United States Patent **6,269,765**
Chu , et al. **August 7, 2001**

Collection devices for plasma immersion ion implantation

Abstract

A plasma treatment system (200) for implantation with a novel susceptor with a perforated shield (201) and collection devices (221). The system (200) has a variety of elements such as a chamber in which a plasma is generated in the chamber. The system (200) also has a susceptor disposed in the chamber to support a silicon substrate, which has a surface. The perforated shield (201) draws ions from the implantation toward and through the shield to improve implant uniformity in the substrate. The collection device accumulates charge that can detrimentally influence the substrate during processing. In a specific embodiment, the chamber has a plurality of substantially planar rf transparent windows (26) on a surface of the chamber. The system (200) also has an rf generator (66) and at least two rf sources in other embodiments.

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Parent Case Text

This application claims the benefit of U.S. Provisional Application No. 60/074,394, filed Feb. 11, 1998, the disclosure of which is incorporated by reference.

Claims

What is claimed is:

1. A plasma treatment system for implantation, said system comprising:

a chamber in which a plasma is generated in;

a susceptor having a susceptor face disposed in said chamber to support a substrate comprising a substrate face;

a perforated shield disposed adjacent to and coplanar with said susceptor for modifying an electric field for accelerating particles toward said substrate face, said perforated shield tending to linearize

electric field lines along said substrate face to create a more uniform distribution of particles to be implanted into a depth of said substrate; and

a collection device disposed underlying said perforated shield to collect particles that traverse through said perforated shield, said collection device being at a potential to attract said particles without substantially influencing said linearized electric field, said collection device also preventing a portion of said particles from depositing onto said substrate face.

2. The system of claim 1 wherein said chamber comprises a plurality of substantially planar rf transparent windows on a surface of said chamber.

3. The system of claim 1 further comprising:

an rf generator; and

at least two rf sources, each external to said vacuum chamber and each said rf source electrically connected to said rf generator and juxtaposed to a respective one of said plurality rf transparent windows, and operative to generate said plasma in the vacuum chamber; said rf sources operative to produce a local, substantially uniform plasma proximate said substrate.

4. The system of claim 3 further comprising at least one tuning circuit, each said at least one tuning circuit electrically connected to one of said at least two rf sources.

5. The system of claim 1 wherein said perforated shield is annular in shape and is in parallel alignment with said susceptor face.

6. The system of claim 1 wherein said perforated shield comprises openings occupying at least 80% of an area of said perforated shield.

7. The system of claim 1 wherein said perforated shield comprises openings occupying at least 90% of an area of said perforated shield.

8. The system of claim 1 wherein said collection device is disposed on a portion of said susceptor.

9. A plasma treatment system provided in a cluster tool for implantation, said system comprising:

a chamber in which a plasma is generated;

a susceptor having a susceptor face disposed in said chamber to support a substrate comprising a substrate face;

a perforated shield disposed adjacent to and coplanar with said susceptor for modifying an electric field for accelerating particles toward said substrate face, said perforated shield tending to linearize electric field lines along said substrate face to create a more uniform distribution of particles to be implanted into a depth of said substrate; and

a collection device disposed underlying said perforated shield to collect particles that traverse through said perforated shield, said collection device being at a potential to attract said particles without substantially influencing said linearized electric field, said collection device also preventing a portion of said particles from depositing onto said substrate face, wherein said collection device is biased using a magnitude that is less than a biasing potential between said plasma and said susceptor.

10. A plasma treatment system provided in a cluster tool for implantation, said system comprising:

a chamber in which a plasma is generated;

a susceptor having a susceptor face disposed in said chamber to support a substrate comprising a substrate face;

a perforated shield disposed adjacent to and coplanar with said susceptor for modifying an electric field for accelerating particles toward said substrate face, said perforated shield tending to linearize electric field lines along said substrate face to create a more uniform distribution of particles to be implanted into a depth of said substrate; and

a collection device disposed underlying said perforated shield to collect particles that traverse through said perforated shield, said collection device being at a potential to attract said particles without substantially influencing said linearized electric field, said collection device also preventing a portion of said particles from depositing onto said substrate face, wherein said collection device is biased using a magnitude that is less than a biasing potential between said plasma and said susceptor.

11. The system of claim 1 wherein said system is provided as a stand alone unit.

12. A method for forming a substrate, said method comprising a method for measuring a distribution of implanted particles, said measuring method comprising:

providing a substrate onto a face of a susceptor within a plasma immersion ion implantation chamber, said substrate comprising a surface;

introducing particles in a directional manner toward said substrate where a first portion of said particles implant into substrate to selectively place said ions into a selected depth across a plane of said substrate;

drawing a second portion of said particles using a perforated shield through said perforated shield disposed adjacent to and coplanar with said face of said susceptor to improve uniformity of said first portion of said particles at said selected depth; and

collecting a portion of said second portion of said particles using a plurality of collection devices surrounding said substrate; and

measuring an electric current from each of said collection devices, said measuring providing a plurality of measured electric current values.

13. The method of claim 12 further comprising comparing said measured current values from said respective collection devices against a reference value to determine if said uniformity is within a predefined limit.

14. The method of claim 12 wherein said predefined limit is a unformity variation of less than one percent.

15. The method of claim 12 wherein said substrate is a production wafer.

Description

BACKGROUND OF THE INVENTION

The present invention relates to the manufacture of integrated circuits. More particularly, the present

invention provides a technique for selectively controlling a distribution of impurities that are implanted using a plasma immersion ion implantation or plasma ion source system for the manufacture of semiconductor integrated circuits, for example. But it will be recognized that the invention has a wider range of applicability; it can also be applied to other substrates for multi-layered integrated circuit devices, three-dimensional packaging of integrated semiconductor devices, photonic devices, piezoelectronic devices, microelectromechanical systems ("MEMS"), sensors, actuators, solar cells, flat panel displays (e.g., LCD, AMLCD), biological and biomedical devices, and the like.

Integrated circuits are fabricated on chips of semiconductor material. These integrated circuits often contain thousands, or even millions, of transistors and other devices. In particular, it is desirable to put as many transistors as possible within a given area of semiconductor because more transistors typically provide greater functionality, and a smaller chip means more chips per wafer and lower costs. Some integrated circuits are fabricated on a slice or wafer, of single-crystal (monocrystalline) silicon, commonly termed a "bulk" silicon wafer. Devices on such "bulk" silicon wafer typically use processing techniques such as ion implantation or the like to introduce impurities or ions into the substrate. These impurities or ions are introduced into the substrate to selectively change the electrical characteristics of the substrate, and therefore devices being formed on the substrate. Ion implantation provides accurate placement of impurities or ions into the substrate. Ion implantation, however, is expensive and generally cannot be used effectively for introducing impurities into a larger substrate such as glass or a semiconductor substrate, which is used for the manufacture of flat panel displays or the like.

Accordingly, plasma treatment of large area substrates such as glass or semiconductor substrates has been proposed or used in the fabrication of flat panel displays or 300 mm silicon wafers. Plasma treatment is commonly called plasma immersion ion implantation ("PIII") or plasma source ion implantation ("PSI"). Plasma treatment generally uses a chamber, which has an inductively coupled plasma source, for generating and maintaining a plasma therein. A large voltage differential between the plasma and the substrate to be implanted accelerates impurities or ions from the plasma into the surface or depth of the substrate. A variety of limitations exist with the convention plasma processing techniques.

A major limitation with conventional plasma processing techniques is the maintenance of the uniformity of the plasma density and chemistry over such a large area is often difficult. As merely an example, inductively or transformer coupled plasma sources ("ICP" and "TCP," respectively) are affected both by difficulties of maintaining plasma uniformity using inductive coil antenna designs. Additionally, these sources are often costly and generally difficult to maintain, in part, because such sources which require large and thick quartz windows for coupling the antenna radiation into the processing chamber. The thick quartz windows often cause an increase in rf power (or reduction in efficiency) due to heat dissipation within the window.

Other techniques such as Electron Cyclotron Resonance ("ECR") and Helicon type sources are limited by the difficulty in scaling the resonant magnetic field to large areas when a single antenna or waveguide is used. Furthermore, most ECR sources utilize microwave power which is more expensive and difficult to tune electrically. Hot cathode plasma sources have been used or proposed. The hot cathode plasma sources often produce contamination of the plasma environment due to the evaporation of cathode material. Alternatively, cold cathode sources have also be used or proposed. These cold cathode sources often produce contamination due to exposure of the cold cathode to the plasma generated.

A pioneering technique has been developed to improve or, perhaps, even replace these conventional sources for implantation of impurities. This technique has been developed by Chung Chan of Waban Technology in Massachusetts, now Silicon Genesis Corporation, and has been described in U.S. Pat. No. 5,653,811 ("Chan"), which is hereby incorporated by reference herein for all purposes. Chan generally describes techniques for treating a substrate with a plasma with an improved plasma

processing system. The improved plasma processing system, includes, among other elements, at least two rf sources, which are operative to generate a plasma in a vacuum chamber. By way of the multiple sources, the improved plasma system provides a more uniform plasma distribution during implantation, for example. It is still desirable, however, to provide even a more uniform plasma for the manufacture of substrates. Additionally, Chan's techniques can create particulate contamination during implantation processes using his plasma processing system.

From the above, it is seen that an improved technique for introducing impurities into a substrate is highly desired.

SUMMARY OF THE INVENTION

According to the present invention, a technique including a method and system for introducing impurities into a substrate using plasma immersion ion implantation is provided. In an exemplary embodiment, the present invention provides a system with a novel susceptor with a collection device that improves implantation uniformity during an implantation process.

In a specific embodiment, the present invention provides a plasma treatment system for implantation with a novel susceptor with a collection device. The system has a variety of elements such as a chamber in which a plasma is generated in the chamber. The system also has a susceptor disposed in the chamber to support a substrate (e.g., silicon wafer), which has a surface. A collection device (e.g., Faraday cup) is disposed adjacent to the susceptor to accumulate stray ions or charge to create a more uniform electric field or linearize electric field lines, and to reduce a possibility of particles from defecting off of internal surfaces of the chamber. When the defected particles land on the substrate, they may create functional and/or reliability problems for a resulting semiconductor device. In a specific embodiment, the chamber has a plurality of substantially planar rf transparent windows (but do not need be planar) on a surface of the chamber. The system also has an rf generator and at least two rf sources in other embodiments.

In an alternative embodiment, the present invention provides a method for forming a substrate using a plasma immersion ion implantation system. The method includes a step of providing a substrate (e.g., silicon wafer), which has a surface, onto a susceptor within a plasma immersion ion implantation chamber. The method then introduces and/or accelerates particles (e.g., ions) in a uniform, directional manner toward and through the surface of the substrate to uniformly distribute the particles into a selected depth across a plane of the substrate. The method also introduces particles through a perforated shield that is disposed adjacent to the substrate. The perforated shield tends to adjust the electric field to uniformly distribute the particles across the substrate surface to provide the uniformly placed particles at the selected depth. The method collects a portion, if not all, of the particles that traverse through the perforated shield in one or a plurality of collector devices, e.g., Faraday cups.

In a further alternative embodiment, the present invention provides a method for measuring implantation uniformity. In a specific embodiment, the method is an in-situ measuring technique, but is not limited to such a technique. The method has a variety of steps such providing a substrate (e.g., silicon wafer), which has a surface, onto a susceptor within a plasma immersion ion implantation chamber. The method then introduces and/or accelerates particles (e.g., ions) in a uniform, directional manner toward and through the surface of the substrate to distribute the particles into a selected depth across a plane of the substrate. In one embodiment, the method also introduces particles through a perforated shield that is disposed adjacent to the substrate. The perforated shield tends to adjust the electric field to more uniformly distribute the particles across the substrate surface to provide the uniformly placed particles at the selected depth. The method collects a portion, if not all, of the particles that traverse through the perforated shield in one or a plurality of collector devices, e.g., Faraday cups. To determine implantation uniformity, the method measures an electric current from each of the collection devices, where the measuring step provides a plurality of measured electric current values, which will be compared against a standard reference. The method

determines if the measured values are within a predetermined range of the reference, and if necessary, adjusts one or more of a plurality of inductive sources to adjust the implantation process for another measurement. The present method can be used to adjust implantation uniformity in preferred embodiments. Alternatively, the present invention can be used to adjust selective non-uniformity in other applications.

Numerous advantages are achieved by way of the present invention over conventional techniques. For example, the present invention provides a relatively easy way to implement device for improving implantation uniformity across a substrate such as a wafer in a specific embodiment. In some embodiments, the present invention provides a system that produces fewer non-silicon particles (e.g., aluminum, iron, chrome, nickel) that may introduce defects into a substrate, for example. In still other embodiments, the present invention can be implemented into conventional PIII systems using kits or tools to provide the collection devices. Accordingly, the present invention is generally cost effective and easy to implement. These and other advantages or benefits are described throughout the present specification and are described more particularly below.

These and other embodiments of the present invention, as well as its advantages and features are described in more detail in conjunction with the text below and attached Figs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram of a conventional plasma treatment system.

FIG. 1A illustrates a quartz liner in FIG. 1.

FIG. 1B is a top view of a substrate in FIG. 1.

FIG. 2 is an overview of a plasma treatment system according to one embodiment of the invention,

FIG. 2A is a front view of a susceptor and a shield in the system of FIG. 2.

FIG. 2B is a top view of the susceptor and shield.

FIG. 2C illustrates details of openings in a perforated shield according to an embodiment of the invention.

FIG. 2D is a side view of the collection device in FIG. 2.

FIG. 2E is a flow diagram of a process in accordance with the invention.

FIG. 2F is a top view of a wafer and collection device.

FIG. 3 illustrates a configuration of plasma sources.

FIG. 4 illustrates Faraday cups for measuring field uniformity.

FIG. 4A illustrates a special wafer fabricated with Faraday cups.

FIG. 5 illustrates array of plasma sources.

FIG. 6 illustrates one embodiment of a plasma source.

FIG. 7 is a side view of a plurality of plasma sources.

FIG. 8 illustrates an embodiment of the system with a pair of plasma sources.

DESCRIPTION OF SPECIFIC EMBODIMENTS

The present invention provides an improved plasma immersion ion implantation system. In an exemplary embodiment, the present invention provides an improved pedestal (or susceptor), including a collector or charge collection device(s), for securing a wafer during implantation. Additionally, the present invention provides a novel susceptor design for reducing impurities that can attach to a silicon wafer surface. This improved pedestal provides fewer sputtered contamination directed toward the silicon wafer or other substrate, which reduces a possibility of particulate contamination on the wafer. By way of less contamination, the present system provides improved substrates and the like.

1. Conventional Plasma Processing System

In brief overview and referring to FIG. 1, conventional plasma processing system 10 includes a vacuum chamber 14 having a vacuum port 18 connected to a vacuum pump (not shown). The system 10 includes a series of dielectric windows 26 vacuum sealed by o-rings 30 and attached by removable clamps 34 to the upper surface 22 of the vacuum chamber 14. Removably attached to some of these dielectric windows 26 are rf plasma sources 40, in a system having a helical or pancake antennae 46 located within an outer shield/ground 44. Cooling of each antenna is accomplished by passing a cooling fluid through the antenna. Cooling is typically required only at higher power. The windows 26 without attached rf plasma sources 40 are usable as viewing ports into the chamber 14. The removability of each plasma source 40 permits the associated dielectric window 26 to be cleaned or the plasma source 40 replaced without the vacuum within the system 10 being removed. Although glass windows are used, other dielectric material such as quartz or polyethylene may be used for the window material.

Each antenna 46 is connected to an rf generator 66 through a matching network 50, through a coupling capacitor 54. Each antenna 46 also includes a tuning capacitor 58 connected in parallel with its respective antenna 46. Each of the tuning capacitors 58 is controlled by a signal D, D', D" from a controller 62. By individually adjusting the tuning capacitors 85, the output power from each rf antenna 46 can be adjusted to maintain the uniformity of the plasma generated. Other tuning means such as zero reflective power tuning may also be used to adjust the power to the antennae. The rf generator 66 is controlled by a signal E from the controller 62. The controller 62 controls the power to the antennae 46 by a signal F to the matching network 50.

The controller 62 adjusts the tuning capacitors 58 and the rf generator 66 in response to a signal A from a sensor 70 monitoring the power delivered to the antennae 46, a signal B from a fast scanning Langmuir probe 74 directly measuring the plasma density and a signal C from a plurality of Faraday cups 78 attached to a substrate wafer holder 82. The Langmuir probe 74 is scanned by moving the probe (double arrow I) into and out of the plasma. With these sensors, the settings for the rf generator 66 and the tuning capacitors 58 may be determined by the controller prior to the actual use of the system 10 to plasma treat a substrate. Once the settings are determined, the probes are removed and the wafer to be treated is introduced. The probes are left in place during processing to permit real time control of the system. Care must be taken to not contaminate the plasma with particles evaporating from the probe and to not shadow the substrate being processed.

This conventional system has numerous limitations. For example, the conventional system 10 includes wafer holder 82 that is surrounded by a quartz liner 101. The quartz liner is intended to reduce unintentional contaminants sputtered from the sample stage to impinge or come in contact with the substrate 103, which should be kept substantially free from contaminates. Additionally, the quartz liner is intended to reduce current load on the high voltage modulator and power supply. The quartz liner, however, often attracts impurities or ions 104 that attach themselves to the quartz liner by way of charging, as shown by FIG. 1A. By way of this attachment, the quartz liner becomes charged, which changes the path of ions 105 from a normal trajectory 107. The change in path can

cause non-uniformities during a plasma immersion implantation process. FIG. 1B shows a simplified top-view diagram of substrate 103 that has high concentration regions 111 and 109, which indicate non-uniformity. In some conventional systems, the liner can also be made of a material such as aluminum. Aluminum is problematic in conventional processing since aluminum particles can sputter off of the liner and attach themselves to the substrate. Aluminum particles on the substrate can cause a variety of functional and reliability problems in devices that are manufactured on the substrate. A wafer stage made of stainless steel can introduce particulate contamination such as iron, chromium, nickel, and others to the substrate. A paper authored by Zhineng Fan, Paul K. Chu, Chung Chan, and Nathan W. Cheung, entitled "Dose and Energy Non-Uniformity Caused By Focusing Effects During Plasma Immersion Ion Implantation," to be published in Applied Physics Letters describes some of the limitations mentioned herein.

Additionally, the conventional system introduces ions 108 toward the substrate surface in a non-uniform manner. As shown, ions accelerate toward the substrate surface at varying angles and fluxes. These varying angles and fluxes tend to create a non-uniform ion distribution in the substrate material. The non-uniform distribution of ions in the substrate can create numerous problems. For example, a non-uniform distribution of ions in a substrate used for a film transfer process such as Smart Cut.TM. or a controlled cleaving process can ultimately create a non-uniform detached film, which is highly undesirable in the manufacture of integrated circuits. Accordingly, it is generally desirable to form a uniform distribution of ions at a selected in the substrate material for film transfer processes.

2. Present Plasma Immersion Systems

FIG. 2 is a simplified overview of a plasma treatment system 200 for implanting impurities according to an embodiment of the present invention. This diagram is merely an illustration and should not limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, modifications, and alternatives. For easy reading, some of the reference numerals used in FIG. 1 are used in FIG. 2 and others. In a specific embodiment, system 200 includes a vacuum chamber 14 having a vacuum port 18 connected to a vacuum pump (not shown). The system 10 includes a series of dielectric windows 26 vacuum sealed by o-rings 30 and attached by removable clamps 34 to the upper surface 22 of the vacuum chamber 14. Removably attached to some of these dielectric windows 26 are rf plasma sources 40, in one embodiment having a helical or pancake antennae 46 located within an outer shield/ground 44. Other embodiments of the antennae using capacitive or inductive coupling may be used. Cooling of each antenna is accomplished by passing a cooling fluid through the antenna. Cooling is typically required only at higher power. The windows 26 without attached rf plasma sources 40 are usable as viewing ports into the chamber 14. The removability of each plasma source 40 permits the associated dielectric window 26 to be cleaned or the plasma source 40 replaced without the vacuum within the system 10 being removed. Although glass windows are used in this embodiment, other dielectric material such as quartz or polyethylene may be used for the window material.

Each antenna 46 is connected to an rf generator 66 through a matching network 50, through a coupling capacitor 54. Each antenna 46 also includes a tuning capacitor 58 connected in parallel with its respective antenna 46. Each of the tuning capacitors 58 is controlled by a signal D, D', D" from a controller 62. By individually adjusting the tuning capacitors 85, the output power from each rf antenna 46 can be adjusted to maintain the uniformity of the plasma generated. Other tuning means such as zero reflective power tuning may also be used to adjust the power to the antennae. In one embodiment, the rf generator 66 is controlled by a signal E from the controller 62. In one embodiment, the controller 62 controls the power to the antennae 46 by a signal F to the matching network 50.

The controller 62 adjusts the tuning capacitors 58 and the rf generator 66 in response to a signal A from a sensor 70 (such as a Real Power Monitor by Comdel, Inc., Beverly, Mass.) monitoring the power delivered to the antennae 46, a signal B from a fast scanning Langmuir probe 74 directly

measuring the plasma density and a signal C from a plurality of Faraday cups 78 attached to a substrate wafer holder 82. The Langmuir probe 74 is scanned by moving the probe (double arrow I) into and out of the plasma. With these sensors, the settings for the rf generator 66 and the tuning capacitors 58 may be determined by the controller prior to the actual use of the system 10 to plasma treat a substrate. Once the settings are determined, the probes are removed and the wafer to be treated is introduced. In another embodiment of the system, the probes are left in place during processing to permit real time control of the system. In such an embodiment using a Langmuir probe, care must be taken to not contaminate the plasma with particles evaporating from the probe and to not shadow the substrate being processed. In yet another embodiment of the system, the characteristics of the system are determined at manufacture and the system does not include a plasma probe.

In a specific embodiment, system 200 includes a susceptor design with a shield 201, as shown in FIGS. 2 and 2A. The shield can be annular in shape to surround a periphery of susceptor 82, as shown in FIG. 2. The shield is provided at the same electrical potential as the susceptor to draw particles 205 uniformly toward the shield and susceptor. In the embodiment shown in FIG. 2A, the shield is placed between the susceptor surface and the substrate 203. Alternatively, the shield can be placed underlying the susceptor or at the same height in parallel alignment with the susceptor face. The shield reduces any "fringing" influences that can create non-uniform electric field lines along the face of the substrate 203. The shield is selectively adjusted and/or located to improve uniformity of implanted particles (e.g., distribution of particles) into a substrate. Accordingly, a uniform distribution of particles 205 impinge onto and into the surface of the substrate across the radial direction of the substrate. Additionally, particles also penetrate through the shield as shown. In this embodiment, the shield is perforated. The perforated shield reduces the demand on the power supply which is used to bias the shield. Furthermore, the system includes charge or particle collection devices 223 and 221. Collection devices are defined on the pedestal or a region underlying the shield. These collection devices are designed to accumulate stray charge and/or particles (e.g., ions) that traverse through the shield. In a specific embodiment, the collection devices are placed in a symmetrical configuration surrounding the susceptor. The collection devices can be placed in a single row surrounding the susceptor or in multiple rows surrounding the susceptor. The quantity, spacing, and configuration of the devices are selected for the particular application.

FIG. 2B shows a simplified top-view diagram of the shield and susceptor according to an embodiment of the present invention. As shown, the shield 201 has a plurality of openings 215, which allow particles to pass therethrough during an implantation process. The openings are circular, but are not limited to this shape. Additionally, the openings are distributed along lines in parallel alignment with the susceptor to provide a uniform or more linear electrical field and sufficient mechanical strength. Openings are each generally smaller toward a center region of the shield and begin progressively larger toward an edge of the shield. As shown, smaller openings are formed toward the shield center and larger openings are formed toward the shield edge. In other embodiments, opening density increases toward an outer region of the shield and decreases toward and inner region of the shield. Stray charge or ions 211 traverse through the shield and accumulate or become trapped in collection devices 221. Collection devices 221 as shown in FIG. 2A prevent a possibility of stray ions or charge from returning back into the chamber and onto the surface of substrate 203 as shown in FIG. 2A. Additional collection devices 223 are disposed on pedestal 207. These collection devices also accumulate charge and or particles 217 that may possibility deflect contamination onto the surface of substrate 203. Each of the collection devices is biased at V.sub.c to accumulate charge and/or particles without influencing the electric fields that create a uniform distribution of implanted ions.

FIG. 2C shows details of openings in the perforated shield according to an embodiment of the present invention. The diagram shows the shield 201 and openings 215. As noted above, particles 215 traverse through the openings during implantation. In a specific embodiment, the shield has rounded edges, which reduce high voltage regions that may occur on sharp edges. That is, the edges are substantially free from sharp right angles and other shapes that create high voltage regions. By

reducing the high voltage regions, electrical arcing and other detrimental influences are reduced or eliminated. An area of openings 215 should be at a selected value relative to the total area of the shield including the area of the support structure 201 or frame and the area of the openings according to an embodiment of the present invention. In one embodiment, the openings are at least 60% of the total area. In other embodiments, the openings are at least 70% or 80% or 90% or greater of the total area. The limitation of the size and region occupied by the openings is generally predicated by the mechanical strength of the shield. That is, the shield should not bend or yield in a substantial manner.

According to an embodiment, the shield can be made of a suitable material for improving mechanical strength, for reducing contamination, and for improving the distribution of particles or ions. In a specific embodiment, the suitable material should be sufficiently rigid. This material can be selected from an aluminum, an aluminum alloy, stainless steel, a silicon bearing material, and others. In an embodiment using a non-silicon bearing material shield material, the shield can be coated with a silicon bearing material to reduce particulate contamination for processing silicon wafers, for example. Alternatively, the shield can be made exclusively of the silicon bearing material. This silicon bearing material includes, among others, polycrystalline silicon, amorphous silicon, crystalline silicon, and others. The silicon bearing material is preferably used in embodiments where silicon wafers are being processed. That is, similar materials should be used in the interior regions of the chamber as the substrate material in order to reduce or possibly eliminate contamination and alike.

FIG. 2D is a simplified side-view diagram 221 of the collection device 221 used in the above embodiments. The collection device 221 uses a Faraday cup design. The cup 221 has a perforated lid 227, which is designed to allow ions or charged species 229 to pass therethrough. Ions 231 that traverse through the perforated lid enter cup 233 by way of electrical biasing. In most cases, the electrical biasing occurs at a voltage which is lower in magnitude than the biasing voltage placed between the plasma and the substrate. The lower magnitude can be about 10 V for a high voltage bias at about -100 kV at the substrate. The voltage (or voltages) applied to the cup (or cups) is selected to attract or accumulate stray ions or charged particles without substantially interfering with the electric field distribution required to produce a uniform distribution of particles through a substrate, for example. In a specific embodiment, electrical current 231 can be measured from the accumulation of charge in the cup. This current indicates that charge is being collected by the cup. Current indications or measurements can be used to adjust particle uniformity in the substrate, for example. Of course, the collection device can also have other configurations.

In a specific embodiment, the present invention provides a process, which can be in-situ, for adjusting particle uniformity in an implanted substrate, for example. The present process includes a variety of steps, which are shown in reference to a simplified flow diagram 250 of FIG. 2E. Reference to FIG. 2F can should also be made in order to fully appreciate and understand the present in-situ monitoring technique. The process 250 begins with step 251, but is not limited. A sample or trial wafer 254 is loaded into a chamber of a plasma immersion ion implantation apparatus, such as the one described herein, but can be others. Alternatively, a production wafer can also be monitored for process integrity during implantation. The wafer rests on a susceptor, which is surrounded with a perforated shield, which can be similar to the one described herein. A plurality of collection devices 252 surround the susceptor. The collection devices are placed in a symmetric configuration around the susceptor for capturing and/or accumulating a portion of accelerated particles during an implantation process. The collection devices 252 include a first set 252A and a second set 252B, where the first set is placed in a line surrounding and parallel to a peripheral region of the susceptor and the second set is placed next to the first set (and in parallel alignment with the peripheral region of the susceptor) but in a region further away from the susceptor. Additionally collection devices (not shown) can also be used.

The method performs a step of providing a plasma and implanting (step 255) a portion of particles from the plasma into the substrate (i.e, wafer), where a portion of the particles also accumulate in

one or more of the collection devices. That is, a portion of the particles accelerated by the implant step collects or accumulates in one or more of the collection devices, step 257, which surround the wafer. As the particles are being accumulated, charge also accumulates since the particles are directly proportional to charged, e.g., ions. The number of charged particles can be measured by way of an electric current that is derived from a collection device.

Accordingly, the present method measures electric current derived from each of the collection devices, step 259. In a specific embodiment, a current meter can be coupled to each of the collection devices for measuring current flow. Alternatively, any other conventional technique for measuring current can be used. In some embodiments, the current meter or meters can be coupled to a controller or the like. The controller tracks and stores the measured current values from the present method.

In a specific embodiment, the measured current value or values from each of the collection devices is compared (step 261) to each other or to a standard. In an embodiment where the standard is used, the standard values (or value) are current reference values for a desired uniform distribution of particles in a wafer, for example. If the measured current values are within a predetermined range of the standard values or value, the uniformity measuring process is done, step 263. Alternatively, if the measured current values are relatively equal to or similar to or within a predetermined range (e.g., 13% or less) of each other, the uniformity measuring process is done, step 263. In most embodiments, substantially equal or uniform current measurements found in the collection devices equate to a substantially uniform distribution of particles in the implanted wafer. Otherwise, the method adjusts one or more of the plasma sources in a desired manner such as those described herein and returns via branch 267 to another implanting step 255. The method returns to the implanting step to perform another measurement of electric current, which is used to determine implantation uniformity. In a specific embodiment, the uniformity distribution of particles in the wafer does not vary by more than 3 percent, or more than 2 percent, or more than 1 percent, or more than 0.5 percent, or more than 0.1 percent.

The present method for detecting or adjusting implantation distribution is merely an example. It will be recognized that other variations, modifications, and alternatives exist. Accordingly, the present method can be performed in another sequence of steps, or be further combined with other steps. Alternatively, steps can be removed in the present method. Furthermore, the present method can be used to monitor process uniformity of the implanted particles during production. That is, the present method monitors via the collection devices implantation uniformity in production substrates such as wafers, flat panel displays, MEMS, integrated circuits, and the like. Of course, the particular steps and sequence of steps used depends upon the application.

Referring to FIG. 3, the configuration of plasma sources 40 may be such that a plurality of physically smaller plasma sources 40 produce a uniform plasma over an area greater than that of sum of the areas of the individual sources. In the embodiment of the configuration shown, four-inch diameter plasma sources 40 spaced at the corners of a square at six inch centers produce a plasma substantially equivalent to that generated by a single twelve inch diameter source. Therefore, by providing a vacuum chamber 14 with a plurality of windows 26, the various configurations of plasma sources 40 may be formed to produce a uniform plasma of the shape and uniformity desired. Antennae such as those depicted do not result in rf interference between sources when properly shielded as shown.

Multiple rf plasma sources can excite electron cyclotron resonance in the presence of a multi-dipole surface magnetic field. Such a surface magnetic field would, for example, be approximately 1 KG at the pole face and would drop to a few Gauss at about 10 cm. from the pole face. In such a system, electron cyclotron resonance may be established, with the electron cyclotron resonance frequency (in Hz) being given by the expression nu=2.8.times.10.sup.6 (B) where B is the magnetic field strength in Gauss. Thus, if the fundamental electron cyclotron resonance frequency is 13.56 MHz (that is, the frequency supplied by the rf generator) the magnetic field required (as applied by the magnets) is 4.8 G, for resonance coupling to take place. Higher harmonics of the fundamental resonance frequency

may be achieved by increasing the magnetic field proportionately. Thus for a second harmonic to be coupled, the magnetic field would have to be increased to 9.6 G. Such ECR coupling is most effective at lower pressures (P<1 mTorr). The use of the small rf plasma sources permit such magnets to be positioned so as to make electron cyclotron resonance possible.

The Faraday cups 78 used to measure the uniformity of the field and the plasma dose, in one embodiment, are positioned near one edge in the surface of the wafer holder 82 (FIG. 4). The flat edge 86 of wafer 90 is positioned on the wafer holder 82 such that Faraday cups 78 of the wafer holder 82 are exposed to the plasma. In this way the plasma dose experienced by the wafer 90 can be directly measured. Alternatively, a special wafer 90', as shown in FIG. 4A, is fabricated with a plurality of Faraday cups 78 embedded in the wafer 90'. This special wafer 90' is used to set the rf generator 66 and the tuning capacitors 58 to achieve the desired plasma density and uniformity. Once the operating parameters have been determined, the special wafer 90' is removed and the wafers 90 to be processed placed on the wafer holder 82.

Referring to FIG. 5, although the system 200 has been described in terms of a planar array of plasma sources 40 located on the upper surface of the vacuum chamber 14, the plasma sources 40 may be distributed over other surfaces of the vacuum chamber 14' to generate a uniform volume of plasma. Such a system is particularly effective in batch processing.

Referring to FIG. 6, in another embodiment, a quartz window 100 is not attached to the vacuum chamber 14, but instead encloses one end of the shield 44 of the plasma source 40'. In this embodiment, a tube 104 attached to an opening 108 in the quartz window 100 provides a gas feed to form a plasma of a specific gas. In this case, the plasma source 40' is not attached to a window 26 in the wall of the vacuum chamber 14, but is instead attached to the vacuum chamber 14 itself. Such plasma sources 40' can produce plasmas from specific gasses as are required by many processes. Several such plasma sources 40' can be aligned to sequentially treat a wafer 90 with different plasmas as in the embodiment of the in line system shown in FIG. 7. In this embodiment, wafers 90 are moved by a conveyor 112 through sequential zones, in this embodiment zones I and II, of a continuous processing line 114. Each zone is separated from the adjacent zones by a baffle 116. In one embodiment, the gas in zone I is SiH.sub.4 used in Si-CVD processing, while the gas in zone II is PH.sub.3 used in doping. In another embodiment, a cluster tool having load-locks to isolate each processing chamber from the other chambers, and equipped with a robot includes the rf plasma sources 40 of the invention for plasma CVD and plasma etching.

FIG. 8 depicts an embodiment of the system of the invention using two plasma sources. In this embodiment each source is an inductive pancake antenna 3-4 inches in diameter. Each antenna 46 is constructed of a 1/4 inch copper tube and contains 5-6 turns. Each antenna 46 is connected to a matching network 50 through a respective 160 pf capacitor. The matching network 50 includes a 0.03 mu H inductor 125 and two variable capacitors 130, 135. One variable capacitor 130 is adjustable over the range of 10-250 pf and the second capacitor 135 is adjustable over the range of 5-120 pf. The matching network 50 is tuned by adjusting the variable capacitor 130, 135. The matching network 50 is in turn connected to an rf source 66 operating at 13.56 mHz. A series of magnets 140, 145 are positioned around the circumference of the chamber in alternating polarity every 7 cm to form a magnetic bucket.

With the chamber operating at 1 m Torr pressure, the power to the antenna 46 is 25 W per antenna or about 50 W total. With the pressure in the chamber reduced to 0.1 m Torr, the power is increased to 200 W per antenna or 400 W total. The resulting plasma at 50 W total power has a substantially uniform density of 10.sup.11 atoms/cm.sup.3. The uniformity and the density may be further improved using four of such sources. With the chamber operating at 1 m Torr pressure, the power to the antenna 46 is 25 W per antenna or about 50 W total. With the pressure in the chamber reduced to 0.1 m Torr, the power is increased to 200 W per antenna or 400 W total. The resulting plasma at 50 W total power has a substantially uniform density of 10.sup.11 atoms/cm.sup.3. The uniformity and the density may be further improved using four of such sources.

While the above description is generally described in a variety of specific embodiments, it will be recognized that the invention can be applied in numerous other ways. For example, the improved susceptor design with collection device(s) can be combined with the embodiments of the other Figs. Additionally, the embodiments of the other Figs. can be combined with one or more of the other embodiments. The various embodiments can be further combined or even separated depending upon the application. Accordingly, the present invention has a much wider range of applicability than the specific embodiments described herein.

Additionally, although the above has been generally described in terms of a PIII system, the present invention can also be applied to a variety of other plasma systems. For example, the present invention can be applied to a plasma source ion implantation system. Alternatively, the present invention can be applied to almost any plasma system where ion bombardment of an exposed region of a pedestal occurs. Accordingly, the above description is merely an example and should not limit the scope of the claims herein. One of ordinary skill in the art would recognize other variations, alternatives, and modifications.

While the above is a full description of the specific embodiments, various modifications, alternative constructions and equivalents may be used. Therefore, the above description and illustrations should not be taken as limiting the scope of the present invention which is defined by the appended claims.

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