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(19) **United States**(12) **Patent Application Publication****Satoyoshi et al.**(10) **Pub. No.: US 2005/0241769 A1**(43) **Pub. Date: Nov. 3, 2005**(54) **PLASMA PROCESSING APPARATUS AND
PLASMA PROCESSING METHOD****Publication Classification**(75) Inventors: **Tsutomu Satoyoshi**, Yamanashi (JP);
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Apr. 30, 2004 (JP) JP2004-136566

Dec. 28, 2004 (JP) JP2004-381290

(57) **ABSTRACT**

A plane parallel plasma processing apparatus includes an impedance adjustment unit having a capacitive component, which is disposed between a lower electrode and a processing chamber. The impedance adjustment unit adjusts the value of the impedance over the path extending from an upper electrode to a grounded casing of a matching circuit via plasma, the lower electrode and the wall of the processing chamber to a level lower than the value of the impedance over the path extending from the upper electrode to the grounded casing of the matching circuit via the plasma and the wall of the processing chamber, and thus, highly uniform plasma can be generated by minimizing the generation of plasma in the space between the cathode electrode and the processing chamber wall.

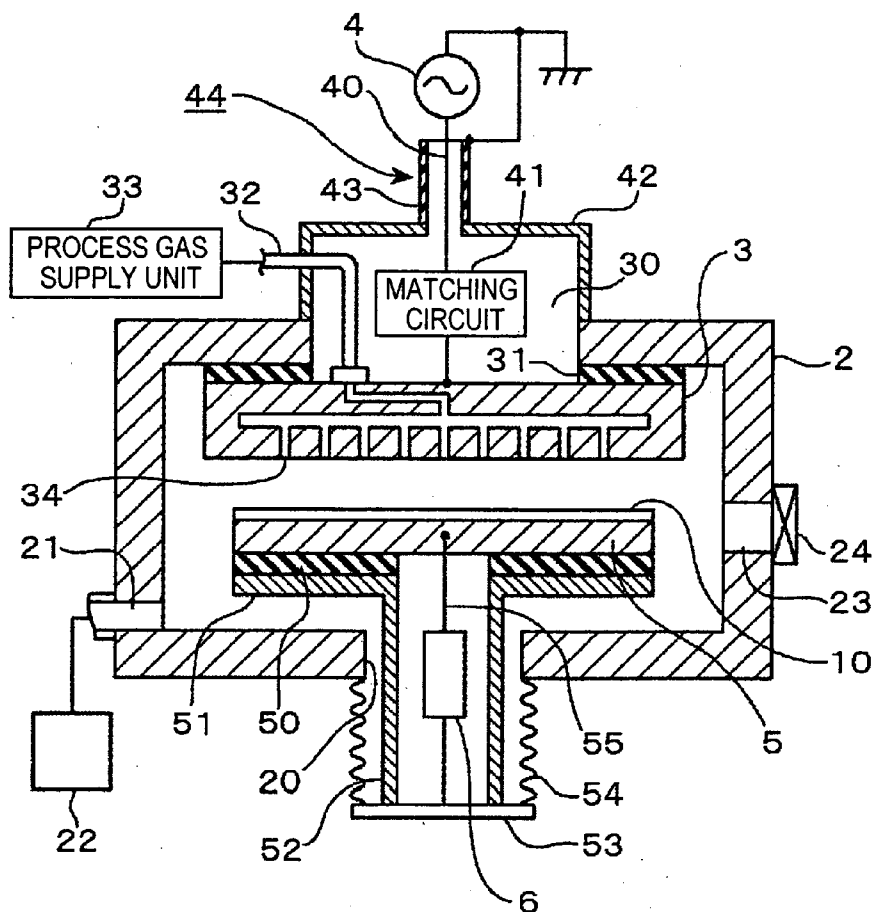


FIG.1

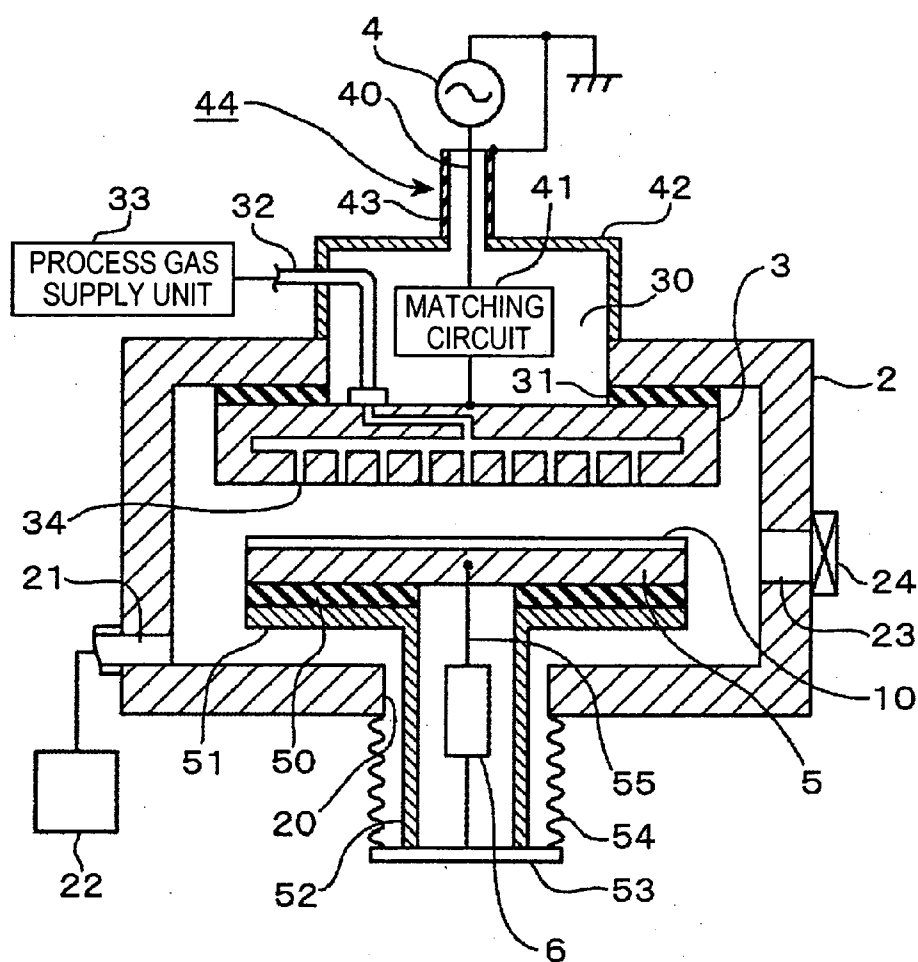


FIG.2

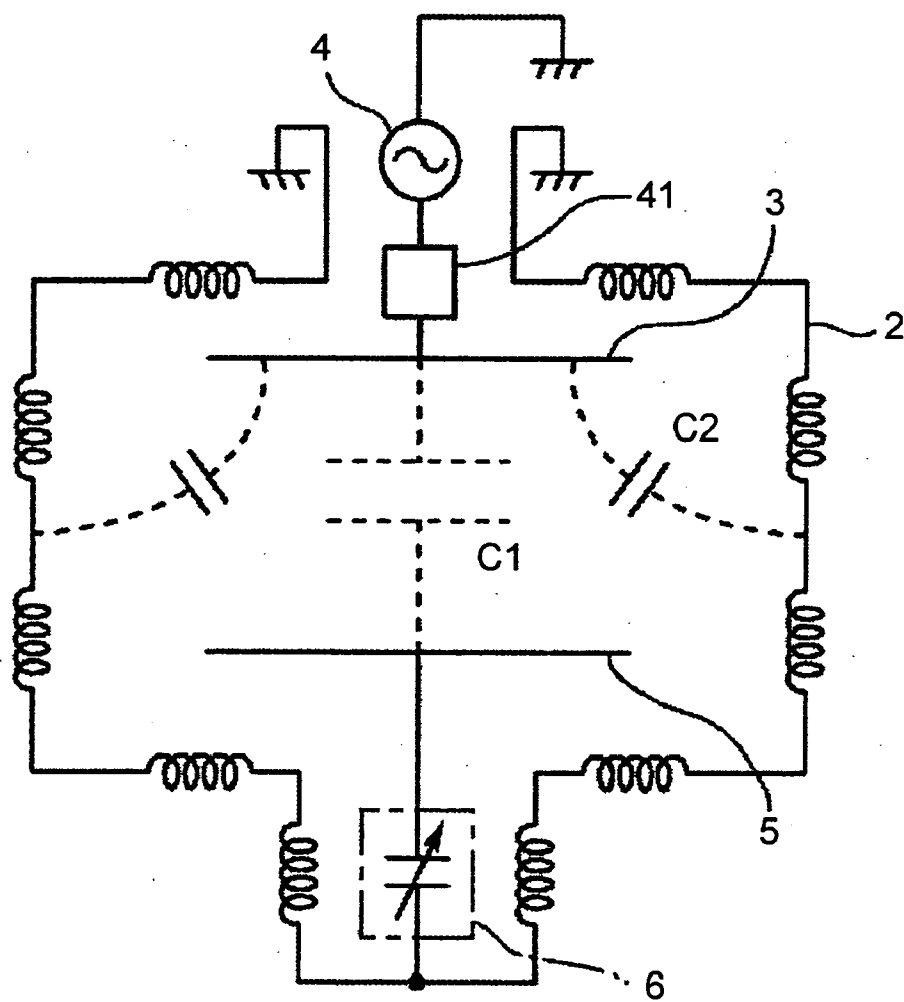


FIG.3A

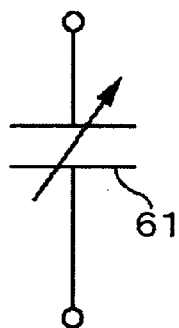


FIG.3B

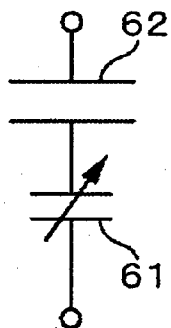


FIG.3C

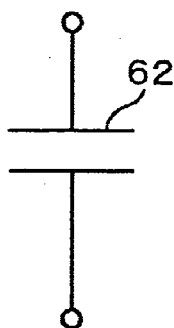


FIG.3D

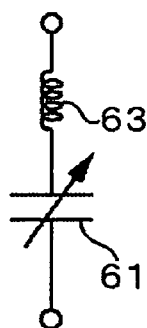


FIG.3E

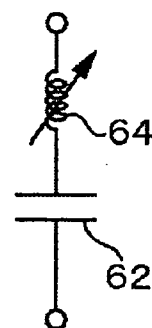


FIG.4

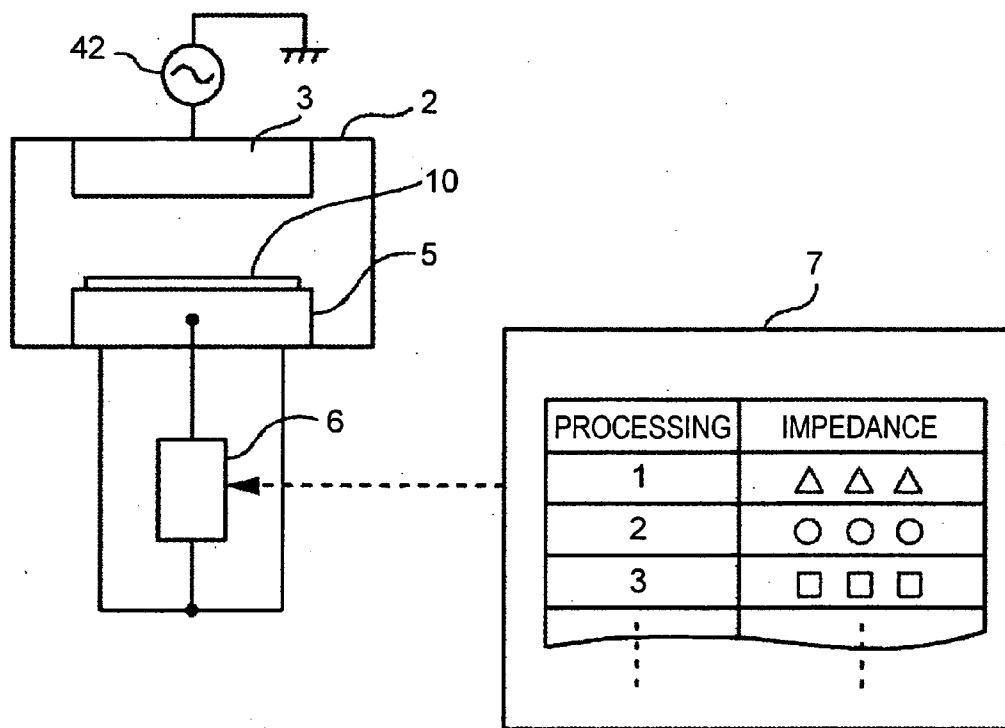


FIG.5A

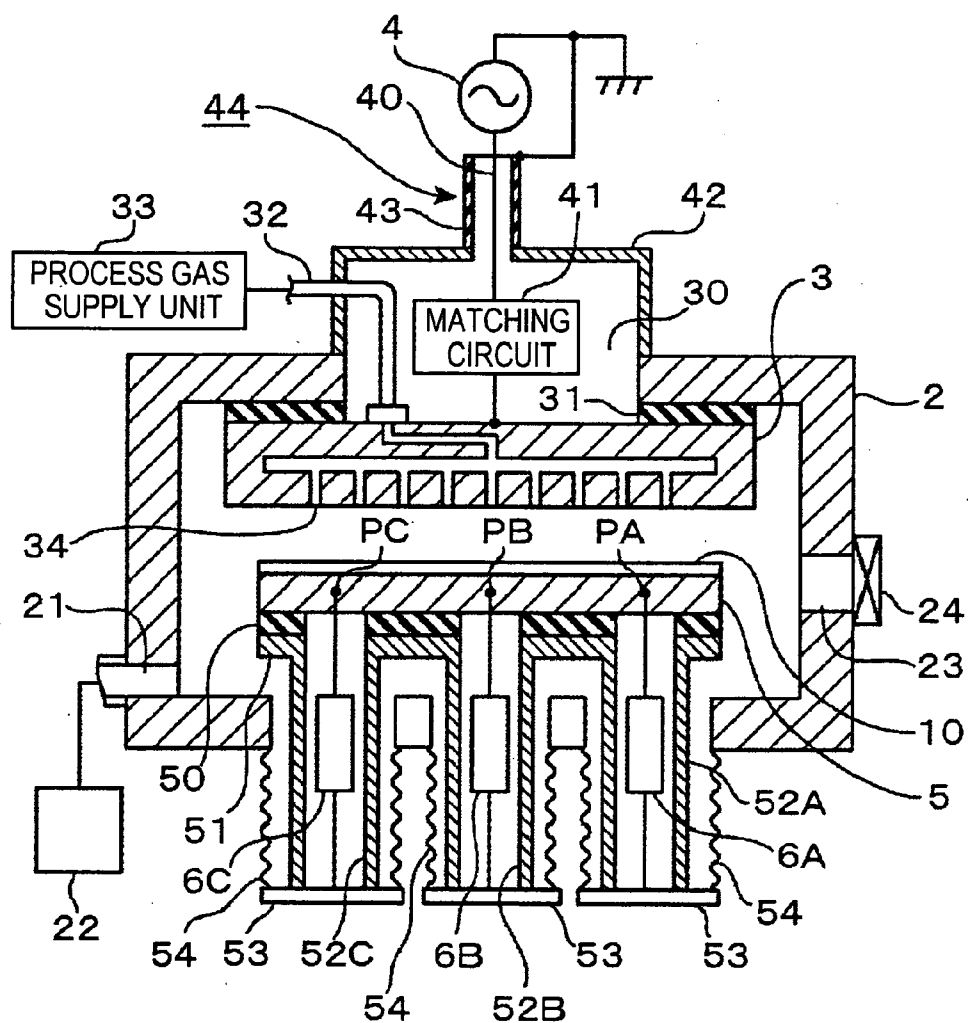


FIG.5B

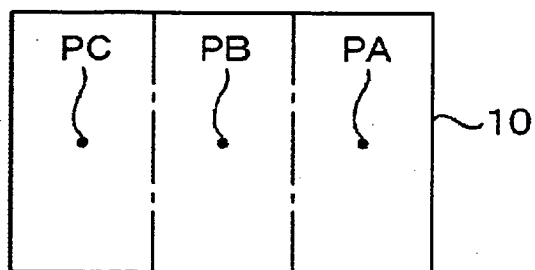


FIG.6

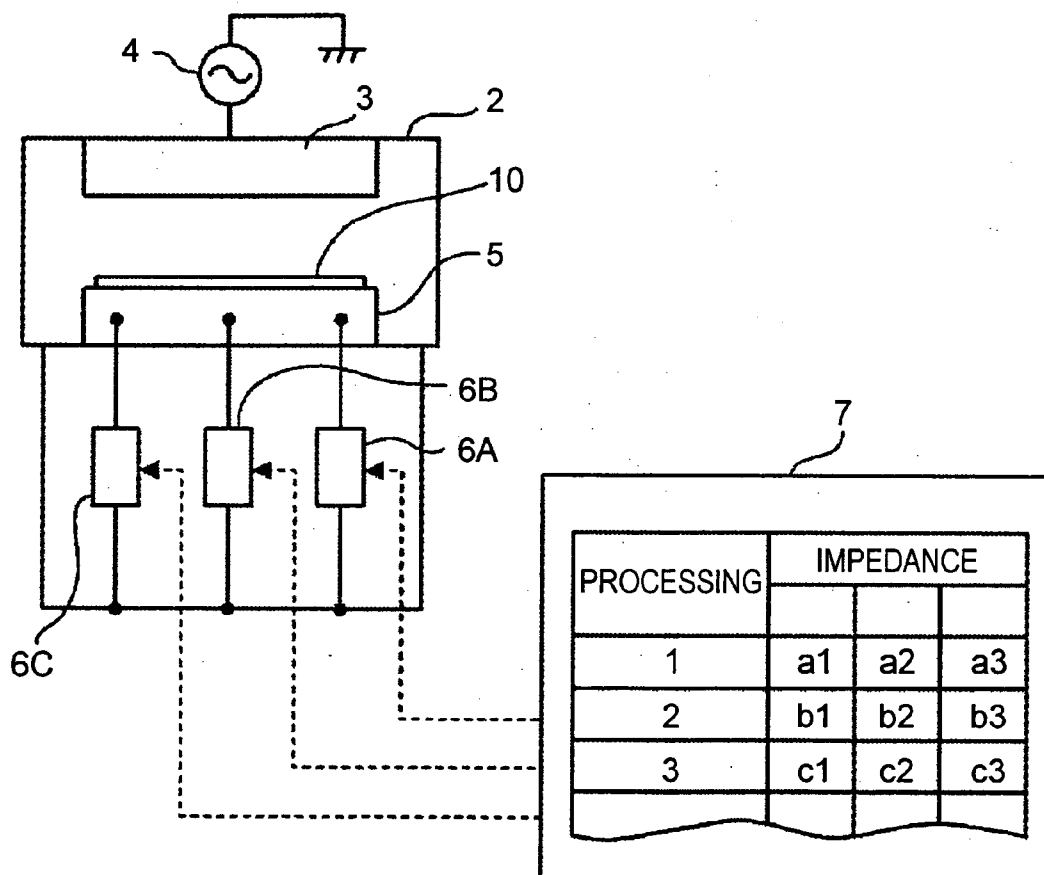


FIG.7A

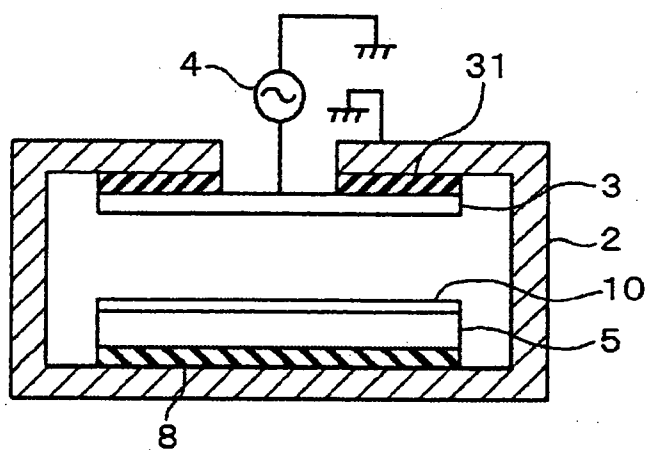


FIG.7B

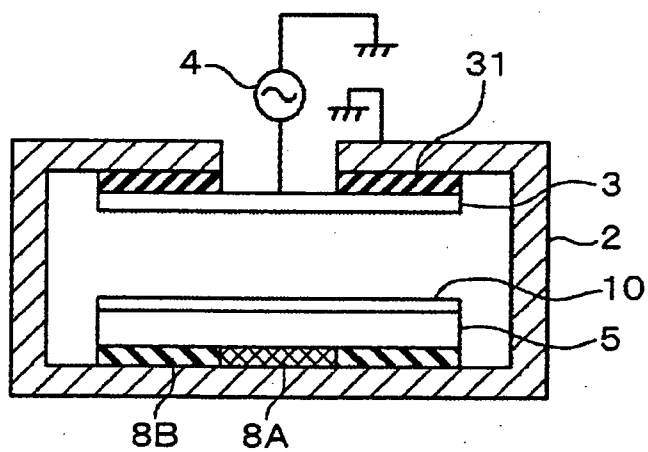


FIG.7C

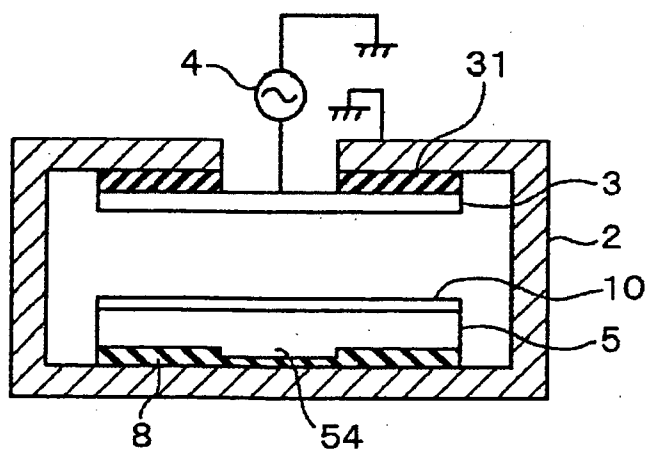


FIG.8

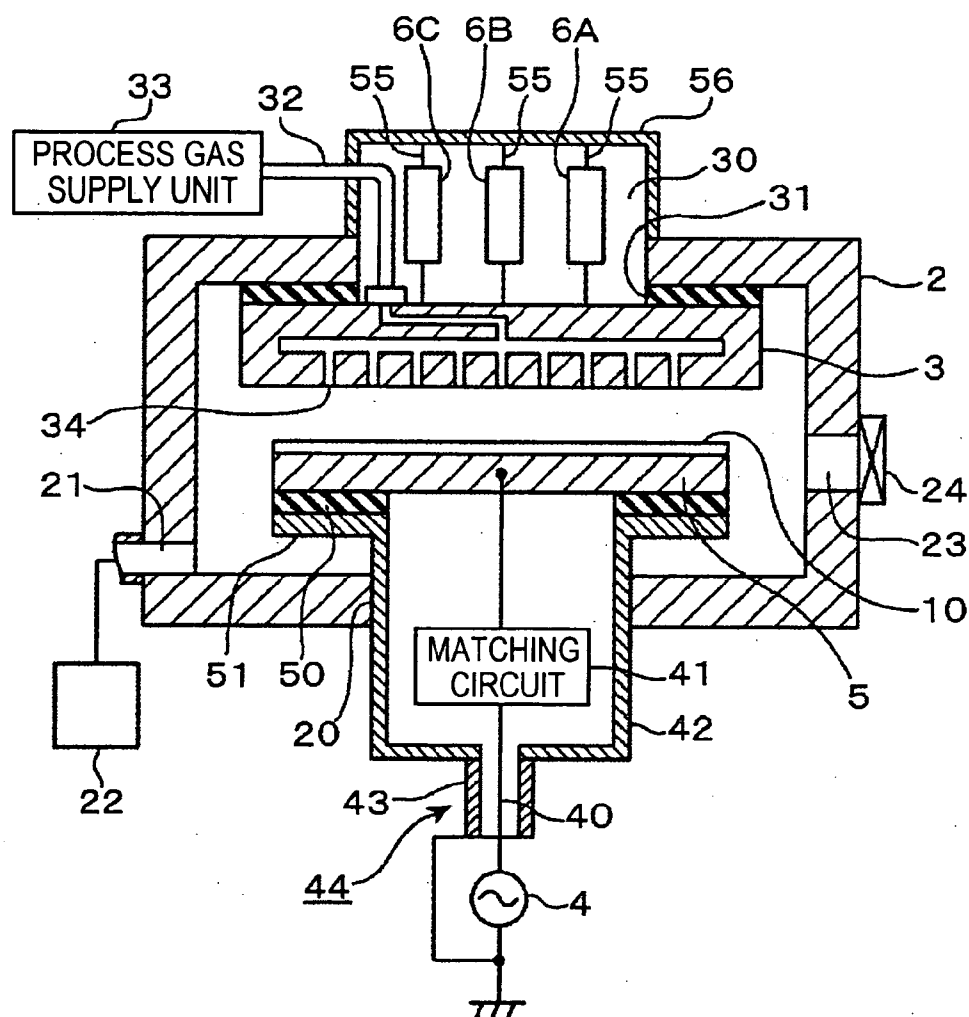


FIG. 9

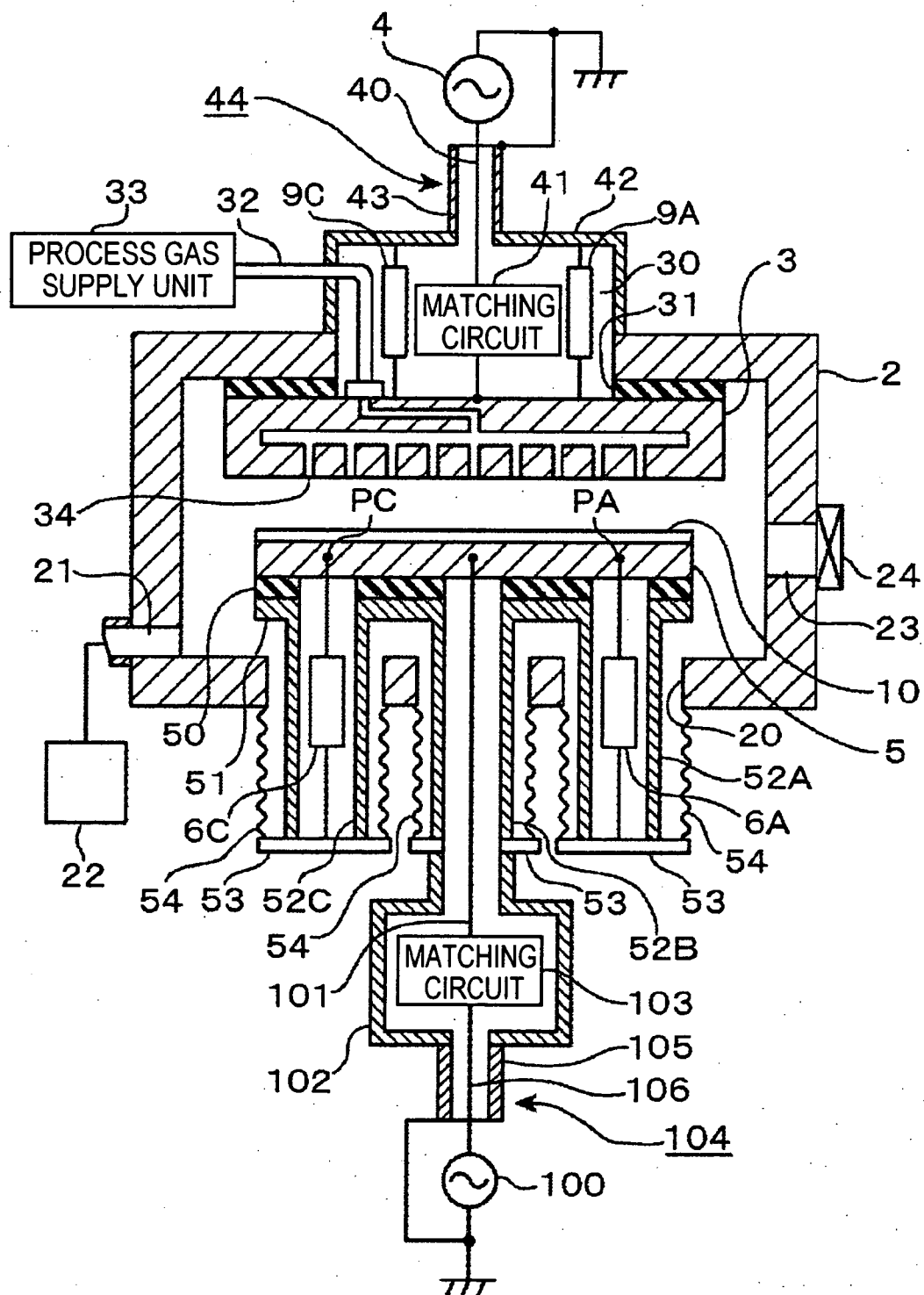


FIG.11

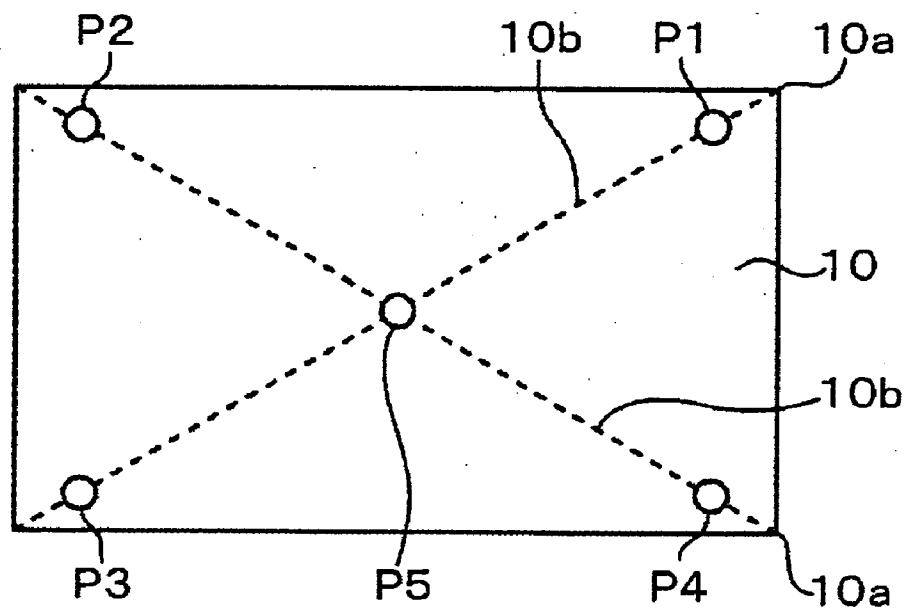


FIG.12

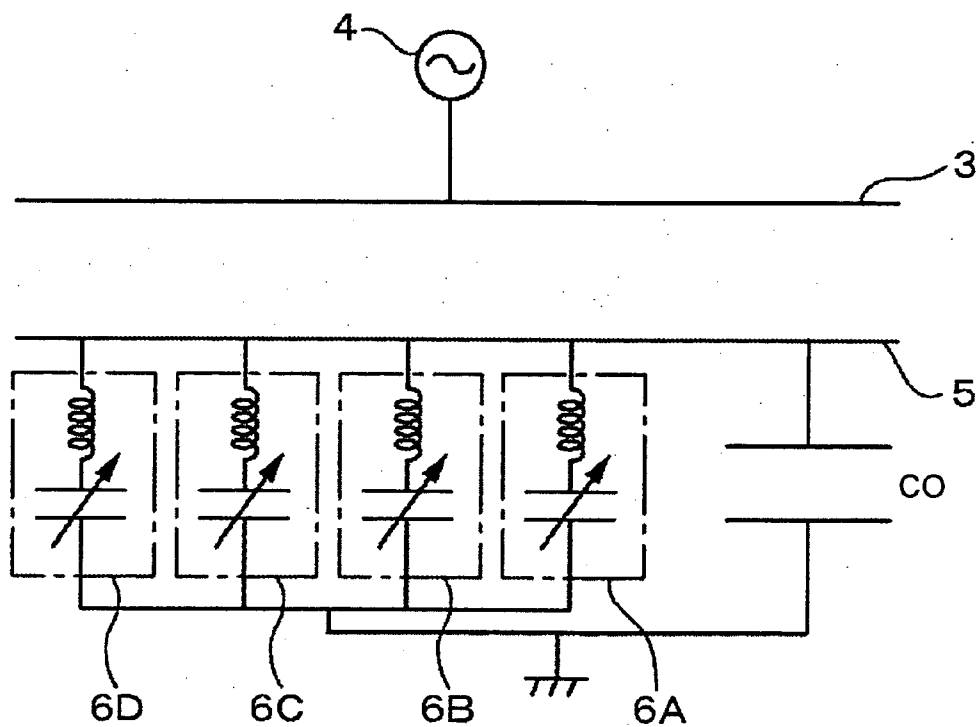


FIG.13

TRIMMER POSITION	CAPACITANCE	RESISTANCE	Z(L-C)	Z (TOTAL)	LOWER CURRENT	UPPER V _{pp}	VISUALLY OBSERVED PLASMA STATE
0	1000	-11.7	-2.79	-0.59			
1	920	-12.8	-3.82	-0.76			
2	839	-14.0	-5.05	-0.94	57	2065	x
3	758	-15.5	-6.54	-1.13	73	2160	Δ
4	677	-17.3	-8.40	-1.34	77	2210	Δ
5	596	-19.7	-10.75	-1.56	79	2236	⊙
6	515	-22.8	-13.85	-1.79	78	2231	○
7	434	-27.1	-18.11	-2.04	78	2217	○
8	358	-33.3	-24.32	-2.30	76	2178	Δ
9	271	-43.3	-34.38	-2.59	72	2124	Δ
10	191	-61.5	-52.53	-2.89	66	2046	x
11	110	-106.8	-97.81	-3.21	0		

FIG.14

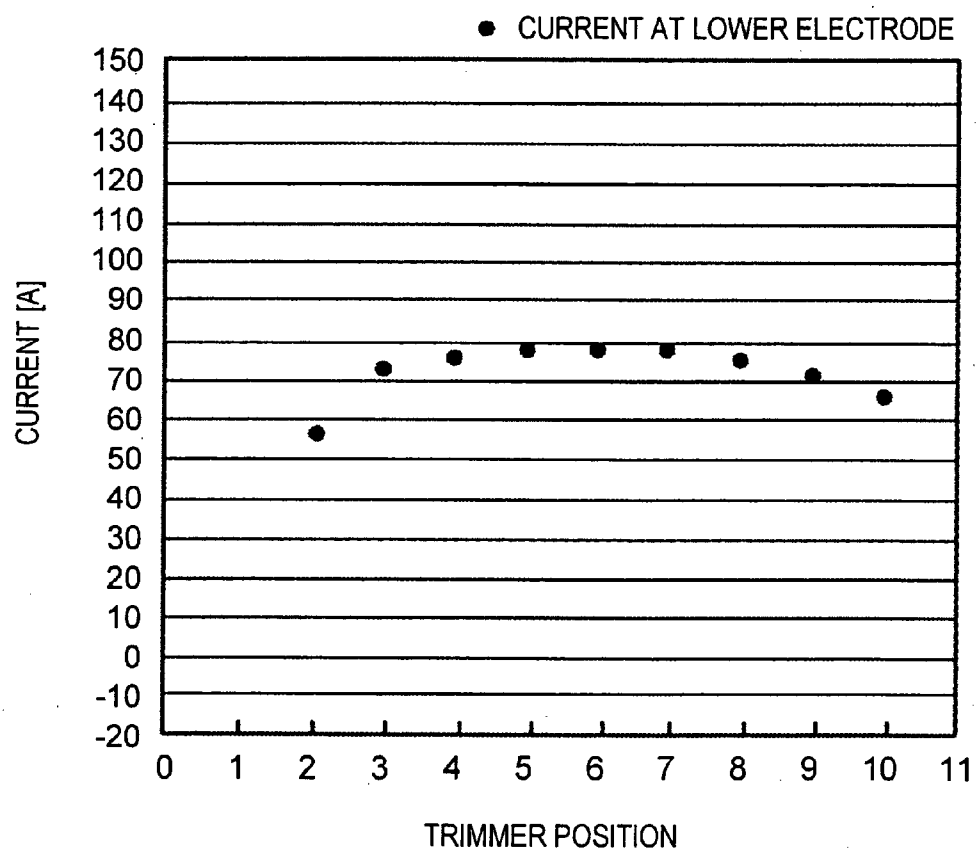
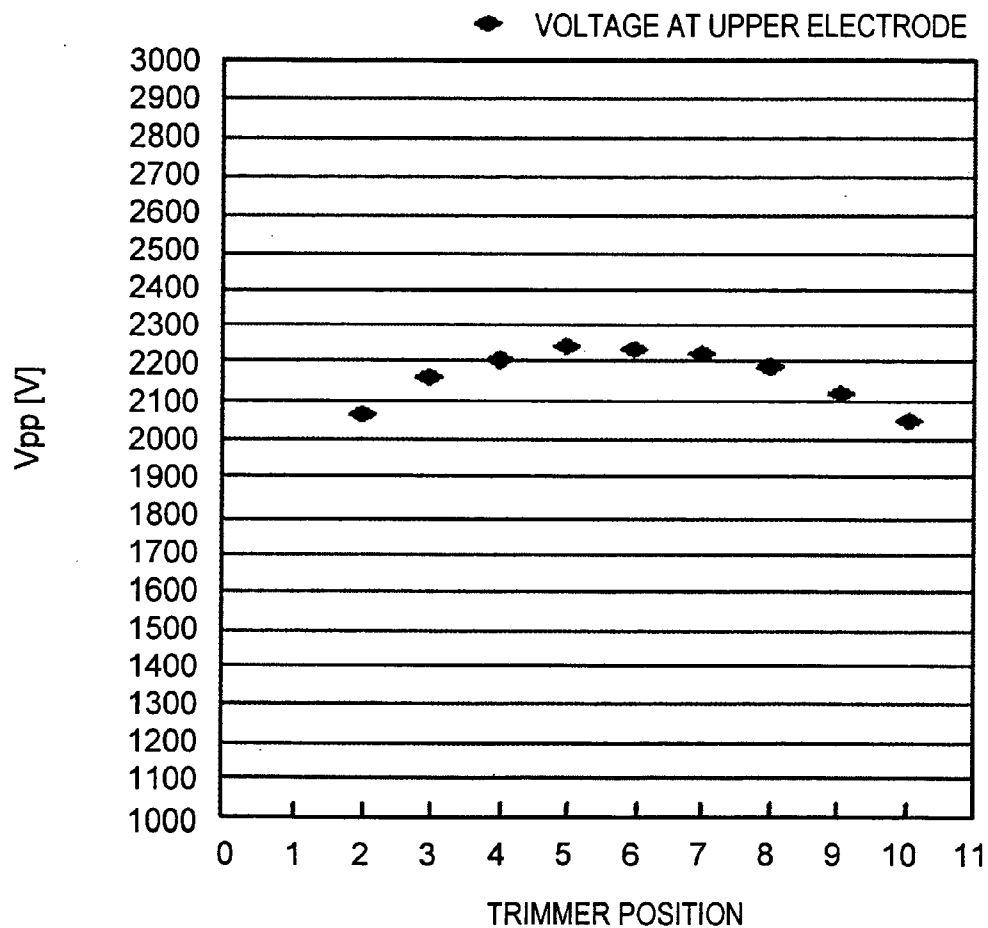


FIG.15



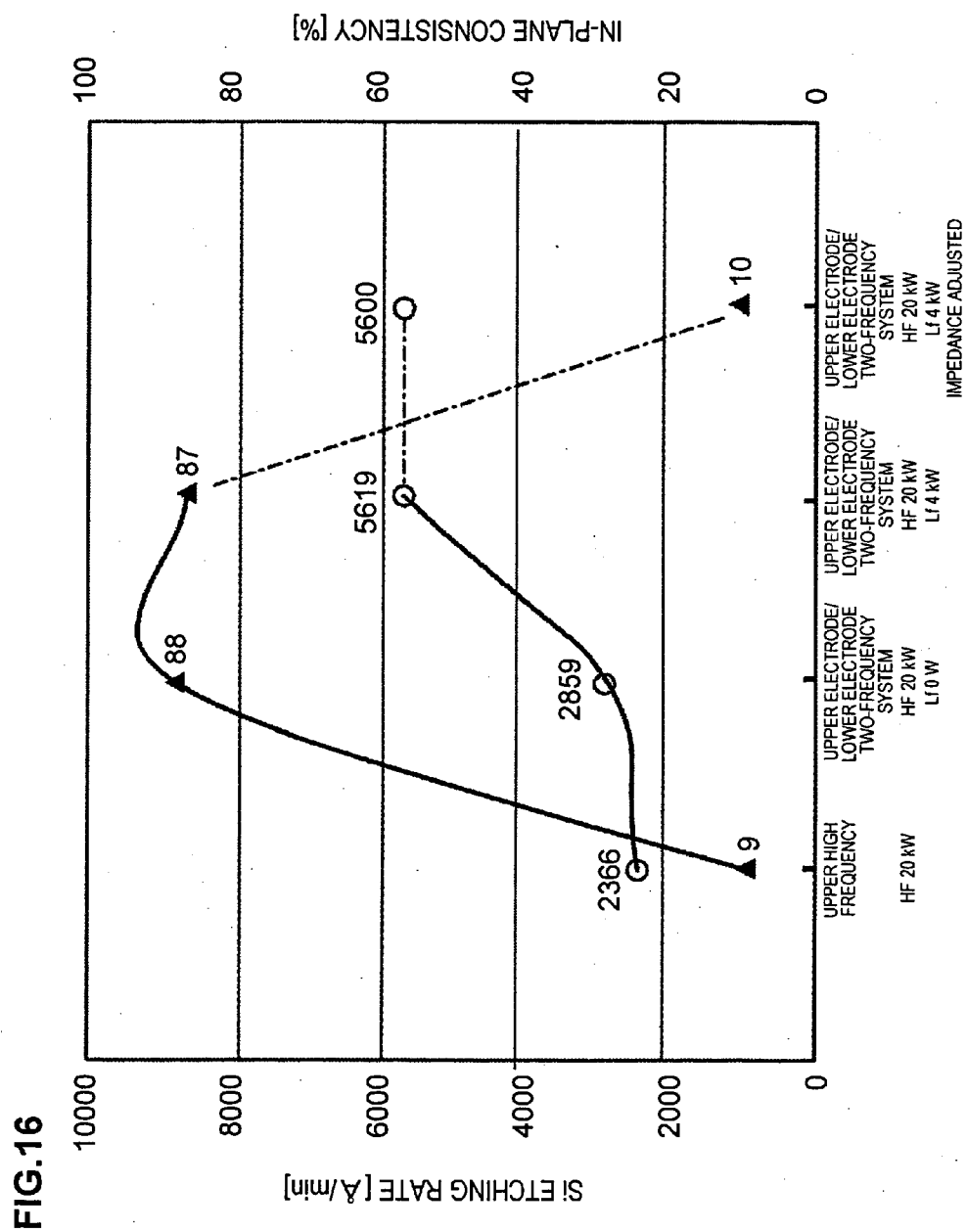


FIG.17

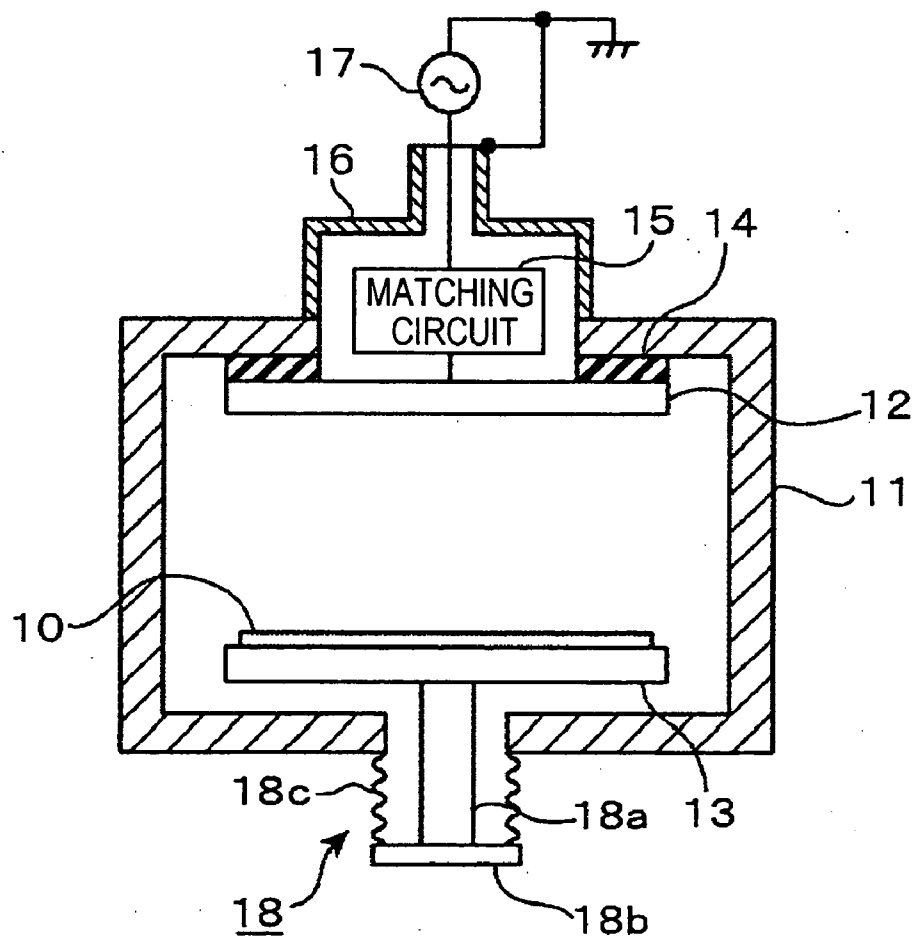
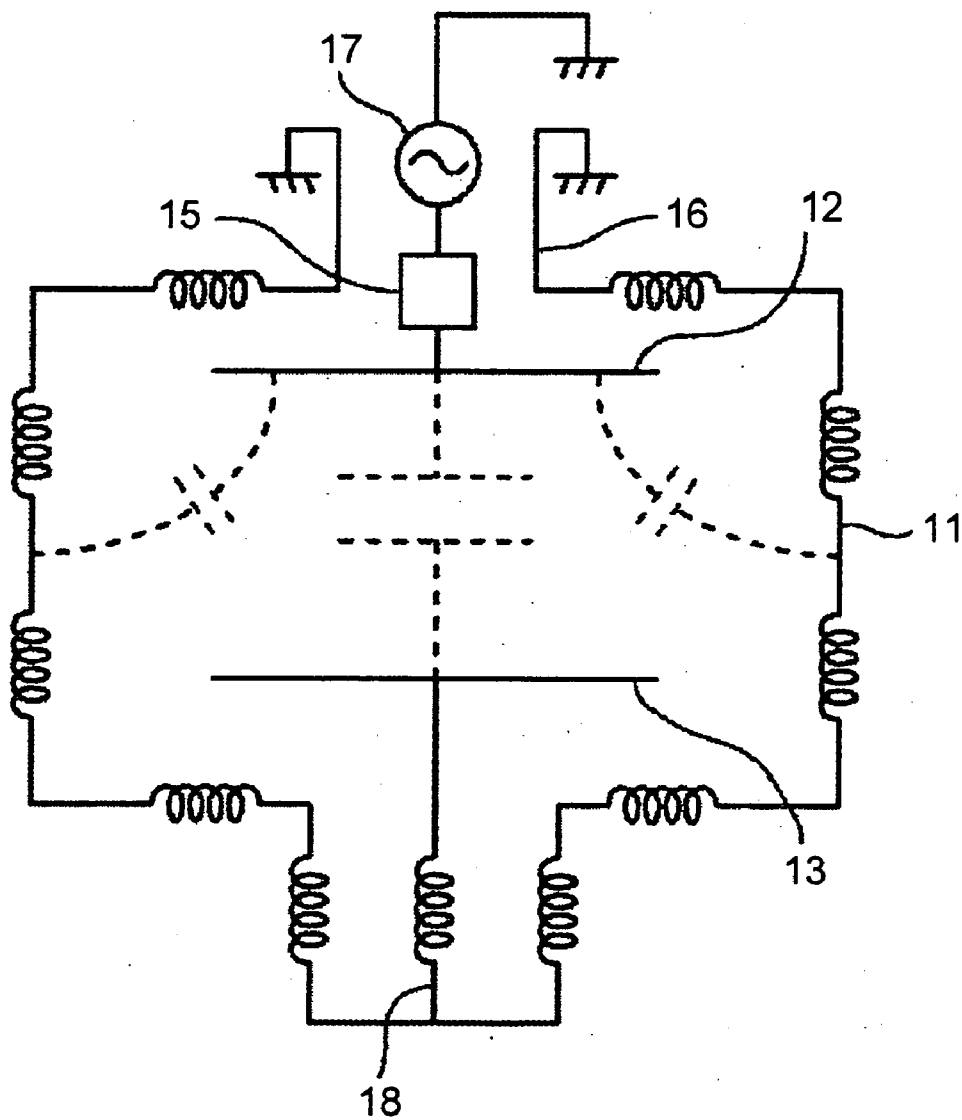


FIG.18



PLASMA PROCESSING APPARATUS AND PLASMA PROCESSING METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The disclosure of Japanese Patent Application No. JP2004-381290, filed Dec. 28, 2004, entitled "plasma processing apparatus" and Application No. JP2004-136566, filed Apr. 30, 2004, entitled "plasma processing apparatus". The contents of that applications are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a plasma processing apparatus and a plasma processing method to be adopted when executing a process such as etching on a substrate with plasma generated from a process gas by applying high-frequency power.

[0004] 2. Description of Related Art

[0005] During the production of semiconductor devices and flat panel devices such as liquid crystal display devices, plasma processing apparatuses including plasma etching apparatuses and plasma CVD (Chemical Vapor Deposition) film forming apparatuses are utilized to execute an etching process, a film forming process and the like on workpieces such as semiconductor wafers and glass substrates.

[0006] FIG. 17 shows a plane parallel plasma processing apparatus used in the related art. This plasma processing apparatus includes an upper electrode 12 disposed in a processing chamber 11 constituted of, for instance, aluminum and utilized as a gas shower head through which a gas is supplied and a lower electrode 13 disposed in the processing chamber 11 so as to face opposite the upper electrode 12 and utilized as a stage on which a substrate 10 is placed. The upper electrode 12, which is set by an insulating member 14 in a fully floating state electrically relative to the processing chamber 11, is connected to a high-frequency power source 17 via a matching circuit 15 to constitute a cathode electrode.

[0007] The lower electrode is connected to the processing chamber 11 via a conductive passage 18 to constitute an anode electrode. The conductive passage 18 in this example is constituted with a shaft 18a, a support plate 18b and a bellows member 18c. The upper side of the processing chamber 11 is connected with the high-frequency power source 17 via a matching box 16 which is a grounded casing, and more specifically, it is grounded through its connection to the outer layer of the coaxial cable connecting the high-frequency power source 17 and the matching box 16.

[0008] FIG. 18 is an equivalent circuit diagram of the conductive path through which a high-frequency current flows in the plasma processing apparatus shown in FIG. 17. Since the upper electrode 12 and the lower electrode 13 are capacitively coupled while plasma is generated inside the processing chamber 11, the high-frequency current from the high-frequency power source 17 flows through the path extending from the high-frequency power source 17 to the ground sequentially via the matching circuit 15, the upper

electrode 12, the lower electrode 13 via the plasma, the conductive passage 18, the wall of the processing chamber 11 and the matching box 16.

[0009] The size of glass substrates for flat panels used in liquid crystal displays and the like among substrates that are processed in plasma processing apparatuses is expected to further increase and glass substrates as large as 1.5 m² must be processed in plasma processing apparatuses in the near future. As a larger processing chamber 11 is utilized to handle such large glass substrates, the inductance component in the processing chamber 11 is bound to increase, to result in weaker coupling of the upper electrode 12 and the lower electrode 13, which leads to a concern that plasma may be generated between the upper electrode 12 and the wall of the processing chamber 11 (shown as capacitive coupling in FIG. 18). If plasma is generated in this manner, the distribution of plasma inside the processing chamber 11 becomes uneven with more plasma concentrating in the periphery to give rise to problems in that the processed substrate 10 does not achieve a high level of planar uniformity and in that the inner wall of the processing chamber 11, the internal parts and the like become damaged readily or become worn out faster.

[0010] Patent Reference Literature 1 discloses a technology for controlling the diffusion of the plasma by providing an impedance adjustment circuit between the lower electrode and the ground. However, this technology whereby different settings are selected at the impedance adjustment circuit for a film forming process and for a cleaning process so as to achieve plasma conditions matching the individual processes, does not address the problems discussed above and Patent Reference Literature 1 does not disclose any solutions to these problems.

[0011] (Patent Reference Literature 1) Japanese Laid Open Patent Publication No. H11-31685, paragraph (0014)

SUMMARY OF THE INVENTION

[0012] An object on the present invention, which has been completed with the background described above, is to provide a plasma processing apparatus and a plasma processing method that prevent generation of plasma between the cathode electrode and the wall of the processing chamber and make it possible to execute plasma processing on the substrate to achieve a high level of planar uniformity by generating a uniform field of plasma.

[0013] The present invention provides a plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising a cathode electrode and an anode electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber a high-frequency power source having one end thereof connected to the cathode electrode via a matching circuit, and an impedance adjustment unit having one end thereof connected to the anode electrode and another end thereof connected to the processing chamber and containing a capacitive component, is characterized in that the substrate is placed on either the cathode electrode or the anode electrode that is located on the lower side, and the impedance adjustment unit adjusts a value of impedance occurred in a path extending from the

cathode electrode to a grounded casing of the matching circuit via the plasma, the anode electrode and a wall of the processing chamber to a level lower than a value of impedance occurred in a path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma and the wall of the processing chamber.

[0014] The cathode electrode and the anode electrode are described above as being “insulated from the processing chamber,” which means that they are in a fully floating state electrically relative to the processing chamber over the area excluding the impedance adjustment unit.

[0015] It is to be noted that the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the wall of the processing chamber may also be referred to as the path extending along the direction in which the plasma achieves uniformity relative to the substrate. In addition, the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma and the wall of the processing chamber may also be referred to as the path along which the plasma density becomes higher relative to the wall of the processing chamber (i.e., the path extending along the direction in which the plasma distribution becomes non-uniform relative to the substrate).

[0016] In another aspect of the present invention, a plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber containing a process gas, comprising a cathode electrode and an anode electrode facing opposite each other on an upper side and a lower side within the processing chamber and insulated from the processing chamber, a high-frequency power source having one end thereof connected to the cathode electrode via a matching circuit and an impedance adjustment unit having a capacitive component with one end thereof connected to the anode electrode and another end thereof connected to the processing chamber, is characterized in that the substrate is placed on either the cathode electrode or the anode electrode that is located on the lower side and that the impedance adjustment unit adjusts the value of the impedance over a path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the wall of the processing chamber so as to achieve a minimum impedance value. Through the adjustment of “the impedance over the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the wall of the processing chamber so as to achieve a minimum impedance value”, the value of the impedance may be adjusted substantially to the minimum value and may be adjusted to a value within a 2% range (namely, $0.98x-1.02x$; x =the minimum value) with respect to the minimum value.

[0017] A plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber, a first high-frequency power source having one end thereof connected to the upper electrode via a first matching circuit and supplying the high-frequency power within a range of 10 MHz to 30 MHz, a second high-

frequency power source having one end thereof connected to the lower electrode via a second matching circuit and supplying the high-frequency power within a range of 2 MHz to 6 MHz, a first impedance adjustment unit having one end thereof connected to the lower electrode and another end thereof connected to the processing chamber and containing a capacitive component, and a second impedance adjustment unit having one end thereof connected to the upper electrode and another end thereof connected to the processing chamber and containing a capacitive component, is characterized in that the substrate is placed on the lower electrode, the first impedance adjustment unit adjusts a value of impedance occurred in a path extending from the upper electrode to a grounded casing of the first matching circuit via the plasma, the lower electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the upper electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the first high-frequency power source, and the second impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the second high-frequency power source.

[0018] A plasma processing apparatus according to the present invention for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber containing the process gas achieved in another aspect of the present invention adopted in an upper electrode/lower electrode two-frequency system, comprising an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber, a first high-frequency power source that supplies 10 MHz to 30 MHz power with one end thereof connected to the upper electrode via a first matching circuit, a second high-frequency power source that supplies 2 MHz to 6 MHz power with one end thereof connected to the lower electrode via a second matching circuit, a first impedance adjustment unit having a capacitive component with one end thereof connected to the lower electrode and another end thereof connected to the processing chamber and a second impedance adjustment unit having a capacitive component with one end thereof connected to the upper electrode and another end thereof connected to the processing chamber, is characterized in that the substrate is placed on the lower electrode, that the first impedance adjustment unit adjusts the value of the impedance at the frequency of the first high-frequency power source over a path extending from the upper electrode to a grounded casing of the first matching circuit via the plasma, the lower electrode and the wall of the processing chamber so as to achieve a minimum impedance value and that the second impedance adjustment unit adjusts the value of the impedance at the frequency of the second high-frequency power source over a path extending from the lower electrode to a grounded casing of the second matching

circuit via the plasma, the upper electrode and the processing chamber wall so as to achieve a minimum impedance value.

[0019] The present invention may also be adopted in a lower electrode two-frequency system having a first high-frequency power source and a second high-frequency power source connected to the lower electrode. In such an application, A plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising, an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber, a first high-frequency power source having one end thereof connected to the lower electrode via a first matching circuit and supplying the high-frequency power within a range of 10 MHz to 30 MHz, a second high-frequency power source having one end thereof connected to the lower electrode via a second matching circuit and supplying the high-frequency power within a range of 2 MHz to 6 MHz, and a first impedance adjustment unit and a second impedance adjustment unit having one end thereof connected to the upper electrode and another end thereof connected to the processing chamber and containing a capacitive component respectively, is characterized in that the substrate is placed on the lower electrode, the first impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the first matching circuit via the plasma, the upper electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the first high-frequency power source, and the second impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the second high-frequency power source.

[0020] Another plasma processing apparatus according to the present invention for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber containing the process gas, adopted in a lower electrode two-frequency system and comprising an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber, a first high-frequency power source that supplies 10 MHz to 30 MHz power with one end thereof connected to the lower electrode via a first matching circuit, a second high-frequency power source that supplies 2 MHz to 6 MHz power with one end thereof connected to the lower electrode with a second matching circuit and a first impedance adjustment unit and a second impedance adjustment unit each having a capacitive component with one end thereof connected to the upper electrode and another end thereof connected to the processing chamber, is characterized in that

the substrate is placed on the lower electrode, that the first impedance adjustment unit adjusts the value of the impedance over a path extending from the lower electrode to a grounded casing of the first matching circuit via the plasma, the upper electrode and the wall of the processing chamber so as to achieve a minimum impedance value and that the second impedance adjustment unit adjusts the value of the impedance over a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and the processing chamber wall so as to achieve a minimum impedance value.

[0021] In each of the plasma processing apparatuses described above, the following control may be executed by the individual units in the plasma processing apparatus when adjusting the value of the impedance over the path extending along the direction in which the plasma achieves uniformity relative to the substrate to a level lower than the value of the impedance over the path through which the plasma density increases relative to the wall (i.e., the path extending along the direction in which the plasma distribution becomes non-uniform relative to the substrate) and when adjusting the value on the impedance over the path through which the plasma becomes distributed more evenly relative to the substrate so as to achieve the minimum impedance value.

[0022] Namely, it is desirable that an impedance value, which will provide a value within a 10% range with respect to the maximum high-frequency current value when the value of the high-frequency current at a specific frequency flowing to the anode electrode is altered by adjusting the value of the high-frequency impedance at the frequency, be set at each impedance adjustment unit. If the anode electrode constitutes the lower electrode, for instance, the impedance adjustment unit should be connected on its other end to the bottom of the processing chamber. To make the most of the impedance adjustment unit, it should be ensured that the other end of the impedance adjustment unit and the processing chamber are connected with each other in an area considerably distanced from the cathode electrode to avoid plasma generation occurring between the cathode electrode and the connecting area. Accordingly, the connection may be achieved at a position achieving a height equal to the height of the anode electrode in the processing chamber, or at a position on the side opposite from the side on which the anode electrode is present (e.g., on the lower side when the anode electrode constitutes the lower electrode, and on the upper side when the anode electrode constitutes the upper electrode).

[0023] The impedance adjustment unit may be constituted by using, for instance, a variable-capacity capacitor so as to allow the impedance value to be varied, or it may be achieved by using, for instance, a dielectric plate constituting a capacitive component disposed between the anode electrode and the inner surface of the processing chamber. By using an impedance adjustment unit that allows the impedance value to be varied, a plasma processing apparatus according to the present invention may adopt a structure having a control unit having stored therein data correlating each plasma processing type with the impedance adjustment value of the impedance adjustment unit (correlating each plasma processing type with an adjustment value at the first impedance adjustment unit and an adjustment value at the second impedance adjustment unit when the plasma processing apparatus includes the first and second impedance

adjustment units), which outputs a control signal to be used to adjust the impedance adjustment unit by reading out an impedance adjustment value corresponding to a selected plasma processing type.

[0024] It is desirable that the plasma processing apparatus according to the present invention include a plurality of impedance adjustment units with the individual impedance adjustment units connected on one end to the anode electrode at positions distanced from one another along the longish side of the anode electrode. In an application in an upper electrode/lower electrode two-frequency system, the plasma processing apparatus should include a plurality of first impedance adjustment units with the individual impedance adjustment units connected on one end thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode and a plurality of second impedance adjustment units with the individual impedance adjustment units connected on one end thereof to the upper electrode at positions distanced from one another along the longish side of the upper electrode. In addition, according to the present invention adopted in a lower electrode two-frequency system, the plasma processing apparatus should include a plurality of first impedance adjustment units with the individual impedance adjustment units connected on one end thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode and a plurality of second impedance adjustment units with the individual impedance adjustment units connected on one end thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode.

[0025] The plasma processing apparatus having a plurality of impedance adjustment units as described above is ideal in an application in which a substrate with an area equal to or greater than 1 m^2 , e.g., a large rectangular substrate, and is particularly effective when the sum of the high-frequency power used in the apparatus is equal to or greater than 10 kW.

[0026] According to the present invention, the generation of plasma between the cathode electrode and the wall of the processing chamber is controlled and, as a result, a plasma process can be executed on the substrate to achieve a high level of planar uniformity by generating evenly distributed plasma.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] FIG. 1 is a longitudinal cross section, schematically illustrating the overall structure of the plasma processing apparatus achieved in a first embodiment of the present invention;

[0028] FIG. 2 is a circuit diagram of a circuit equivalent to the embodiment;

[0029] FIG. 3A shows an example of a structure that may be adopted in the impedance adjustment unit in the embodiment;

[0030] FIG. 3B shows another example of a structure that may be adopted in the impedance adjustment unit in the embodiment;

[0031] FIG. 3C shows yet another example of a structure that may be adopted in the impedance adjustment unit in the embodiment;

[0032] FIG. 3D shows yet another example of a structure that may be adopted in the impedance adjustment unit in the embodiment;

[0033] FIG. 3E shows yet another example of a structure that may be adopted in the impedance adjustment unit in the embodiment;

[0034] FIG. 4 shows an example of a structure that may be adopted in the embodiment;

[0035] FIG. 5A is a longitudinal cross section, schematically showing the overall structure of the plasma processing apparatus achieved as a variation of the embodiment;

[0036] FIG. 5B shows how the substrate may be divided in the embodiment;

[0037] FIG. 6 is a circuit diagram of a circuit equivalent to the embodiment in FIG. 5A;

[0038] FIG. 7A is a longitudinal cross section, schematically showing the overall structure of the plasma processing apparatus achieved as a variation of the embodiment;

[0039] FIG. 7B is a longitudinal cross section, schematically showing another overall structure of the plasma processing apparatus achieved as a variation of the embodiment;

[0040] FIG. 7C is a longitudinal cross section, schematically showing another overall structure of the plasma processing apparatus achieved as a variation of the embodiment;

[0041] FIG. 8 is a longitudinal cross section, schematically showing the overall structure of the plasma processing apparatus achieved as a variation of the embodiment;

[0042] FIG. 9 is a longitudinal cross section, schematically showing the overall structure of the plasma processing apparatus achieved in a second embodiment of the present invention;

[0043] FIG. 10 is a longitudinal cross section, schematically showing the overall structure of the plasma processing apparatus achieved in a third embodiment of the present invention;

[0044] FIG. 11 illustrates the installation positions for the impedance adjustment units set in correspondence to specific points on the substrate;

[0045] FIG. 12 is a circuit diagram of the circuit constituted with the impedance adjustment units used in a test conducted to verify the advantages of the embodiments of the present invention;

[0046] FIG. 13 presents data indicating the overall results of the test;

[0047] FIG. 14 shows the relationship between the adjustment position assumed at the impedance adjustment unit and the high-frequency current, indicated as the results of the test;

[0048] FIG. 15 shows the relationship between the adjustment position assumed at the impedance adjustment unit and the high-frequency voltage, indicated as the results of the test;

[0049] FIG. 16 is a characteristics diagram indicating the silicon etching rate and the etching rate consistency within the plane of the substrate, indicated as the results of another test;

[0050] FIG. 17 is a longitudinal cross section, schematically showing the overall structure of a plasma processing apparatus in the related art; and

[0051] FIG. 18 is a circuit diagram of a circuit equivalent to the plasma processing apparatus in the related art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

[0052] The plasma processing apparatus achieved in the first embodiment of the present invention as an etching apparatus for etching a glass substrate for a liquid crystal display device is now explained. Reference numeral 2 in FIG. 1 indicates a processing chamber assuming the shape of an angular tube, which is constituted of, for instance, aluminum with anodized surfaces. On the upper side inside the processing chamber 2, an upper electrode 3 also to be used as a gas shower head through which a process gas is supplied is disposed, and an insulating member 31 disposed along the opening edge of an opening 30 at the upper surface of the processing chamber 2 sets the upper electrode 3 in a fully floating state electrically relative to the processing chamber 2. In addition, the gas shower head constituted with the upper electrode 3 is connected with a process gas supply unit 33 via a gas supply passage 32 and includes numerous gas holes 34 through which the gas supplied via the gas supply passage 32 is delivered into the processing chamber 2.

[0053] The upper electrode 3 is connected with a high-frequency power source 4 via a matching circuit 41 and a conductive passage 40. In addition, a matching box 42 is disposed so as to surround the opening 30 at the processing chamber 2 and to hold therein the matching circuit 41. The top portion of the matching box 42 extends as an outer layer portion 43 which constitutes, together with the conductive passage 40, a coaxial cable 44, and the outer layer portion 43 is grounded. In this example, the matching box 42 constitutes a grounded casing of the matching circuit.

[0054] In the processing chamber 2, a lower electrode 5 to be also used as a stage on which a substrate 10 is placed is disposed at the bottom, and the lower electrode 5 is supported at a support portion 51 via an insulating member 50. Thus, the lower electrode 5 is fully floating with respect to the processing chamber 2 electrically. At the center of the lower surface of the support portion 51, a protective pipe 52 passing through an opening 20 formed at the bottom wall of the processing chamber 2 and extending downward is disposed. The protective pipe 52 is supported on its bottom side by a conductive support plate 53 having a diameter larger than that of the protective pipe 52, which also seals the pipe. At the peripheral edge of the support plate 53, the lower end of a conductive bellows member 54 is fixed, and the upper end of the bellows member 54 is fixed to the opening edge of the opening 20 at the processing chamber 2. The bellows member 54 pneumatically seals the inner space in which the protective pipe 52 is disposed from the atmosphere side

space, and the stage 5 is allowed to move up/down by an elevator mechanism (not shown) via the support plate 53.

[0055] One end of a conductive passage 55 disposed within the protective pipe 51 is connected to the lower electrode 5, with an impedance adjustment unit 6 disposed in the conductive passage 55. Another end of the conductive passage 55 is connected to the bottom of the processing chamber 2 via the support plate 53 and the bellows member 54. A portion of the processing chamber 2 located in the vicinity of the upper electrode 3, e.g., the upper surface of the processing chamber 2, is grounded via the matching box 42 and then the outer layer portion 43 of the coaxial cable 44, as explained earlier. The upper electrode 3 and the lower electrode 5 are respectively equivalent to a cathode electrode and an anode electrode in this example.

[0056] An evacuation passage 21 is connected to the side wall of the processing chamber 2, with a vacuum evacuation means 22 connected to the evacuation passage 21. In addition, a gate valve 24 used to open/close a transfer port 23 through which the substrate 10 is transferred is disposed at the side wall of the processing chamber 2.

[0057] In the structure described above, a high-frequency current flows through the path extending from the high-frequency power source 4 to the ground sequentially via the matching circuit 41, the upper electrode 3, the plasma, the lower electrode 5, the impedance adjustment unit 6, the processing chamber 2, the matching box 42 and the outer layer portion 43 of the coaxial cable 44. Since there is a concern that the high-frequency current may flow to the wall of the processing chamber 2 from the upper electrode 3 via the plasma as explained in reference to the related art, the impedance in the path (the return path) extending from the lower electrode 5 to the top of the processing chamber 2 is adjusted with the impedance adjustment unit 6.

[0058] FIG. 2 presents a diagram of a circuit equivalent to the high-frequency current circuit in the plasma processing apparatus shown in FIG. 1. Since the processing chamber 2 can be regarded as an inductance component, it is shown as an inductor. C1 indicates a capacitive component representing the plasma present between the upper electrode 3 and the lower electrode 5, whereas C2 indicates a capacitive component representing the plasma present between the upper electrode 3 and the wall of the processing chamber 2.

[0059] The object of the embodiment is to adjust the impedance $j(-1/\omega C1 + \omega L - 1/\omega C)$ over the path extending from the lower electrode 5 to the top of the processing chamber 2 to a level lower than the impedance over the path extending from the upper electrode 3 through the plasma and then the wall of the processing chamber 2 through which the plasma density increases relative to the wall by canceling out the capacitance (C1) of the plasma and the inductance (L) in the path extending from the lower electrode 5 to the top of the processing chamber 2 with the capacitive component (C) of the impedance adjustment unit 6. For these purposes, the impedance adjustment unit 6 includes a capacitive component. Such an impedance adjustment unit 6 may be achieved by adopting any of various modes. For instance, the impedance adjustment unit 6 may be constituted by using a variable-capacity capacitor 61, as shown in FIG. 3A, by using a capacitor 62 with a fixed capacity in combination with a variable-capacity capacitor 61, as shown in FIG. 3B, by using a capacitor 62 with a fixed capacity, as

shown in **FIG. 3C**, by using a variable-capacity capacitor **61** in combination with an inductor **63**, as shown in **FIG. 3D** or by using an inductor **64** which allows the inductance to be varied in combination with a capacitor **62** with a fixed capacity, as shown in **FIG. 3E**. Even in a plasma processing apparatus having the fixed capacity capacitor **62** alone, the impedance value can be adjusted by replacing the capacitor **62** with a capacitor having a different capacity.

[0060] While the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate should be ideally reduced by ascertaining the values of the electrical current flowing through the path in correspondence to varying impedance values assumed at the impedance adjustment unit **6** through tests conducted as detailed later and selecting an impedance value corresponding to the maximum current value, i.e., by setting a value that will minimize the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate, it is desirable to ensure that a value corresponding to a current value within a 2% range with respect to the maximum value or at least a 10% range with respect to the maximum current value in a practical application.

[0061] The functions and the advantages of the embodiment described above are now explained. After the substrate **10** is transferred into the processing chamber **2** on a transfer arm (not shown) from a load lock chamber (not shown) by opening the gate valve **24**, the substrate **10** is transferred onto the lower electrode **5** through cooperation of the transfer arm and an elevator pin (not shown) passing through the lower electrode **5**. Then, the gate valve **24** is closed, the process gas is supplied into the processing chamber **2** from the process gas supply unit **33** via the upper electrode **3**, and the pressure inside the processing chamber **2** is maintained at a predetermined level by evacuating the processing chamber **2** vacuously with the vacuum evacuation means **22**. The process gas becomes excited as 10 kW high-frequency power at, for instance, 10 MHz to 30 MHz frequency from the high-frequency power source **4** is applied between the upper electrode **3** and the lower electrode **5**, thereby generating plasma. The process gas may be constituted with, for instance, a gas containing halogen such as a gas containing a halogen compound, an oxygen gas and an argon gas or the like.

[0062] As the plasma is generated, the high-frequency current flows through the path extending from the upper electrode **3** to the ground sequentially via the plasma, the lower electrode **5**, the impedance adjustment unit **6**, the processing chamber **2**, the matching box **42** and the outer layer portion **43** of the coaxial cable **44** along the direction in which the plasma becomes more uniform relative to the substrate. Since the value of the impedance in the path is set substantially to the minimum value, smaller than the value of the impedance in the path extending from the upper electrode **3** to the ground sequentially via the plasma, the processing chamber **2**, the matching box **42** and the outer layer portion **43** of the coaxial cable **44**, plasma is not generated readily between the upper electrode **3** and the wall of the processing chamber **2**. As a result, the plasma is allowed to concentrate in the space between the upper electrode **3** and the lower electrode **5** and the plasma present above the substrate **10** achieves a high level of planar uniformity. As the surface of the substrate **10** is etched with

this plasma achieving a high level of planar uniformity, the etching rate sustains a high level of consistency and thus, uniform etching is achieved within the plane. In addition, the damage to or wear of the inner wall of the processing chamber **2** and internal parts is minimized.

[0063] In the embodiment, optimal adjustment values to be set at the impedance adjustment unit **6** in correspondence to various types of processing may be stored in memory as, for instance, a table at a storage unit of a control unit **7**, the optimal adjustment value corresponding to a specific processing type having been selected may be read out from the data, e.g., the table and a control signal may be output from the control unit **7** to an actuator at the impedance adjustment unit **6** which may be a motor for driving the trim mechanism of the variable-capacity capacitor, as shown in **FIG. 4**. More specifically, such optimal value settings may be determined in correspondence to various etching processes which are executed continuously to one another, or the optimal value settings may be determined in correspondence to different film forming processes which are executed continuously to one another.

[0064] In the embodiment, when processing the substrate with plasma generated by applying high-frequency power to the space between the cathode electrode and the anode electrode, the impedance adjustment unit having a capacitive component, which is disposed between the anode electrode (constituted with the electrode facing opposite the electrode connected with the high-frequency power source) and the processing chamber, adjusts the value of the impedance in the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the processing chamber wall to a level lower than the value of the impedance in the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma and the processing chamber wall. As a result, plasma is not generated readily in the space between the cathode electrode and the processing chamber wall and plasma with highly consistent distribution is generated to enable plasma processing with a high level of planar uniformity at the substrate.

[0065] (Variations of the First Embodiment)

[0066] In a variation of the embodiment, the plasma processing apparatus include a plurality of impedance adjustment units e.g., impedance adjustment units **6A**, **6B** and **6C**, as shown in **FIGS. 5A** and **5B**. It is desirable that the individual impedance adjustment units **6A**, **6B** and **6C** be connected on one end thereof to the lower electrode **5** at positions PA, PB and PC distanced from one another along the longish side of the lower electrode **5** (along the lateral direction). To explain this in specific terms, a rectangular substrate **10** is divided into three separate areas, as indicated by the chain lines in **FIG. 5B**, for instance, and the impedance in the path between each divided area and the processing chamber **2** is set to an optimal value. The term "optimal value" refers to a value at which highly consistent plasma is achieved, and such an optimal value is determined for each of the impedance adjustment units **6A**, **6B** and **6C** in correspondence to each type of processing through, for instance, repeated tests conducted in advance.

[0067] To explain the plasma processing apparatus in further detail in reference to a specific example, if the plasma intensity is high around the center, the capacitive

value at the impedance adjustment unit **6B** corresponding to the central area is increased so as to raise the value of the impedance between the lower electrode **5** and the processing chamber **2** over the central area and the capacity values at the impedance adjustment units **6A** and **6C** corresponding to the peripheral areas are reduced so as to shift the plasma with the high intensity from the center toward the periphery. It is a prerequisite in such an embodiment that the impedance values at the individual impedance adjustment units **6A**, **6B** and **6C** be set so as to adjust the value of the impedance over the path extending along the direction in which the plasma becomes more uniform relative to the substrate as described earlier, including the value of the impedance at the parallel connection circuit constituted with the impedance adjustment unit **6A**, **6B** and **6C** to a level lower than the value of the impedance over the path extending from the upper electrode **3** and then through the plasma and along the wall of the processing chamber **2**, through which the plasma density increases relative to the wall. The intensity of the plasma over the plane of the substrate **10** can be fine-adjusted by adjusting the impedance values at the individual impedance adjustment units while satisfying the prerequisite, which proves extremely effective for generating highly consistent plasma to process large size substrates. Bearing in mind that it is difficult to sustain plasma in a uniform state over the plane of a large size substrate with an area of 1 m² or more, e.g., a rectangular substrate used for a flat panel display, the inventor learned that the plasma consistency can be improved and any abnormal discharge that might otherwise occur locally can be prevented by fine-adjusting the plasma distribution. The structure having a plurality of impedance adjustment units is particularly effective when the sum of the high-frequency power is significant at 10 kW or more, since an abnormal discharge tends to occur readily under such circumstances.

[0068] As shown in **FIGS. 5A and 5B**, the impedance adjustment units **6A**, **6B** and **6C** are enclosed inside protective pipes **52A**, **52B** and **52C** respectively, extending from the lower surface of a support portion **51** at positions corresponding to the positions **PA**, **PB** and **PC** mentioned earlier. Support plates **53**, which are independent of one another, are each provided in correspondence to one of the protective pipes **52A** to **52C** and a bellows member **54** is provided between each support plate **53** and the processing chamber **2** as has been described in reference to **FIG. 1**.

[0069] When dividing the lower electrode **5** into separate impedance adjustment areas, as described above, it does not need to be divided into three areas and instead, it may be halved both longitudinally and laterally to form four divided areas, for instance, and in such a case, an impedance adjustment unit should be provided in correspondence to each of the four divided areas.

[0070] In this embodiment, too, adjustment values to be selected for the individual impedance adjustment units **6A**, **6B** and **6C** should be stored in memory at the storage unit of the control unit **7** in correspondence to each type of processing and the optimal impedance values should be set at the individual impedance adjustment units **6A**, **6B** and **6C** in correspondence to a selected processing type, as shown in **FIG. 6**.

[0071] In addition, instead of using a capacitive element such as a variable-capacity capacitor or a fixed capacity

capacitor to constitute an impedance adjustment unit **6**, a dielectric plate or the like that constitutes a capacitive component may be used as shown in **FIGS. 7A to 7C**. In the example presented in **FIG. 7A**, an impedance adjustment unit constituted with a dielectric plate **8** is detachably mounted between the lower electrode **5** and the bottom of the processing chamber **2**. The capacitive value of the dielectric plate **8** is set to a level at which the prerequisite conditions with regard to the impedance value over the path are satisfied mentioned earlier.

[0072] In the example presented in **FIG. 7B**, which corresponds to the example presented in **FIG. 5A** showing a plurality of impedance adjustment units **6A**, **6B** and **6C**, the capacity at the dielectric plate over the central area (e.g., a rectangular area in a plan view) is varied from the capacity in the peripheral area (the angular ring-shaped area in a plan view), by using two different types of dielectric plates **8A** and **8B**. While the different capacities are achieved by using different materials and sustaining a consistent thickness for the entire dielectric plate, different capacities may instead be achieved for the central area and the peripheral area by, for instance, increasing the thickness of the lower electrode **5** over the central area and thus reducing the thickness of the dielectric plate **8** over the corresponding area in the example presented in **FIG. 7C**.

[0073] While the high-frequency power source **4** is connected to the upper electrode **3** in the embodiment described above, the high-frequency power source **4** may instead be connected to the lower electrode **5**. In such a case, the impedance adjustment unit **6** should be connected between the upper electrode **3** and an upper portion of the processing chamber **2**, e.g., the upper surface of the processing chamber **2**. While the impedance adjustment unit **6** may be disposed between the upper electrode **3** and the side wall of the processing chamber **2** under these circumstances, it is not desirable to dispose the impedance adjustment unit at a position lower than the upper electrode **3**. **FIG. 8** shows an apparatus of this type having three impedance adjustment units **6A** to **6C**. The three impedance adjustment units **6A** to **6C** may be installed at positions corresponding to **PA** to **PC** in **FIGS. 5A and 5B**, for instance. However, the number of impedance adjustment units **6** is not limited to three and the apparatus may include two impedance adjustment units **6** or four or more impedance adjustment units **6**. In addition, the apparatus may include a single impedance adjustment unit **6** instead of a plurality of impedance adjustment units.

[0074] By adopting the variation in which a plurality of impedance adjustment units are employed with the individual impedance adjustment units connected on one side to the anode electrode at positions distanced from one another along the longish side of the anode electrode and the impedance can be thus adjusted individually for each of the plurality of divided areas of the anode electrode defined along the plane of the substrate, the plasma distribution can be adjusted more accurately compared to an impedance adjustment over a single area and, as a result, highly consistent plasma is achieved. For instance, as it becomes difficult to achieve a highly consistent plasma state within the plane when handling a large substrate with an area of 1 m² or more, the plasma consistency can be improved and also an abnormal discharge that might otherwise occur locally can be prevented by fine-adjusting the plasma distribution. The structure having a plurality of impedance

adjustment units is particularly effective when the sum of the high-frequency power is significant at 10 kW or more since an abnormal discharge tends to occur readily under such circumstances.

Second Embodiment

[0075] The second embodiment of the present invention is adopted in an upper electrode/lower electrode two-frequency type plasma processing apparatus having a high-frequency power source 4 disposed in conjunction with the upper electrode 3 and a high-frequency power source 100 disposed in conjunction with the lower electrode 5, as shown in FIG. 9. In this plasma processing apparatus, a conductive passage 101 is wired inside the protective pipe 52B located on the lower side in the structure shown in FIG. 5A, a matching box 102 is disposed at the lower end of the protective pipe 52B, a matching circuit 103 connected to the conductive passage 101 is housed inside the matching box 102 and the high-frequency power source 100 is connected to the matching circuit 103. The bottom portion of the matching box 102 extends as an outer layer portion 105, which constitutes a coaxial cable 104 together with a conductive passage 106 and the outer layer portion 105 is grounded.

[0076] The matching circuits 41 and 103 in this example respectively constitute a first matching circuit and a second matching circuit. The high-frequency power sources 4 and 100 respectively constitute a first high-frequency power source and a second high-frequency power source, and the first high-frequency power source 4 located on the upper side outputs, for instance, 10 kW high-frequency power with a frequency of 10 MHz to 30 MHz, whereas the second high-frequency power source 100 located on the lower side outputs, for instance, 3 kW high-frequency power with a frequency of 2 MHz to 6 MHz. The high-frequency power output from the first high-frequency power source 4 activates the process gas, whereas the power output from the second high-frequency power source 100 attracts the ions in the plasma toward the substrate 10. It is to be noted that the matching boxes 42 and 102 respectively constitute a grounded casing for the first matching circuit and a grounded casing for the second matching circuit in the embodiment. Although not shown in FIG. 9, a high pass filter is disposed between the upper electrode 3 and the matching circuit 41 and a low pass filter is disposed between the lower electrode 5 and the matching circuit 103 so as to ensure that the high-frequency component of the high-frequency power source 4 does not enter the high-frequency power source 100 and the high-frequency component of the high-frequency power source 100 does not enter the high-frequency power source 4. In this example, the lower electrode 5 constitutes an anode electrode in relation to the first high-frequency power source 4, and the upper electrode 3 constitutes an anode electrode in relation to the second high-frequency power source 100.

[0077] A plurality of impedance adjustment units 9A and 9C are disposed between the upper electrode 3 and the matching box 42, and the impedance adjustment units 9A and 9C are connected to an upper portion, e.g., the ceiling, of the processing chamber 2 via the matching box 42. While the illustration includes two impedance adjustment units 9A and 9C on the upper side and two impedance adjustment units 6A and 6C on the lower side, three or more impedance

adjustment units may be provided on each side or a single impedance adjustment unit may be provided on each side. In addition, the matching box 42 constitutes the grounded casing for the first matching circuit 41, which allows the high-frequency current from the first high-frequency power source 4 to return to the high-frequency power source 4 through the top portion of the processing chamber 2, and the matching box 102 constitutes the grounded casing for the second matching circuit 103, which allows the high-frequency current from the second high-frequency power source 100 to return to the high-frequency power source 100 from the bottom portion of the processing chamber 2.

[0078] The lower impedance adjustment units 6A and 6C constitute a first impedance adjustment units in conjunction with which a filter for allowing the high-frequency component corresponding to the high-frequency band of the first high-frequency power source 4 alone to pass through is provided. The upper impedance adjustment units 9A and 9C constitute second impedance adjustment units in conjunction with which a filter for allowing the high-frequency component corresponding to the high-frequency band of the second high-frequency power source 100 alone to pass through is provided. Namely, the high-frequency current from the first high-frequency power source 4 flows through a path extending from the high-frequency power source 4 to the ground sequentially via the matching circuit 41, the upper electrode 3, the plasma, the lower electrode 5, the impedance adjustment units 6A and 6C, the processing chamber 2, the matching box 42 and the outer layer portion 43 of the coaxial cable 44, whereas the high-frequency current from the second high-frequency power source 100 flows through a path extending from the high-frequency power source 100 to the ground sequentially via the matching circuit 103, the lower electrode 5, the plasma, the upper electrode 3, the impedance adjustment units 9A and 9C, the processing chamber 2, the matching box 102 and the outer layer portion 105 of the coaxial cable 104.

[0079] The first impedance adjustment units 6A and 6B adjust the value of the impedance at the high-frequency of the first high-frequency power source 4 over the path extending from the upper electrode 3 to the matching box 42 (the grounded casing of the first matching circuit) via the plasma, the lower electrode 5 and the wall of the processing chamber 2 along the direction in which the plasma becomes more uniform relative to the substrate, to a level lower than the value of the impedance at the high frequency of the first high-frequency power source 4 over the path extending from the upper electrode 3 to the matching box 42 via the plasma and the wall of the processing chamber 2 along the direction in which the plasma density increases relative to the wall. While the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate should be ideally reduced by ascertaining the values of the electrical current flowing from the first high-frequency power source 4 through the path extending along the direction in which the plasma becomes more uniform relative to the substrate in correspondence to varying impedance values and selecting an impedance value corresponding to the maximum current value, i.e., by setting a value that will minimize the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate, it should be insured in a practical application that a value corresponding to a current value within a 2% range with respect to the maximum current

value or at least within a 10% range with respect to the maximum current value is set. The value of the current in the path extending along the direction in which the plasma becomes more uniform relative to the substrate may be determined as the sum of the current values provided by, for instance, ammeters connected to the impedance adjustment units 6A and 6C.

[0080] The second impedance adjustment units 9A and 9C adjust the value of the impedance at the high-frequency of the second high-frequency power source 100 over the path extending from the lower electrode 5 to the matching box 102 via the plasma, the upper electrode 3 and the wall of the processing chamber 2 along the direction in which the plasma becomes more uniform relative to the substrate to a level lower than the value of the impedance at the high-frequency of the second high-frequency power source 100 over the path extending from the lower electrode 5 to the matching box 102 via the plasma and the wall of the processing chamber 2 along the direction in which the plasma density increases relative to the wall. While the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate should be ideally reduced by ascertaining the values of the electrical current flowing from the second high-frequency power source 100 through the path extending along the direction in which the plasma becomes more uniform relative to the substrate in correspondence to varying impedance values and selecting an impedance value corresponding to the maximum current value, it should be ensured in a practical application that a value corresponding to a current value within a 2% range with respect to the maximum value or at least a 10% range with respect to the maximum current value is set.

Third Embodiment

[0081] The third embodiment of the present invention is adopted in a lower electrode two-frequency type plasma processing apparatus having a first high-frequency power source 4 and a second high-frequency power source 100 both provided in conjunction with the lower electrode 5, as shown in FIG. 10. In this plasma processing apparatus, the protective pipe 45 is connected via an insulating layer 50 to the lower side of the lower electrode 5, the lower end of the protective pipe 45 passes through the bottom surface of the processing chamber 2 and a matching box 42 is connected to the lower end of the protective pipe 45. Two matching circuits 41 and 103 are disposed inside the matching box 42, with the matching circuits 41 and 103 individually connected on one end thereof to the lower electrode 5 respectively via conductive passages 46 and 101 disposed inside the protective pipe 45 and the first high-frequency power source 4 and the second high-frequency power source 100 respectively connected to the other ends of the matching circuits 41 and 103. Reference numerals 44 and 104 indicate the coaxial cables described earlier. The frequencies and the power levels of the high-frequency power output from the first high-frequency power source 4 and the second high-frequency power source 100 are equal to those in the embodiment shown in FIG. 9.

[0082] A plurality of first impedance adjustment units, e.g., three impedance adjustment units 6A to 6C, and a plurality of second impedance adjustment units, e.g., three impedance adjustment units 9A to 9C, are individually

connected on one end thereof to the upper electrode 3, and the ends of the impedance adjustment units 6A to 6C and 9A to 9C on the other side are connected to an upper portion, e.g., the ceiling, of the processing chamber 2 via a conductive cover member 56 covering the opening 30 of the processing chamber 2. Instead of providing three first impedance adjustment units and three second impedance adjustment units, a first impedance adjustment unit constituted with a single impedance adjustment unit and a second impedance adjustment unit constituted with a single impedance adjustment unit may be used, or the number of impedance adjustment units included in the first and second impedance adjustment units may be two or four or more. In this example, too, a filter for allowing only the high-frequency component corresponding to the high-frequency band of the first high-frequency power source 4 to pass through is provided in conjunction with the first impedance adjustment units 6A to 6C. In addition, a filter for allowing only the high-frequency component corresponding to the high-frequency band of the second high-frequency power source 100 to pass through is provided in conjunction with the second impedance adjustment units 9A to 9C.

[0083] In addition, the matching box 42 is used both as the grounded casing for the first matching circuit, which allows the high-frequency current from the first high-frequency power source 4 to return to the high-frequency power source 4 through the bottom of the processing chamber 2, and the grounded casing for the second matching circuit, which allows the high-frequency current from the second high-frequency power source 100 to return to the high-frequency power source 100 through the bottom of the processing chamber 2.

[0084] The high-frequency current from the first high-frequency power source 4 flows through the path extending from the high-frequency power source 4 to the matching box 42 sequentially via the matching circuit 41, the lower electrode 5, the plasma, the upper electrode 3, the first impedance adjustment units 6A to 6C and the processing chamber 2, whereas the high-frequency current from the second high-frequency power source 100 flows through the path extending from the high-frequency power source 100 to the matching box 42 sequentially via the matching circuit 103, the lower electrode 5, the plasma, the upper electrode 3, the second impedance adjustment units 9A to 9C and the processing chamber 2.

[0085] The first impedance adjustment units 6A to 6C adjust the value of the impedance at the high frequency of the first high-frequency power source 4 over the path extending from the lower electrode 5 to the matching box 42 via the plasma, the upper electrode 3 and the wall of the processing chamber 2 along the direction in which the plasma becomes more uniform relative to the substrate to a level lower than the value of the impedance at the high frequency of the first high-frequency power source 4 over the path extending from the lower electrode 5 to the matching box 42 via the plasma and the wall of the processing chamber 2 along the direction in which the plasma density increases relative to the wall. While the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate should be ideally reduced by ascertaining the values of the electrical current flowing from the first high-frequency power source 4 through the path extending along the direction in which the

plasma becomes more uniform relative to the substrate in correspondence to varying impedance values and selecting an impedance value corresponding to the maximum current value, i.e., by setting a value that will minimize the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate, it should be insured in a practical application that a value corresponding to a current value within a 2% range with respect to the maximum current value or at least within a 10% range with respect to the maximum current value is set.

[0086] The second impedance adjustment units 9A to 9C adjust the value of the impedance at the high frequency of the second high-frequency power source 100 over the path extending from the lower electrode 5 to the matching box 42 via the plasma, the upper electrode 3 and the wall of the processing chamber 2 along the direction in which the plasma becomes more uniform relative to the substrate to a level lower than the value of the impedance at the high frequency of the second high-frequency power source 100 over the path extending from the lower electrode 5 to the matching box 42 via the plasma and the wall of processing chamber 2 along the direction in which the plasma density increases relative to the wall. While the impedance in the path extending along the direction in which the plasma becomes more uniform relative to the substrate should be ideally reduced by ascertaining the values of the electrical current flowing from the second high-frequency power source 100 through the path extending along the direction in which the plasma becomes more uniform relative to the substrate in correspondence to varying impedance values and selecting an impedance value corresponding to the maximum current value, it should be ensured in a practical application that a value corresponding to a current value within a 2% range with respect to the maximum value or at least a 10% range with respect to the maximum current value is set.

[0087] It is to be noted that the impedance adjustment units achieved in the embodiments shown in FIGS. 8 through 10 may each be constituted with a dielectric material containing a capacitive component as shown in FIGS. 7A through 7C in reference to which an explanation has already been provided. In addition, the data correlating individual plasma processing types with specific adjustment values to be set at the impedance adjustment units may be prepared so as to automatically adjust the impedance adjustment units in correspondence to a given plasma processing type, as shown in FIG. 4.

[0088] FIG. 11 presents an example of a layout that may be adopted when providing a plurality of impedance adjustment units. In this example, impedance adjustment units are disposed at positions corresponding to five points which include four points P1 to P4 at the four corners and a point P5 at the center of the rectangular substrate 10 (over areas in which those five points are projected).

[0089] The optimal distance between the upper electrode 3 and the lower electrode 5 and the optimal processing pressure to be assumed in an apparatus having the high-frequency power source 4 connected to the upper electrode 3, as shown in FIGS. 1, 5A and 9 are respectively 50 mm to 300 mm and 13 Pa to 27 Pa (100 mTorr to 200 mTorr). In an apparatus having the high-frequency power source 4 connected to the lower electrode 5, as shown in FIGS. 8 and

10, on the other hand, it is desirable to set the distance between the electrodes to a value within a range of 200 mm to 700 mm and the processing pressure to a level within a range of 0.7 Pa to 13 Pa (5 mTorr to 100 mTorr).

[0090] (Tests)

[0091] Next, tests conducted to verify the advantages of the embodiments of the present invention are described.

[0092] (Test 1)

[0093] A Test Method

[0094] A plane parallel plasma processing apparatus such as that shown in FIG. 5A, having four impedance adjustment areas defined at the lower electrode (the lower electrode in FIG. 5A includes three divided areas) was used as a test apparatus. Four impedance adjustment units (6A to 6D) each constituted by connecting in series an inductor 63 and a variable-capacity capacitor 61 were connected in parallel to one another, as shown in FIG. 12. It is to be noted that the capacitive component indicated as C0 in FIG. 12 corresponds to the capacity of the dielectric member between the lower electrode and the processing chamber.

[0095] The trimmers of the variable-capacity capacitors were adjusted to various positions so as to set the impedance at the impedance adjustment units were set to different values. The state of the plasma generated in the processing chamber was visually observed, the current flowing through the conductive path extending between the impedance adjustment units and the processing chamber (the current flowing to the lower electrode) was detected and the voltage at the upper electrode was measured at each impedance setting. The plasma was generated with the distance between the upper electrode and the lower electrode set to 60 mm, a mixed gas containing SF6 gas, HCl gas and He gas was used as the plasma generating gas, the frequency and the level of the power output from the high-frequency power source set to 13.56 MHz and 7.5 kW and the pressure set to 20 Pa (150 mTorr).

[0096] B Test Results

[0097] FIG. 13 shows the relationships among the variable-capacity capacitor trimmer position, the capacity at the capacitor, the impedance at the capacitor, the impedance value Z (L-C) at the impedance adjustment unit, the value of the total impedance including C0 between the lower electrode and the processing chamber, the value of the current (lower current) flowing to the lower electrode, the value of the voltage (upper voltage) at the upper electrode and the visually observed plasma state. The visually observed plasma state was evaluated by using the following criterion; highly consistent light emission (⊙), fairly good consistency in light emission (○), slightly poor consistency in light emission (Δ) and poor consistency in light emission (X). In addition, the lower current value and the upper voltage value in FIG. 13 are graphed respectively in FIGS. 14 and 15. The unit of the capacitive value is pF, the unit of the impedance at the capacitor and the impedance value is Ω and the units of the current value and the voltage value are respectively A and V.

[0098] As the test results indicate, the lower current peaked at 79 A and the best plasma state was achieved at 79 A. The plasma state with the lower current at 78 A was evaluated to be fairly good and the plasma state with the

lower current at 72 A was evaluated to be slightly poor. In addition, the plasma state at 66 A or lower was very poor. Accordingly, the impedance value should be adjusted so as to substantially maximize the lower current. With the measuring error and the like taken into consideration, it is desirable to ensure that the lower current is within a 10% range with respect to the maximum value and it is even more desirable to assure a lower current within a 2% range with respect to the maximum value. When the lower current value is substantially maximized, the upper voltage value, too, is substantially maximized, which means that the value of the impedance between the lower electrode and the processing chamber is substantially minimized. In other words, when the lower current value is substantially maximized, the level of the current flowing from the upper electrode to the wall of the processing chamber via the plasma is substantially at the minimum level and, under such circumstances, the plasma consistency is improved without an electrical discharge occurring between the upper electrode and the wall of the processing chamber.

[0099] (Test 2)

[0100] A Test Method

[0101] A two-frequency type plane parallel plasma processing apparatus such as that shown in FIG. 9, having an upper high-frequency power source 4 and a lower high-frequency power source 100, was used as a test apparatus to etch a silicon film formed at the surface of a rectangular substrate with an area of 2000 mm×2200 mm. The processing was executed under the following conditions.

[0102] Process gas: SF₆ gas, HCl gas and He gas

[0103] frequency and level of power output from upper high-frequency

[0104] power source: 13.56 MHz and 20 kW

[0105] frequency and level of power output from lower high-frequency

[0106] power source: 3.2 MHz and 4 kW

[0107] processing pressure: 20 Pa (150 mTorr)

[0108] In addition, five impedance adjustment units were provided in conjunction with the high-frequency component from the high-frequency power source 4 of the upper side at positions corresponding to the four corners and the center of the rectangular substrate and likewise, five impedance adjustment units were provided in conjunction with the high-frequency component from the high-frequency power source 100 of the lower side at positions corresponding to the four corners and the center of the rectangular substrate. Each impedance adjustment unit was constituted by connecting in series a variable-capacity capacitor and an inductor, as shown in FIG. 3D. With an ammeter serially inserted at each impedance adjustment unit, an adjustment point at which the value of the current (the sum of the current values detected with the individual ammeters) running toward the lower electrode was at its lowest was determined. Then, the average of the etching rates at numerous positions set within the plane of the substrate surface and the etching rate consistency within the plane at the adjustment point were ascertained. In addition, the etching rate average and the etching rate consistency within the plane were investigated in a similar manner by processing the substrate under

conditions identical to the processing conditions detailed above but without providing the impedance adjustment units, by setting the power applied to the lower electrode to 0 and by dispensing with the high-frequency power source of the lower side.

[0109] B Test Results

[0110] The results of the test are presented in FIG. 16. As the test results indicate, the etching rate was improved by connecting a high-frequency power source to the lower electrode as well as to the upper electrode, over the etching rate of the system having high-frequency power source connected to the upper electrode alone. While the etching rate consistency within the plane is compromised in the upper electrode/lower electrode two-frequency system, the etching rate consistency within the plane can still be improved by adjusting the impedance with the impedance adjustment units so as to minimize the value of the current flowing to the lower electrode.

[0111] The operations of the individual units in the plasma processing apparatus achieved in each of the embodiments described above are related with one another and thus they may be considered to be steps in an operational sequence. But assuming such a perspective, the present invention can be embodied as a plasma processing method.

[0112] While the invention has been particularly shown and described with respect to preferred embodiments thereof by referring to the attached drawings, the present invention is not limited to these examples and it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit, scope and teaching of the invention.

What is claimed is:

1. A plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising:

a cathode electrode and an anode electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber;

a high-frequency power source having one end thereof connected to the cathode electrode via a matching circuit; and

an impedance adjustment unit having one end thereof connected to the anode electrode and another end thereof connected to the processing chamber and containing a capacitive component, wherein:

the substrate is placed on either the cathode electrode or the anode electrode that is located on the lower side; and

the impedance adjustment unit adjusts a value of impedance occurred in a path extending from the cathode electrode to a grounded casing of the matching circuit via the plasma, the anode electrode and a wall of the processing chamber to a level lower than a value of impedance occurred in a path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma and the wall of the processing chamber.

2. The plasma processing apparatus according to claim 1, wherein:

the impedance adjustment unit adjusts the value of the impedance occurred in the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the wall of the processing chamber so as to minimize.

3. The plasma processing apparatus according to claim 1, wherein:

the impedance adjustment unit sets the value of the impedance occurred in the path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma, the anode electrode and the wall of the processing chamber so as to flow a current to the anode electrode within a range of 10% of a maximum value of the current flowing to the anode electrode by adjusting the value of the impedance by controlling the current flowing to the anode electrode.

4. The plasma processing apparatus according to claim 1, wherein:

the impedance adjustment unit is constituted so as to be able to vary the value of the impedance.

5. The plasma processing apparatus according to claim 1, further comprising:

a control unit memorizing impedance adjustment data related to various plasma processing types, reading out the impedance adjustment data corresponding to a plasma processing type selected from the various plasma processing types and outputting a control signal for adjusting the value of the impedance to the impedance adjustment unit based on the impedance adjustment data.

6. The plasma processing apparatus according to claim 1, wherein:

the impedance adjustment unit is constituted with a dielectric member having the capacitive component and be located between the anode electrode and the processing chamber.

7. The plasma processing apparatus according to claim 1, wherein:

a plurality of impedance adjustment units are provided and the plurality of the impedance adjustment units are individually connected on one end thereof to the anode electrode at positions distanced from one another along the longish side of the anode electrode.

8. A plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising:

an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber;

a first high-frequency power source having one end thereof connected to the upper electrode via a first matching circuit and supplying the high-frequency power within a range of 10 MHz to 30 MHz;

a second high-frequency power source having one end thereof connected to the lower electrode via a second

matching circuit and supplying the high-frequency power within a range of 2 MHz to 6 MHz;

a first impedance adjustment unit having one end thereof connected to the lower electrode and another end thereof connected to the processing chamber and containing a capacitive component; and

a second impedance adjustment unit having one end thereof connected to the upper electrode and another end thereof connected to the processing chamber and containing a capacitive component, wherein:

the substrate is placed on the lower electrode;

the first impedance adjustment unit adjusts a value of impedance occurred in a path extending from the upper electrode to a grounded casing of the first matching circuit via the plasma, the lower electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the upper electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the first high-frequency power source; and

the second impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the second high-frequency power source.

9. The plasma processing apparatus according to claim 8, wherein:

the first impedance adjustment unit adjusts the value of the impedance occurred in the path extending from the upper electrode to the grounded casing of the first matching circuit via the plasma, the lower electrode and the wall of the processing chamber by the high-frequency power of the first high-frequency power source so as to minimize; and

the second impedance adjustment unit adjusts the value of the impedance occurred in the path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source so as to minimize.

10. The plasma processing apparatus according to claim 8, wherein:

the first impedance adjustment unit sets the value of the impedance so as to flow a current to the lower electrode within a range of 10% of a maximum value of the current flowing to the lower electrode by adjusting the value of the impedance by controlling the current of the frequency of the first high-frequency power source; and

the second impedance adjustment unit sets the value of the impedance so as to flow a current to the upper

electrode within a range of 10% of a maximum value of the current flowing to the upper electrode by adjusting the value of the impedance by controlling the current of the frequency of the second high-frequency power.

11. The plasma processing apparatus according to claim 8, wherein:

the first impedance adjustment unit and the second impedance adjustment unit are constituted so as to be able to vary the value of the impedance corresponding to the frequency of the first high-frequency power source and the value of the impedance corresponding to the frequency of the second high-frequency power source respectively.

12. The plasma processing apparatus according to claim 8, further comprising:

a control unit memorizing impedance adjustment data for the first impedance adjustment unit and impedance adjustment data for the second impedance adjustment unit related to various plasma processing types, reading out the impedance adjustment data for the first impedance adjustment unit and the impedance adjustment data for the second impedance adjustment unit corresponding to a plasma processing type selected from the various plasma processing types and outputting a control signal for adjusting the value of the impedance to the first impedance adjustment unit and the second impedance adjustment unit based on the impedance adjustment data for the first impedance adjustment unit and the impedance adjustment data for the second impedance adjustment unit.

13. The plasma processing apparatus according to claim 8, wherein:

the first impedance adjustment unit is constituted with a dielectric member having the capacitive component and be located between the lower electrode and the processing chamber; and

the second impedance adjustment unit is constituted with a dielectric member having the capacitive component and be located between the upper electrode and the processing chamber.

14. The plasma processing apparatus according to claim 8, wherein:

a plurality of first impedance adjustment units are provided and the plurality of the first impedance adjustment units are individually connected on one end thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode; and

a plurality of second impedance adjustment units are provided and the plurality of the second impedance adjustment units are individually connected on one end thereof to the upper electrode at positions distanced from one another along the longish side of the upper electrode.

15. A plasma processing apparatus for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, comprising:

an upper electrode and a lower electrode facing opposite each other on an upper side and a lower side inside the processing chamber and insulated from the processing chamber;

a first high-frequency power source having one end thereof connected to the lower electrode via a first matching circuit and supplying the high-frequency power within a range of 10 MHz to 30 MHz;

a second high-frequency power source having one end thereof connected to the lower electrode via a second matching circuit and supplying the high-frequency power within a range of 2 MHz to 6 MHz; and

a first impedance adjustment unit and a second impedance adjustment unit having one end thereof connected to the upper electrode and another end thereof connected to the processing chamber and containing a capacitive component respectively, wherein:

the substrate is placed on the lower electrode;

the first impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the first matching circuit via the plasma, the upper electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the first high-frequency power source; and

the second impedance adjustment unit adjusts a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the high-frequency power of the second high-frequency power source.

16. The plasma processing apparatus according to claim 15, wherein:

the first impedance adjustment unit adjusts the value of the impedance occurred in the path extending from the lower electrode to the grounded casing of the first matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the first high-frequency power source so as to minimize; and

the second impedance adjustment unit adjusts the value of the impedance occurred in the path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma, the upper electrode and the wall of the processing chamber by the high-frequency power of the second high-frequency power source so as to minimize.

17. The plasma processing apparatus according to claim 15, wherein:

the first impedance adjustment unit sets the value of the impedance so as to flow a current to the upper electrode within a range of 10% of a maximum value of the current flowing to the upper electrode by adjusting the value of the impedance by controlling the current of the frequency of the first high-frequency power source; and

the second impedance adjustment unit sets the value of the impedance so as to flow a current to the upper electrode within a range of 10% of a maximum value of the current flowing to the upper electrode by adjusting the value of the impedance by controlling the current of the frequency of the second high-frequency power source.

18. The plasma processing apparatus according to claim 15, wherein:

the first impedance adjustment unit and the second impedance adjustment unit are constituted so as to be enable to vary the value of the impedance corresponding to the frequency of the first high-frequency power source and the value of the impedance corresponding to the frequency of the second high-frequency power source respectively.

19. The plasma processing apparatus according to claim 15, further comprising:

a control unit memorizing impedance adjustment data for the first impedance adjustment unit and impedance adjustment data for the second impedance adjustment unit related to various plasma processing types, reading out the impedance adjustment data for the first impedance adjustment unit and the impedance adjustment data for the second impedance adjustment unit corresponding to a plasma processing type selected from the various plasma processing types, outputting a control signal for adjusting the value of the impedance to the first impedance adjustment unit and outputting a control signal for adjusting the value of the impedance to the second impedance adjustment unit.

20. The plasma processing apparatus according to claim 15, wherein:

the first impedance adjustment unit is constituted with a dielectric member having the capacitive component and be located between the upper electrode and the processing chamber; and

the second impedance adjustment unit is constituted with a dielectric member having the capacitive component and be located between the upper electrode and the processing chamber.

21. The plasma processing apparatus according to claim 15, wherein:

a plurality of first impedance adjustment units are provided and the plurality of the first impedance adjustment units are individually connected on one end thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode; and

a plurality of second impedance adjustment units are provided and the plurality of the second impedance adjustment units are individually connected on one end

thereof to the lower electrode at positions distanced from one another along the longish side of the lower electrode.

22. The plasma processing apparatus according to claim 1, wherein:

an area of the substrate is equal to or greater than 1 m².

23. The plasma processing apparatus according to claim 8, wherein:

an area of the substrate is equal to or greater than 1 m².

24. The plasma processing apparatus according to claim 15, wherein:

an area of the substrate is equal to or greater than 1 m².

25. The plasma processing apparatus according to claim 22, wherein:

a sum of the high-frequency power used in the plasma processing apparatus is equal to or greater than 10 kW.

26. The plasma processing apparatus according to claim 23, wherein:

a sum of the high-frequency power used in the plasma processing apparatus is equal to or greater than 10 kW.

27. The plasma processing apparatus according to claim 24, wherein:

a sum of the high-frequency power used in the plasma processing apparatus is equal to or greater than 10 kW.

28. The plasma processing apparatus according to claim 1, wherein:

the cathode electrode and the anode electrode respectively constitute an upper electrode and a lower electrode;

the frequency of the high-frequency power source is within a range of 10 MHz to 30 MHz;

an area of the substrate is equal to or greater than 1 m²;

a distance between the upper electrode and the lower electrode is within a range of 50 mm to 300 mm;

a processing pressure is set at a value within a range of 13 Pa to 27 Pa; and

the substrate is etched by using a process gas containing halogen.

29. The plasma processing apparatus according to claim 1, wherein:

the cathode electrode and the anode electrode respectively constitute a lower electrode and an upper electrode;

the frequency of the high-frequency power source is within a range of 10 MHz to 30 MHz;

an area of the substrate is equal to or greater than 1 m²;

a distance between the upper electrode and the lower electrode is within a range of 200 mm to 700 mm;

a processing pressure is set at a value within a range of 0.7 Pa to 13 Pa; and

the substrate is etched by using a process gas containing halogen.

30. The plasma processing apparatus according to claim 8, wherein:

an area of the substrate is equal to or greater than 1 m²;

the first high-frequency power source is connected to the upper electrode;

a distance between the upper electrode and the lower electrode is within a range of 50 mm to 300 mm;

a processing pressure is set at a value within a range of 13 Pa to 27 Pa; and

the substrate is etched by using a process gas containing halogen.

31. The plasma processing apparatus according to claim 15, wherein:

an area of the substrate is equal to or greater than 1 m²;

the first high-frequency power source is connected to the lower electrode;

a distance between the upper electrode and the lower electrode is within a range of 200 mm to 700 mm;

a processing pressure is set at a value within a range of 0.7 Pa to 13 Pa; and

the substrate is etched by using a process gas containing halogen.

32. A plasma processing method for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, wherein:

disposing a cathode electrode and an anode electrode so as to face opposite each other on an upper side and a lower side inside the processing chamber and insulating the cathode electrode and the anode electrode from the processing chamber;

connecting a high-frequency power source to one end of the cathode electrode via a matching circuit;

placing the substrate on either the cathode electrode or the anode electrode that is located on the lower side;

disposing an impedance adjustment unit containing a capacitive component with one end thereof connected to the anode electrode and another end thereof connected to the processing chamber; and

adjusting a value of impedance occurred in a path extending from the cathode electrode to a grounded casing of the matching circuit via the plasma, the anode electrode and a wall of the processing chamber to a level lower than a value of impedance occurred in a path extending from the cathode electrode to the grounded casing of the matching circuit via the plasma and the wall of the processing chamber by the impedance adjustment unit.

33. A plasma processing method for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, wherein:

disposing an upper electrode and a lower electrode so as to face opposite each other on an upper side and a lower side inside the processing chamber and insulating the upper electrode and the lower electrode from the processing chamber;

connecting a first high-frequency power source for supplying the high-frequency power within a range of 10 MHz to 30 MHz to one end of the upper electrode via a first matching circuit;

connecting a second high-frequency power source for supplying the high-frequency power within a range of 2 MHz to 6 MHz to one end of the lower electrode via a second matching circuit and;

placing the substrate on the lower electrode;

disposing a first impedance adjustment unit containing a capacitive component with one end thereof connected to the lower electrode and another end thereof connected to the processing chamber;

disposing a second impedance adjustment unit containing a capacitive component with one end thereof connected to the upper electrode and another end thereof connected to the processing chamber; and

adjusting a value of impedance occurred in a path extending from the upper electrode to a grounded casing of the first matching circuit via the plasma, the lower electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the upper electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the first impedance adjustment unit; and

adjusting a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and a wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the second impedance adjustment unit.

34. A plasma processing method for processing a substrate with plasma generated from a process gas by supplying high-frequency power into a processing chamber, wherein:

disposing an upper electrode and a lower electrode so as to face opposite each other on an upper side and a lower side inside the processing chamber and insulating the upper electrode and the lower the electrode from the processing chamber;

connecting a first high-frequency power source for supplying the high-frequency power within a range of 10 MHz to 30 MHz to one end of the lower electrode via a first matching circuit;

connecting a second high-frequency power source for supplying the high-frequency power within a range of 2 MHz to 6 MHz to one end of the lower electrode via a second matching circuit and;

placing the substrate on the lower electrode;

disposing a first impedance adjustment unit containing a capacitive component with one end thereof connected to the upper electrode and another end thereof connected to the processing chamber;

disposing a second impedance adjustment unit containing a capacitive component with one end thereof connected to the upper electrode and another end thereof connected to the processing chamber; and

adjusting a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the first matching circuit via the plasma, the upper electrode and a wall of the processing chamber by the high-frequency power of the first high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the first matching circuit via the plasma and the wall of the processing chamber by the first impedance adjustment unit; and

adjusting a value of impedance occurred in a path extending from the lower electrode to a grounded casing of the second matching circuit via the plasma, the upper electrode and a wall of the processing chamber by the high-frequency power of the second high-frequency power source to a level lower than a value of impedance occurred in a path extending from the lower electrode to the grounded casing of the second matching circuit via the plasma and the wall of the processing chamber by the second impedance adjustment unit.

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