A apparatus for plasma processing a substrate is provided. The apparatus comprises a processing chamber, a substrate support disposed in the processing chamber, and a lid assembly coupled to the processing chamber. The lid assembly comprises a conductive gas distributor such as a face plate coupled to a power source, and a heater coupled to the conductive gas distributor. A zoned blocker plate is coupled to the conductive gas distributor and a cooled gas cap is coupled to the zoned blocker plate. A tuning electrode may be disposed between the conductive gas distributor and the chamber body for adjusting a ground pathway of the plasma. A second tuning electrode may be coupled to the substrate support, and a bias electrode may also be coupled to the substrate support.
CONTROLLING TEMPERATURE IN SUBSTRATE PROCESSING SYSTEMS

FIELD
[0001] Embodiments described herein relate to semiconductor manufacturing apparatus and methods. Specifically, embodiments described herein relate to plasma processing chambers for semiconductor substrates.

BACKGROUND
[0002] For over 50 years, the number of transistors formed on an integrated circuit has doubled approximately every two years. This two-year-doubling trend, also known as Moore’s Law, is projected to continue, with devices formed on semiconductor chips shrinking from the current critical dimension of 20-30 nm to below 100 Angstroms in future fabrication processes currently being designed. As device geometries shrink, fabrication geometries grow. As the 300 mm wafer replaced the 200 mm wafer years ago, the 300 mm wafer will shortly be replaced by the 400 mm wafer. With processing of large area semiconductor substrate growing in sophistication, even larger fabrication geometries for logic chips may be within reach.

[0003] Uniformity in processing conditions has always been important to semiconductor manufacturing, and as critical dimensions of devices continue to decline and fab geometries increase, tolerance for non-uniformity also declines. Non-uniformity arises from numerous causes, which may be related to device properties, equipment features, and the chemistry and physics of fabrication processes. As the semiconductor manufacturing industry progresses along Moore’s Law, there is a continuing need for fabrication processes and equipment capable of very uniform processing.

SUMMARY
[0004] Embodiments described herein provide an apparatus for processing a semiconductor substrate, with a processing chamber, a substrate support disposed
in the processing chamber, and a lid assembly comprising a conductive gas
distributor coupled to a source of electric power and a heater contacting the
conductive gas distributor. The lid assembly may also have a zoned blocker plate
coupled to the conductive gas distributor that provides multiple separate pathways
for process gases into the interior of the processing chamber. A gas cap provides
portals to the various gas pathways, and includes a thermal control conduit for
circulating a fluid.

[0005] An electrode may be positioned between the conductive gas distributor
and the body of the processing chamber. The electrode may be a tuning electrode
for adjusting plasma conditions in the chamber, and may be an annular member
surrounding a portion of the processing volume. The electrode may be coupled to a
tuning circuit, which may be an LLC circuit comprising an electronic controller such
as a variable capacitor, which may be used to adjust a ground pathway of the
processing chamber. An electronic sensor may be used to monitor an electrical
condition of the electrode 108, and may be coupled to the electronic controller for
real-time, closed-loop control.

[0006] One or two electrodes may also be coupled to the substrate support. One
electrode may be a bias electrode, and may be coupled to a source of electric
power. The other electrode may be a second tuning electrode, and may be coupled
to a second tuning circuit having a second electronic sensor and a second electronic
controller.

[0007] The heater and thermal control conduits of the lid assembly may be used
to control a temperature of the conductive gas distributor during substrate
processing, while the first and second tuning electrodes may be used to control
deposition rate and thickness uniformity independently.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] So that the manner in which the above-recited features of the present
invention can be understood in detail, a more particular description of the invention,
briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0009] Figure 1 is a schematic cross-sectional view of a processing chamber 100 according to one embodiment.

[0010] Figure 2 is a schematic top view of an apparatus 200 according to another embodiment.

[0011] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.

**DETAILED DESCRIPTION**

[0012] Embodiments described herein provide an apparatus for processing a semiconductor substrate. Figure 1 is a schematic cross-sectional view of a processing chamber 100, according to one embodiment. The processing chamber 100 features a chamber body 102, a substrate support 104 disposed inside the chamber body 102, and a lid assembly 106 coupled to the chamber body 102 and enclosing the substrate support 104 in a processing volume 120. Substrates are provided to the processing volume 120 through an opening 126, which may be conventionally sealed for processing using a door.

[0013] The lid assembly 106 comprises an electrode 108 disposed adjacent to the chamber body 102 and separating the chamber body 102 from other components of the lid assembly 106. The electrode 108 may be an annular, or ring-like member, and may be a ring electrode. The electrode 108 may be a continuous loop around a circumference of the processing chamber 100 surrounding the
processing volume 120, or may be discontinuous at selected locations if desired. A pair of isolators 110 and 112, each of which may be a dielectric material such as a ceramic or metal oxide, for example aluminum oxide and/or aluminum nitride, contacts the electrode 108 and separates the electrode 108 electrically and thermally from a conductive gas distributor 114. The conductive gas distributor 114, which may be a conductive face plate, is in thermal contact, and may be in physical contact, with a heater 116.

[0014] In an embodiment where the conductive gas distributor 114 is a conductive face plate, the conductive face plate may be a flat, conductive, plate-like member having a substantially uniform thickness, and a surface of the conductive face plate may be substantially parallel to an upper surface of the substrate support 104. The conductive face plate may be metal, such as aluminum or stainless steel and may be coated in some embodiments with a dielectric material such as aluminum oxide or aluminum nitride.

[0015] The heater 116 includes a heating element 176, which may be resistive element, such as an electrical conductor designed to radiate heat, or a conductive element, such as a conduit for a heating fluid. The conductive gas distributor 114 features openings 118 for admitting process gas into the processing volume 120. An edge portion 180 of the conductive gas distributor 114 is accessible along the side of the processing chamber 100 to allow coupling of the conductive gas distributor 114 to a source of electric power 142, such as an RF generator. DC power, pulsed DC power, and pulsed RF power may also be used.

[0016] A zoned blocker plate comprising a first zoned plate 152 and a second zoned plate 158 contacts the conductive gas distributor 114 and provides multiple gas pathways through the lid assembly 106. While the embodiment shown in Figure 1 is an example of one configuration of such a zoned blocker plate, other configurations of a zoned blocker plate, including configurations having more than two zoned plates, are conceivable. The first zoned plate 152 has one or more plenums 154 for circulating process gases through a first pathway for distribution to
the processing volume 120 through openings 156 in the first zoned plate that are in fluid communication with the openings 118 of the conductive gas distributor 114. The second zoned plate 158 also has one or more plenums 160 for circulating process gases through a second pathway for distribution to the processing volume 120 through openings 178 in the second zoned plate that are in fluid communication with pass-through openings 162 of the first zoned plate 152 and the openings 118 of the conductive gas distributor 114.

[0017] A gas cap 164 is disposed in contact with the second zoned plate 158, and provides portals for flowing process gases separately to the plenums 154 in the first zoned plate 152 and the plenums 160 in the second zoned plate 158, allowing the process gases to flow to the processing volume 120 without contacting each other prior to arriving in the processing volume 120. The gas cap 164 also features a portal 166 in fluid communication with a pass-through opening 168 in the second zoned plate 158 and the first zoned plate 152, and with one of the openings 118, for passing process gas directly into the processing volume 120 through a third gas pathway, if desired. The gas cap 164 also features a conduit 170 for circulating a fluid through the gas cap 164. The fluid may be a thermal control fluid, such as a cooling fluid. Water is an example of a cooling fluid that may be used, but other fluids, liquid and solid, may also be used. The thermal control fluid is provided to the conduit 170 through an inlet 172 and is withdrawn from the conduit 170 through an outlet 174. The gas cap 164 is in thermal communication with the first and second zoned plates 152 and 158, and with the conductive gas distributor 114. The heater 116 and the thermally controlled gas cap 164 together provide thermal control for the conductive gas distributor 114 to allow temperature uniformity from edge to center and from substrate to substrate. Gases are evacuated from the processing volume 120 through a portal 178, which may be coupled to a vacuum source (not shown), which may be located at any convenient location along the chamber body, and which may be associated with a pumping plenum, if desired.

[0018] The electrode 108 may be coupled to a tuning circuit 128 that controls a ground pathway of the processing chamber 100. The tuning circuit 128 comprises
an electronic sensor 130 and an electronic controller 134, which may be a variable capacitor. The tuning circuit 128 may be an LLC circuit comprising one or more inductors 132. The electronic sensor 130 may be a voltage or current sensor, and may be coupled to the electronic controller 134 to afford a degree of closed-loop control of plasma conditions inside the processing volume 120.

[0019] A second electrode 122 may be coupled to the substrate support 104. The second electrode 122 may be embedded within the substrate support 104 or coupled to a surface of the substrate support 104. The second electrode 122 may be a plate, a perforated plate, a mesh, a wire screen, or any other distributed arrangement. The second electrode 122 may be a tuning electrode, and may be coupled to a second tuning circuit 136 by a conduit 146, for example a cable having a selected resistance such as 50 Ω, disposed in a shaft 144 of the substrate support 104. The second tuning circuit 136 may have a second electronic sensor 138 and a second electronic controller 140, which may be a second variable capacitor. The second electronic sensor 138 may be a voltage or current sensor, and may be coupled to the second electronic controller 140 to provide further control over plasma conditions in the processing volume 120.

[0020] A third electrode 124, which may be a bias electrode, may be coupled to the substrate support 104. The third electrode may be coupled to a second source of electric power 150 through a filter 148, which may be an impedance matching circuit. The second source of electric power 150 may be DC power, pulsed DC power, RF power, pulsed RF power, or a combination thereof.

[0021] The lid assembly 106 and substrate support 104 of Figure 1 may be used with any processing chamber for plasma or thermal processing. One example of a plasma processing chamber with which the lid assembly 106 and substrate support 104 may be beneficially used is the PRODUCER® platform and chambers available from Applied Materials, Inc., located in Santa Clara, California. Chambers from other manufacturers may also be used with the components described above.
In operation, the processing chamber 100 affords real-time control of temperature in the lid assembly 106 and of plasma conditions in the processing volume 120. A substrate is disposed on the substrate support 104, and process gases are flowed through the lid assembly 106 according to any desired flow plan. A temperature set point is established for the conductive gas distributor, and is controlled by operation of the heater 116 and by circulation of a cooling fluid through the conduit 170. Electric power is coupled to the conductive gas distributor 114 to establish a plasma in the processing volume 120. Because the temperature of the conductive gas distributor 114 is controlled, less electric power is dissipated through heating of the conductive gas distributor 114 and other components of the lid assembly 106, and the temperature of the conductive gas distributor 114 is stabilized from center to edge and from substrate to substrate, beginning with the first substrate processed in the processing chamber 100. The substrate may be subjected to an electrical bias using the third electrode 124, if desired.

Upon energizing a plasma in the processing volume 120, a potential difference is established between the plasma and the first electrode 108. A potential difference is also established between the plasma and the second electrode 122. The electronic controllers 134 and 140 may then be used to adjust the flow properties of the ground paths represented by the two tuning circuits 128 and 136. A set point may be delivered to the first tuning circuit 128 and the second tuning circuit 136 to provide independent control of the plasma density uniformity from center to edge and deposition rate. In embodiments where the electronic controllers are both variable capacitors, the electronic sensors may adjust the variable capacitors to maximize deposition rate and minimize thickness non-uniformity independently.

Figure 2 is a schematic top view of an apparatus 200 according to another embodiment. The apparatus 200 is a collection of processing chambers, all of which may be embodiments of the processing chamber 100 of Figure 1, coupled to a transfer chamber 208 and a load-lock assembly 204. The processing chambers 100 are generally grouped in tandem units 202, each of which has a single supply of
process gases 212. The tandem units 202 are positioned around the transfer chamber 208, which typically has a robot 210 for manipulating substrates. The load-locks assembly 204 may feature two load-lock chambers 206, also in a tandem arrangement.

[0025] Figure 3 is a schematic cross-sectional view of a processing chamber 300, according to another embodiment. The process chamber 300 of Figure 3 is similar in most respects to the process chamber 100 of Figure 1, including the conductive gas distributor 114 and the heater 116. The process chamber 300 has a different tuning circuit 302 coupled to the second electrode 122. The tuning circuit 302 features the sensor 138, which may be a VI sensor, coupled in parallel to the second electronic controller 140 and a first inductor 306. The second electronic controller is coupled to a second inductor 304. The first and second inductors 306 and 304 are both grounded. The tuning circuit 302 may be an LLC circuit with a variable component, such as a variable capacitor or a variable inductor, and may be similar to, or the same as, the tuning circuit 128. The different tuning circuits of the Figure 1 and Figure 3 embodiments demonstrate that tuning circuits may be devised for different embodiments having different static and variable components designed to provide tuning of the plasma profile for chambers with different electrical characteristics.

[0026] Figure 4A is a top perspective view of a conductive gas distributor 400 that may be used with the process chamber 100 or the process chamber 300. The conductive gas distributor 400 is a disk-shaped member for use in a chamber with cylindrical geometry for processing disk-like substrates. Gas flows through a plurality of gas passages 402 arranged in concentric rows. In the embodiment of Figure 4A, the distributor 400 has three rows of gas passages having radius between about 25% and about 95%, for example between about 40% and about 60%, of the radius of the distributor 400. A plurality of openings 404 are positioned at a peripheral region of the distributor 400. The openings 404 may have a diameter between about x and about y, and may be spaced at regular angular intervals along
a circumference of the distributor 400. The openings 404 may be attachment openings, instrumentation openings, or gas flow openings.

[0027] A side 406 of the distributor 400 has a plurality of support insertion openings 408 formed therein. The support insertion openings 408 allow a support member to be inserted to clamp the distributor 400 to a lid stack and/or to move the distributor 400 conveniently. The support insertion openings 408 may have an oval or eliptical shape, or may be an stretched circle shape with substantially straight sides. The openings 408 typically have a transverse dimension at least about 1/3 the thickness of the distributor 400, and a meridian of the openings 408 typically coincides with a meridian of the distributor 400. In other words, the openings 408 are typically centered along the thickness of the distributor 400. In the embodiment of Figure 4A, the openings 408 have a major dimension, measured along the circumference of the distributor 400, of about 1.75", but the major dimension may be between about 0.25" and about 3", or more. In the embodiment of Figure 4A, the openings 408 have a minor, or transverse, dimension of about 0.5". The distributor 400 of Figure 4 may have a thickness between about 0.25" and about 3", such as about 1". The openings 408 may be spaced evenly around a circumference of the distributor 400. The embodiment of Figure 4A features three support insertion openings 408 distributed at angles of 120 degrees, but any useful number of support insertion openings 408 may be provided.

[0028] A plurality of instrumentation openings 410 are provided on the side of the distributor 400. The instrumentation openings 410 may be used to insert instruments or probes to measure any useful parameter. Temperature is commonly measured by inserting temperature probes, such as thermocouples, into one or more of the instrumentation openings 410. The instrumentation openings 410 may have any convenient diameter. In the embodiment of Figure 4A, the instrumentation openings have a diameter of about 0.2". The instrumentation openings 410 may couple to a conduit (not shown) that extends a distance into the distributor 400 to accomodate insertion of an instrument. In the embodiment of Figure 4A, the conduit extends about 1.5" into the distributor 400 along a radius thereof. The conduit may
extend any desired direction into the distributor 400, which along a radius of the
distributor 400 or a chord of the distributor 400. The conduit has a profile selected
based on the type of instrument to be inserted and the type of measurement to be
made. In the embodiment of Figure 4A, a thermocouple is inserted into the
instrumentation openings 410, so the conduit coupled to each opening 410 has a
profile that accommodates the thermocouple while brining surfaces of the distributor
400 into intimate proximity with the thermocouple to facilitate temperature
measurement. The instrumentation openings 410 may have any convenient angular
spacing along the circumference of the distributor 400. In Figure 4A, two of the
instrumentation openings 410 are spaced an angular distance of 90 degrees apart.

[0029] An instrumentation opening 410 may be located at an abutment face 412
on the side of the distributor 400. Every instrumentation opening 410 of the
distributor 400 is associated with an abutment face 412. The abutment face 412
provides a flat margin around the instrumentation opening 410 for full insertion of the
instrument. The abutment face 412 has an area larger than the area of the
instrumentation opening 410 to provide space for engagement of the instrument. A
ratio of a circumferential dimension of the abutment face 412 to the diameter of the
instrumentation opening 410 may be between about 3:1 and about 10:1, for example
about 7.5"1. In Figure 4A, the abutment face 412 has a dimension in the
circumferential direction between about .75" and about 2.0", for example about 1.5".
The abutment face 412 may have a dimension in the transverse direction up to the
thickness of the distributor 400. A ratio of the thickness of the distributor 400 to the
transverse dimension of the abutment face 412 may be between about 3:1 and
about 1:1.

[0030] The distributor 400 has an RF connection 414 on a side of the distributor
400. The RF connection 414 comprises two openings 416 located at an abutment
face 418. The two openings 416 accommodate each accommodate an RF
electrode from an RF connector, and the abutment face 418 provides a flat surface
for full engagement of the RF connector. The openings 416 may be separated by a
center-to-center distance between about 0.5" and about 1.5", such as about 0.75".
The two openings 416 may each have any convenient diameter for connecting to an RF source. In the embodiment of Figure 4A, the openings 416 have a minimum edge-to-edge separation of about 0.4", each opening 416 having a diameter of about 0.35".

[0031] Figure 4B is a bottom perspective view of the conductive gas distributor 400. The distributor 400 has a plurality of positioning notches 420 formed in an edge 422 of the distributor 400. The positioning notches 420 provide a means to register the distributor 400 with a positioning feature on an adjacent component of the chamber 100 or the chamber 300. The notches 420 may be open in an outward radial direction to allow for radial thermal movement of the distributor 400 while maintaining the distributor in a substantially constant centered position in the chamber 100 or 300. The notches 420 may have a radial depth between about 0.1" and about 1", for example about 0.3", and a depth from a bottom surface 422 of the distributor 400 between about 0.1" and about 0.5", for example about 0.1 1". The notches 420 may be regularly or irregularly spaced around the circumference of the distributor 400, and any convenient number of notches 420 may be used. In Figure 4B, three notches 420 are spaced at angular intervals of 120 degrees about the circumference of the distributor 400.

[0032] The notches 420 of Figure 4B have an angular displacement with respect to the support insertion openings 408 that is between about 5 degrees and about 30 degrees, such as about 16 degrees. Depending on the transverse dimension of the support insertion openings 408 and the depth of the notches 420, the notches 420 may be aligned with the support insertion openings 408. If a distance between a boundary 424 of one of the notches 420 and a boundary 426 of one of the support insertion openings 408 is greater than about 0.1", the notches 420 and the openings 408 may be aligned or overlapping. Otherwise, any convenient angular displacement may be used.

[0033] The distributor 400 has a seal groove 430 along the bottom surface 422 near a periphery of the distributor 400. The seal groove 430 receives a resilient
member, such as an o-ring, which forms a seal between the bottom surface 422 and
an adjacent chamber component, such as an isolator 112. The seal groove 430 has
an inner radius 432 and an outer radius 434. A wall of the seal groove 430 is
elevated at the outer radius 434 with respect to the inner radius 432, such that a
peripheral ring 436 of the distributor 400 contacts the adjacent chamber component
to provide a seal interface against which the resilient member presses to form the
seal. The seal groove 430 is wider at the bottom of the seal groove than at the top
to provide retention of the resilient member inside the seal groove 430, and a width
of the seal groove 430 at the top thereof is typically smaller than a width of the
resilient member, which elastically deforms upon insertion through the top of the
seal groove 430.

[0034] The seal groove 430 is near the edge 422 of the distributor 400. The
outer radius 434 of the seal groove 430 is located inward of the notches 420 by a
distance less than about 0.1", such as about 0.08". At the bottom of the seal groove
430, an extremity of the seal groove 430 may be a distance of less than 0.05", such
as about 0.03", from the nearest extremity of a notch 420.

[0035] While the foregoing is directed to embodiments of the invention, other and
further embodiments of the invention may be devised without departing from the
basic scope thereof.
What is claimed is:

1. An apparatus for processing a semiconductor substrate, comprising:
   a processing chamber;
   a substrate support disposed in the processing chamber; and
   a lid assembly comprising a conductive gas distributor coupled to a source of electric power and a heater contacting the conductive gas distributor.

2. The apparatus of claim 1, wherein the lid assembly further comprises a zoned blocker plate between the conductive gas distributor and a gas cap.

3. The apparatus of claim 2, wherein the gas cap comprises a fluid circulation conduit, and the gas cap is in thermal communication with the conductive gas distributor.

4. The apparatus of claim 2, wherein the conductive gas distributor is a conductive face plate.

5. The apparatus of claim 3, wherein the conductive gas distributor has openings, the zoned blocker plate has openings, the gas cap has openings, the openings of the gas cap are in fluid communication with openings in the zoned blocker plate and the conductive gas distributor, and the openings of the zoned blocker plate are in fluid communication with openings in the conductive gas distributor.

6. The apparatus of claim 3, wherein the heater contacts a periphery of the conductive gas distributor.

7. The apparatus of claim 3, wherein the conductive gas distributor comprises an instrumentation opening.

8. The apparatus of claim 7, wherein the conductive gas distributor further comprises a support insertion opening.
9. The apparatus of claim 8, wherein the conductive gas distributor further comprises an abutment plate for an RF connection.

10. An apparatus for processing a semiconductor substrate, comprising:
    a processing chamber comprising a chamber body;
    a substrate support disposed in the processing chamber;
    a lid assembly comprising a conductive face plate coupled to a source of electric power, a zoned blocker plate contacting the conductive face plate, and a cooled gas cap contacting the zoned blocker plate and in thermal communication with the conductive face plate, and a heating ring disposed in contact with the conductive face plate.

11. The apparatus of claim 10, wherein the heating ring is also in contact with the zoned blocker plate.

12. The apparatus of claim 11, wherein the conductive face plate comprises an instrumentation opening and a support insertion opening.

13. The apparatus of claim 12, wherein the heating ring comprises a fluid conduit.

14. The apparatus of claim 13, wherein the heating ring comprises a resistive heating element.

15. The apparatus of claim 13 or 14, wherein the conductive face plate further comprises an abutment plate for an RF connection.
## A. CLASSIFICATION OF SUBJECT MATTER

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)**

- HOIL 21/02; H01L 21/3065; H05H 1/46; C23F 4/00; H01L 21/205; H01L 21/306; B01J 3/00; H01L 21/3; H01L 21/465; C23C 16/455; C23C 16/00

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

- Korean utility models and applications for utility models
- Japanese utility models and applications for utility models

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

- eKOMPASS (KIPO internal) & keywords: chamber, lid, conductive gas distributor, electrode, heater, cooler

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

* Special categories of cited documents:
  - "A" document defining the general state of the art which is not considered to be of particular relevance
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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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### Date of the actual completion of the international search
13 January 2014 (13.01.2014)

### Date of mailing of the international search report
13 January 2014 (13.01.2014)

### Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City,
302-701, Republic of Korea
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### Authorized officer

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Telephone No. +82-42-481-8291
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