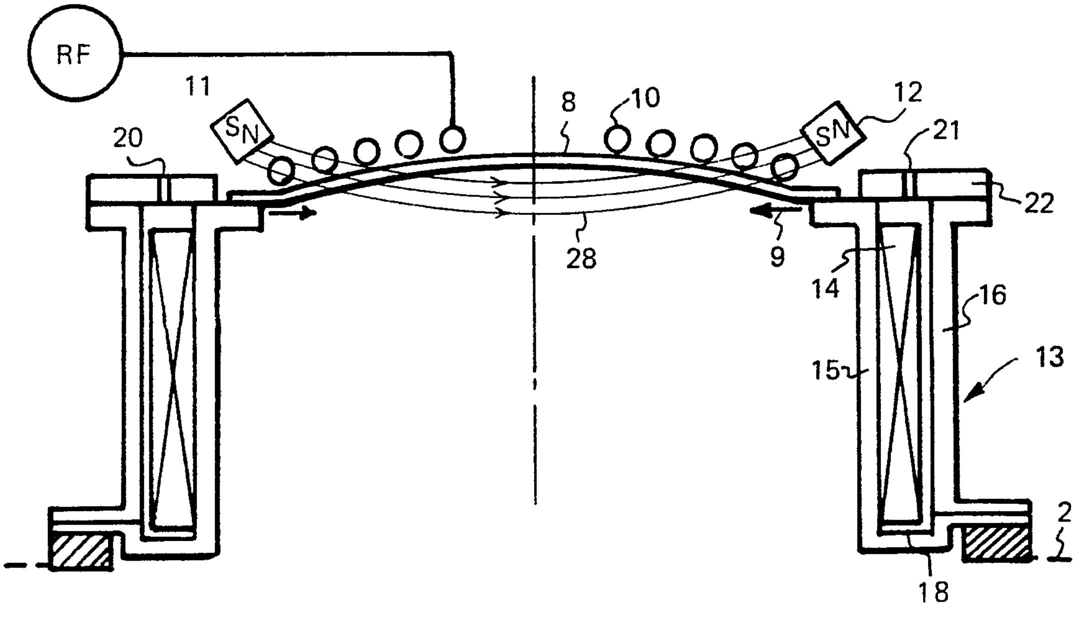

Fig. 6.

ELECTRODE ASSEMBLY AND APPARATUS

This invention relates to an electrode assembly and to apparatus incorporating such an electrode assembly. In particular it relates to an electrode assembly for use in plasma processing apparatus, such as a reactive dry etching apparatus or a plasma deposition apparatus.

The manufacture of integrated circuits on a wafer of a semi-conductor material generally involves a whole series of processing steps in the course of which layers of material are deposited on or grown on selected areas of the wafer or selected areas of the wafer are modified by techniques such as ion implantation so as to produce the desired junctions between semi-conductor layers of different composition.

A number of these processing steps may involve application of a photo-resist layer to the wafer in order to protect those areas of the wafer where treatment is not wanted. Often application of a photo-resist layer is preceded by an oxidation step in which the surface of the wafer is heated in a suitable oxidising atmosphere, e.g. oxygen, in order to form a layer of silicon dioxide on the surface of the wafer. Thereafter it is necessary to etch the wafer in order to remove the layer of silicon dioxide from those areas which are not protected by the photo-resist layer so as to expose the underlying silicon-based substrate for further treatment, e.g. sputtering or ion implantation. In any such etching step the aim is to effect anisotropic etching, that is to say to etch only material lying on that part of the surface of the wafer which is not protected by the photo-resist layer so that etching proceeds only in a direction normal to the surface of the underlying silicon-based layer and so that lateral etching, which would lead to undercutting of the edges of the photo-resist layer, is avoided.

Initially wet etching methods were used in order to strip silicon dioxide from the underlying silicon-based substrate, at least in those areas which are not protected by a photo-resist layer. The baths used for such etching processes contain noxious chemicals, such as hydrofluoric acid, which represent a considerable health and safety hazard. Moreover the use of liquid etching solutions complicates the production process. In addition etching occurs isotropically on all areas of the exposed silicon dioxide layer with the result that some undercutting of the edges of the photo-resist layer inevitably occurs, thus giving rise to loss of precision of definition of the areas protected by the photo-resist.

More recently there has been developed the so-called reactive dry etching process which can be used, for example, for removal of silicon dioxide layers. In this case the wafer to be etched is exposed to an atmosphere of an etchant gas, such as hexafluoroethane or a mixture of hexafluoroethane and trifluoromethane, which is simultaneously subjected to plasma discharge conditions. The plasma discharge is thought to result in production of F^+ ions and CF_3^+ ions, as well as $CF_3^\cdot$ radicals; these reactive species then react with and remove the silicon dioxide so as to expose the underlying silicon based layer.

An apparatus has been described by C. Le Jeune et al for reactive dry etching or plasma deposition in which an r.f. frequency (13.56 MHz) is applied to a multi-tubular copper cathode mounted within an earthed cylindrical vacuum chamber having a plurality of elongate ferrite magnets arranged at spaced intervals around the periphery of the chamber, each with its magnetic axis arranged radially with respect to the chamber and with the magnets arranged with alternating polarities around the periphery of the chamber. Gas can be admitted to the chamber which is further provided with an anticathode of independent polarity which is capacitively coupled to earth. Further details can be found in a paper which appeared in Proceedings of the 3ème Symposium International sur le Gravure Seche et le Dépôt Plasma en Microelectronique, Cachan, 26-29 November 1985, pages 145 to 153 entitled "Triode HF a confinement multipolaire pour réacteur de gravure ou de dépôt".

The use of microwaves to produce plasmas for anisotropic etching of silicon using SF_6/Ar has been described by C. Pomot et al, J. Vac. Sci, Technol., B4(1), Jan/Feb 1986, pages 1 to 5. This apparatus includes a cylindrical vacuum chamber, operating at earth potential for safety reasons, which is lined with permanent magnets.

A plasma etching reactor with a multipolar field confinement layer is described by T.D. Mantei et al in Appl. Phys. Lett. 43(1), 1 July 1983, pages 84 to 86, in Abstract No. 279 in Extended Abstracts of the Electrochemical Society Meeting, Vol. 86-2, (1986), page 418, and in Solid State Technology, April 1985, pages 263 to 265. The magnets are positioned around the vacuum chamber wall which must be earthed for safety reasons. Hot tungsten filaments are used to produce the plasma. However the use of hot filaments is unsatisfactory as they burn out after a relatively short period of operation and there is a risk of sputtered material from the filaments contaminating the wafer or other substrate being etched.

For deposition of layers on a semi-conductor wafer one technique that can be used is plasma deposition. This process is also known as glow discharge deposition or as plasma enhanced chemical vapour deposition. For example, a layer of silicon can be applied by exposing the wafer to an atmosphere of silane under plasma producing conditions. The methods used heretofore have, however, been relatively slow processes and their use in production of integrated microcircuits represents a bottle neck in the overall production process.

Use of a cylindrical multipole magnetic wall in conjunction with a hot cathode d.c. discharge for production of a silane plasma is described by B. Drevillon et al in Appl. Phys. Lett. 37(7), 1 October 1980, pages 646 to 648. This apparatus uses hot filaments which burn out in use and may result in contamination of the deposited silicon layer with material sputtered from the hot filament.

Plasma generation by means of r.f. excitation relies upon the ability of electrons to respond to the high frequency field and the inability of ions to do so because of their relatively high inertia. As a result electrons are stripped off the gas molecules. The electrons then become trapped by the magnetic confinement cusps formed by the alternately north and south poles which face the plasma, leaving a positively charged plasma in the central part of the plasma generation chamber.

An electrode assembly with a primary electrode which can be connected to an r.f. generator is described in EP-A-0261922. This electrode assembly can be used for plasma etching or for plasma deposition.

The present invention seeks to provide an improved form of electrode assembly for use in plasma processing and an improved form of plasma processing apparatus incorporating such an electrode assembly. In particular it seeks to provide an electrode assembly and apparatus capable of efficient operation at commercially acceptable radio frequencies such as 13.56 MHz or a multiple thereof.

According to the present invention there is provided an electrode assembly for use in a plasma processing apparatus comprising an open-ended body defining a first part of a vacuum chamber and a substrate table within the first part of the vacuum chamber adapted for supporting a substrate to be treated and for connection to a power source, the electrode assembly comprising:

(a) a primary electrode comprising electrically conductive wall means defining a plasma chamber which is open at both ends;

(b) a dielectric member which extends across one end of the chamber;

(c) insulating means at the other end of the plasma chamber for insulating the primary electrode from the body of the vacuum chamber when the electrode assembly is mounted on the body of the vacuum chamber;

(d) gas inlet means for admission to the plasma chamber of a plasma forming gas;

(e) r.f. generator means associated with the dielectric member for inductively generating a plasma in the gas in the plasma chamber; and

(f) primary magnet means for trapping electrons adjacent the wall of the plasma chamber in use of the electrode assembly by producing lines of magnetic flux within the plasma chamber which extend in a curve from the wall of the plasma chamber and return thereto so as to form an arch over a respective one of a plurality of wall regions which extend substantially longitudinally of the wall of the plasma chamber in a zone which is, in use, above and spaced from the substrate table.

The invention further provides a plasma processing apparatus for treating a substrate under plasma forming conditions in a reactant gas atmosphere comprising

(1) a vacuum chamber comprising an open-ended body defining a first part of a vacuum chamber;

(2) a substrate table within the first part of the vacuum chamber adapted for supporting a substrate to be treated and for connection to a power source; and

(3) an electrode assembly fitted to the open end of the first part of the vacuum chamber in vacuum tight manner and defining a second part of the vacuum chamber;

the electrode assembly comprising:

(a) a primary electrode comprising electrically conductive wall means defining a plasma chamber which is open at both ends and provides the second part of the vacuum chamber;

(b) a dielectric member which extends across one end of the plasma chamber;

(c) insulating means at the other end of the plasma chamber for insulating the primary electrode from the body of the vacuum chamber;

(d) gas inlet means for admission to the plasma chamber of a plasma forming gas;

(e) r.f. generator means associated with the dielectric member for inductively generating a plasma in the gas in the plasma chamber; and

(f) primary magnet means for trapping electrons adjacent the wall of the plasma chamber in use of the ion gun by producing lines of magnetic flux within the plasma chamber which extend in a curve from the wall of the plasma chamber and return thereto so as to form an arch over a respective one of a plurality of wall regions which extend substantially longitudinally of the wall of the plasma chamber in a zone above and spaced from the substrate table.

In the electrode assembly of the present invention inductive r.f. coupling is used to generate a plasma in the plasma chamber. This is in contrast to the prior art designs of electrode assembly, such as that of EP-A-0261922, which utilise capacitative r.f. coupling to generate the plasma.

Although it is possible to use a concave or dished dielectric member to extend across the said one end of the plasma chamber so that there is a cavity formed by the dielectric member at that end of the plasma chamber, it is preferred to use as near flat a dielectric member as possible. Hence minimal dishing of the dielectric member is preferred. However, it may not be practical to avoid all dishing of the dielectric member as it must be ensured that the integrity of the vacuum equipment be preserved and that all risk of fracture of the dielectric member due to pressure differences exerted across it during operation is substantially obviated.

Preferably the r.f. generator means associated with the dielectric member comprises a coil which lies adjacent to, or is embedded within, the dielectric member. Hence the coil is preferably flat or as near flat as is practicable. Preferably it comprises a spirally wound coil.

With this preferred configuration it is possible to utilise efficiently relatively high frequency r.f. signals, e.g. signals of 13.56 MHz. Optimisation of the plasma density within the plasma chamber, when the plasma is generated within a radio frequency inductively driven plasma chamber, is a function of power supply frequency and the design of energising coil used. With the preferred substantially flat spirally wound generator coil the advantages are:

1. The inductance associated with the plasma loop current of ionising electrons can be kept reasonably low. This prevents the induced electric field from reaching values where the energy gained by the electrons between gas collisions would be such as to take their ionisation cross section well past its optimum.
2. Losses to the walls are minimised.
3. High energy ionising electrons spiralling out of the plasma loop are contained in the electrode structure. This effect can be further enhanced by a superimposed magnetic dipole field which penetrates the energising coil.
4. There is an electrodynamic force which tends to push the whole plasma loop current down towards the substrate table.
5. The Q factor of the drive coil is reasonably high which in turn means a high power efficiency.

At the ion densities required for adequate extracted beam current density the bulk plasma behaves as a good conductor and hence has a low skin depth to r.f. electromagnetic fields. This means for inductive coupling that the induced currents flow in circuits which are largely on the plasma surface and close to the driving coil. The impedance which the plasma presents to the induced currents may be shown to be a series combination of inductance and resistance, and therefore the plasma loop driving potential, i.e. the line integral of the induced electric field, is the sum of two vectors at 90° to each other in the time domain. Primary ionizing electrons within the plasma skin depth are accelerated by this field and ideally the average energy gained should be such as to take the electrons ionising cross section, which is a function of their energy, to its maximum value. If the induced electric field is too large, as a result of adverse geometry etc, electrons gain so much energy before collision that their cross section falls to a low value and low ionization results almost regardless of power input. A correct balance is required between the resistive and inductive components of the electric field for the particular conditions of operation, hence the inductive component must not be too large. At 13.56 MHz using a solenoidal energising coil the plasma inductive reactance is getting too high but for a relatively small spiral coil the plasma reactance is smaller.

The flat spiral coil has further advantages in that it allows the total surface area exposed to plasma to be considerably reduced and this reduces the loss of electrons to the plasma chamber walls.

It may further be shown that the overall power efficiency of the coupling transformer, which is formed with the driving coil as primary and the plasma circuit as secondary is given by

$$E = \frac{k^2Qp}{k^2Qp + Qs + 1/Qs}$$

where k is the coefficient of coupling and the Q terms represent the quality factors of the primary and secondary circuits, e.g. $Qp = wLp/\surd p$ the ratio of coil inductive reactance to its resistance. Maximum efficiency is achieved for arbitrary plasma conditions when k^2Qp is as high as possible; k is maximised by placing the coil as close to the plasma as other restrictions will allow and then the driving coil's Qp must not fall to values so low as to produce thermal "runaway". This can occur if a coil is not optimally wound or is not water cooled, whereby, as a result of the positive temperature coefficient of copper, a rise in the coil's temperature produces a rise in its a.c. resistance ($\surd p$) and hence a further rise in temperature. The efficiency of the driving transformer then falls since Qp falls with increasing $\surd p$ and most of the power supplied goes to heating the coil instead of energising the plasma. Simple coil structures always yield the greatest Q values and the spiral is no exception although it may have a lower Q than a large solenoid.

By appropriate choice of geometry for the spiral driving coil and by modifying the magnetic field strength and/or distribution within the plasma chamber it is possible to tune the excitation of the discharge for a variety of gases, e.g. Ar, O_2 or N_2.

The primary electrode may be allowed to adopt a floating potential in use of the electrode assembly. Alternatively the primary electrode may be arranged for connection to earth. A switch may be provided to allow the primary electrode either to adopt a floating voltage or to be connected to earth.

The substrate table is preferably connected to an r.f. power source.

The plasma chamber may have any convenient cross section and its interior dimensions may vary with depth from the open end or from one of its open ends. In a particularly preferred form the plasma chamber has a substantially cylindrical wall; in this case the plasma chamber is of circular cross section. However it is also envisaged that the plasma chamber can be elliptical in section or polygonal in section, e.g. octagonal or duodecagonal.

Although it is convenient to form the plasma chamber of uniform cross section throughout its depth, it is alternatively possible to form the primary electrode with a plasma chamber of varying cross section, for example a conical plasma chamber or a barrel-shaped plasma chamber.

The primary magnet means conveniently comprises an annular pole plate and a plurality of elongate magnets magnetically coupled with the pole plate, each aligned substantially longitudinally with respect to the plasma chamber and each having its magnetic axis aligned substantially radially with respect to the plasma chamber, and with the polarities of the magnets alternating around the pole plate. Conveniently permanent magnets are used, although the use of electromagnets is not ruled out.

The primary magnets are preferably selected to have a magnetic field strength of at least about 1 kGauss, for example a magnetic field strength in the range of from about 1 kGauss to about 2 kGauss. Such field strengths can be attained with the aid of rare earth magnets. such as samarium-cobalt magnets.

This multipolar arrangement of primary magnets gives rise to a magnetic field within the plasma chamber whose lines of magnetic force form arches over longitudinal regions of the wall of the plasma chamber from the north pole of one magnet to the south pole of each of the magnets adjacent thereto. In this way a series of more or less open-ended magnetic "tunnels", each extending longitudinally of the plasma chamber and parallel to its axis, is formed. This magnetic field pattern traps many, but not all, of the electrons formed in production of the plasma and enhances the plasma density. However, some of the electrons can escape to the wall of the body of the vacuum chamber, thereby inducing a suitable negative voltage on the primary electrode, for example a voltage in the range of from about - 10 volts to about - 50 volts. Such a self bias voltage should not be so large, however, that there is danger of sputtering of the electrode materials, since sputtered material could contaminate a substrate being treated.

Separate r.f. power sources may be used to provide r.f. power to the r.f. generator means and to the substrate table respectively. Alternatively a single r.f. power supply may be used, the output from which is divided between the r.f. generator means and the substrate table.

Typically the r.f. generator means associated with the dielectric member operates at a frequency in the range of from about 1 MHz up to about 45 MHz, e.g. at about 2 MHz or, more preferably, at one of the industrially allotted wavebands within this range of frequencies, e.g. at 13.56 MHz or 27.12 MHz or 40.68 MHz.

In a preferred form an electrode assembly according to the invention further includes secondary magnet means associated with the r.f. generator means for producing a magnetic dipole field that penetrates the r.f. energising coil or other form of r.f. generator means.

The plasma processing apparatus is operated under plasma forming conditions. Such conditions include operation at a low pressure, preferably at a pressure of less than about 10^{-4} millibar. Typically the pressure of operation lies in the range of from about 5×10^{-4} millibar to about 10^{-2} millibar, e.g. about 2×10^{-3} millibar.

In a reactive dry etching process for etching silicon dioxide layers, the reactant gas may be, for example, a silicon halide, such as SiF_4 or $SiCl_4$, or a halocarbon, such as a fluorocarbon, such as hexafluoroethane or a mixture of hexafluoroethane and trifluoromethane.

Materials containing both chlorine and fluorine substituents may also be used, such as CF_2Cl_2.

In a typical plasma deposition process, the reactant gas is silane (SiH_4).

The voltage of the primary electrode, in operation, if this is allowed to adopt a floating potential, is typically from about -20 volts to about -40 volts, whilst the voltage of the substrate table may vary from about -100 volts up to about -2000 volts.

In order that the invention may be clearly understood and readily carried into effect, a preferred form of plasma processing apparatus will now be described, by way of example only, with reference to the accompanying semi-diagrammatic drawings, in which:

Figure 1 is a vertical section through a plasma processing apparatus;

Figure 2 is a plan view of the top of the electrode assembly of the apparatus of Figure 1;

Figure 3 is a partial horizontal section through the plasma chamber of the apparatus of Figures 1 and 2;

Figure 4 is an enlarged view of part of Figure 3;

Figure 5 is a view of the primary magnet array of the apparatus of Figures 1 to 4; and

Figure 6 illustrates the magnetic field produced by the secondary magnets of the electrode assembly shown in Figures 1 and 2.

Referring to the drawings, a plasma processing apparatus 1 comprises a vacuum chamber (indicated diagrammatically at 2) surmounted by an electrode assembly 3. Electrode assembly 3 comprises a plasma generator 4 mounted on top of an open ended plasma chamber 5. A substrate table 6 carrying a substrate 7 which is to be subjected to ion etching, such as a silicon wafer, is placed below plasma chamber 5 in the vacuum chamber 2.

Plasma generator 4 comprises a dielectric member 8 which closes the top open end of plasma chamber 5. A number of gas inlet nozzles are provided, as indicated by arrows 9, through which a plasma forming gas, such as argon, or a mixture of a plasma forming gas and an etchant gas, such as O_2, Cl_2, SF_6, CF_4, C_2F_6 or a C_2F_6/CHF_3 mixture, can be admitted to the plasma chamber 5. An r.f. coil 10 surmounts member 8 and is connected to a suitable r.f. power source operating at, for example 13.56 MHz. Magnets 11, 12 are provided for a purpose which will be further described below.

Plasma chamber 5 comprises an open-ended metallic body 13, made of aluminium or of an aluminium alloy or of another conductive non-magnetic material, within which are mounted a plurality of primary bar magnets 14. For ease of assembly body 13 is made in two parts, i.e. an inner part 15 and an outer part 16, between which the primary magnets 14 are positioned.

As can be seen from Figure 3, there are thirty-two primary bar magnets 14 secured longitudinally to the cylindrical outer face of inner part 15. Preferably the strongest available magnets, e.g. rare earth magnets, such as samarium-cobalt magnets, are used. Typically such magnets exhibit a field strength of the order of 1 to 2 kGauss. As illustrated in Figure 3 there are thirty-two primary magnets 14. However, a larger or smaller number of primary magnets, for example thirty or less (e.g. twenty-four) or up to forty or more (e.g. forty-eight), may be used, provided always that there is an even number of primary magnets 14. Such primary magnets 14 are evenly spaced around the outer periphery of inner part 15 with their longest dimension arranged substantially parallel to the axis of the plasma chamber 5. As indicated in Figure 4, however, the magnetic axes of primary magnets 14 are arranged radially with respect to plasma chamber 5 so that their respective north and south poles (indicated as N and S respectively in Figure 4) are separated in the direction of their shortest dimension, the primary magnets 14 being arranged with alternating magnetic polarity around the periphery of inner part 15.

Above primary magnets 14 is an annular groove 17 and below them a corresponding annular groove 18. Grooves 17 and 18 communicate one with another via spaces 19 between adjacent primary magnets 14. The grooves 17 and 18 and the spaces 19 form channels for coolant fluid (e.g. water) by means of which the primary magnets 14 and body 13 can be cooled in use. Reference numerals 20 and 21 indicate coolant fluid supply and withdrawal conduits provided in annular member 22. Baffles 23, 24 are provided in grooves 17, 18, as can be seen in Figure 5, in order to make the coolant fluid follow a predetermined path.

Figure 4 indicates the lines of magnetic force 25 produced by primary magnets 14. These lines of force extend from the inner surface of body 13 into cavity 26 in plasma chamber 5 and back into the wall of cavity 26 in an arch over regions 27 which extend parallel to the axis of body 5. Lines of force 25 trap electrons from the plasma which is formed in plasma chamber 5, leaving the gas in the central part of plasma chamber 5 depleted of electrons and containing free positive ions, such as F^+ and CF_3^+ ions. Conveniently r.f. power supply 30 is driven at the same frequency as r.f. generator coil 10, e.g. 13.56 MHz.

Figure 2 illustrates in plan view the positions of the optional secondary magnets 11 and 12 relative to the r.f. generator coil 10. These secondary magnets produce a magnetic dipole field which penetrates the energizing coil 10. The shape of this magnetic field is shown diagrammatically in Figure 6. As can be seen from Figure 6 magnets 11 and 12 have their axes of magnetisation arranged so that either a north pole or a south pole faces the dielectric member 8 and so that the lines of force 28 penetrate the r.f. generator coil 10 and form an arch over the inner face of dielectric member 8.

Reference numeral 29 indicates an r.f. power source connected to coil 10. A similar r.f. power source 30 is used to deliver r.f. power to substrate table 6 via capacitor 31. Primary electrode 13 is either earthed or is left on open circuit 30 so that it can adopt a floating voltage.

Vacuum chamber 2 can be evacuated by means of a suitable vacuum pumping system 32 connected via line 33 to vacuum chamber 2.

In use of plasma processing apparatus 1 vacuum chamber 2 is evacuated to a pressure of typically about 10^{-5} millibar to about 10^{-7} millibar. A plasma forming gas, e.g. argon, a mixture of a plasma forming gas and a reactive gas, e.g. O_2, Cl_2, SF_6, CF_4, C_2F_6 or a C_2F_6/CHF_3 mixture (for example, a 20:1 $C_2F_6:CHF_3$ molar mixture), is admitted via inlets 9. R.f. coil 10 is then excited to generate a plasma. Electrons released are trapped within regions 27 by the magnetic lines of force 24.

Under the influence of the r.f. signal from coil 10 the gas supplied via inlets 9 is dissociated to form a plasma of ions and free electrons in plasma chamber 5, the ions filling the central part of chamber 5 whilst the electrons are trapped adjacent the walls of chamber 5 by the magnetic lines of force 24. Because of the geometrical separation of the r.f. generating coil 10 from the zones 27 of the magnetic confinement region in plasma chamber 5 the plasma in the central part of chamber 5 is substantially uniform and has a relatively low plasma potential. Because the arches formed by the lines of magnetic force 24 over the regions 27 are open ended some of the electrons can escape to the substrate table 6. This gives rise to a negative bias on substrate table 6 which consequently attracts the positive ions (e.g. F^+ and/or CF_3^+ if C_2F_6 or a C_2F_6/CHF_3

mixture is used). This enhances bombardment of the substrate 7 with such ions, thereby enhancing the etching rate.

Typically the power delivered by r.f. power supply 30 is of the order of 75 watts whilst the power delivered by r.f. power supply 29 is of the order of 1 kilowatt. This results in establishment of a reactive plasma as indicated by development of a lilac glow within vacuum chamber 2. The magnetic field pattern established by magnets 4 enhances the plasma density. Under such conditions a high rate of etching of silicon dioxide can be achieved with very good uniformity of etching over the wafer. Highly anisotropic etching is also observed from the areas of the wafer 7 which are not protected by the photo-resist until the underlying silicon layer is exposed. To prevent lateral etching of the silicon dioxide layer under the photo-resist and hence undercutting of the photo-resist layer, it is important to stop etching after the areas not protected by photo-resist have been laid bare of silicon dioxide and before any significant amount of lateral etching can take place.

In a similar way it is possible to use the illustrated apparatus for plasma deposition of materials on a substrate, such as a silicon wafer, for example by plasma decomposition of silicon hydride to deposit silicon.

It will be appreciated by those skilled in the art that, although two separate r.f. power sources 29 and 30 are shown, the necessary r.f. frequency power can be drawn from a single power source and divided as necessary.

In a modification of the illustrated apparatus a load lock is provided for introduction of silicon wafers. In this way the step of opening the chamber 1 by raising its upper portion is obviated.

It will be appreciated by those skilled in the art that, as the drawings are diagrammatic, further items, such as securing bolts, insulating sleeves therefor, clamps, Orings and gaskets, will be required in practice in order to enable the necessary low pressure operating environment within vacuum chamber 2 to be established and maintained. Such items of equipment will be provided as necessary in accordance with conventional practice.

As a heated cathode is not used to generate the plasma the illustrated apparatus can be used with any type of inert or reactive gas. Typical gases that can be used include argon, O_2, Cl_2, SF_6, CF_4, C_2F_6, CHF_3 and mixtures of two or more thereof.

CLAIMS

1. An electrode assembly for use in a plasma processing apparatus comprising an open-ended body defining a first part of a vacuum chamber and a substrate table within the first part of the vacuum chamber adapted for supporting a substrate to be treated and for connection to a power source, the electrode assembly comprising:

(a) a primary electrode comprising electrically conductive wall means defining a plasma chamber which is open at both ends;

(b) a dielectric member which extends across one end of the chamber;

(c) insulating means at the other end of the plasma chamber for insulating the primary electrode from the body of the vacuum chamber when the electrode assembly is mounted on the body of the vacuum chamber;

(d) gas inlet means for admission to the plasma chamber of a plasma forming gas;

(e) r.f. generator means associated with the dielectric member for inductively generating a plasma in the gas in the plasma chamber; and

(f) primary magnet means for trapping electrons adjacent the wall of the plasma chamber in use of the electrode assembly by producing lines of magnetic flux within the plasma chamber which extend in a curve from the wall of the plasma chamber and return thereto so as to form an arch over a respective one of a plurality of wall regions which extend substantially longitudinally of the wall of the plasma chamber in a zone which is, in use, above and spaced from the substrate table.

2. An electrode assembly according to claim 1, in which the dielectric member is flat or is minimally dished.

3. An electrode assembly according to claim 1 or claim

2, in which the r.f. generator means associated with the dielectric member comprises a coil which lies adjacent to, or is embedded within, the dielectric member.

4. An electrode assembly according to claim 3, in which the coil is flat or substantially flat.

5. An electrode assembly according to claim 3 or claim 4, in which the r.f. generator means comprises a spirally wound coil.

6. An electrode assembly according to any one of claims 1 to 5, in which the primary electrode is arranged so that it can adopt a floating potential in use of the electrode assembly.

7. An electrode assembly according to any one of claims 1 to 5, in which the primary electrode is arranged for connection to earth.

8. An electrode assembly according to any one of claims 1 to 5, in which a switch is provided to allow the primary electrode either to adopt a floating voltage or to be connected to earth.

9. An electrode assembly according to any one of claims 1 to 8, in which the plasma chamber has a substantially cylindrical wall.

10. An electrode assembly according to any one of claims 1 to 9, in which the primary magnet means comprises an annular pole plate and a plurality of elongate magnets magnetically coupled with the pole plate, each aligned substantially longitudinally with respect to the plasma chamber and each having its magnetic axis aligned

substantially radially with respect to the plasma chamber, and with the polarities of the magnets alternating around the pole plate.

11. An electrode assembly according to claim 10, in which the primary magnets are permanent magnets.

12. An electrode assembly according to claim 11, in which the primary magnets have a magnetic field strength in the range of from about 1 kGauss to about 2 kGauss.

13. An electrode assembly according to claim 12, in which the primary magnets are rare earth magnets.

14. An electrode assembly according to any one of claims 1 to 13, in which the r.f. generator means associated with the dielectric member is arranged to operate at a frequency in the range of from about 1 MHz up to about 45 MHz.

15. An electrode assembly according to claim 14, in which the r.f. generator means is arranged to operate at 13.56 MHz.

16. An electrode assembly according to any one of claims 1 to 15, which further includes secondary magnet means associated with the r.f. generator means for producing a magnetic dipole field that penetrates the r.f. generator means.

17. An electrode assembly according to claim 1 constructed and arranged substantially as herein described and illustrated in the accompanying drawings.

18. A plasma processing apparatus for treating a

substrate under plasma forming conditions in a reactant gas atmosphere comprising

(1) a vacuum chamber comprising an open-ended body defining a first part of a vacuum chamber;

(2) a substrate table within the first part of the vacuum chamber adapted for supporting a substrate to be treated and for connection to a power source; and

(3) an electrode assembly fitted to the open end of the first part of the vacuum chamber in vacuum tight manner and defining a second part of the vacuum chamber; the electrode assembly comprising:

(a) a primary electrode comprising electrically conductive wall means defining a plasma chamber which is open at both ends and provides the second part of the vacuum chamber;

(b) a dielectric member which extends across one end of the plasma chamber;

(c) insulating means at the other end of the plasma chamber for insulating the primary electrode from the body of the vacuum chamber;

(d) gas inlet means for admission to the plasma chamber of a plasma forming gas;

(e) r.f. generator means associated with the dielectric member for inductively generating a plasma in the gas in the plasma chamber; and

(f) primary magnet means for trapping electrons adjacent the wall of the plasma chamber in use of the ion gun by producing lines of magnetic flux within the plasma chamber which extend in a curve from the wall of the plasma chamber and return thereto so as to form an arch over a respective one of a plurality of wall regions which extend substantially longitudinally of the wall of the plasma chamber in a zone above and spaced from the substrate table.

19. A plasma processing apparatus according to claim

18, in which the dielectric member is flat or is minimally dished.

20. A plasma processing apparatus according to claim 18 or claim 19, in which the r.f. generator means associated with the dielectric member comprises a coil which lies adjacent to, or is embedded within, the dielectric member.

21. A plasma processing apparatus according to claim 20, in which the coil is flat or substantially flat.

22. A plasma processing apparatus according to claim 20 or claim 21, in which the r.f. generator means comprises a spirally wound coil.

23. A plasma processing apparatus according to any one of claims 18 to 22, in which the primary electrode is arranged so that it can adopt a floating potential in use.

24. A plasma processing apparatus according to any one of claims 18 to 22, in which the primary electrode is arranged for connection to earth.

25. A plasma processing apparatus according to any one of claims 18 to 22, in which a switch is provided to allow the primary electrode either to adopt a floating voltage or to be connected to earth.

26. A plasma processing apparatus according to any one of claims 18 to 25, in which the substrate table is connected to an r.f. power source.

27. A plasma processing apparatus according to any one of claims 18 to 26, in which the plasma chamber has a substantially cylindrical wall.

28. A plasma processing apparatus according to any one of claims 18 to 27, in which the primary magnet means comprises an annular pole plate and a plurality of elongate magnets magnetically coupled with the pole plate, each aligned substantially longitudinally with respect to the plasma chamber and each having its magnetic axis aligned substantially radially with respect to the plasma chamber, and with the polarities of the magnets alternating around the pole plate.

29. A plasma processing apparatus according to claim 28, in which the primary magnets are permanent magnets.

30. A plasma processing apparatus according to claim 28 or claim 29, in which primary magnets are selected to have a magnetic field strength in the range of from about 1 kGauss to about 2 kGauss.

31. A plasma processing apparatus according to claim 30, in which the primary magnets are rare earth magnets.

32. A plasma processing apparatus according to any one of claims 18 to 31, in which separate r.f. power sources are used to provide r.f. power to the r.f. generator means and to the substrate table respectively.

33. A plasma processing apparatus according to any one of claims 18 to 31, in which a single r.f. power supply is used, the output from which is divided between the r.f. generator means and the substrate table.

34. A plasma processing apparatus according to any one of claims 18 to 33, in which the r.f. generator means associated with the dielectric body operates at a frequency

in the range of from about 1 MHz up to about 45 MHz.

35. A plasma processing apparatus according to claim 34, in which the r.f. generator means is arranged to operate at 13.56 MHz.

36. A plasma processing apparatus according to any one of claims 18 to 35, in which the electrode assembly further includes secondary magnet means associated with the r.f. generator means for producing a magnetic dipole field that penetrates the r.f. generator means.

37. A plasma processing apparatus according to claim 18 constructed and arranged substantially as herein described and illustrated in the accompanying drawings.

Published 1990 at The Patent Office, State House, 66/71 High Holborn, London WC1R 4TP. Further copies may be obtained from The Patent Office.
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