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(71) **Applicant** *(for all designated States except US)*: **LAM RESEARCH CORPORATION** [US/US]; 4650 Cushing Parkway, Fremont, CA 94538 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **DHINDSA, Rajinder** [US/US]; 3670 Rollingside Drive, San Jose, CA 95148 (US). **SRINIVASAN, Mukund** [US/US]; 43484 Laurel Glen Common, Fremont, CA 94539 (US).

(74) **Agent: CHENG, Lie-Yea**; Martine Penilla & Gencarella, 710 Lakeway Drive, Suite 200, Sunnyvale, CA 94538 (US).

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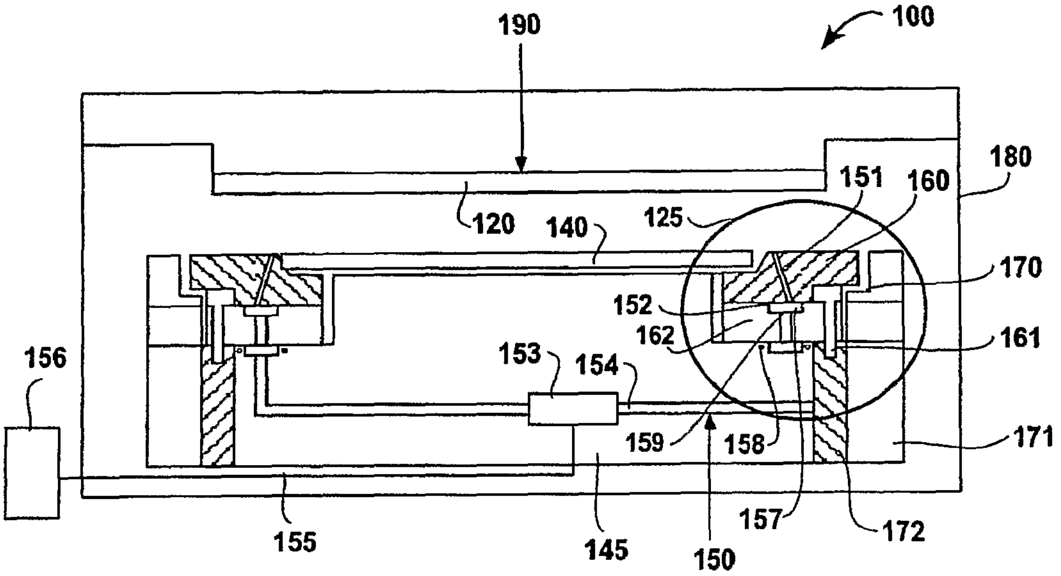

(57) **Abstract:** Broadly speaking, the embodiments of the present invention provides an improved plasma processing mechanism, apparatus, and method to increase the process uniformity at the very edge of the substrate. In an exemplary embodiment, a plasma processing chamber is provided. The plasma processing chamber includes a substrate support configured to receive a substrate. The plasma processing chamber also includes an annular ring having a plurality of gas channels defined therein. The annular ring is proximate to an outer edge of the substrate support and the annular ring is coupled to the substrate support. The plurality of gas channels is connected to an edge gas plenum surrounding the substrate support. The edge gas plenum is connected to a central gas plenum disposed within and near the center of the substrate support through a plurality of gas supply channels.

PROCESS TUNING GAS INJECTION FROM THE SUBSTRATE EDGE

By Inventors:
Rajinder Dhindsa and Mukund Srinivasan

BACKGROUND

[1] In the fabrication of semiconductor based devices (e.g. integrated circuits or flat panel displays), layers of material may alternately be deposited onto and etched from a substrate surface (e.g., the semiconductor wafer or the glass panel). As is well known in the art, the deposition of material layer(s) and etching of the material layer(s) may be accomplished by a variety of techniques, including plasma-enhanced deposition and etching. In plasma-enhanced deposition or etching, the actual deposition or etching of the substrate takes place inside a plasma processing chamber. During the deposition or etching process, a plasma is formed from a suitable source gas to deposit a material layer on the substrate or to etch areas of substrate that are unprotected by the etch mask, leaving behind the desired pattern.

[2] The shrinking feature sizes and the implementation of new materials in next generation of device fabrication on larger substrate sizes have challenged plasma etch and plasma deposition processing equipments to maintain the uniformities or process results from centers to the very edges of substrates. The larger sizes of the substrates and the smaller device sizes result in larger numbers of devices close to the very edges of the substrates (or wafers). This makes controlling of processing results at the very edges of substrates very critical.

[3] At the very edge of the substrate, the deposition or etching plasma non-uniformity increases due to a few factors. For example, during plasma etching, the etching by-product concentration at the substrate edge is different from the center of the substrate due to the lacking of etching by-product source beyond the substrate edge. The lower etching by-product concentration can affect the etching uniformity at the very edge of the substrate. In addition, the substrate temperature is different at the substrate edge. Conventional plasma etching system usually has a substrate cooling mechanism in the substrate support to cool the

substrate during etching process to maintain the substrate at a certain temperature. The very edge of the substrate sometimes hangs outside the substrate support and does not receive the same degree of cooling from the cooling mechanism in the substrate support as the rest of the substrate. The different substrate temperature at the very edge of the substrate can also increase the etching non-uniformity at the very edge of the substrate. Additionally, the etching gas concentration at the very edge of the substrate is different from the etching gas concentration over the rest of the substrate due to overloading of etching gas at the very edge of the substrate. The overloading is caused by less etching gas being consumed by the etching process at the very edge of the substrate compared to etching gas being consumed over the rest of the substrate. This overloading of etching gas can also increase the etching non-uniformity at the very edge of the substrate. The RF coupling effect at the very edge of the substrate is also different from the rest of the substrate due to the edge of the substrate overhanging the support and also due to the different material used for the edge ring that surrounds the substrate support. The different RF coupling effect can affect plasma generation efficiency and density and therefore can increase the etch non-uniformity at the very edge of the substrate.

[4] Although not affected by the same factors as plasma etching processes, plasma deposition processes also show increased edge non-uniformity. Typically, the edge non-uniformity affects up to 20 mm to 30 mm from the very edge of the substrate. The plasma uniformity within this region (20 mm to 30 mm from the very edge of the substrate) makes the deposition or etching uniformity much worse than the rest of the substrate, especially within about 10 mm to the very edge of the substrate. The poor edge uniformity renders the devices that are within about 10 mm to the very edge of the substrate non-usable.

[5] In view of the foregoing, there is a need for a method and apparatus that provides an improved plasma processing mechanism to increase the process uniformity at the very edge of the substrate to increase device yield of semiconductor substrates.

SUMMARY

[6] Broadly speaking, the present invention fills these needs by providing an improved plasma processing mechanism to increase the process uniformity at the very edge of the substrate. It should be appreciated that the present invention can be implemented in

numerous ways, including as a process, an apparatus, or a system. Several inventive embodiments of the present invention are described below.

[7] In one embodiment, a plasma processing chamber is provided. The plasma processing chamber includes a substrate support configured to receive a substrate. The plasma processing chamber also includes an annular ring having a plurality of gas channels defined therein. The annular ring is proximate to an outer edge of the substrate support and the annular ring is coupled to the substrate support. The plurality of gas channels is connected to an edge gas plenum surrounding the substrate support. The edge gas plenum is connected to a central gas plenum disposed within and near the center of the substrate support through a plurality of gas supply channels.

[8] In another embodiment, a tuning gas assembly for a plasma processing system is provided. The tuning gas assembly includes an annular ring having a plurality of tuning gas channels defined therein. The annular ring is proximate to an outer edge of the substrate support and the annular ring is coupled to a substrate support in the plasma processing system. The plurality of tuning gas channels supply a tuning gas approximate to an edge of the substrate support. The tuning gas assembly also includes an edge tuning gas plenum, wherein the plurality of tuning gas channels are connected to the edge gas plenum surrounding the substrate support. In addition, the tuning gas assembly includes a central tuning gas plenum disposed within and near the center of the substrate support through a plurality of tuning gas supply channels.

[9] In yet another embodiment, a method of improving plasma uniformity at an edge of a substrate in a plasma processing chamber is provided. The method includes supplying a process gas from a gas distribution plate disposed above a substrate support. The method also includes introducing a tuning gas containing at least one component of the processing gas from a bottom region of the plasma processing chamber towards an outer edge of the substrate, contemporarily with supplying the processing gas. The tuning gas is supplied by a central gas plenum disposed within the substrate support. In addition, the method includes generating plasma by powering at least one electrode in the process chamber.

[10] Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[11] The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings, and like reference numerals designate like structural elements.

[12] Figure 1 shows a schematic cross-sectional diagram of one embodiment of a substrate etching system.

[13] Figure 2 shows a top view of an embodiment of the tuning gas assembly.

[14] Figure 3A shows an embodiment of an enlarged area 125 of Figure 1.

[15] Figure 3B shows a process flow of using a process flow of using a tuning gas at the substrate edge to improve etch uniformity at the very edge of the substrate

[16] Figure 3C shows another embodiment of an enlarged area 125 of Figure 1.

[17] Figure 3D shows a process flow of using the tuning gas at the substrate edge to prevent substrate backside etch by-product deposition.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[18] Several exemplary embodiments for an improved plasma etching system, method and apparatus will now be described. It will be apparent to those skilled in the art that the present invention may be practiced without some or all of the specific details set forth herein. It will also be apparent to those skilled in the art that the present invention may be practiced for plasma deposition.

[19] As described earlier, due to increasing sizes of substrate and smaller feature sizes, a large number of devices exist on the very edge of substrate. Improving process uniformity at the very edge of substrate would improve yield of devices on the very edge of substrate. One embodiment of the present invention provides a process tuning gas source at the very edge of the substrate. For the following description of the various embodiments of the invention, we will use etching plasma as an example. However, the concept can apply to plasma deposition and plasma deposition chambers.

[20] For plasma etching processes, the etch rates tend to drop significantly at the very edge of the substrate due to factors such as different etching by-product concentration, different substrate temperature, different etching gas concentration, and different RF coupling effect at the very edge of substrate. To increase the etching rate at the very edge of substrate, many schemes have been tried, including using dual-gas feed to supply different concentrations of reactive gas(es) from the center and the edge of the gas distribution plate. Although dual-gas feed improves the etching rate at the very edge of substrate, improvement are provided through the embodiment described herein. Further details of dual-gas feed is described in commonly assigned U.S. Patent No. 6.432,831, titled "Gas Distribution Apparatus for Semiconductor Processing," issued on August 13, 2002.

[21] In one embodiment, a process tuning gas is supplied from a tuning gas source right next to the edge of the substrate. Figure 1 shows a cross-sectional view of a plasma processing apparatus 100 that has a tuning gas source surrounding the substrate support. This embodiment includes a substrate support 145, which is also an electrode, that is composed of a conductive material and is operatively coupled to a power supply (not shown). The RF power supply may be a multiple frequency power supply. For example, the power source can have a mixture of frequencies at 2 MHz, 27 MHz, and/or 60 MHz. Plasma may be generated when RF power is communicated to the electrode (or substrate support 145) to the process gas inside the process chamber. The process gas is supplied to the process chamber through gas feed 190 to the gas distribution plate 120, which may also be an electrode.

[22] Surrounding the substrate support 145 is an edge ring 160 that provides tuning gas injection channels 151, which is part of the tuning gas assembly 150. The edge ring 160 may be made of semi-conductive material, such as silicon, or made of insulator. Below the edge ring 160 is a coupling ring 162, which houses an edge tuning gas plenum 152 and tuning gas supply channels 154. The edge tuning gas plenum 152 and the tuning gas supply channels are also part of the tuning gas assembly 150. The coupling ring 162 may be made of dielectric material, such as quartz. The coupling ring 162 provides connection between the edge ring 160 and the lower end of the substrate support 145.

[23] In one embodiment, spacer ring 170 is disposed next to the edge ring 160. The spacer ring 170 may be made of insulator, such as quartz. The spacer ring is disposed above a

insulating material 171. The insulating material 171 may be made of insulator, such as quartz. The insulating material 171 is coupled to a peripheral ring 172, which allows the insulating material 171 to be attached to the substrate support 145. The peripheral ring may be made of insulator, such as ceramic. The edge ring 160, the coupling ring 162 and the peripheral ring 172 any be secured together by a securing device 161. In one embodiment the securing device 161 may be a bolt. One skilled in the art will appreciate that only suitable securing devices may be used here.

[24] The tuning gas supply channels 154 intersect the edge tuning gas plenum 152 at junctions 159. At the interface between the coupling ring 162 and the lower portion of substrate support 145, there may be an optional interfacial plenum 157. The coupling ring is secured to the substrate support 145 by a securing device 158. Tuning gas supply channels 154 are connected to a central tuning gas plenum 153, which is disposed within the substrate support 145. Tuning gas(es) is supplied from a tuning gas container(s) 156 to the central tuning gas plenum 153 through a tuning gas line 155. The tuning gas described here could be a single gas or a mixture of gases. It should be appreciated that there may be more than one tuning gas container, if more than one type of tuning gases are used.

[25] The substrate 140 may be electrostatically clamped or "chucked" to the substrate support 145 using well-known systems and methods. These well-known systems and methods include coating the substrate support 145 (or electtode) with a dielectric material that incorporates high-voltage electrodes (not shown) for chucking and dechucking purposes.

[26] Figure 2 shows an embodiment of a top view of the tuning gas supply assembly 150. The central tuning gas plenum 153 receives the supply of tuning gas from the tuning gas container 156 through a tuning gas line 155. The central tuning gas plenum 153 supplies tuning gas to the edge tuning gas plenum 152 through six tuning gas supply channels 154, which are distributed evenly around the central tuning gas plenum 253. It should be appreciated that there could be more than six or less than six of tuning gas supply channels 154. The tuning gas supply channels 154 are distributed evenly around the circumference of the central tuning gas plenum 153. The tuning gas supply channels 154 intersect with the edge tuning gas plenum 152 at junctions 159. On the top surface edge tuning gas plenum and also at the bottom of the tuning gas injection channels 151 are the bottoms of tuning gas injection channels 151_B. The tops of the tuning gas injection channels 151_T and the tuning

gas injection channels 151 are also shown in Figure 2. As shown in the Figures 2, there could be many tuning gas injection channels. In one embodiment, the number of tuning gas injection channels 151 may range between about 12 to about 1200. Typically, the tuning gas injection channels are cylinders with diameters between about 0.3 mm to about 5 mm. In one embodiment, the diameter of the injection channel 151 is 0.5 mm. However, the tuning gas injection channels do not have to be cylindrical and can be in other shapes, such as a cone or inverted cone. The embodiment in Figure 2 shows that the tuning gas injection channels 151 point toward the center of the substrate. However, the tuning gas injection channels 151 do not necessary point toward the center of the substrate. As long as the channels 151 point to the edge (or circumference) of the substrate, the tuning gas can be delivered to the desired region, which is the edge of the substrate. The tuning gas is supplied to central tuning gas plenum 153 first to uniformly distribute the tuning gas to the edge tuning gas plenum 152.

[27] Figure 3A shows an embodiment of an enlarged view of circle 125 of Figure 1. In this embodiment, the tuning gas injection channels 151A is drilled at an angle α from the vertical axis X. The angle α can be between about 0 degree to about 60 degrees, preferably between about 10 degrees to about 30 degrees. The angle α of the tuning gas injection channels 151A affects the direction of the tuning gas being carried on the substrate surface, and, therefore, affects how the tuning gas is distributed near the edge of the substrate. The tuning gas is directed toward a region 175 above the surface of the edge of the substrate. Using high aspect ratio contact (HARC) etch as an example, the processing gas for HARC includes gases, such as O_2, CF_4, C_4F_6, C_4F_8 and Ar. C_4F_6 and C_4F_8 are polymerizing gases that help to make sidewall polymers to protect the etched contact sidewall. Additional tuning gas, such as O_2, CF_4, C_4F_6, C_4F_8, Ar, or a combination of these gases, may be supplied to the edge of the substrate to improve the etch uniformity at the very edge of the substrate. In one embodiment, the flow rate may be between about 1 sccm to about 20 sccm. Another example is photoresist ashing where oxygen is the main reactive gas in photoresist ashing. Therefore, O_2 can be used as tuning gas in the embodiments described herein. The flow rate of O_2 tuning gas may be between about 1 sccm to about 20 sccm in one embodiment. The O_2 tuning gas can also be diluted with an inert gas, such as He.

[28] Figure 3B shows a process flow of using a tuning gas at the substrate edge to improve etch uniformity at the very edge of the substrate. At operation 301, an etching gas (or gas

mixture) is supplied to the plasma process chamber from the main gas source, such as from the gas distribution plate, and also from the tuning gas injection holes. At operation 303, an etching plasma is generated by powering the electrode(s). With the introduction of the tuning gas, the etch rate at the substrate edge can be increased and etch uniformity at the very edge of substrate can be improved. Typically, the edge non-uniformity renders the devices that are within about 10 mm to the very edge of the substrate non-usable. However, the edge non-uniformity affects up to 20 mm to 30 mm from the very edge of the substrate. With the introduction of the tuning gas, the edge non-uniformity can be greatly improved, or even completely eliminated.

[29] Figure 3C shows another embodiment of an enlarged view of circle 125 of Figure 1. The tuning gas injection channels can be used to supply inert gas to the region 126 below the substrate 140 to prevent deposition of etch by-product in the exposed region 126 below the substrate 140. In this embodiment, the tuning gas injection channels 151B is drilled at an angle β from the vertical axis X. The angle β can be between about 0 degree to about 90 degrees, preferably between about 30 degrees to about 60 degrees. The angle β of the tuning gas injection channels 151B affects the direction of the inert gas being carried on the substrate surface and therefore affects how the inert gas is distributed near the backside of the edge of the substrate. The tops of the tuning gas injection channels $151B_T$ are below the substrate 140. The tops of tuning gas injection channels direct the inert gas toward an exposed region 127 at the edge of the substrate and right below the edge of the substrate to prevent etch by-product entering the exposed region 126 below the edge of the substrate 140 to thereby precluding backside deposition. Etch by-product (polymer) deposited on the backside of substrate, also called bevel polymer, is very hard to clean and can generate particles. Inert gas, such as He or Ar, can be supplied to the tuning gas injection channels 151B. In one embodiment, the inert gas can be flowed at a total flow rate between about 10 sccm to about 200 sccm.

[30] Figure 3D shows a process flow of using the tuning gas at the substrate edge to prevent substrate backside etch by-product deposition. At operation 305, an etching gas (or gas mixture) is supplied to the plasma process chamber from the main gas source, such as from the gas distribution plate, and an inert gas is supplied from the tuning gas injection holes to the exposed region below the edge of the substrate. At operation 307, an etching

plasma is generated by powering the electrode(s) and the inert gas is injected to the exposed region below the edge of the substrate to prevent the etch by-product from depositing in the exposed region below the edge of the substrate. With the introduction of the inert gas in the exposed region below the edge of the substrate, etch by-product deposition in that exposed region can be greatly reduced or completedly eliminated.

[31] The concept of the injection of tuning gas toward the edge of the substrate from a bottom region of the chamber can be used any processing chamber. Even non-plasma processing chambers used for depositing or etching substrates can utilize this concept. For plasma processing chamber, the plasma source can be inductive, capacitive or a combination of both inductive and capacitive. The concept of the invention can be used for processing any type of substrates, including, but not limited to, semiconductor substrates, flat panel displays and solar panels.

[32] Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. Accordingly, the present embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

What is claimed is:

Claims

1. A plasma processing chamber, comprising:

a substrate support configured to receive a substrate; and

an annular ring having a plurality of gas channels defined therein, the annular ring proximate to an outer edge of the substrate support and the annular ring is coupled to the substrate support, the plurality of gas channels being connected to an edge gas plenum surrounding the substrate support, the edge gas plenum being connected to a central gas plenum disposed within and near the center of the substrate support through a plurality of gas supply channels.

2. The plasma processing chamber of claim 1, wherein the plurality of gas channels are cylindrical and the diameters of the plurality of gas channels are between about 0.3 mm to about 5 mm.

3. The plasma processing chamber of claim 1, wherein each of the plurality of gas channels is pointed toward the center of the substrate at an angle between about 0 degree to about 60 degree from a vertical axis of the each of the plurality of gas channels.

4. The plasma processing chamber of claim 1, wherein there are at least 12 gas channels.

5. The plasma processing chamber of claim 1, wherein there are at least 6 gas supply channels.

6. The plasma processing chamber of claim 1, wherein the plurality of gas channels are configured to direct a process tuning gas to be carried to a region above a surface of an edge of the substrate.

7. The plasma processing chamber of claim 1, wherein the processing tuning gas includes at least one processing gas.

8. The plasma processing chamber of claim 1, wherein the plurality of gas channels are configured to direct an inert gas to be carried to an exposed region below an edge of the substrate.

9. A tuning gas assembly for a plasma processing system, comprising:

an annular ring having a plurality of tuning gas channels defined therein, the annular ring approximate to an outer edge of the substrate support and the annular ring is coupled to a substrate support in the plasma processing system, wherein the plurality of tuning gas channels supply a tuning gas approximate to an edge of the substrate support;

an edge tuning gas plenum, wherein the plurality of tuning gas channels are connected to the edge gas plenum surrounding the substrate support; and

a central tuning gas plenum disposed within and near the center of the substrate support through a plurality of tuning gas supply channels.

10. The tuning gas assembly of claim 9, wherein the plurality of tuning gas channels are cylindrical and the diameters of the plurality of tuning gas channels are between about 0.3 mm to about 5 mm.

11. The tuning gas assembly of claim 9, wherein each of the plurality of tuning gas channels is pointed toward the center of the substrate at an angle between about 0 degree to about 60 degree from a vertical axis of the each of the plurality of tuning gas channels.

12. The tuning gas assembly of claim 9, wherein there are at least 12 tuning gas channels.

13. The tuning gas assembly of claim 9, wherein there are at least 6 tuning gas supply channels.

14. The tuning gas assembly of claim 9, wherein the plurality of tuning gas channels are configured to direct a process tuning gas to be carried to a region above a surface of an edge of a substrate supported by the substrate support.

15. The plasma processing chamber of claim 9, wherein the plurality of tuning gas channels are configured to direct an inert gas to be carried to an exposed region below an edge of a substrate supported by the substrate support.

16. The plasma processing chamber of claim 10, wherein the plurality of tuning gas injection holes are configured to direct the tuning gas to be carried to an exposed region at the edge of the substrate and right below the edge of the substrate

17. A method of improving plasma uniformity at an edge of a substrate in a plasma processing chamber, comprising method operations of:

supplying a process gas from a gas distribution plate disposed above a substrate support;

contemporarily with supplying the processing gas, introducing a tuning gas containing at least one component of the processing gas from a bottom region of the plasma processing chamber towards an outer edge of the substrate, wherein the tuning gas is supplied by a central gas plenum disposed within the substrate support; and

generating plasma by powering at least one electrode in the process chamber.

18. The method of claim 17, wherein the tuning gas increases the plasma density at the end of the substrate.

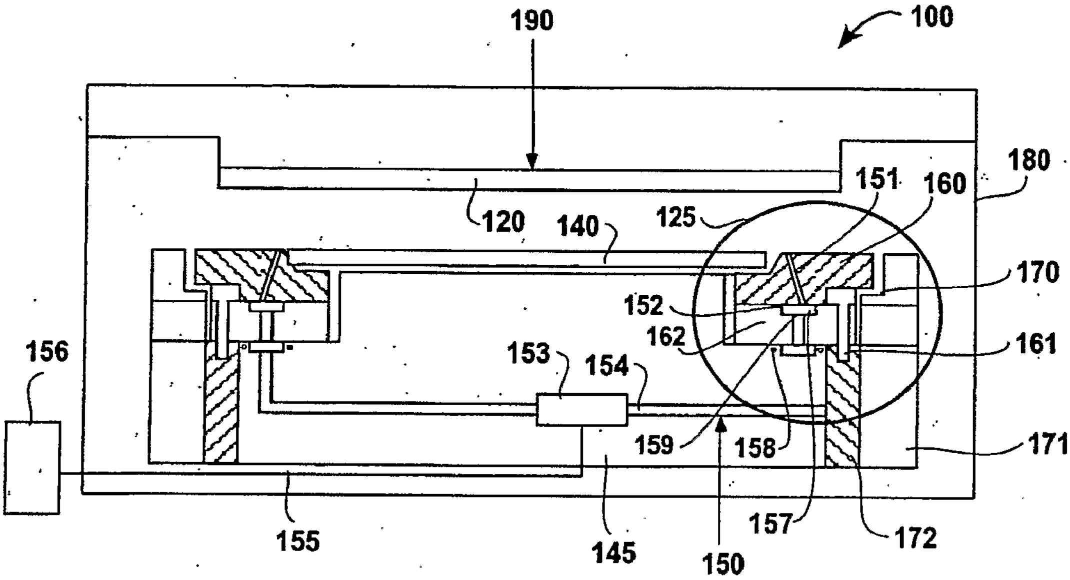
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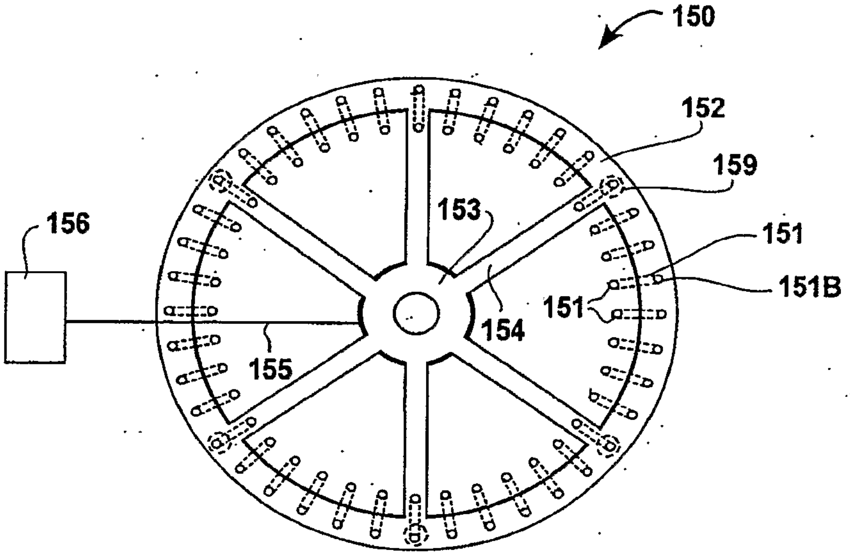
FIG. 1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151B
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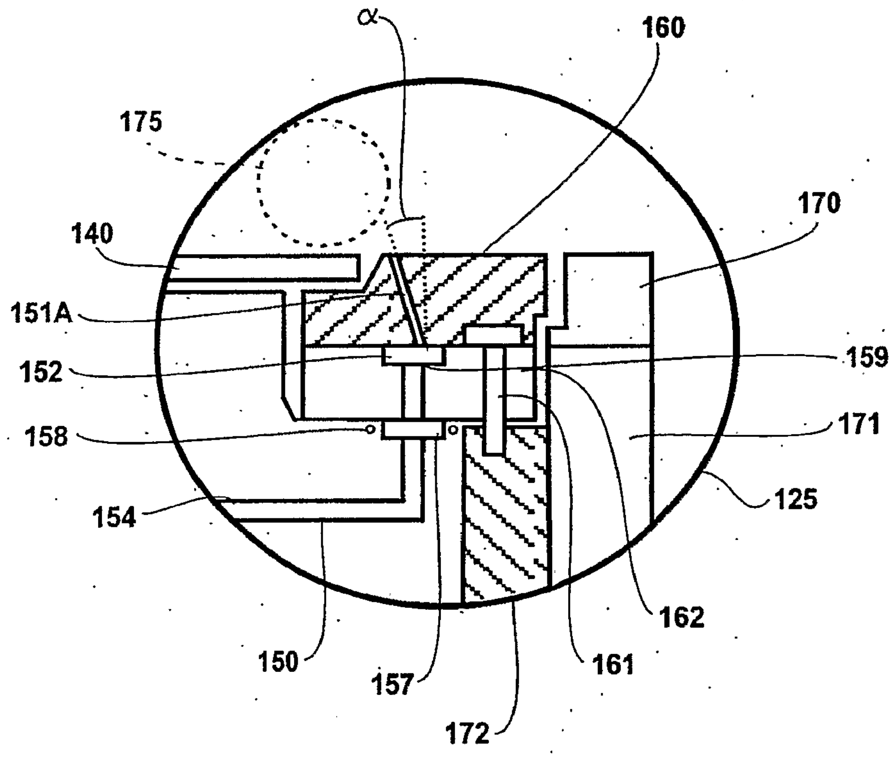
FIG. 2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151A
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150
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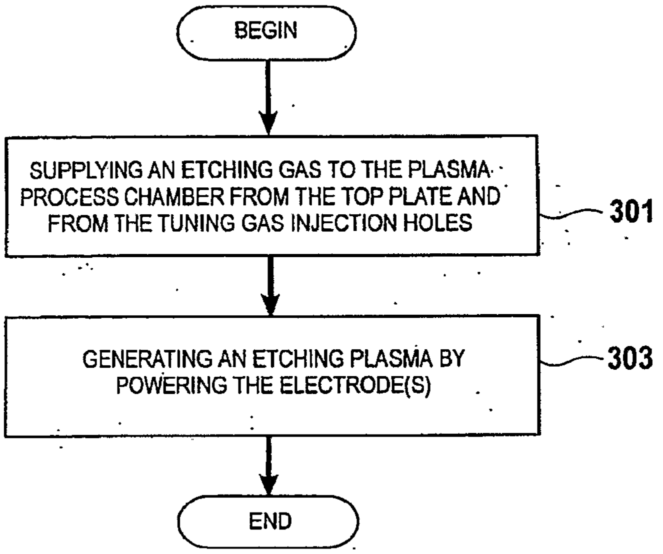
161
172

FIG. 3A


BEGIN
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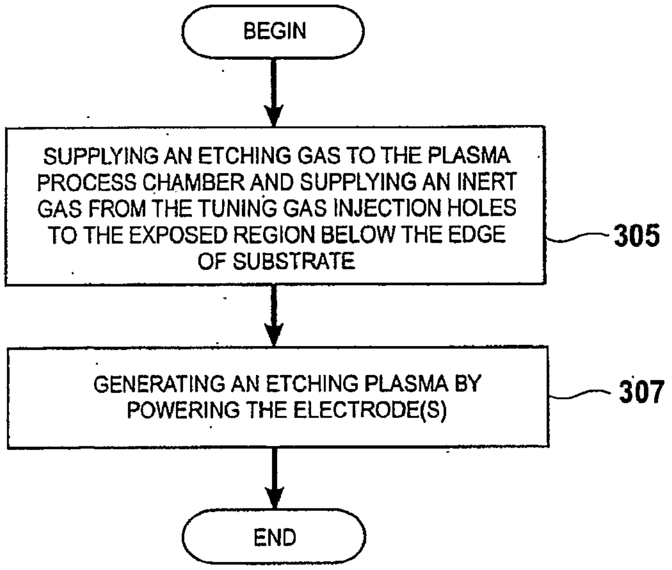
301
GENERATING AN ETCHING PLASMA BY POWERING THE ELECTRODE(S)
303
END

FIG. 3B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SUPPLYING AN ETCHING GAS TO THE PLASMA PROCESS CHAMBER AND SUPPLYING AN INERT GAS FROM THE TUNING GAS INJECTION HOLES TO THE EXPOSED REGION BELOW THE EDGE OF SUBSTRATE
305
GENERATING AN ETCHING PLASMA BY POWERING THE ELECTRODE(S)
307
END

FIG. 3C

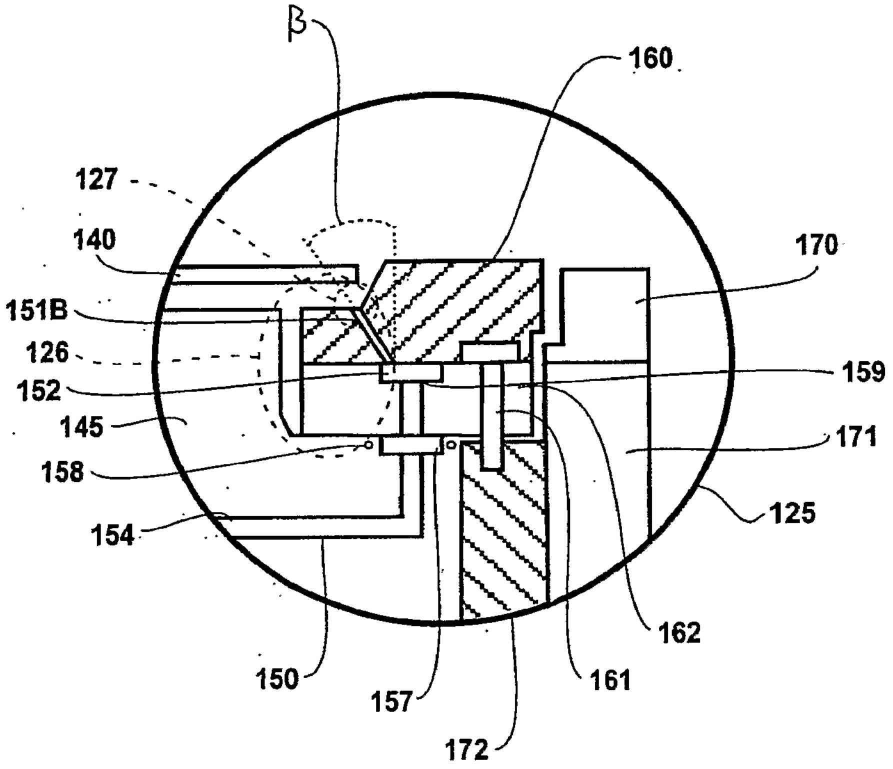
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FIG. 3D