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(54) **Title:** ELECTROSTATICALLY CLAMPED EDGE RING FOR PLASMA PROCESSING

(57) **Abstract:** A coupling ring assembly including an edge ring supported by an electrostatic edge ring chuck and a method of improving the temperature control of an edge ring in a plasma processing chamber. The edge ring can be made of a conductive material such as silicon or silicon carbide and temperature control of the edge ring can be enhanced by supplying heat transfer gas such as helium between opposed surfaces of the edge ring and the edge ring chuck.

Electrostatically Clamped Edge Ring for Plasma Processing

Field of the Invention

The present invention relates to an improved apparatus and method for plasma processing and, in particular, an improved apparatus and method for plasma etching semiconductor substrates.

Background of the Invention

In the field of semiconductor processing, vacuum processing chambers are generally used for etching and chemical vapor deposition (CVD) of materials on substrates by supplying an etching or deposition gas to the vacuum chamber and application of an RF field to the gas to energize the gas into a plasma state. Examples of parallel plate, transformer coupled plasma (TCP^{TM}) which is also called inductively coupled plasma (ICP), and electron-cyclotron resonance (ECR) reactors and components thereof are disclosed in commonly owned U.S. Patent Nos. 4,340,462; 4,948,458; 5,200,232 and 5,820,723. U.S. Patent No. 4,793,975 also discloses a parallel plate plasma reactor.

During processing of semiconductor substrates, the substrates are typically held in place within the vacuum chamber on substrate holders by mechanical clamps and electrostatic clamps (ESC). Examples of such clamping systems and components thereof can be found in commonly owned U.S. Patent Nos. 5,262,029 and 5,838,529. An example of a monopolar chuck can be found in U.S. patent No. 4,665,463 and examples of bipolar chucks can be found in U.S. Patent Nos. 4,692,836 and 5,055,964. In order to cool the substrates, cooling gas such as helium can be supplied to the backside of the substrate. Examples of such cooling can be found in U.S. Patent Nos. 5,160,152; 5,238,499; 5,350,479; and 5,534,816.

Substrate supports can include consumable (sacrificial) edge rings around the substrate for purposes of confining plasma to the area above the wafer and/or protect the ESC from erosion by the plasma. For instance, an edge ring arrangement is described in commonly owned U.S. Patent Nos. 5,805,408, 5,998,932 and 6,013,984. Other examples of edge ring arrangements can be found in U.S. Patent Nos. 5,494,523; 5,986,874; 6,022,809; 6,096,161; and 6,117,349.

In plasma processing arrangements wherein a sacrificial ring surrounds a wafer, it would be desirable to improve the thermal contact between the ring and an underlying portion of the substrate support. By improving thermal coupling, improved temperature control of the ring could be realized and the clearances required between the ring and the wafer could be reduced. It would also be desirable if the RF impedance path from the baseplate to the plasma in the area above the wafer could be more closely matched to the RF impedance path from the baseplate to the plasma in the area of the edge ring in order to improve plasma uniformity near the edge of the wafer.

Summary of the Invention

The present invention provides a coupling ring assembly adapted to surround a substrate support in a plasma reaction chamber. The coupling ring assembly comprising a member having an annular support surface and an electrostatic chuck on the support surface.

The present invention also provides a plasma reaction chamber comprising a wafer support on which a wafer to be processed can be mounted and an electrostatic edge ring chuck on which an edge ring can be supported during processing. In a preferred embodiment of the plasma reaction chamber, the substrate support comprises a baseplate having an electrostatic wafer chuck on an upper surface thereof. In another preferred embodiment of the plasma reaction chamber, the edge ring chuck is part of a coupling ring assembly.

The present invention also provides a method of treating a semiconductor substrate such as a wafer in a plasma chamber wherein the plasma chamber comprises a substrate support, an electrostatic wafer chuck on an upper surface of the substrate support and an electrostatic edge ring chuck on which an edge ring can be supported. In a preferred embodiment, the method comprises the steps of electrostatically clamping a wafer to the wafer chuck, electrostatically clamping an edge ring to the edge ring chuck, supplying a process gas to the interior of the plasma chamber, energizing the process gas into a plasma state, and processing the wafer with the plasma.

Brief Description of the Drawings

FIGURE 1 is a partial view of a parallel plate plasma processing apparatus according to the present invention;

FIGURE 2 is a partial view of a plasma chamber comprising an edge ring chuck mounted on a coupling ring according to one embodiment of the present invention;

FIGURE 3 is a partial view of a plasma chamber comprising an edge ring chuck mounted on a baseplate according to another embodiment of the present invention;

FIGURE 4 is a partial view of a plasma chamber according to the invention comprising an integral edge ring/wafer chuck mounted on a baseplate; and

FIGURE 5 is a partial view of a plasma chamber according to another embodiment of the invention comprising an edge ring adapted to fit into a groove in the baseplate between the wafer and edge ring chucks.

Detailed Description of the Preferred Embodiments

The invention provides an improved substrate support arrangement for a plasma reactor wherein a sacrificial edge ring surrounds a semiconductor substrate such as a silicon wafer. In arrangements wherein an edge ring merely rests on the underlying substrate support and is held in place by gravity and/or frictional engagement with the substrate support, the ring can become very hot during plasma processing of the substrate. In the case where the substrate overlies a portion of the edge ring, the thermal expansion of the edge ring during plasma processing makes it necessary to provide sufficient clearance between the edge ring and the substrate so that the hot edge ring does not lift the substrate off of the substrate support. In the case where an electrostatic chuck is used to secure the substrate to a substrate support comprising a powered electrode which supplies an RF bias to the substrate, the RF impedance path from the powered electrode through the ESC and substrate to the plasma can be different than the RF impedance path from an outer portion of the powered electrode through the edge ring to the plasma and thus cause a nonuniform plasma density at the edge of the substrate The invention overcomes such problems by providing an electrostatic edge ring chuck which improves thermal coupling of the edge ring to the substrate support. In addition, by selecting materials for the edge ring chuck and edge ring according to the invention, it is possible to provide more uniformity of the plasma density across the substrate due to improved RF impedance path matching.

FIGURE 1 shows a parallel plate plasma reaction chamber 10 according to one embodiment the invention. The apparatus comprises an upper electrode 11 and a lower electrode assembly 12. The lower electrode assembly comprises a baseplate 13 and an electrostatic wafer chuck 14 mounted on an upper surface thereof. A coupling ring 15 rests on a flange 16 of the baseplate. The coupling ring 15 has an edge ring chuck 17 mounted on an upper surface thereof. An edge ring 18 is supported on the exposed upper surface of the edge ring chuck 17. A wafer 19 is mounted on the wafer chuck 14 such as to overlap the wafer chuck and the inner surface of the edge ring 18. The wafer 19 overlaps the edge of the wafer chuck so that the exposure of the edge of the wafer chuck 14 to the ions in the plasma is reduced. The exposure of the edges of the wafer chuck 14 to the plasma can cause erosion thereby reducing the life of the chuck 14. An edge ring 18 surrounds the wafer chuck 14 to further protect the edges of the wafer chuck 14 from ions in the plasma. The edge ring 18 is a consumable or replaceable part. The wafer 19 overhangs the wafer chuck 14 and a portion of the edge ring 18 extends under the edge of the wafer 19. Typically, the wafer 19 overhangs the edge of the wafer chuck 14 by 1 to 2 mm. In order to provide a greater degree of protection to the wafer chuck 14, the top of the edge ring 18 is positioned as closely as possible to the underside of the wafer 19. The expansion of the edge ring during processing requires a clearance gap between the underside of the wafer and the edge ring. If the edge ring is placed too close to the wafer backside, the thermal expansion of the edge ring during processing can actually force the wafer off of the chuck, aborting the process.

FIGURE 2 is an enlarged view of the lower electrode assembly 12 of FIGURE 1. The wafer 19 is shown overlapping the edge ring 18 to form a gap or clearance 23 between the wafer backside and the edge ring 18. The inner edge of the edge ring 18 abuts the outer edge of the wafer chuck 14 thus maintaining the edge ring 18 in a desired position with respect to the wafer 19. As shown, the edge ring 18 rests on a coupling ring assembly which comprises a coupling ring 15 and an electrostatic edge ring chuck 17 secured to an upper surface thereof. The edge ring chuck 17 can extend completely across the coupling ring 15 or the edge ring chuck 17 can be located in a recess in the upper surface of the coupling ring 15. The coupling ring 15 can be supported on the base plate 13 with or without mechanical or adhesive fastening such as a plurality of bolts 24. The edge ring chuck 17 can be supplied with DC power by a suitable power supply arrangement such as a DC power supply 26 using a lead wire 28 extending through a passage in one of the bolts 24. In order to improve thermal transfer between the edge ring 15 and the base plate 13, a heat transfer gas such as He or process gas from a gas source 30 can be supplied via gas passage 32 to the interface between the coupling ring 15 and the base plate 13 and/or between the edge ring chuck 17 and the edge ring 18. The gas passage 32 can extend through the base plate 13 and coupling ring 15 at one or more locations spaced around the base plate 13, e.g., extending through passages in the bolts 28. The edge ring chuck 17 can be a mono-polar or bi-polar chuck.

FIGURES 3 - 5 show variations of another embodiment of the present invention wherein the edge ring chuck is mounted on the base plate rather than on a coupling ring. As shown in FIGURE 3, an edge ring chuck is supported on the baseplate 32 and a wafer chuck 36 supports a wafer 38. To promote heat transfer, a gas supply 30 can supply a heat transfer gas through gas passage 32 into an interface between the edge ring chuck 34 and the edge ring 30.

FIGURE 4 shows another embodiment of the plasma chamber of the invention comprising an integral (one-piece) wafer and edge ring chuck. As shown, a peripheral portion of the upper surface of the integral wafer/edge ring 40 chuck is recessed to allow a wafer 42 mounted on a central portion of the chuck to overlap an edge ring 44 mounted on the peripheral portion of the chuck. The electrode of the edge ring chuck is shown powered by a DC power supply 46. The internal electrode (mono-polar) or electrodes (bi-polar) of the edge ring portion of the chuck are preferably electrically isolated from the internal electrode or electrodes of the wafer portion of the chuck.

FIGURE 5 shows another embodiment of the plasma chamber of the present invention wherein the edge ring chuck 50 and the wafer chuck 52 are mounted directly on baseplate 54 such that the upper surfaces of the edge ring and wafer chucks 50, 52 are approximately coplanar. A groove 56 on baseplate 54 separates the edge ring and wafer chucks 50, 52. The edge ring 58 has an axially extending portion 60 configured to engage the groove in the baseplate 56 and a radially extending portion 62. A lower surface of the radially extending portion 62 rests on the edge ring chuck 50. The axially extending portion of the edge ring 60 is sized to allow for expansion of the edge ring during processing. The axially and radially extending portions of the edge ring 60, 62 are connected by a transition portion 64 which is configured to allow a wafer 66 to overlap an inner surface of the edge ring 58. As with the other embodiments, the underside of the edge ring 58 is supplied with a heat transfer gas 68. The interfaces between the axially extending portion of the edge ring 60 and the groove in the baseplate 56 can also be provided with heat transfer gas to further improve thermal coupling of the baseplate and edge ring.

Better temperature control of the edge ring results in numerous process advantages. First, controlling the temperature of the edge ring reduces the amount of thermal expansion of the edge ring and thus allows for smaller clearances between the top of the edge ring and the underside of the wafer. For example, when the edge ring merely rests on the underlying coupling ring or substrate support, the clearance between the backside of the wafer and the edge ring is typically in the range of 0.005 or 0.006 inches. With an electrostatically clamped edge ring, however, this clearance can be reduced to 0.002 to 0.003 inches. By reducing the clearance between the edge ring and the wafer, the edge of the wafer chuck is protected to a greater degree from erosion by the plasma. Further, the tendency of particles generated during plasma processing to build up on the edge of the chuck is reduced. Particle build-up can prevent the wafer from uniformly contacting the wafer chuck resulting in diminished clamping capacity. Reducing the temperature of the edge ring can also increase the longevity of the edge ring since the chemical reaction rates of the edge ring material with the ions in the plasma will be lower at lower temperatures.

Using an electrostatic chuck to clamp the edge ring can also lead to improvements in wafer etch characteristics. Improvements in etch uniformity can result from both matching the temperature of the wafer and edge ring as well as from matching the RF impedance path through the wafer and the edge ring. First, if the wafer and edge ring are similar in temperature during processing, the etch characteristics can be made more uniform near the edge of the wafer. Second, by using an edge ring chuck made of the same materials as the wafer chuck, the impedance path from the RF powered base plate through the hot edge ring can be made more similar to the impedance path from the RF powered base plate through the wafer. This is particularly true when the wafer and edge ring are made from the same material (e.g., silicon). The current density in the plasma region adjacent the wafer and edge ring surfaces is influenced by the RF impedance of these surfaces. By matching the RF impedance of the edge ring and wafer, the current flow from the plasma to the wafer surface can be made more uniform near the edge of the wafer thus improving the plasma uniformity and etch performance of the reactor.

Electrostatically clamping the edge ring can also result in reduced costs of operating plasma processing equipment when compared to other methods of securing the edge ring such as adhesive bonding or mechanical fastening. For example, since there is no need to bond the edge ring to another member, the cost of the consumable edge ring can be reduced. Also, with electrostatic clamping, the edge ring has no exposed screw heads that are covered in a separate step prior to operating the equipment.

The edge ring can be made from any conductive material including, but not limited to, silicon, silicon nitride, silicon carbide and aluminum nitride. The edge ring material is preferably the same as the wafer material in order to improve RF coupling uniformity.

The edge ring chuck can be made from any suitable material such as those used in conventional electrostatic wafer chucks including anodized aluminum, polyimides and ceramic materials. The edge ring chuck is preferably made from a ceramic material such as alumina or aluminum nitride. The electrode or electrodes of the edge ring chuck can be made from any suitable conductive material. With sintered ceramic chucks, the electrodes are preferably made from a refractory metal such as tungsten or molybdenum which can withstand the high temperatures encountered during sintering. The edge ring chuck can be made by a sintering process such as sandwiching a refractory metal electrode (tungsten ink) between two ceramic green sheets and firing to form the sintered structure. The edge ring chuck can be of the coulombic (fully insulating) or Johnsen-Rahbeck type (semi-conducting).

The edge ring chuck may be secured to the coupling ring or substrate support using any of the methods and materials known in the art for securing wafer chucks. The edge ring chuck, for example, may be secured using a high temperature polymer adhesive such as a silicone adhesive.

Although the present invention has been described in connection with preferred embodiments thereof, it will be appreciated by those skilled in the art that additions, deletions, modifications, and substitutions not specifically described can be made without departing from the spirit and scope of the invention as defined in the appended claims.

<u>What is claimed is</u>:

1. A coupling ring assembly adapted to surround a substrate support in a plasma reaction chamber, said coupling ring assembly comprising:

a member having an annular support surface; and

an electrostatic chuck on the support surface.

2. The coupling ring assembly of claim 1, wherein the electrostatic chuck comprises a ceramic body with one or more embedded electrodes.

3. The coupling ring assembly of claim 1, wherein the electrostatic chuck is bonded to the support surface with an adhesive.

4. The coupling ring assembly of claim 1, further comprising at least one gas passage extending through the member and the electrostatic chuck, the gas passage being adapted to supply a heat transfer gas to an exposed surface of the electrostatic chuck.

5. The coupling ring assembly of claim 1, further comprising an edge ring adapted to be clamped to the member by the electrostatic chuck.

6. A plasma reaction chamber, comprising:

a substrate support on which a wafer to be processed can be mounted; and

an electrostatic edge ring chuck on which an edge ring can be supported during processing.

7. The plasma chamber of claim 6, wherein the substrate support comprises a baseplate having an electrostatic wafer chuck on an upper surface thereof.

8. The plasma chamber of claim 6, wherein the edge ring chuck is part of a coupling ring assembly comprising an annular base with the electrostatic edge ring chuck on an upper surface of the annular base and wherein a lower surface of the annular base contacts an upper surface of the substrate support.

9. The plasma chamber of claim 7, wherein an upper surface of the wafer chuck is higher than an upper surface of the edge ring chuck.

10. The plasma chamber of claim 7, further comprising a groove in the baseplate between the wafer and edge ring chucks.

11. The plasma chamber of claim 6, further comprising an edge ring supported on the edge ring chuck such that a lower surface of the edge ring is in contact with the edge ring chuck.

12. The plasma chamber of claim 11, wherein the edge ring comprises an electrically conductive material.

13. The plasma chamber of Claim 12, wherein the edge ring comprises silicon.

14. The plasma chamber of claim 11, wherein the edge ring includes a recess on an inside edge of an upper surface thereof and wherein the recess is adapted to fit beneath a wafer mounted on the wafer chuck.

15. The plasma chamber of claim 7, wherein the baseplate comprises an electrically conductive material.

16. The plasma chamber of claim 15, wherein the baseplate is an RF driven

electrode.

17. The plasma chamber of claim 7, further comprising an edge ring supported on the edge ring chuck such that a lower surface of the edge ring is in contact with the edge ring chuck.

18. The plasma chamber of claim 17, wherein the plasma reaction chamber comprises a parallel plate reactor having an upper electrode facing the baseplate.

19. The plasma chamber of claim 18, further comprising a wafer mounted on the wafer chuck such that the outer edge of the wafer overhangs the edge ring with a clearance gap between the lower surface of the wafer and an upper surface of the edge ring.

20. The plasma chamber of claim 19, wherein the wafer overhangs the inner edge of the edge ring.

21. The plasma chamber of claim 19, wherein the clearance gap has a maximum spacing of about 0.002 to about 0.003 inches.

22. The plasma chamber of claim 8, wherein the coupling ring assembly is bolted or screwed to the substrate support.

23. The plasma chamber of Claim 6, wherein the plasma chamber is a semiconductor etching apparatus.

24. A method of treating a semiconductor substrate in the plasma chamber of claim 7, said method comprising the steps of:

electrostatically clamping a wafer to the wafer chuck;
electrostatically clamping an edge ring to the edge ring chuck;
supplying a process gas to the interior of the plasma chamber;
energizing the process gas into a plasma state; and
processing the wafer with the plasma.

25. The method of claim 24, further comprising controlling the temperature of the edge ring by supplying a heat transfer gas between opposed surfaces of the edge ring and the annular base.

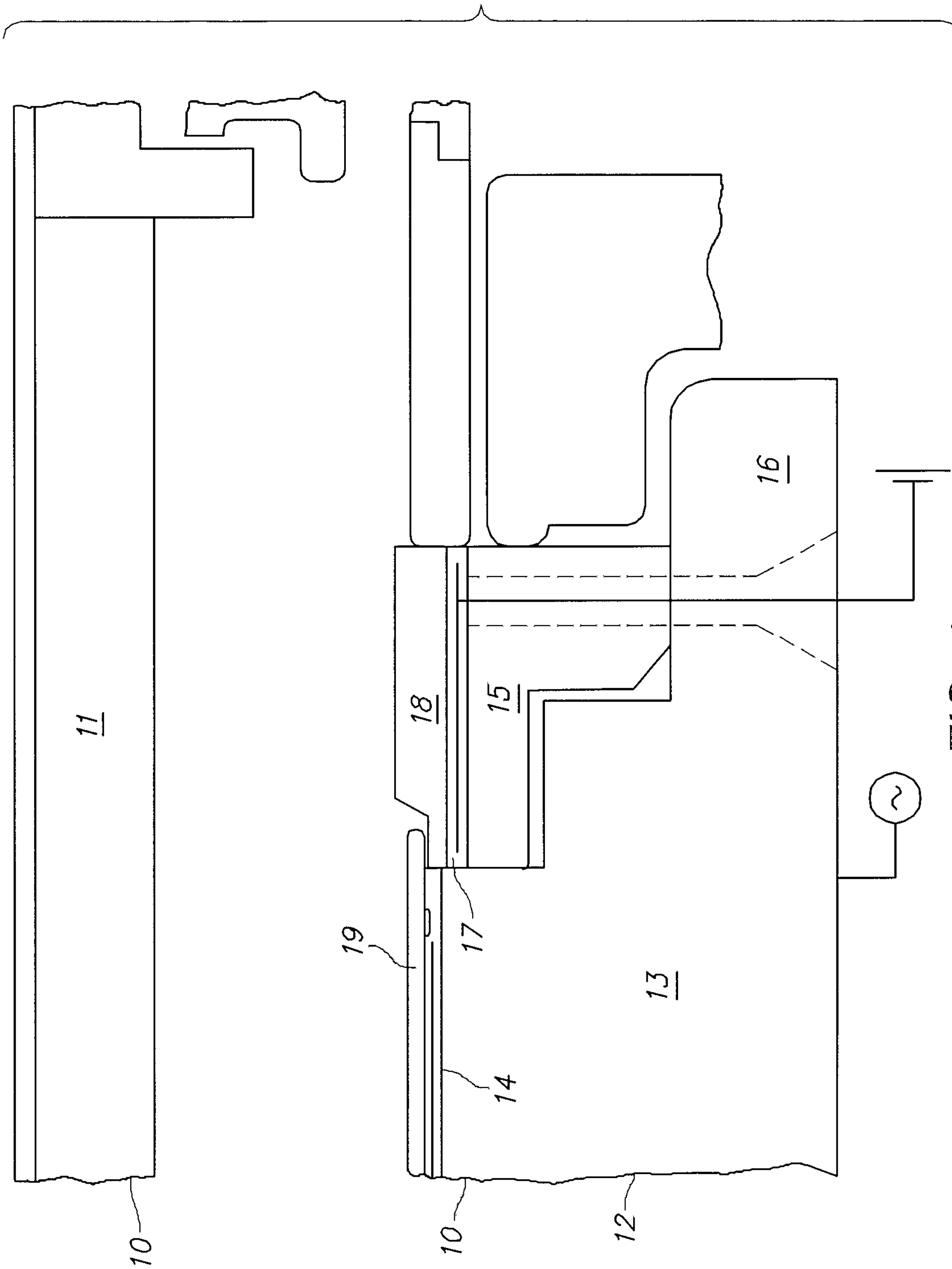

FIG. 1

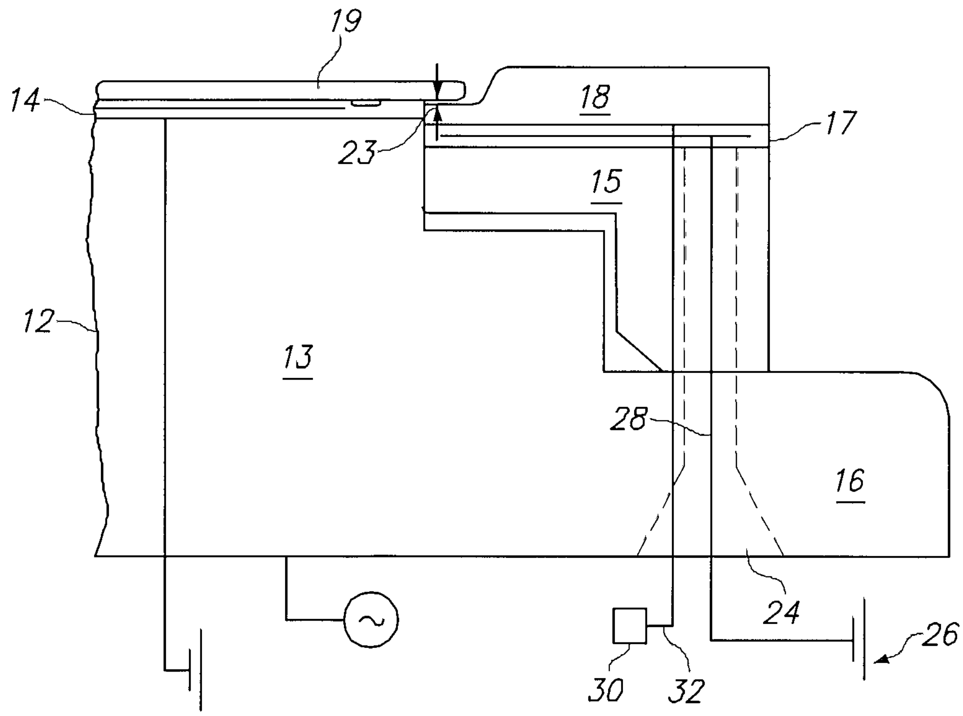

FIG. 2

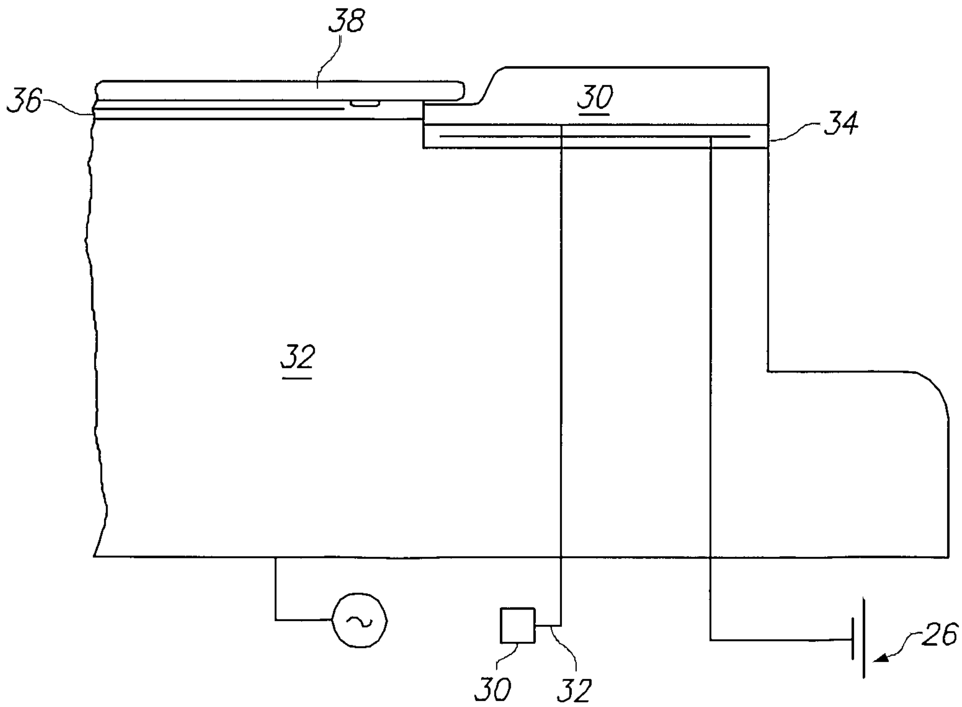

FIG. 3

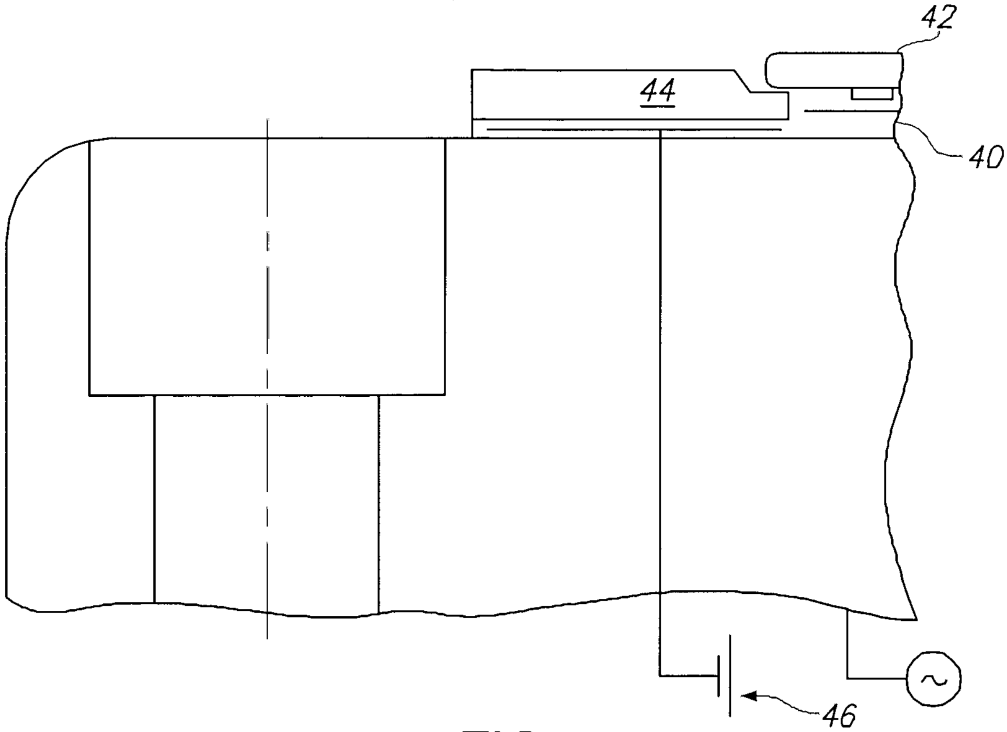

FIG. 4

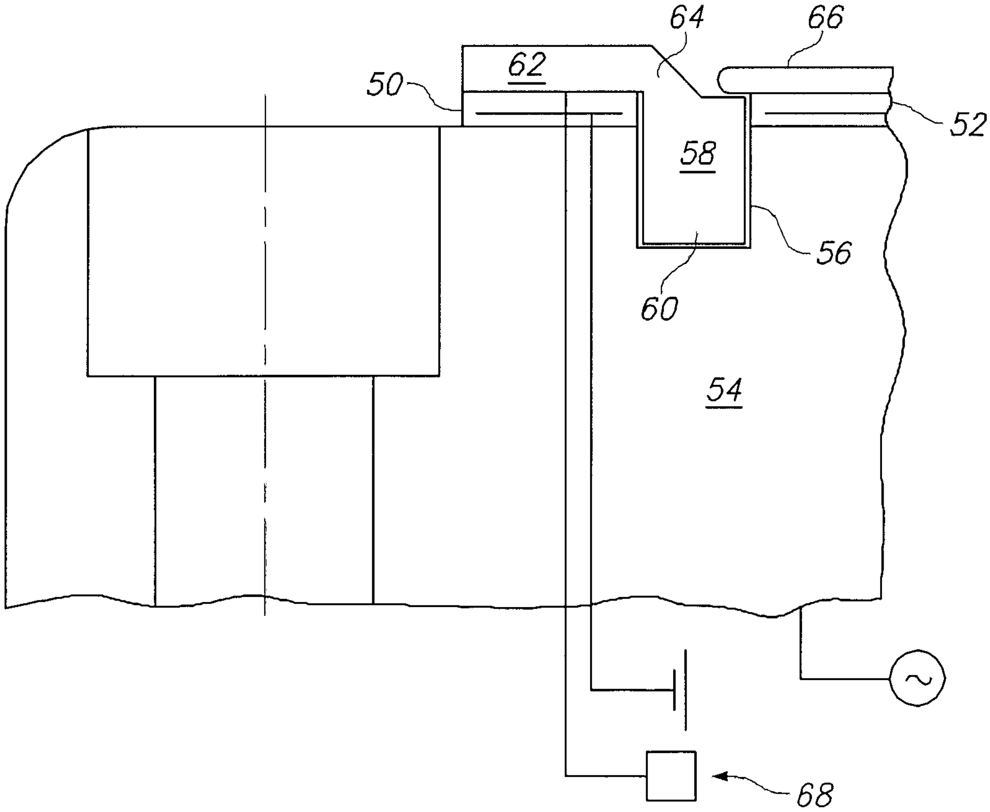

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/30286

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C23C 16/00; C23F 1/02
US CL : 118/723E, 723ER, 728; 156/345
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 118/723E, 723ER, 728; 156/345

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
BRS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,805,408 A (MARASCHIN et al.) 8 September 1998, figures 1-3 and their description.	1-25
A	US 5,998,932 A (LENZ) 7 December 1999, figures 3-4 and their descriptions.	1-25
A	US 6,022,809 A (FAN) 8 February 2000, figures 1-2 and their descriptions.	1-25
A	US 5,494,523 A (STEGER et al.) 27 February 1996, figures 3-4 and their descriptions.	1-25

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Luz L. Alejandro Telephone No. 703-308-0661

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