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(54) **METHOD AND APPARATUS FOR PLASMA DOPING**

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(57) **ABSTRACT**

A method for impurity implantation, in which a substrate is positioned on a table provided within a chamber in which a vacuum will be introduced and also an implantation impurity is supplied. A first high frequency electric power is applied to a plasma generating element to thereby generate a plasma so that the impurity in the chamber is implanted in the substrate. Also, a second high frequency electric power is applied to the table. Detected are a condition of the plasma in the chamber and a voltage or current in the table. A controller controls at least one of the first and second high frequency electric power sources according to the detected condition of the plasma and/or the detected voltage or current, thereby controlling an implantation concentration of the impurity to be implanted.

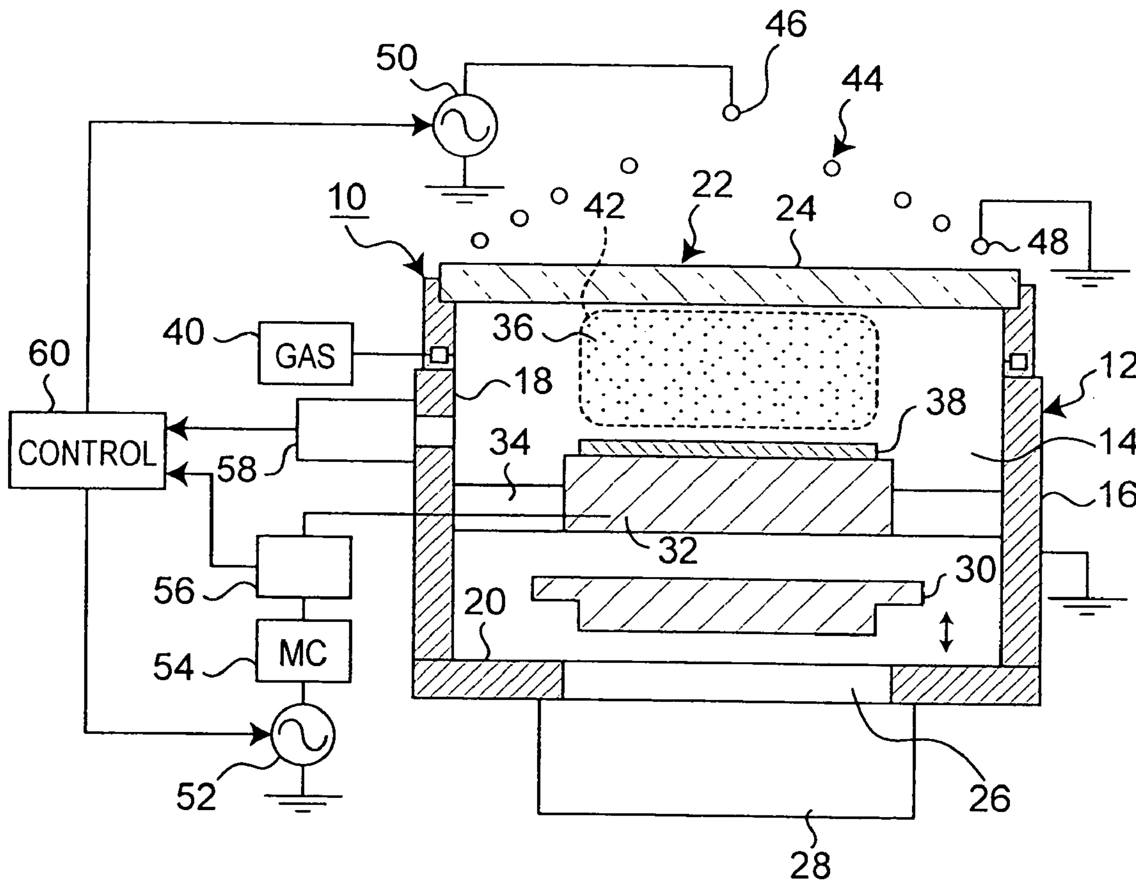


Fig.1

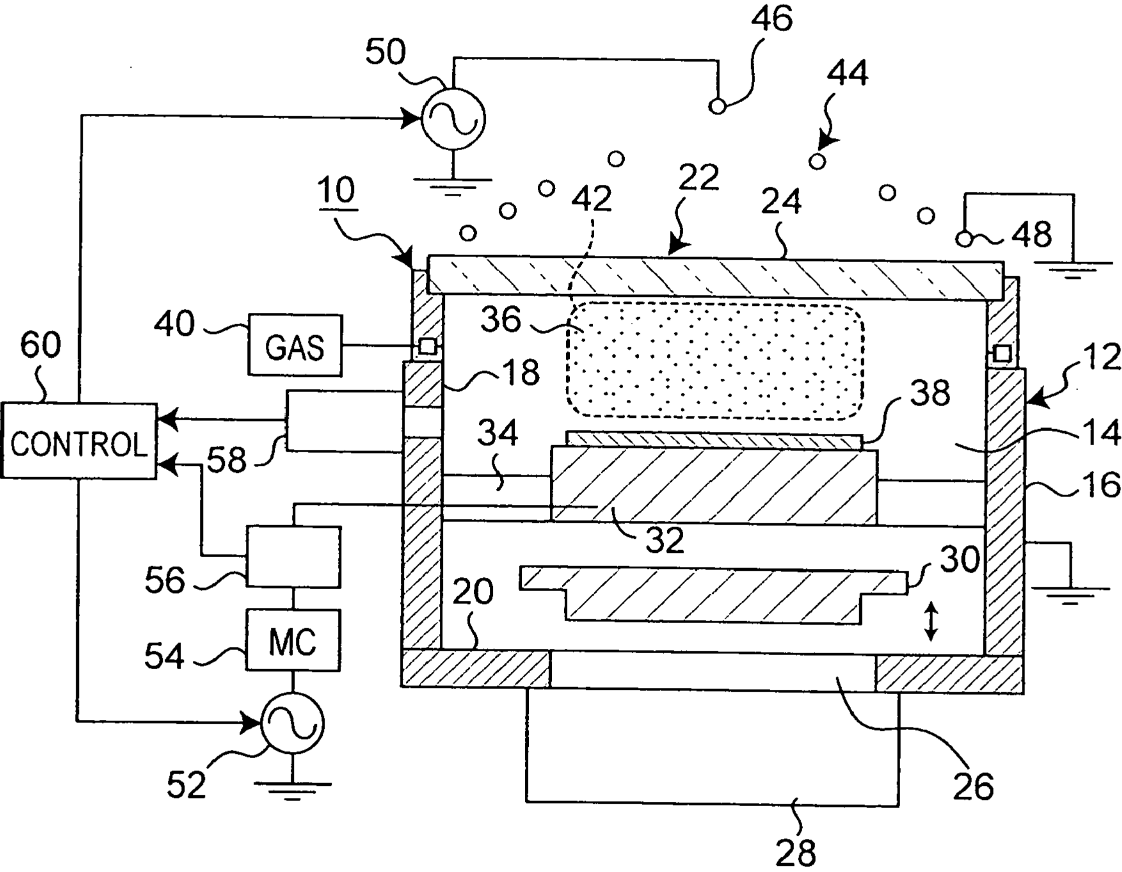


Fig.2

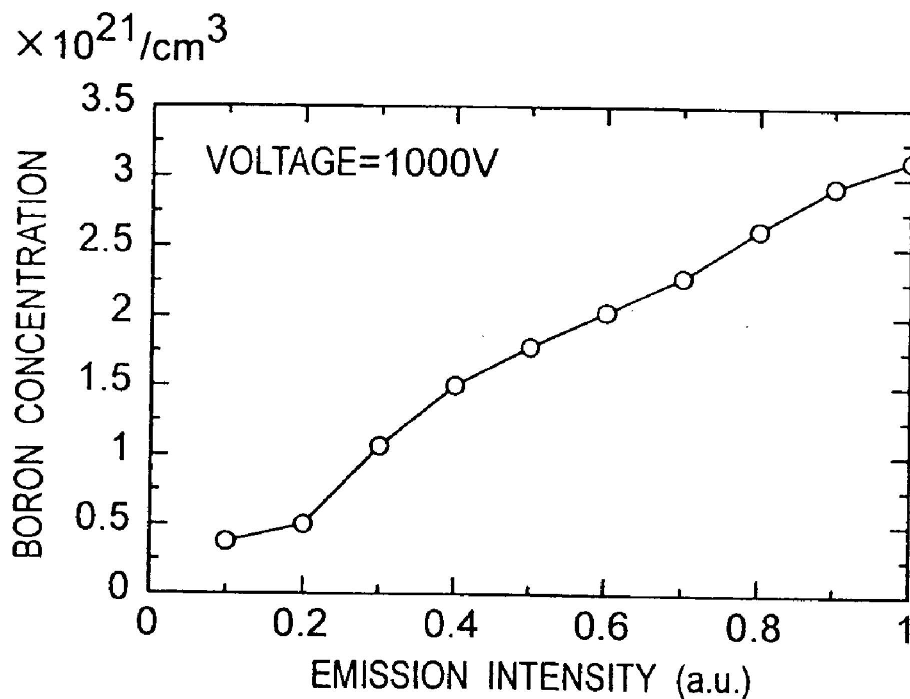


Fig.3

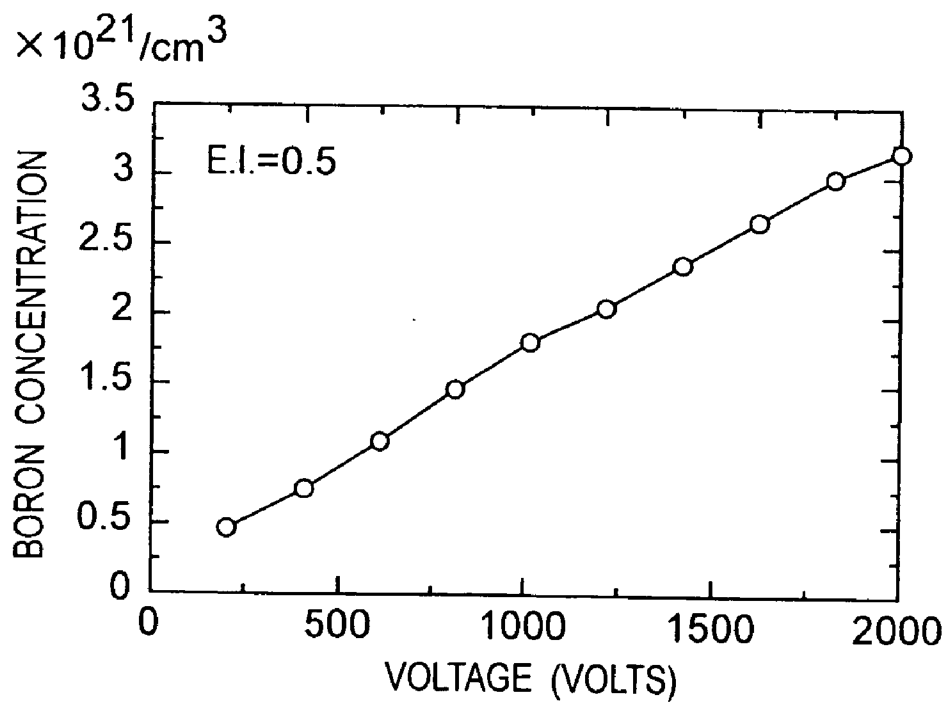


Fig.4

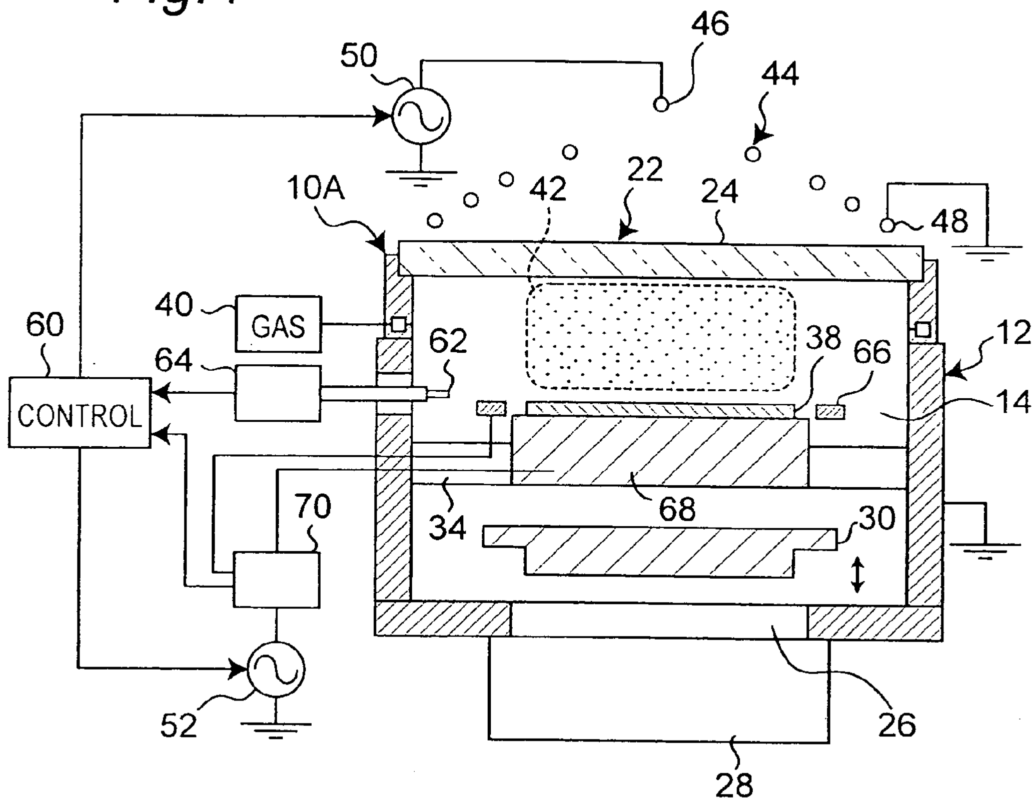


Fig.5

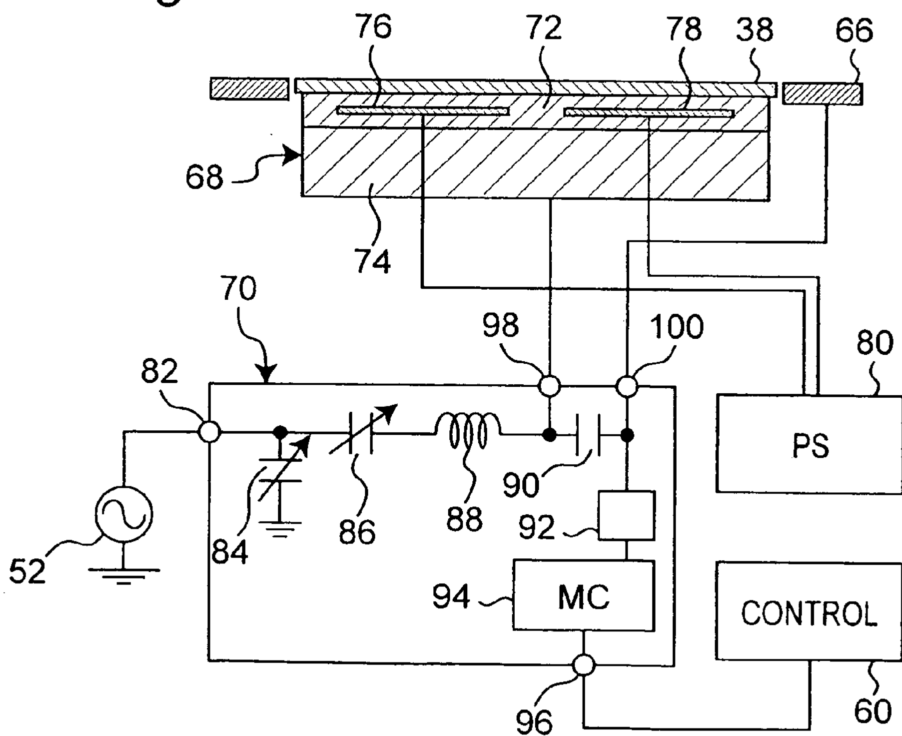


Fig.6

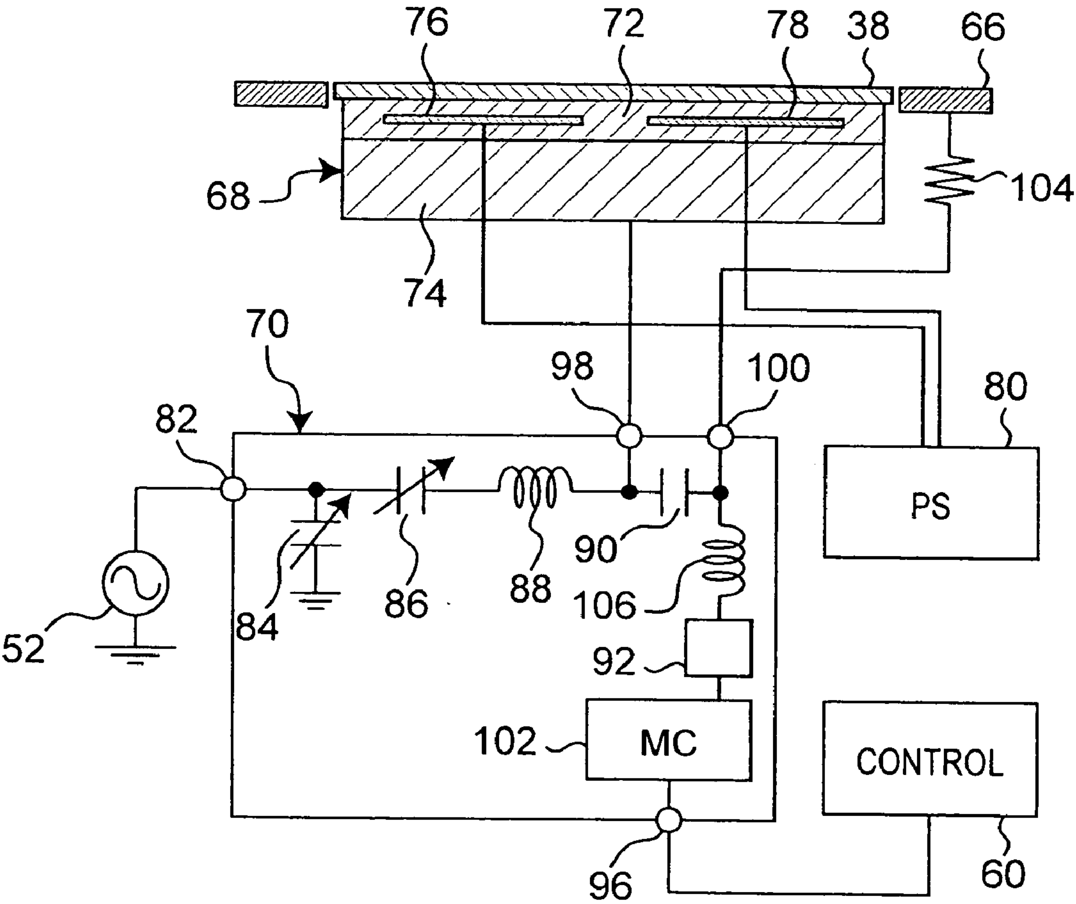
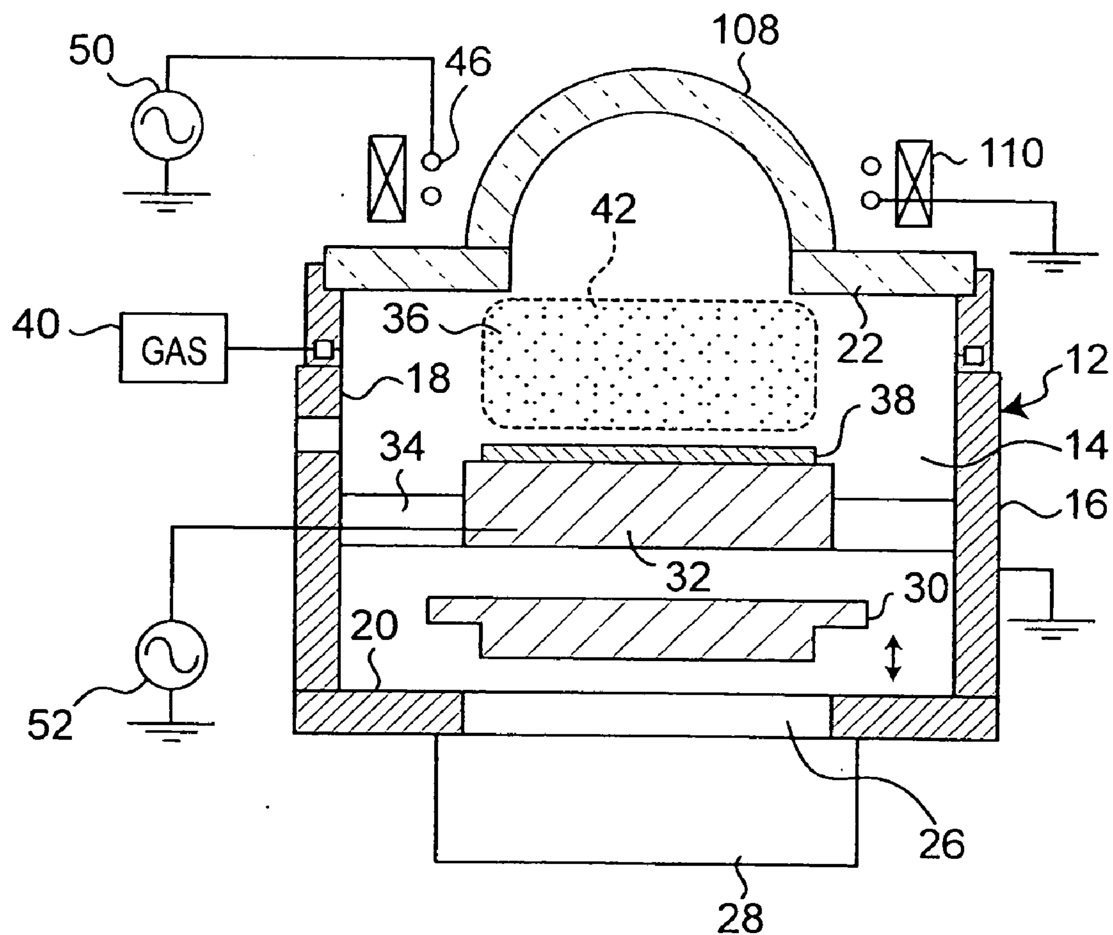


Fig.7



METHOD AND APPARATUS FOR PLASMA DOPING

[0001] This is a divisional application of Ser. No. 10/611, 867, filed July 3, 2003.

RELATED APPLICATION

[0002] The present application claims the benefit of a patent application No. 2002-202484 filed in Japan on Jul. 11, 2002, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0003] The present invention relates to a method and apparatus for doping an impurity ion into a substrate such as a semiconductor substrate by the use of a plasma doping, or plasma implantation technique.

BACKGROUND OF THE INVENTION

[0004] U.S. Pat. No. 4,912,065 discloses plasma doping by which an ionized impurity is implanted into a substrate with a reduced energy. Also, Japanese Patent No. 2,718,926 discloses a method for controlling a concentration of the implanted impurity, in which a high frequency current is measured while discharging and thereby it is controlled.

[0005] However, the control method has a disadvantage that changing the high frequency power and thereby controlling the high frequency current results in unwanted changes of electron density, impurity ion density in the plasma and ion energy to be applied to the substrate, thereby making it difficult to control the concentration.

SUMMARY OF THE INVENTION

[0006] Therefore, an object of the present invention is to provide a method and apparatus in which a doping concentration can be controlled with ease.

[0007] According to a method and apparatus for plasma doping of the present invention, a substrate is positioned on a table provided within a chamber in which a vacuum will be introduced and also an implantation impurity will be supplied. A first high frequency electric power is applied to a plasma generating element to thereby cause a plasma to be generated in the chamber so that the impurity in the chamber is implanted in the substrate. Also, a second high frequency electric power is applied to the table. Detected are a condition of the plasma in the chamber and a voltage or current in the table. A controller controls at least one of the first and second high frequency electric power according to the detected condition of the plasma and/or the detected voltage or current, thereby controlling an implantation concentration of the impurity to be implanted.

[0008] In another aspect of the present invention, a voltage or current is detected in an electrode connected through a capacitor to the table. Then, the controller controls at least one of the first and second high frequency electric power according to the detected condition of the plasma and/or the detected voltage or current, thereby controlling an implantation concentration of the impurity to be implanted.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a schematic cross sectional view of a doping device according to the first embodiment of the present invention.

[0010] FIG. **2** is a graph showing an emission intensity versus boron concentration relationship.

[0011] FIG. **3** is a graph showing a high frequency voltage versus boron concentration relationship.

[0012] FIG. **4** is a schematic vertical cross sectional view of a doping device according to the second embodiment of the present invention.

[0013] FIG. **5** is a circuit diagram of a matching circuit and also shows a structure of a table.

[0014] FIG. **6** is a circuit diagram showing a modification of the matching circuit.

[0015] FIG. **7** is a schematic cross sectional view of a modification of the doping device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] With reference to the drawings, various embodiments of a method and apparatus for plasma doping of the present invention will be described hereinafter.

[0017] Referring to FIG. **1**, there is shown a plasma doping device, generally indicated by reference numeral **10**, according to the present invention. The doping device **10** has a cylindrical container **12** defining a chamber **14** therein. The container **12** has a first portion **16** defining side walls **18** and a bottom wall **20** of the container **12** and a second portion **22** defining a top wall **24** of the container **12**. The first portion **16** of the container **12** is made of electrically conductive material such as aluminum and stainless steel and is electrically grounded to the earth. The second portion **22** of the container **12**, i.e., top wall **24**, is made of dielectric material such as silica glass, through which a high frequency electric field is induced in the chamber **14**. The bottom wall **20** has an opening **26** defined therein and fluidly connected to a vacuum pump **28** such as a turbo-molecular pump. Provided in the chamber **14** and adjacent to the opening **26** is a valve member **30** which is supported by an elevating device (not shown) so that an open ratio of the opening **26** and thereby the vacuum in the chamber **12** is controlled to a certain value such as 0.04 Pa by elevating the valve member **30**.

[0018] Provided also in the chamber **14** is a table **32** which is made of an electrically conductive material such as aluminum and stainless steel. The table **32** is supported at the center of the chamber **14** by a plurality of insulating supports **34** and spaced a certain distance away from the top dielectric wall **24** so that a certain volume of space **36** is defined for a plasma formation. Also, the table **32** has a flat top surface for supporting a substrate **38** such as a silicon plate to which a predetermined ion is implanted.

[0019] A plasma gas supply source **40**, i.e., impurity supply, is fluidly connected to the chamber **14** so that a certain gas including argon (Ar) and diborane (B_2H_6) is supplied therefrom into the chamber **14**. For example, the amounts of argon and diborane gas are controlled to 10 sccm (standard cubic centimeters per minute) and 5 sccm, respectively.

[0020] In order to produce a plasma **42**, in particular Inductively Coupled Plasma (ICP) in the plasma formation space **36**, a plasma generating element or spiral coil **44** is arranged above the dielectric wall **24** and outside the cham-

ber **14** in an coaxial fashion with the cylindrical container **12**. As shown in the drawing, the central end portion **46** of the coil **44** is positioned higher than the opposite peripheral end portion **48** so that the coil **44** outlines a conical configuration. Also, the central end portion **46** of the coil **44** is connected to a first high frequency power source **50** capable of applying a high frequency electric power. Used for the first frequency power source **50** is a power source capable of controlling a voltage through a frequency control within the frequency range of 300 kHz to 3 GHz or through a pulse width modulation in order to change a density of the plasma generated in the chamber. In this embodiment, a frequency of 13.56 MHz is initially applied to the coil **44**, for example. On the other hand, the peripheral end portion **48** of the coil **44** is grounded to the earth.

[0021] Also, in order to provide a negative polarity to the table **32** and the substrate **38** relative to the plasma **42** a second high frequency power source **52** is electrically connected to the table **32** through a matching circuit **54** and a voltage detector **56** (second monitor). The second high frequency power source **52**, which is used for changing an ionization energy, may be a conventional power source which is similar to or different from that of the first high frequency power source. For example, a power source capable of controlling a voltage through a frequency control within in the frequency range of 300 kHz to 3 GHz or through a pulse width modulation is used. In this embodiment, a frequency of 600 kHz is initially applied to the table **32**, for example. Also the implantation device **10** of this embodiment employs an optical emission spectroscopy for detecting a condition of plasma generated in the chamber **14** and then controlling a dose of ion implantation. To this end, provided is a light detector **58** (first monitor) capable of detecting and measuring an amount of light emitted from the plasma in the chamber **14**. The monitors **56** and **58** are connected to a controller **60**, which in turn is connected to the first and second power sources **50** and **52** for controlling the high frequency powers to be applied to the coil **44** and the table **32**, respectively.

[0022] In operation of the ion implantation device **10** so constructed, the substrate **38** is positioned on the table **32** so that the substrate **38** makes substantially full surface contact with opposing surface of the table **32**. In this condition, the mixture of gas with Ar and B_2H_6 is supplied from the plasma gas supply source **40** into the chamber **14**. Also, the chamber **14** is vacuumed by the pump **28** and the vacuum is controlled by the upward and/or downward movement of the valve member **30** and, as a result, by the adjustment of the opening ratio of the opening **26**. Under this condition, once the high frequency power source **50** is turned on to induce the high frequency electric field in the chamber **14**, the plasma **42** is generated above the substrate **38** in the space **36**. Simultaneously generated between the plasma **42** and the substrate **38** is a sheath voltage, causing the boron implantation into the top surface of the substrate **38** to form an ultra thin boron implantation layer.

[0023] Using the implantation device, tests were made to determine a relationship between an emission intensity and an implanted boron concentration when 1,000 volts was applied to the table and substrate and a relationship between a voltage applied to the second high frequency power source and the Boron Concentration when the emission intensity of plasma was controlled at 0.5 (a.u.) by the control of AC power to the coil. The results are illustrated in FIGS. **2** and **3**, respectively, which indicate that the boron concentration increased with the emission intensity and with the applied voltage. This means that each of the emission intensity and the voltage indicates a condition of the plasma and has a direct relationship with the boron concentration. This in turn means that the boron concentration is controlled by controlling the output of the first high frequency power source **50** corresponding to the light emission of the plasma **42** measured by the light detector **58**, and/or by controlling the output of the second frequency power source **52**, i.e., the voltage applied to the table **32** and measured by the voltage detector **56**. Therefore, according to the implantation device **10** of the present invention, the controller **60** is programmed to control either or both of the outputs of the first and second high frequency power sources, **50** and **52**, causing a desired dose of ion to be implanted in the surface of the substrate **38**. Specifically, in this operation the first power source is feedback controlled to make the plasma vapor phase constant and also the second power source is feedback controlled to attain a constant voltage or power.

[0024] Referring to FIG. **4**, another implantation device, generally indicated by reference numeral **10**A, according to the second embodiment of the present invention will be described. In this embodiment, a single probe method is employed for detecting the condition of plasma generated in the chamber **14** and then controlling a dose of ion implantation. To this end, a single probe **62** with a rod-like electrode made of tungsten is projected in the chamber **14** and adjacent to the plasma formation space **36**. Also, the probe **62** is electrically connected to a device **64** for monitoring a current density, which in turn is connected to the controller **60**. The current density corresponds to the emission intensity of the plasma, which means that the current density detected by the device **64** is used at the controller **60** for controlling the condition of the generated plasma and then the implanted boron concentration in the substrate.

[0025] In addition, an annular monitoring electrode **66** made of electrically conductive material is provided around a table **68** and connected to a matching circuit **70**. FIG. **5** shows a detail of the matching circuit **70** and a structure of the table **68** of this embodiment. As shown, the table **68** has an upper plate portion **72** made of insulating material for supporting the implantation substrate **38** and a lower plate portion **74** made of conductive material and supporting the upper plate portion. The upper plate portion **72** includes at least one pair of chucking electrodes, a first electrode **76** and a second electrode **78**, embedded therein. The first and second chucking electrodes **76** and **78** are connected to a DC power source **80** so that a certain DC voltage is applied between the chucking electrodes **76** and **78** to form an electrostatic force for holding the substrate **38** on the table **68**.

[0026] The matching circuit **70** has a high frequency input terminal **82** which connects between the high frequency power source **52** and a capacitor **84**. The terminal **82** is also connected through another capacitor **86**, a coil **88**, a capacitor **90**, a low pass filter **92**, and a monitoring circuit **94** with a potentiometer to another terminal **96** which is connected to the controller **60**. Also, the opposite ends of the capacitor **90** are connected to a first output terminal **98** connected to the

lower plate portion **74** of the table **68** and a second output terminal **100** connected to the annular monitoring electrode **66**.

[**0027**] With the arrangement, a high frequency electric power is supplied from the power source **52** through the capacitor **86**, the coil **88**, the capacitor **90** and the output terminal **100** to the annular monitoring electrode **66**. In this instance, the voltage of the annular monitoring electrode **66** is the same as that of the output terminal **100**, so that a voltage which is in proportion to the DC voltage of the monitoring electrode **66** is obtained by the monitoring circuit **94**. The obtained voltage, which also corresponds to the voltage of the table in the first embodiment, is then used at the controller **60** to control the implantation boron concentration.

[**0028**] Also in this matching circuit **70**, the capacitor **90** separates the monitoring electrode **66** from the lower plate portion **74** of the table **68**, which prevents a generation of a large negative voltage in the lower plate portion **74** which would cause a deterioration of the insulating, upper plate portion **72**. The low pass filter **92** removes the high frequency power.

[**0029**] In the previous embodiment, the annular monitoring electrode is electrically floated in the circuit, so that no electric current flows in the circuit. Contrary to this, in order to flow an electric current in the circuit and thereby obtain a voltage using the detected current, modifications may be made to the circuit as shown in FIG. **6**. Specifically, in this modification a monitoring circuit **102** in the matching circuit **54** has a first circuit part (not shown) for detecting an electric current flowing therethrough and a second circuit part (not shown) for calculating a voltage corresponding to the detected current. In addition, typically a resistor which is installed in the first circuit for detecting the electric current has a reduced resistance, which can result in an overheat and a resultant malfunctioning in the monitoring circuit. To prevent this, preferably a resistor **104** is connected in series to the annular monitoring electrode **66** to reduce the electric current flowing into the monitoring circuit. Also, as shown in FIG. **6** an additional coil **106** may be connected between the capacitor **90** and the monitoring circuit **102** to prevent a high frequency current from flowing into the monitoring circuit **102**.

[**0030**] Tests were conducted by the use of the implantation device shown in FIG. **6**. In the tests, the substrate was positioned on the table. The implantation gas mixture including Ar and B_2H_6 was supplied into the chamber. Amounts of argon and diborane were controlled to 10 sccm (standard cubic centimeters per minute) and 5 sccm, respectively. The pressure in the chamber was maintained at 0.04 Pa. Under the condition, the spiral coil and the table (the lower plate portion) were applied with high frequency powers from the power sources **50** and **52**, respectively. As a result, it was confirmed that the boron was implanted in the surface of the substrate.

[**0031**] Also, in the tests the high frequency powers to the spiral coil and the table (the lower plate portion) were changed. Simultaneously, detected were the electric current flowing in the monitoring electrode and the implanted boron concentration in an interior of the substrate, spaced 1.0 nm away from the top surface of the substrate.

[**0032**] The result showed that the boron concentration increases substantially in proportion to the ion current density if the DC current flowing in the annular electrode is kept constant and, on the other hand, that the boron concentration increases substantially in proportion to the DC current in the annular electrode if the ion current density is kept constant. This means that the boron concentration is controlled in a very precise manner by controlling the high frequency power to the spiral coil to keep the ion current density constant and also controlling another high frequency power to the table to keep the current in the monitoring electrode constant.

[**0033**] Although various embodiments have been described so far, the implantation device of the present invention may be modified and/or improved in various manners. For example, as shown in FIG. **7**, a semidome top wall **108** may be used instead for the plate-like top wall in FIGS. **1** and **4**. In this embodiment, a coil may be arranged in a non-spiral fashion. Also, a magnetic coil **110** for generating a magnetic field passing through the top wall toward the substrate may be provided, which allows generation of a helicon wave plasma or a magnetic neutral loop plasma, each having an elevated density than the inductively coupled plasma. Alternatively, a combination of a microwave emission antenna and the magnetic coil may be used. In this embodiment, an electron cyclotron resonance plasma is generated in the chamber, which has an elevated density relative to the inductively coupled plasma. In these modifications, a DC magnetic field or a low frequency magnetic field less than 1 kHz may be generated in the chamber by controlling the electric current flowing in the magnetic coil.

[**0034**] Also, although the semiconductor plate made of silicon is used for the substrate, it may be made of any material.

[**0035**] Further, although the boron is used for the implantation impurity, i.e., dopant, another impurity including arsenic, phosphorus, aluminum, and antimony may be implanted instead or additionally.

[**0036**] Further, although argon Ar is used for the dilution gas, it may be replaced with another gas made of nitrogen and helium, for example.

[**0037**] Furthermore, although the impurity is introduced in the gaseous form, i.e., B_2H_6, the impurity may be integrated in or on a certain substrate (impurity supply) and then is separated therefrom by sputtering, for example, into the chamber.

[**0038**] In addition, although the optical emission spectroscopy and the single probe method have been described in the previous embodiments for monitoring the condition of plasma in the chamber, another method can be used instead, including laser induced fluorescence method, infrared laser absorption spectroscopy, vacuum ultra violet absorption spectroscopy, laser scattering method, double probe method, triple probe method and quadrupole mass spectroscopy.

[**0039**] Also, although the voltage to be applied to the table is monitored in the previous embodiments, an electric current flowing therethrough may be monitored instead.

[**0040**] Further, although the voltage and current in the monitoring electrode are monitored in the previous embodiments, a high frequency current therein may be monitored instead.

Parts List

[0041] **10**: ion implantation device

[0042] **12**: container

[0043] **14**: chamber

[0044] **16**: first portion of container

[0045] **18**: side wall

[0046] **20**: bottom wall

[0047] **22**: second portion of container

[0048] **24**: top wall

[0049] **26**: opening

[0050] **28**: vacuum pump

[0051] **30**: valve member

[0052] **32**: table

[0053] **34**: support

[0054] **36**: space

[0055] **38**: substrate

[0056] **40**: plasma gas supply source

[0057] **42**: plasma

[0058] **44**: spiral coil

[0059] **46**: central end portion of coil

[0060] **48**: peripheral end portion of coil

[0061] **50**: first high frequency power source

[0062] **52**: second high frequency power source

[0063] **54**: matching circuit

[0064] **56**: voltage detector (second monitor)

[0065] **58**: light detector (first monitor)

[0066] **60**: controller

[0067] **62**: prove (single probe)

[0068] **64**: current density monitoring device

[0069] **66**: annular monitoring electrode

[0070] **68**: table

[0071] **70**: matching circuit

[0072] **72**: upper plate portion

[0073] **74**: lower plate portion

[0074] **76**: first electrode

[0075] **78**: second electrode

[0076] **80**: DC power source

[0077] **82**: terminal

[0078] **84**, **86**: capacitor

[0079] **88**: coil

[0080] **90**: capacitor

[0081] **92**: low pass filter

[0082] **94**: monitoring circuit

[0083] **96**: terminal

[0084] **98**: output terminal

[0085] **100**: output terminal

[0086] **102**: monitoring circuit

[0087] **104**: resistor

[0088] **106**: coil

1. A plasma doping apparatus, comprising:

a vacuum container defining a vacuum chamber therein;

a gas supply for supplying a gas into the vacuum chamber;

a vacuum generator for generating a vacuum in the vacuum chamber;

a pressure control valve for controlling a pressure of the vacuum chamber;

a substrate electrode provided within the vacuum chamber for supporting a substrate;

a monitoring conductor provided around the substrate electrode;

a power source for supplying an electric power to the substrate electrode and the monitoring conductor;

a coil provided outside the vacuum container;

a plasma gas source for supplying a plasma gas into the vacuum chamber;

a high frequency power supply for supplying a high frequency power to the coil;

a first monitor for monitoring a condition of plasma; and

a second monitor for monitoring an electric voltage or an electric direct current at the monitoring conductor;

wherein the substrate electrode and the monitoring conductor are electrically connected to each other through a capacitor or a resistance, and the substrate electrode is grounded through the coil, a current detector, and the resistance.

2. A plasma doping apparatus, comprising:

a vacuum container defining a vacuum chamber therein;

a gas supply for supplying a gas into the vacuum chamber;

a vacuum generator for generating a vacuum in the vacuum chamber;

a pressure control valve for controlling a pressure of the vacuum chamber;

a substrate electrode provided within the vacuum chamber for supporting a substrate;

a monitoring conductor provided around the substrate electrode;

a power source for supplying an electric power to the substrate electrode and the monitoring conductor;

a plasma gas source;

a high frequency power supply for supply a high-frequency power to the plasma gas source;

a first monitor for monitoring a condition of plasma; and

a second monitor for monitoring an electric voltage or an electric direct current at the monitoring conductor;

wherein the substrate electrode and the monitoring conductor are electrically connected to each other through a capacitor or a resistance, and the substrate electrode is grounded through a coil, a current detector, and the resistance.

* * * * *