# EDGE RING ARRANGEMENTS FOR SUBSTRATE PROCESSING

## BACKGROUND OF THE INVENTION

**[Para 1]** Growth in the semiconductor industry has been driven by advances in plasma processing. Due to the highly competitive nature of the semiconductor, device manufacturers may want to maximize yield and efficiently utilize the real estate available on a substrate. During plasma processing of the substrate, a plurality of parameters may need to be controlled to ensure high yield of devices being processed. A common cause of defective devices is the lack of uniformity during substrate processing. Factors that may affect uniformity are substrate edge effects. Another cause of defective devices may be due to polymeric by-products flaking off from the backside of one substrate onto another substrate during transport.

**[Para 2]** Current fabrication technologies are challenged by the demand for higher performance devices, the pressure to further reduce substrate feature sizes, as well as the implementation of newer optimized substrate materials. For example, it is becoming increasing difficult to maintain the uniformity or process results from the center to the edge of larger substrates (e.g., > 300 mm). In general, for a given feature size, the number of devices on the substrate near the edge increases as the size of the substrate becomes larger. Likewise, for a given substrate size, the number of devices on the substrate near the edge increases as the feature size of the devices decreases. For example, often over 20% the total number of devices on a substrate are located near the perimeter the substrate.

**[Para 3]** Fig. 1 shows a simplified diagram of a capacitively-coupled plasma processing system with a single hot edge ring. In general, a source RF generated by source RF generator 112 is commonly used to generate the plasma as well as control the plasma density via capacitively coupling. Certain etch applications may require upper electrode to be grounded with respect to a lower electrode, which is RF powered. The RF power is at least one of 2MHz, 27 MHz, and 60 MHz. Still other etch applications may require both the upper electrode and the lower electrode to be RF powered using similar RF frequencies.

**[Para 4]** Generally, an appropriate set of gases is flowed through an inlet in an upper electrode 102. The gases are subsequently ionized to form plasma 104, in order to process (e.g., etch or deposit) exposed areas of substrate 106, such as a semiconductor substrate or a glass pane,

positioned with a hot edge ring (HER) 116 (e.g., Si, etc.) on an electrostatic chuck (ESC) 108, which also serves as a powered electrode.

**[Para 5]** Hot edge ring 116 generally performs many functions, including positioning substrate 106 on ESC 108 and shielding the underlying components not protected by the substrate itself from being damaged by the ions of the plasma. Hot edge ring 116, as shown in Fig. 1, is disposed under and around the edge of substrate 106. Hot edge ring 112 may further sit on coupling ring 114 (e.g., quartz, etc.), which is generally configured to provide a current path from chuck 108 to hot edge ring 116.

**[Para 6]** In the example of Fig. 1, insulator rings 118 and 120 are configured to provide insulation between ESC 108 and ground ring 122. Quartz cover 124 is disposed on top of ground ring 122. Material for coupling ring 114 may be quartz or appropriate material to optimize RF coupling from ESC 108 to HER 116. For example, quartz may be employed as coupling ring 114 to minimize RF coupling to HER 116. In another example, aluminum may be employed as coupling ring 114 to get increase RF coupling to HER 116.

**[Para 7]** Due to substrate edge effects, such as electric field, plasma temperature, and the loading effects from process chemistry, the process results near the substrate edge may differ from the remaining (center) area of the substrate during plasma processing. For example, the electric field around substrate 106 edge may change due to changes from RF coupling to HER 116. The equipotential lines of the plasma sheath may become disrupted, causing non-uniform ion angular distribution around the substrate edge.

**[Para 8]** Generally, it is desirable for the electric field to remain substantially constant over the entire surface of the substrate in order to maintain process uniformity and vertical etch profiles. During plasma processing, RF coupling balance between substrate 106 and HER 116 may be optimized by design to maintain process uniformity and vertical etch. For example, RF coupling to HER 116 may be optimized for maximum RF coupling to get uniform etching. However, the RF coupling balance to maintain process uniformity may come at a cost to beveled edge polymer deposition.

**[Para 9]** During the etch process, it may be common for polymer byproducts (e.g., fluorinated polymers, etc.) to form on the substrate backside and/or around the substrate edge. Fluorinated polymers generally are comprised of photo resist material previously exposed to an etch chemistry, or polymer byproducts deposited during a fluorocarbon etch process. In general, a

fluorinated polymer is a substance with a chemical equation of $C_xH_yF_z$, where x, z are integers greater than 0, and y is an integer greater than or equal to 0 (e.g., $CF_4$, $C_2F_6$, $CH_2F_2$, $C_4F_8$, $C_5F_8$, etc.).

**[Para 10]** However, as successive polymer layers are deposited on the edge area as the result of several different etch processes, organic bonds that are normally strong and adhesive will eventually weaken and peel or flake off, often onto another substrate during transport. For example, substrates are commonly moved in sets between plasma processing systems via substantially clean containers, often called cassettes. As a higher positioned substrate is repositioned in the container, a portion of a polymer layer may fall on a lower substrate where dies are present, potentially affecting device yield.

**[Para 11]** Fig. 2 shows a simplified diagram of a substrate in which a set of edge polymers have been deposited on the planar backside is shown. As previously stated, during the etch process, it may be common for polymer by-products (edge polymers) to form on the substrate. In this example, the polymer by-products have been deposited on the planar backside, that is, the side of the substrate away from the plasma. For example, the polymer thickness may be about 250 nm at about 70° 202, 270 nm at about 45° 204, and about 120 nm at 0° 206. In general, the greater the thickness of the polymer, the higher the probability that a portion of the polymer may become dislodged and fall onto another substrate or the chuck, potentially affecting manufacturing yield.

**[Para 12]** For example, RF coupling to HER 116 may be optimized for minimal RF coupling to reduce polymer by-products deposition on beveled edge. However, the RF coupling balance to minimize beveled edge polymer deposition may come at a cost to maintain process uniformity at substrate edge.

**[Para 13]** Hence, aforementioned prior art methods require RF coupling balance between the hot edge ring and the substrate to trade-off between optimizing for edge uniformity or beveled edge polymer deposition. In addition, arcing between the wafer edge and hot edge ring may cause pitting on substrate edge and damage to the devices, thereby reducing yield.

## SUMMARY OF INVENTION

**[Para 14]** The invention relates, in an embodiment, in a plasma processing chamber, a method for processing a substrate. The substrate is disposed above a chuck and surrounded by a first edge ring. The first edge ring is electrically isolated from the chuck. The method includes providing a second edge ring. The second edge ring is disposed below an edge of the substrate.

The method further includes providing a coupling ring. The coupling ring is configured to facilitate RF coupling from an ESC (electrostatic chuck) assembly to the first edge ring, thereby causing the first edge ring to have an edge ring potential during substrate processing and causing the RF coupling to be maximized at the first edge ring and minimized at the second edge ring during the substrate processing.

**[Para 15]** The above summary relates to only one of the many embodiments of the invention disclosed herein and is not intended to limit the scope of the invention, which is set forth in the claims herein. These and other features of the present invention will be described in more detail below in the detailed description of the invention and in conjunction with the following figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[Para 16]** The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

**[Para 17]** FIG. 1 shows a simplified diagram of a capacitively-coupled plasma processing system with a single hot edge ring.

**[Para 18]** FIG. 2 shows a simplified diagram of a substrate in which a set of edge polymers have been deposited on the planar backside is shown.

**[Para 19]** FIG. 3 shows, in accordance with an embodiment of the present invention, a simplified schematic of a capacitively-coupled plasma processing system configured with dual edge rings.

**[Para 20]** FIG. 4 shows, in accordance with an embodiment of the invention, a multi-frequency capacitively coupled plasma processing system with a plurality of hot edge rings.

## DETAILED DESCRIPTION OF EMBODIMENTS

**[Para 21]** The present invention will now be described in detail with reference to a few embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

**[Para 22]** Various embodiments are described hereinbelow, including methods and techniques. It should be kept in mind that the invention might also cover articles of manufacture that includes a computer readable medium on which computer-readable instructions for carrying out embodiments of the inventive technique are stored. The computer readable medium may include, for example, semiconductor, magnetic, opto-magnetic, optical, or other forms of computer readable medium for storing computer readable code. Further, the invention may also cover apparatuses for practicing embodiments of the invention. Such apparatus may include circuits, dedicated and/or programmable, to carry out tasks pertaining to embodiments of the invention. Examples of such apparatus include a general-purpose computer and/or a dedicated computing device when appropriately programmed and may include a combination of a computer/computing device and dedicated/programmable circuits adapted for the various tasks pertaining to embodiments of the invention.

**[Para 23]** In accordance with embodiments of the invention, there are provided arrangements for configuring a plasma processing system to enhance control over plasma processing parameters. Embodiments of the invention include providing independent RF coupling to a plurality of hot edge rings to produce desired electric potential differences between a substrate and each edge ring. Thus, the equipotential lines of the plasma sheath for a given plasma process may be optimized to achieve uniform etching at a substrate edge without sacrificing cleaning of polymer by-products from the beveled edge of the substrate.

**[Para 24]** In one or more embodiments of the invention, a first hot edge ring is disposed around the edge of a substrate. In an embodiment, first HER may be made of silicon (Si), silicon nitride (SiN), and/or silicon dioxide ($SiO_2$). In an embodiment, first HER may further sit on a coupling ring to provide RF coupling from ESC lower electrode to first HER to minimize potential difference between substrate and first HER. Thus, the equipotential lines of the plasma sheath for a given plasma process is optimized to keep ion bombardment to the edge of substrate straight. The vertical ion bombardment at the edge of substrate may ensure uniform etching with respect to the center of the substrate during plasma processing.

**[Para 25]** In an embodiment, a second HER, isolated by an insulator ring, is disposed underneath the edge of a substrate. Second HER may be made from silicon (Si), silicon nitride (SiN), and/or silicon dioxide ($SiO_2$) in an embodiment. Second HER is isolated from the substrate, the first edge ring, an ESC, and an ESC lower body by the insulator ring. The insulator

ring may be made from insulator material such as quartz to achieve RF decoupling from ESC lower electrode. Embodiments of the invention provide for high voltage potential between the substrate and the second HER to cause arcing on the beveled edge of substrate to remove polymer by-products deposited on beveled edge of the substrate.

**[Para 26]** In another embodiment of the invention, a second HER is disposed directly underneath the substrate and on top of the insulator ring. In an embodiment, second HER may be made from SiN or $SiO_2$. In an embodiment, RF coupling to second HER may be optimized to provide maximum potential difference between the substrate and the second HER to induce arcing on the beveled edge of the substrate for cleaning of polymer by-products.

**[Para 27]** The features and advantages of the invention may be better understood with reference to the figures and discussions that follow. Fig. 3 shows, in accordance with an embodiment of the present invention, a simplified schematic of a capacitively-coupled plasma processing system 300 configured with dual edge rings.

**[Para 28]** Plasma processing system 300 may be a single, double, or triple frequency RF capacitively discharge system. In an example, radio frequencies may include, but are not limited to, e.g., 2 MHz, 27 MHz, and 60 MHz. Plasma processing system 300 may be configured to include a substrate 306 being disposed above an electrostatic chuck (ESC) 308. ESC 308, which also serves as a powered electrode, is disposed above an ESC lower electrode 310.

**[Para 29]** Consider the situation wherein, for example, substrate 306 is being processed. During plasma processing, a multifrequency RF generator 312 with a path to ground (not shown to simplify the figure) may supply low RF bias power to ESC lower electrode 310 through an RF match network (not shown to simplify the figure). The RF power from RF generator 312 may interact with a gas (not shown to simplify the figure) to ignite plasma 304 between an upper electrode 302 and substrate 306. Plasma may be employed to etch and/or deposit materials onto substrate 306 to create electronic devices.

**[Para 30]** As shown in Fig. 3, certain etch applications may require upper electrode 302 to be grounded with respect to a lower electrode, which is RF powered. The RF power is at least one of 2MHz, 27 MHz, and 60 MHz. Still other etch applications may require both the upper electrode and the lower electrode to be RF powered using similar RF frequencies.

**[Para 31]** In contrast to the prior art where only one hot edge ring is employed, plasma processing system 300 is configured with a plurality of hot edge rings (HER), e.g., a first HER 314 and a second HER 326 in an embodiment. First HER 314 is disposed around the edge of substrate 306 in accordance with an embodiment of the invention. First HER 314 may be made from silicon (Si), silicon nitride (SiN), and/or silicon dioxide ($SiO_2$) in an embodiment. An insulator ring 320 may provide insulation between first HER 314 and a ground ring 322. A quartz cover ring 324 is disposed on top of ground ring 322. First HER 314 may further sit on a coupling ring 318. Coupling ring 318 may be made from conductive materials such as aluminum or graphite to provide RF coupling from ESC assembly, e.g., ESC 308 and ESC lower electrode 310, to first HER 314.

**[Para 32]** RF coupling from ESC assembly to HER 314 may be optimized to achieve similar plasma sheath between an area of RF sheath voltage (V2) above the substrate edge ring 330 with respect to an area of RF sheath voltage (V1) above the substrate 332 to produce minimal electrical potential differences (V1 – V2) in accordance with an embodiment. Thus, the equipotential lines of the plasma sheath for a given plasma process is optimized to keep ion bombardments to the edge of substrate 306 straight. The vertical ion bombardments at the edge of substrate 306 may ensured uniform etching with respect to the center of the substrate during plasma processing.

**[Para 33]** In the implementation of Fig. 3, second HER 326, isolated by an insulator ring 316, is disposed underneath the edge of substrate 306 in accordance with an embodiment. Second HER 326 may be made from silicon (Si), silicon nitride (SiN), and/or silicon dioxide ($SiO_2$) in an embodiment. Second HER 326 is isolated from substrate 306, first edge ring 314, ESC 308, and ESC lower body 310 by insulator ring 316 in accordance with an embodiment of the invention. Insulator ring 316 may be made from insulator material such as quartz to achieve RF decoupling from ESC assembly.

**[Para 34]** Since RF coupling to second HER 326 may be minimized, the induced voltage (V3) on second HER 326 may be low in comparison the voltage on substrate 306 (V1). The voltage potential (V1 – V3) between substrate 306 and second HER 326 may be high. Due to the high voltage potential between substrate 306 and second HER 326, arcing may occur on the beveled edge of substrate 306. Normally, arcing is an uncontrolled event that is undesirable. However, there are no devices on the beveled edge of a substrate. Thus, arcing or micro-explosion on the beveled edge of substrate 306 may be desirable as a cleaning mechanism to remove

polymer by-products deposited on beveled edge of the substrate in accordance with an embodiment of the invention.

**[Para 35]** In the prior arts, there is only one HER and the RF coupling to the HER is optimized to balance between uniform etching at a substrate edge or deposition of polymer by-products on the beveled edge. Unlike prior art methods, a plurality of HERs may be employed with independent RF coupling to each hot edge ring to achieve both uniform etching and beveled edge cleaning of polymer by-products deposition.

**[Para 36]** In addition to the aforementioned method and arrangement as discussed in Fig. 3, other embodiments may be provided in which a plurality of HERs may be employed to provide separate RF coupling to individual HERs. Fig. 4 shows, in accordance with an embodiment of the invention, a multi-frequency capacitively coupled plasma processing system 400 with a plurality of hot edge rings. Plasma processing system 400 may be configured to include a grounded upper electrode 402, a substrate 406, an electrostatic chuck (ESC) 408, an ESC lower electrode 410, an insulator ring 420, a ground ring 422, and a quartz cover ring 424.

**[Para 37]** Consider the situation wherein, for example, substrate 406 is being processed. Plasma 404 may be struck when gas (not shown to simply the figure) interacts with RF power from an RF power generator 412. Plasma 404 may be employed to etch and/or deposit materials onto substrate 406 to create electronic devices.

**[Para 38]** As aforementioned, substrate edge effects, such as electric field, plasma temperature, and the loading effects from process chemistry, may cause the process results near the substrate edge to differ from the remaining (center) area of the substrate. For example, the equipotential lines of the plasma sheath may become disrupted, causing non-uniform ion angular distribution around the substrate edge.

**[Para 39]** In the implementation of Fig. 4, a first HER 414 is disposed above coupling ring 418 and around the edge of substrate 406. In an embodiment, first HER 414 may be made from silicon. In an embodiment, RF coupling to first HER 414 may be optimized to provide minimal potential difference (V1 – V2) between substrate 406 and first HER 414 to achieve uniform etching at the edge of the substrate.

**[Para 40]** Thus, the equipotential lines of the plasma sheath above the substrate edge ring 430 with respect to the plasma sheath above the substrate 432 are optimized to keep ion

bombardments to the edge of substrate 406 straight. The vertical ion bombardments at the edge of substrate 406 may ensured uniform etching with respect to the center of the substrate during plasma processing.

**[Para 41]** As shown in Fig. 4, a second HER 426 is disposed directly underneath substrate 406 and on top of an insulator ring 416. In an embodiment, second HER 426 may be made from SiN or $SiO_2$. In an embodiment, RF coupling to second HER 426 may be optimized to provide maximum potential difference (V1 – V3) between substrate 406 and second HER 426 to induce arcing on beveled edge of the substrate for cleaning of polymer by-products.

**[Para 42]** As may be appreciated from the foregoing, embodiments of the invention provide methods and arrangements for independent RF coupling of each hot edge ring from a plurality of HERs being provided without employing external hardware devices. By employing independent RF couplings to a plurality of HERs, etching uniformity at substrate edge may be achieve without trading-off cleaning of polymer by-products at the beveled edge. In addition, the design of the hot edge ring arrangement is simple and inexpensive to retrofit to current plasma processing equipment

**[Para 43]** While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents, which fall within the scope of this invention. Also, the title, summary, and abstract are provided herein for convenience and should not be used to construe the scope of the claims herein. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. Although various examples are provided herein, it is intended that these examples be illustrative and not limiting with respect to the invention. Further, in this application, a set of "n" items refers zero or more items in the set. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

# CLAIMS

What is claimed is:

1. In a plasma processing chamber, a method for processing a substrate, said substrate being disposed above a chuck and surrounded by a first edge ring, said first edge ring being electrically isolated from said chuck, comprising:

providing a second edge ring, said second edge ring being disposed below an edge of said substrate; and

providing a coupling ring, wherein said coupling ring is configured to facilitate RF coupling from an ESC (electrostatic chuck) assembly to said first edge ring, thereby causing said first edge ring to have an edge ring potential during substrate processing and causing said RF coupling to be maximized at said first edge ring and minimized at said second edge ring during said substrate processing.

2. The method of claim 1 further comprising providing an insulator ring that is configured to encapsulate said second edge ring.

3. The method of claim 1 further comprising providing an insulator ring, wherein said second edge ring is disposed above said insulator ring.

4. The method of claim 1, wherein said first hot edge ring is formed of a material that includes at least one of silicon, silicon nitride and silicon dioxide.

5. The method of claim 1, wherein said coupling ring is formed of a material that includes at least one of conductive material, aluminum and graphite.

6. The method of claim 1, wherein said wherein said second hot edge ring is formed of a material that includes at least one of silicon, silicon nitride and silicon dioxide.

7. The method of claim 2, wherein said insulator ring is formed of a material that includes at least one of insulator material and quartz.

8. The method of claim 3, wherein said insulator ring is formed of a material that includes at least one of insulator material and quartz.

9. The method of claim 1, wherein said RF power being delivered to said chuck has a set of RF frequencies that includes at least one of about 2 MHz, about 27 MHz, and about 60 MHz.

10. A plasma processing system having a plasma processing chamber configured for processing a substrate, said substrate being disposed above a chuck and surrounded by a first edge ring, said first edge ring being electrically isolated from said chuck, comprising:

a second edge ring, said second edge ring being disposed below an edge of said substrate; and

a coupling ring, wherein said coupling ring is configured to facilitate RF coupling from an ESC (electrostatic chuck) assembly to said first edge ring, thereby causing said first edge ring to have an edge ring potential during substrate processing and causing said RF coupling to be maximized at said first edge ring and minimized at said second edge ring during said substrate processing.

11. The plasma processing system of claim 10 further comprising an insulator ring that is configured to encapsulate said second edge ring.

12. The plasma processing system of claim 10 further comprising an insulator ring, wherein said second edge ring is disposed above said insulator ring.

13. The plasma processing system of claim 10, wherein said first hot edge ring is formed of a material that includes at least one of silicon, silicon nitride and silicon dioxide.

14. The plasma processing system of claim 10, wherein said coupling ring is formed of a material that includes at least one of conductive material, aluminum and graphite.

15. The plasma processing system of claim 10, wherein said wherein said second hot edge ring is formed of a material that includes at least one of silicon, silicon nitride and silicon dioxide.

16. The plasma processing system of claim 11, wherein said insulator ring is formed of a material that includes at least one of insulator material and quartz.

17. The plasma processing system of claim 12, wherein said insulator ring is formed of a material that includes at least one of insulator material and quartz.

18. The plasma processing system of claim 10, wherein said RF power being delivered to said chuck has a set of RF frequencies that includes at least one of about 2 MHz, about 27 MHz, and about 60 MHz.