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(54) **IMMERSION FIELD GUIDED EXPOSURE AND POST-EXPOSURE BAKE PROCESS**

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G03F 7/004 (2006.01)
G03F 7/38 (2006.01)

(52) **U.S. Cl.**
CPC *G03F 7/0045* (2013.01); *G03F 7/38* (2013.01); *G03F 7/70* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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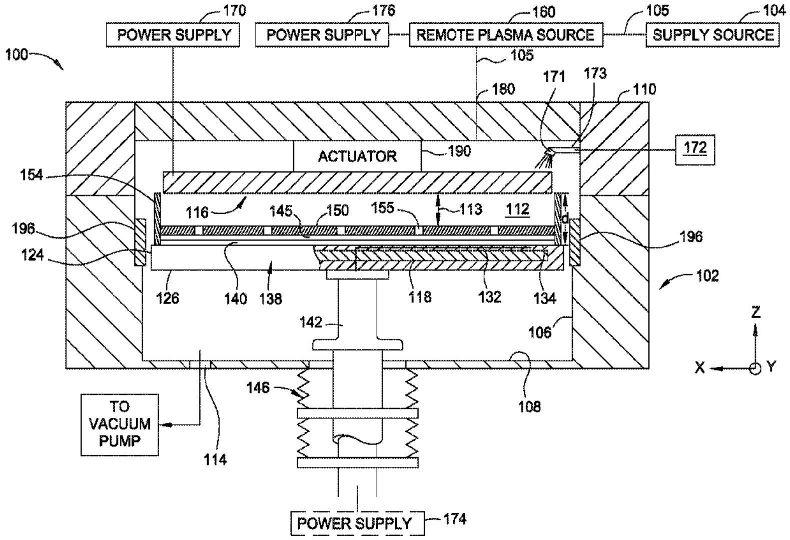
(57) **ABSTRACT**

Methods disclosed herein provide apparatus and method for applying an electric field and/or a magnetic field to a photoresist layer without air gap intervention during photolithography processes. In one embodiment, an apparatus includes a processing chamber comprising a substrate support having a substrate supporting surface, a heat source embedded in the substrate support configured to heat a substrate positioned on the substrate supporting surface, an electrode assembly configured to generate an electric field in a direction substantially perpendicular to the substrate supporting surface, wherein the electrode assembly is positioned opposite the substrate supporting surface having a downward surface facing the substrate supporting surface, wherein the electrode assembly is spaced apart from substrate support defining a processing volume between the electrode assembly and the substrate supporting surface, and a confinement ring disposed on an edge of the substrate support or the electrode assembly configured to retain an intermediate medium.

15 Claims, 9 Drawing Sheets



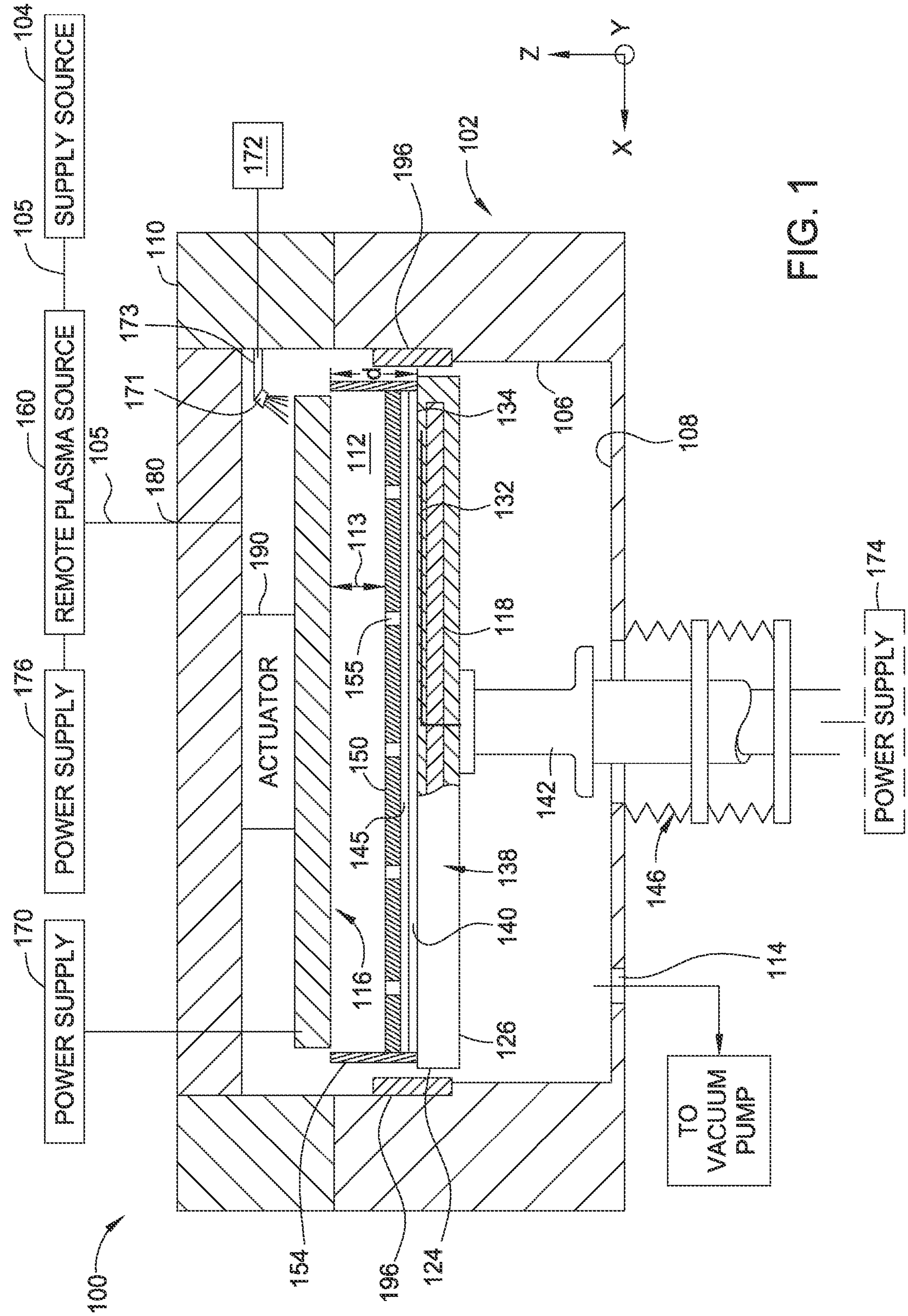

SUPPLY SOURCE
104
105
REMOTE PLASMA SOURCE
160
105
180
POWER SUPPLY
176
POWER SUPPLY
170
172
110
173
171
190
ACTUATOR
196
102
Z
Y
X
d
134
106
108
112
132
113
118
155
150
145
116
140
138
142
146
POWER SUPPLY
174
114
TO VACUUM PUMP
126
154
196
124
100

FIG. 1

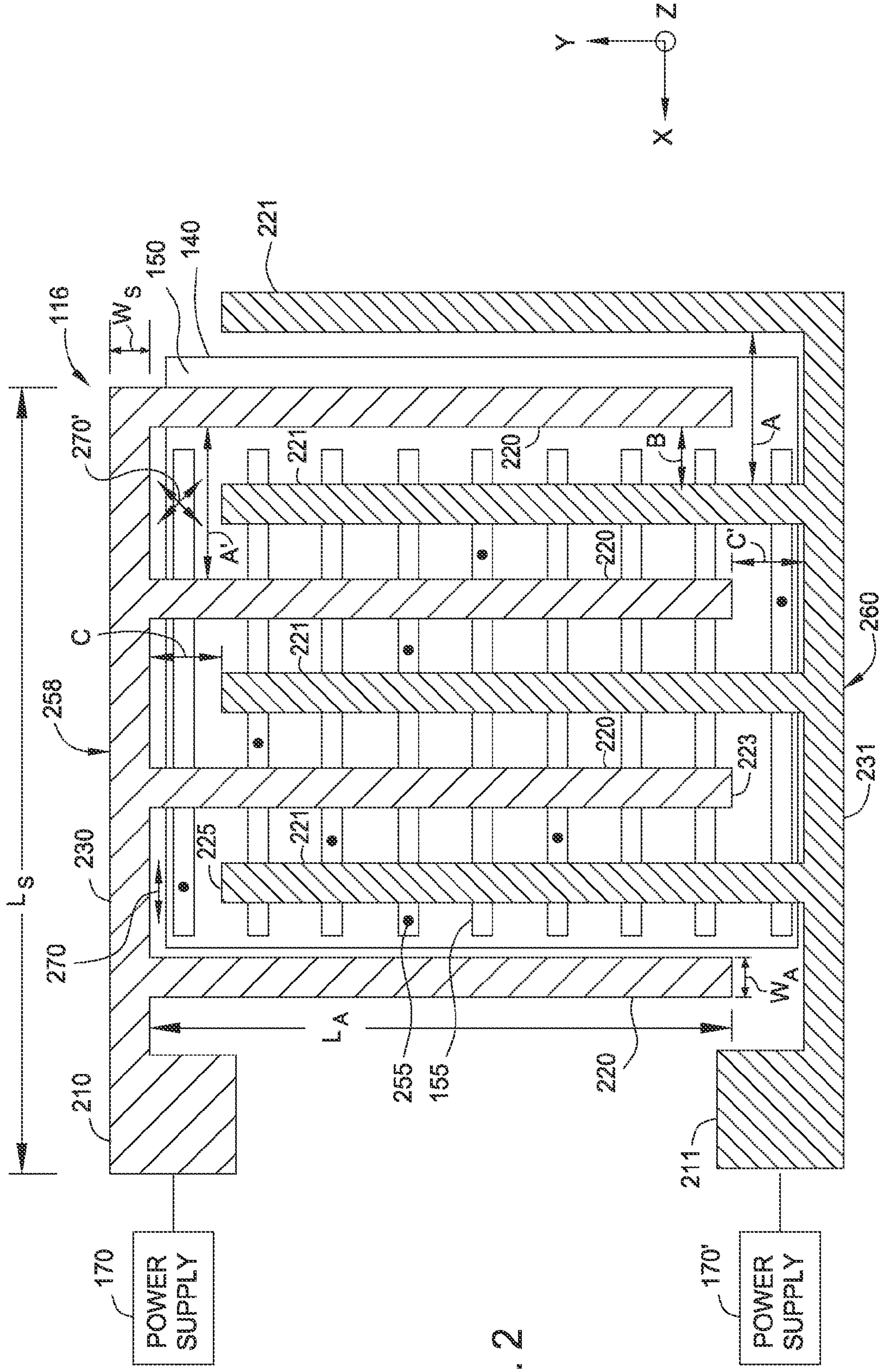
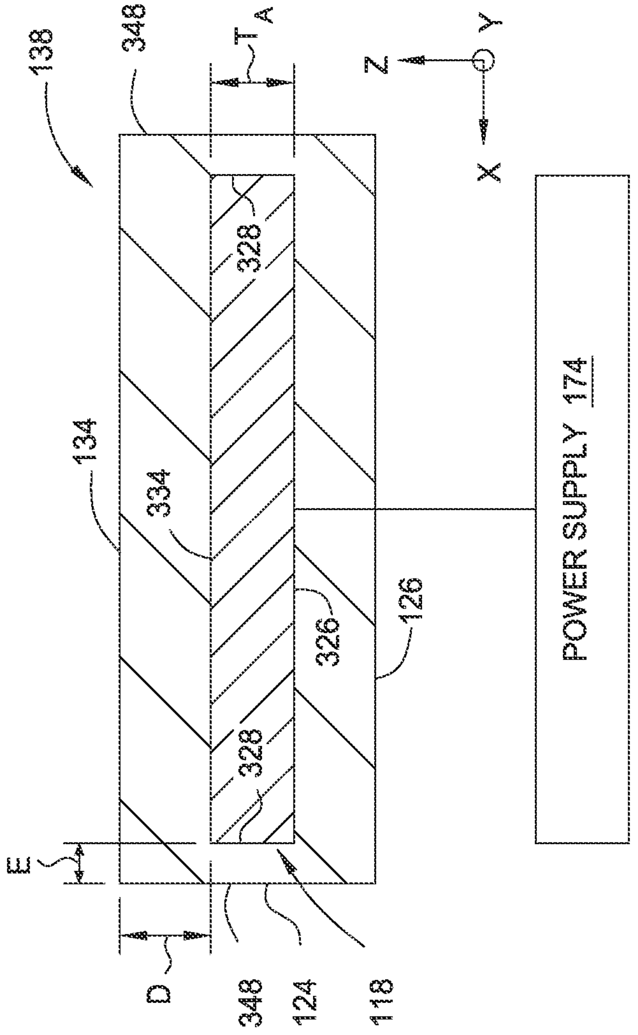

Z
Y
X
221
140
150
116
W_S
270'
220
221
B
A
A'
220
C'
260
C
221
258
220
223
231
230
225
221
270
W_A
L_S
L_A
255
155
220
210
211
POWER SUPPLY
170
POWER SUPPLY
170'

FIG. 2


138
348
T_A
Z
Y
X
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134
334
326
126
POWER SUPPLY 174
328
E
D
348
124
118

FIG. 3

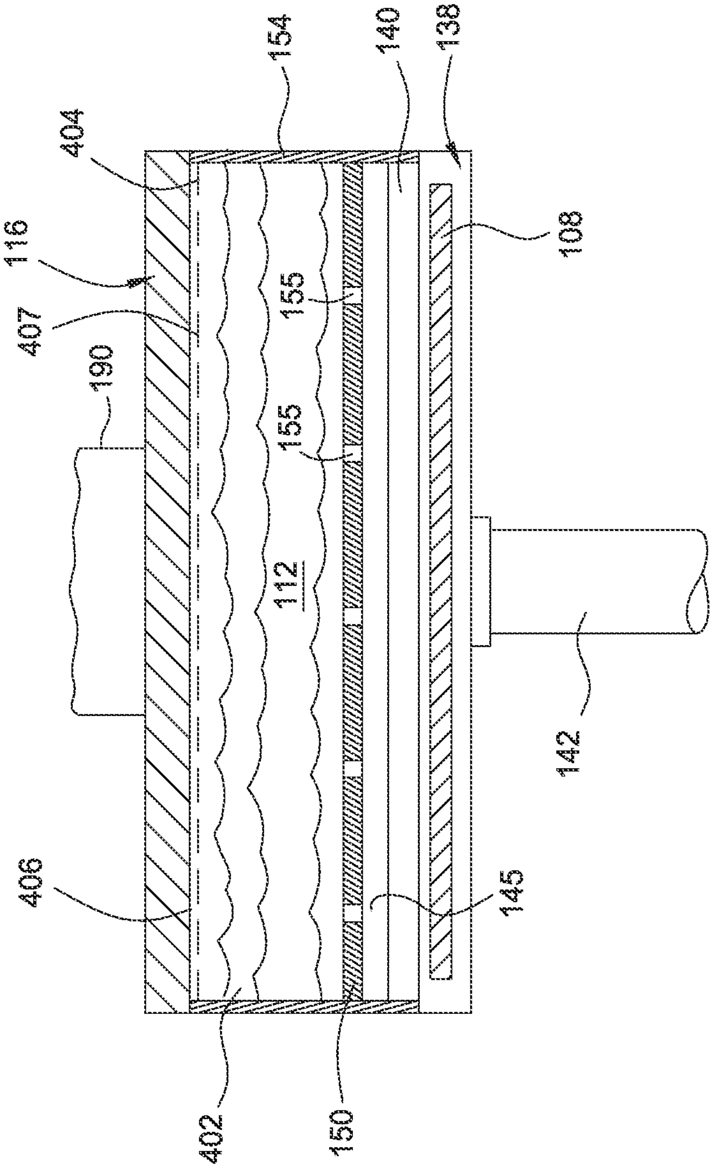


FIG. 4A

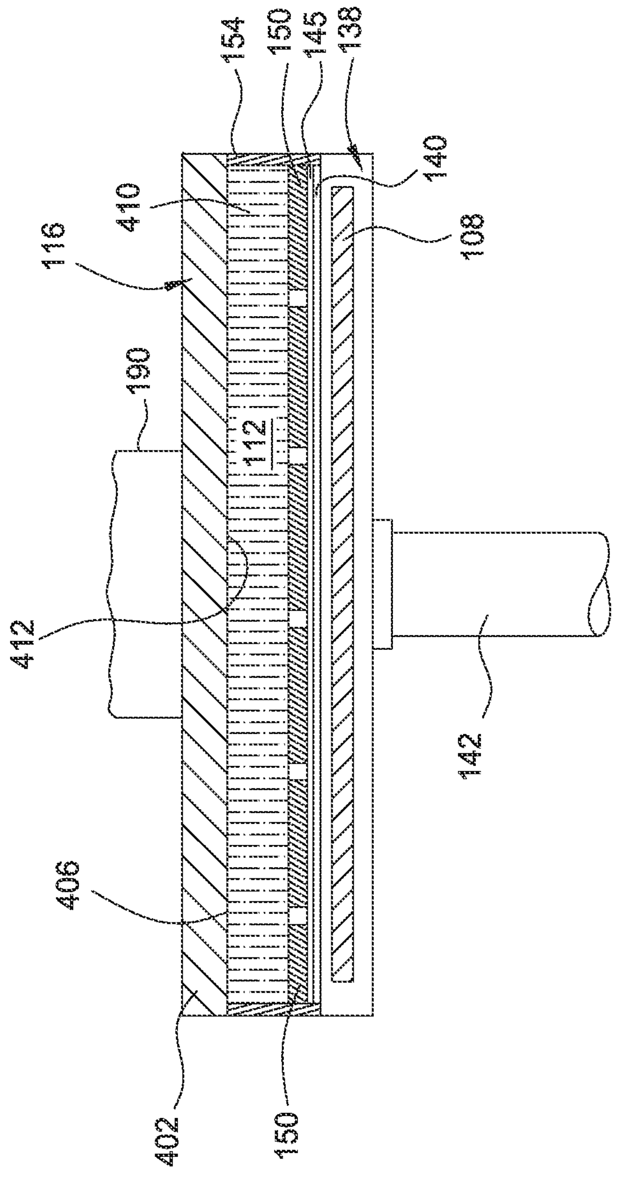


FIG. 4B

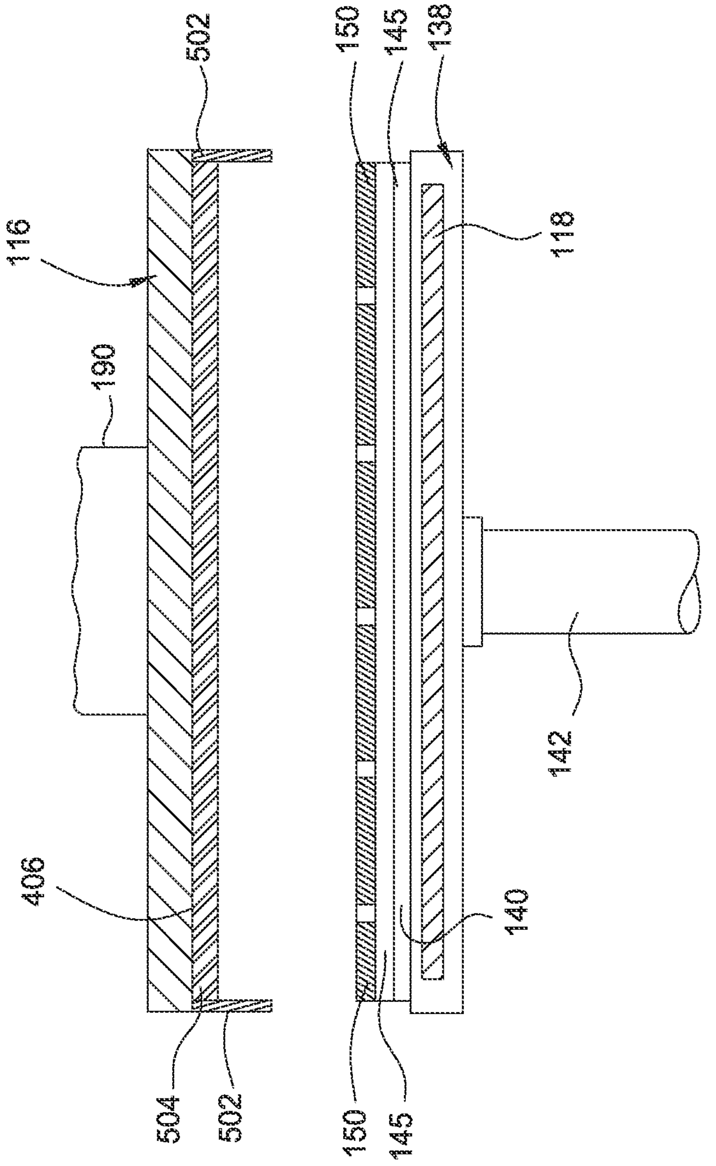


FIG. 5A

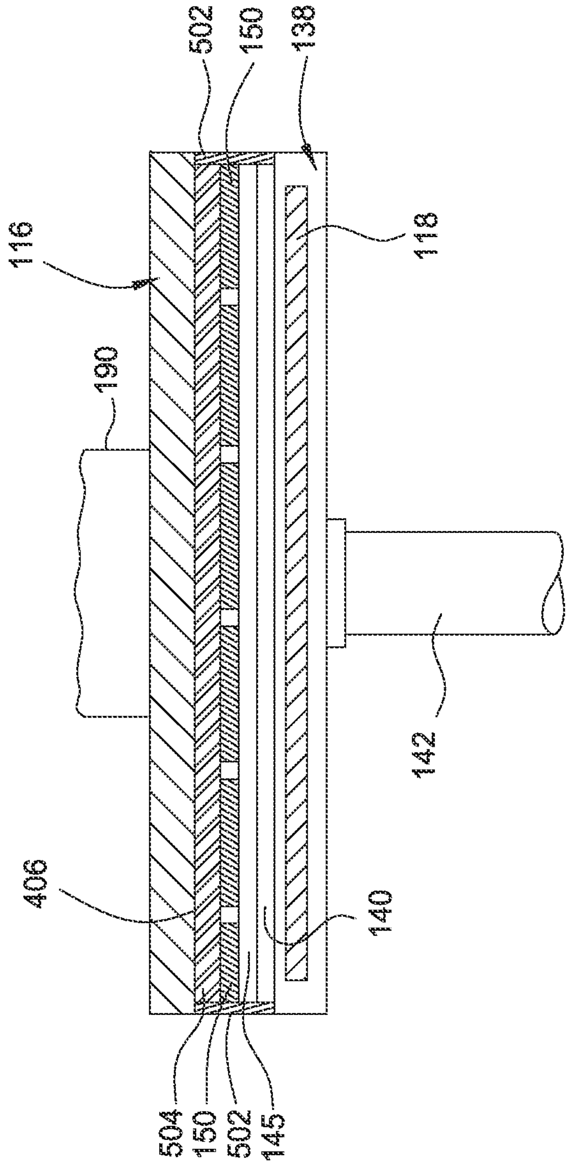
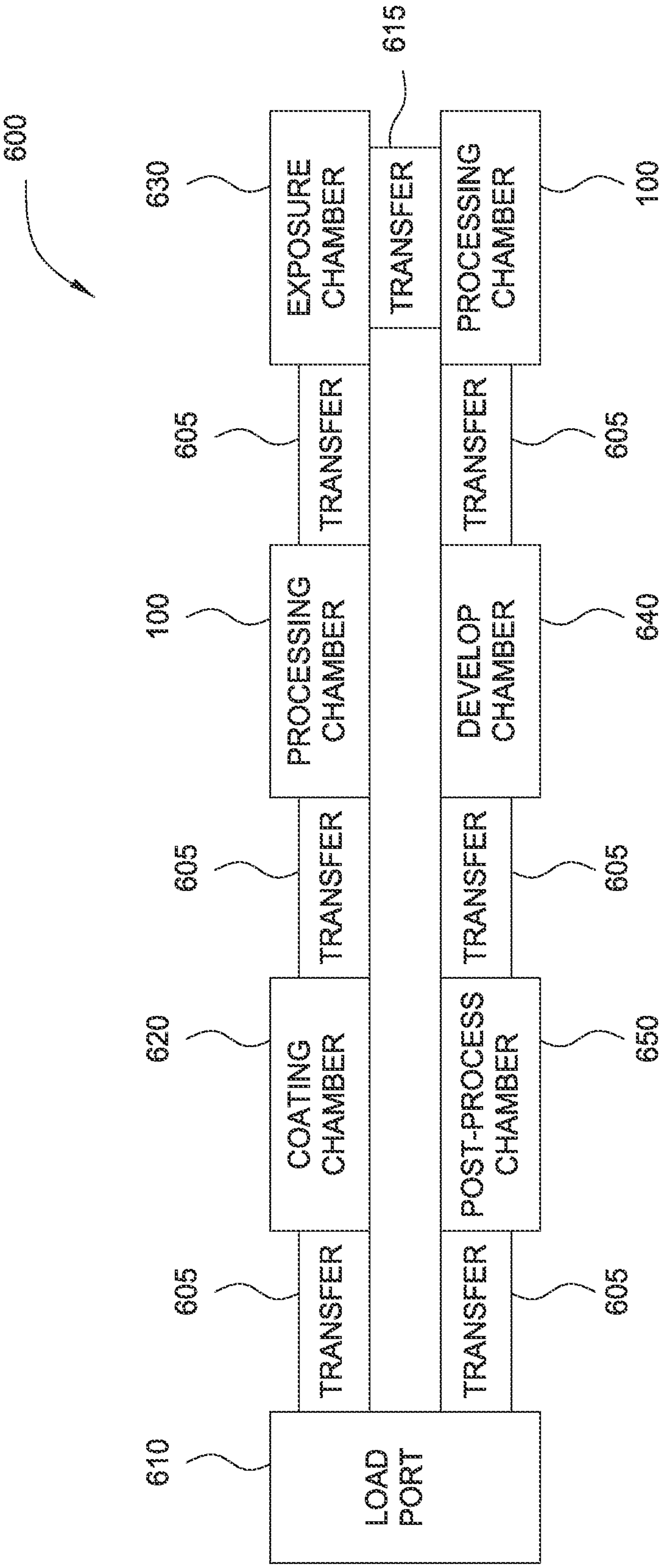


FIG. 5B


600
610
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620
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100
PROCESSING CHAMBER
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TRANSFER
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EXPOSURE CHAMBER
615
TRANSFER
100
PROCESSING CHAMBER
605
TRANSFER
640
DEVELOP CHAMBER
605
TRANSFER
650
POST-PROCESS CHAMBER
605
TRANSFER

FIG. 6

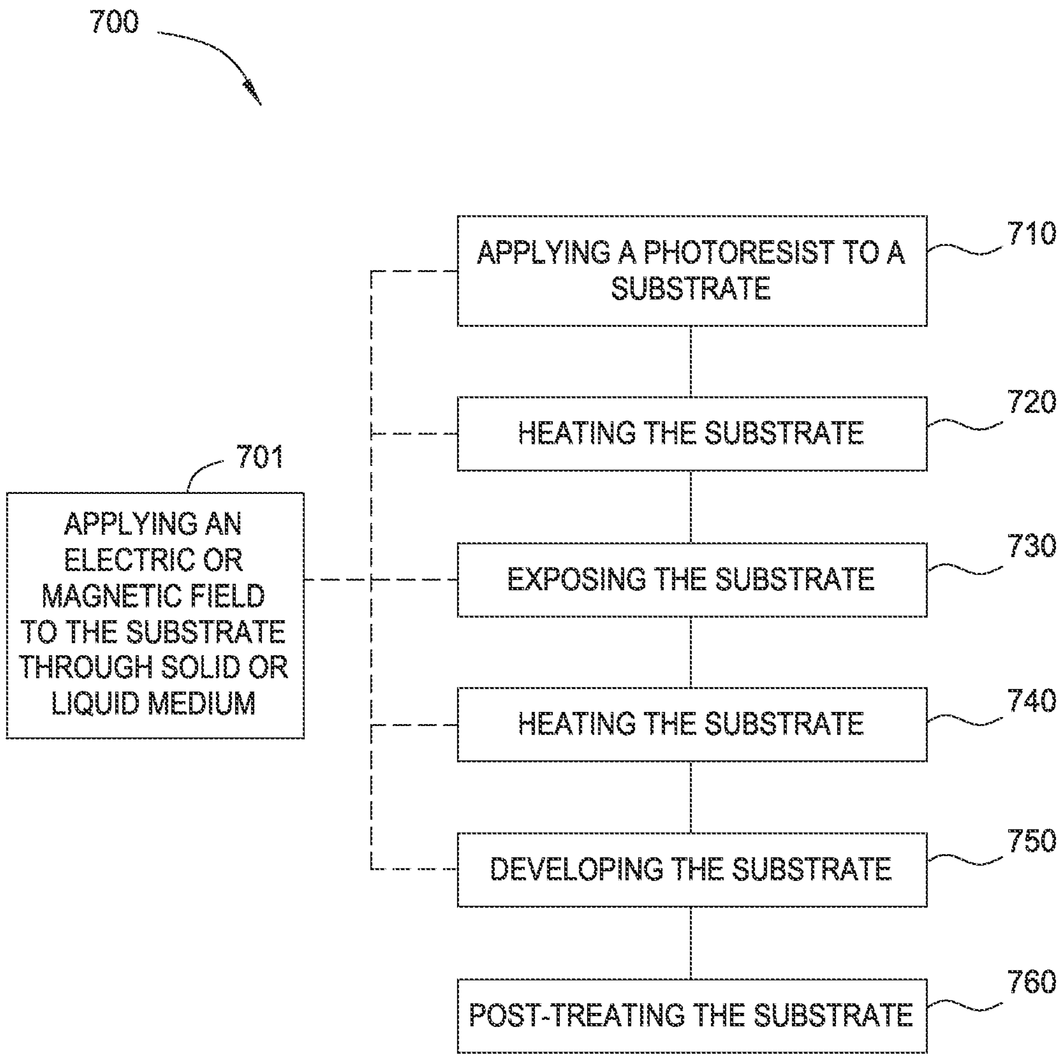
700
701
APPLYING AN ELECTRIC OR MAGNETIC FIELD TO THE SUBSTRATE THROUGH SOLID OR LIQUID MEDIUM
APPLYING A PHOTORESIST TO A SUBSTRATE
710
HEATING THE SUBSTRATE
720
EXPOSING THE SUBSTRATE
730
HEATING THE SUBSTRATE
740
DEVELOPING THE SUBSTRATE
750
POST-TREATING THE SUBSTRATE
760

FIG. 7

IMMERSION FIELD GUIDED EXPOSURE AND POST-EXPOSURE BAKE PROCESS

BACKGROUND

Field

The present disclosure generally relates to methods and apparatuses for processing a substrate, and more specifically to methods and apparatuses for improving photolithography processes.

Description of the Related Art

Integrated circuits have evolved into complex devices that can include millions of components (e.g., transistors, capacitors and resistors) on a single chip. Photolithography may be used to form components on a chip. Generally the process of photolithography involves a few basic stages. Initially, a photoresist layer is formed on a substrate. The photoresist layer may be formed by, for example, spin-coating. A chemically amplified photoresist may include a resist resin and a photoacid generator. The photoacid generator, upon exposure to electromagnetic radiation in the subsequent exposure stage, alters the solubility of the photoresist in the development process. The electromagnetic radiation may have any suitable wavelength, such as a wavelength in the extreme ultra violet region. The electromagnetic radiation may be from any suitable source, such as, for example, a 193 nm ArF laser, an electron beam, an ion beam, or other source. Excess solvent may then be removed in a pre-exposure bake process.

In an exposure stage, a photomask or reticle may be used to selectively expose certain regions of the substrate to electromagnetic radiation. Other exposure methods may be maskless exposure methods. Exposure to light may decompose the photo acid generator, which generates acid and results in a latent acid image in the resist resin. After exposure, the substrate may be heated in a post-exposure bake process. During the post-exposure bake process, the acid generated by the photoacid generator reacts with the resist resin, changing the solubility of the resist during the subsequent development process.

After the post-exposure bake, the substrate, and, particularly, the photoresist layer may be developed and rinsed. Depending on the type of photoresist used, regions of the substrate that were exposed to electromagnetic radiation may either be resistant to removal or more prone to removal. After development and rinsing, the pattern of the mask is transferred to the substrate using a wet or dry etch process.

The evolution of chip design continually requires faster circuitry and greater circuit density. The demands for greater circuit density necessitate a reduction in the dimensions of the integrated circuit components. As the dimensions of the integrated circuit components are reduced, more elements are required to be placed in a given area on a semiconductor integrated circuit. Accordingly, the lithography process must transfer even smaller features onto a substrate, and lithography must do so precisely, accurately, and without damage. In order to precisely and accurately transfer features onto a substrate, high resolution lithography may use a light source that provides radiation at small wavelengths. Small wavelengths help to reduce the minimum printable size on a substrate or wafer. However, small wavelength lithography suffers from problems, such as low through put, increased line edge roughness, and/or decreased resist sensitivity.

In a recent development, an electrode assembly is utilized to generate an electric field to a photoresist layer disposed on the substrate prior to or after an exposure process so as to modify chemical properties of a portion of the photoresist layer where the electromagnetic radiation is transmitted to for improving lithography exposure/development resolution. However, inaccurate field strength control of the electric field generated proximate to the photoresist layer may result in insufficient electric field energy transmitted to the photoresist layer for chemical property alternation. Furthermore, undesired voltage drop between the substrate and the electrode assembly resulting from transmitting from different intermittent medium therebetween may also affect the electric field strength generated to the photoresist layer disposed on the substrate.

Therefore, there is a need for a method and an apparatus for improving photolithography processes with improved control of electric field generation generated to a photoresist layer.

SUMMARY

Disclosed herein are apparatus and methods for applying an electric field and/or a magnetic field to a photoresist layer without air gap intervention during photolithography processes. In one embodiment, an apparatus includes a processing chamber comprising a substrate support having a substrate supporting surface, a heat source embedded in the substrate support configured to heat a substrate positioned on the substrate supporting surface, an electrode assembly configured to generate an electric field in a direction substantially perpendicular to the substrate supporting surface, wherein the electrode assembly is positioned opposite the substrate supporting surface having a downward surface facing the substrate supporting surface, wherein the electrode assembly is spaced apart from substrate support defining a processing volume between the electrode assembly and the substrate supporting surface, and a confinement ring disposed on an edge of the substrate support or the electrode assembly configured to retain an intermediate medium.

In another embodiment, a processing chamber includes a substrate support comprising a substrate supporting surface, an electrode assembly comprising a first electrode disposed in the substrate support and a second electrode positioned opposite the substrate supporting surface, the first and the second electrodes defining a processing volume inbetween configured to generate an electric field in a direction substantially perpendicular to the substrate supporting surface, and an intermediate medium positioned in the processing volume.

In yet another embodiment, a method of processing a substrate, the method includes exposing portions of a photoresist layer disposed on a substrate to electromagnetic radiation to generate charged species from photoacid generator in the photoresist layer and to form substantially parallel lines of material in the photoresist layer having different chemical properties than the portions of the photoresist layer not exposed to the electromagnetic radiation, immersing the photoresist layer in a non-gas phase intermediate medium without exposure to air, and applying an electric field to the photoresist layer while immersing the photoresist layer in the intermediate medium.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, 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 disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

FIG. **1** is a schematic cross-sectional view of an apparatus for processing a substrate, according to one embodiment;

FIG. **2** is a top view of embodiment of an electrode assembly of apparatus of FIG. **1**;

FIG. **3** is schematic side cross-sectional views of one embodiment of a substrate support assembly of the apparatus of FIG. **1** having one embodiment of an electrode assembly embedded therein;

FIGS. **4**A-**4**B are schematic illustration of representations of an intermediate medium that may be used to process a substrate according to the embodiments disclosed herein;

FIGS. **5**A-**5**B are schematic illustration of representations of an intermediate medium that may be used to process a substrate according to the embodiments disclosed herein;

FIG. **6** is a schematic illustration of one representative cluster processing system that may be used to process a substrate according to the embodiments disclosed herein; and

FIG. **7** is a flow diagram of a method of processing a substrate, according to one embodiment.

To facilitate understanding, identical reference numerals have been used, wherever possible, to designate identical elements that are common to the Figures. Additionally, elements of one embodiment may be advantageously adapted for utilization in other embodiments described herein.

DETAILED DESCRIPTION

Methods and apparatuses for minimizing line edge/width roughness and improving exposure resolution in a photolithography process for semiconductor applications are provided. The methods and apparatuses disclosed herein may increase the photoresist sensitivity and productivity of photolithography processes. The random diffusion of charged species generated by a photoacid generator during a post-exposure bake procedure contributes to line edge/width roughness and reduced resist sensitivity. An electrode assembly may be utilized to apply an electric field and/or a magnetic field to the photoresist layer during photolithography processes. The field application may control the diffusion of the charged species generated by the photoacid generator. Furthermore, an intermediate medium is utilized between the photoresist layer and the electrode assembly so as to enhance the electric field generated therebetween. An air gap defined between the photoresist layer and the electrode assembly may result in voltage drop applied to the electrode assembly, thus, adversely lowering the level of the electric field desired to be generated to the photoresist layer. Inaccurate level of the electric field at the photoresist layer may result in insufficient or inaccurate voltage power to drive or create charged species in the photoresist layer in certain desired directions, thus leading to diminished line edge profile control to the photoresist layer. Thus, an intermediate medium is placed between the photoresist layer and the electrode assembly to prevent an air gap from being created therebetween so as to maintain the level of the electric field interacting with the photoresist layer at a certain desired level. By doing so, the charged species generated by the electric field may be guided in a desired direction along the line and spacing direction, preventing the line edge/width roughness that results from inaccurate and random diffusion. Thus, a controlled or desired level of electric field as generated may increase the accuracy and sensitivity of the photoresist layer to exposure and/or development process. In one example, the intermediate medium may be non-gas phase medium, such as a slurry, gel, liquid solution or a solid state medium that may efficient maintain voltage level as applied at a determined range when transmitting from the electrode assembly to the photoresist layer disposed on the substrate.

FIG. **1** is a schematic cross-sectional view of an apparatus for processing a substrate, according to one embodiment. As shown in the embodiment of FIG. **1**, the apparatus may be in the form of a vacuum processing chamber **100**. In other embodiments, the processing chamber **100** may not be coupled to a vacuum source. The processing chamber **100** may be an independent processing chamber. Alternatively, the processing chamber **100** may be part of a processing system, such as, for example, an in-line processing system, a cluster processing system, or the track processing system shown in FIG. **6** (discussed below).

The processing chamber **100** includes chamber walls **102**, an electrode assembly **116**, and a substrate support assembly **138**. The chamber walls **102** include sidewalls **106**, a lid assembly **110**, and a bottom **108**. The chamber walls **102** at least partially enclose a processing volume **112**. The processing volume **112** is accessed through a substrate transfer port (not shown) configured to facilitate movement of a substrate **140** into and out of the processing chamber **100**. In embodiments where the processing chamber **100** is part of a processing system, the substrate transfer port may allow for the substrate **140** to be transferred to and from a transfer chamber.

A pumping port **114** may optionally be disposed through one of the lid assembly **110**, sidewalls **106** or bottom **108** of the processing chamber **100** to couple the processing volume **112** to an exhaust port. The exhaust port couples the pumping port **114** to various vacuum pumping components, such as a vacuum pump. The pumping components may reduce the pressure of the processing volume **112** and exhaust any gases and/or process by-products out of the processing chamber **100**.

The substrate support assembly **138** is centrally disposed within the processing chamber **100**. The substrate support assembly **138** supports the substrate **140** during processing. The substrate support assembly **138** may comprise a body **124** that encapsulates an optional electrode assembly **118** (described in FIG. **3**). The body **124** may comprise, for example, a metal, such as aluminum, or a ceramic. In embodiments where the body **124** comprises a metal, the electrode assembly **118** may be encapsulated within an insulating material (not shown) that insulates the electrode assembly **118** from the metal body **124**. The electrode assembly **118** may be coupled to the power supply **174**. In other embodiments, the electrode assembly **118** may be coupled to a ground. In some embodiments, the electrode assembly **118** is configured to generate an electric field parallel to the x-y plane defined by the first surface **134** of the substrate support assembly **138**. For example, the electrode assembly **118** may be configured to generate an electric field in one of the y direction, x direction or other direction in the x-y plane. In other embodiments, the electrode assembly **118** is configured to generate an electric field perpendicular to the x-y plane defined by the first surface **134** of the substrate support assembly **138**.

Generally, the substrate support assembly **138** has the first surface **134** and a second surface **126**. The first surface **134** is opposite the second surface **126**. The first surface **134** is configured to support the substrate **140**. The second surface **126** has a stem **142** coupled thereto. The substrate **140** is positioned on the first surface **134** of the substrate support assembly **138**. The substrate **140** may be any type of substrate, such as a dielectric substrate, a glass substrate, a semiconductor substrate, or a conductive substrate. The substrate **140** may have a layer **145** disposed thereon. The layer **145** may be any desired layer. In some embodiments, the substrate **140** may have more than one layer **145**. The substrate **140** also has a photoresist layer **150** disposed over the layer **145**. The substrate **140** has been previously exposed to electromagnetic radiation in an exposure stage of a photolithography process. The photoresist layer **150** has latent image lines **155** formed therein from the exposure stage. The latent image lines **155** may be substantially parallel. In other embodiments, the latent image lines **155** may not be substantially parallel.

In some embodiments, the substrate support assembly **138** may be an electrostatic chuck. In some embodiments, the body **124** of the substrate support assembly **138** may encapsulate an embedded heater **132**. The embedded heater **132**, such as a resistive element, is disposed in the substrate support assembly **138**. The embedded heater **132** controllably heats the substrate support assembly **138** and the substrate **140** positioned thereon to a predetermined temperature. The embedded heater **132** is configured to quickly ramp the temperature of the substrate **140** and to control the temperature of the substrate **140**. In some embodiments, the embedded heater **132** is connected to and controlled by the power supply **174**. The power supply **174** may be configured similarly to the power supply **170**, discussed below.

In some embodiments, the processing chamber **100** may include other heating sources. For example, heat lamps may be positioned within or outside the processing chamber **100**. In some embodiments, one or more lasers may be used to heat the photoresist layer **150** (or other layer) positioned on the substrate **140** or the antennas **220**, **221** of the electrode assembly **116** (shown in FIG. **2**). In some embodiments, the substrate support assembly **138** may be configured to circulate a high efficiency heat transfer fluid in order to more quickly increase the temperature of the substrate **140** positioned on the substrate support assembly **138**.

In some embodiments, the substrate support assembly **138** may be configured to provide relative motion between the first surface **134** (and the substrate **140** positioned thereon) and the electrode assembly **116**. For example, the substrate support assembly **138** may be configured to rotate about the z-axis. The substrate support assembly **138** may be configured to continuously or constantly rotate, or the substrate support assembly **138** may be configured to rotate in a step manner. For example, the substrate support assembly **138** may rotate a predetermined amount, such as 90°, 180°, or 270°, and then rotation may stop for a predetermined amount of time. After the predetermined amount of time, the rotation may continue in a step manner or in a continuous manner.

The substrate support assembly **138** may be configured to move vertically (i.e.) in the z-direction. The substrate support assembly **138** may be separated from the electrode assembly **116**. For example, the substrate support assembly **138** and the electrode assembly **116** may be separated by a distance of at least about 0.1 mm. A confinement ring **154** is disposed on an edge of the substrate support assembly **138** circumscribing the substrate support assembly **138** defining a distance d in the z-direction between the first surface **134** of the substrate support assembly **138** and the electrode assembly **116**. The confinement ring **154** may assist maintaining the substrate **140** positioned at a desired place on the first surface **134** of the substrate support assembly **138**. Furthermore, the confinement ring **154** may also confine an intermediate medium, i.e., a non-gas phase medium, such as solid slurry, a gel and/or liquid medium positioned, in the processing volume **112** above the photoresist layer **150** in place. In one example, the confinement ring **154** may have a length, i.e., the defined distance d, between about 0.5 mm and about 10 mm, sufficient to retain the intermediate medium, e.g., substances and/or liquid medium, at a level that covers an entire surface of the photoresist layer **150** disposed on the substrate **140** when the intermediate medium is disposed in the processing volume **112**. Alternatively, the confinement ring may be disposed on an edge of the electrode assembly **116**, extending downwardly toward an edge of the substrate support assembly **138** to assist guiding the substrate **140** in a desired position. In one example, the confinement ring **154** may be manufactured by a ceramic material, conductive material, dielectric material or other suitable material that are chemically inert to the intermediate medium positioned in the processing volume **112**.

In one example, an intermediate medium dispensing tool **173** is disposed in the processing chamber **100** through the chamber walls **102**. The intermediate medium dispensing tool **173** includes a nozzle **171** coupled thereto configured to dispense intermediate medium to the processing volume **112** confined by the confinement ring **154** above the substrate **140**. The intermediate medium dispensing tool **173** is coupled to an intermediate medium source **172**, which provides the intermediate medium to the processing volume **112**. Suitable examples of the intermediate medium includes any suitable liquid, such as water, organic gel, resin, inorganic solution, inorganic gel, slurry, or the like, or any solid material that may be easily melt and later re-solidify to cover substantially an entire surface of the substrate **140**. Details regarding the intermediate medium that may be used will be described later with reference to FIGS. **4**A-**5**B.

The stem **142** is coupled to a lift system (not shown) for moving the substrate support assembly **138** between an elevated processing position (as shown) and a lowered substrate transfer position. The lift system may control the position of the substrate **140** in the z-direction. In some embodiments, the lift system may also be configured to move the substrate **140** in the x-direction, the y-direction, or the x-direction and the y-direction. The stem **142** additionally provides a conduit for electrical and thermocouple leads between the substrate support assembly **138** and other components of the processing chamber **100**. A bellows **146** is coupled to the substrate support assembly **138** to provide a vacuum seal between the processing volume **112** and the atmosphere outside the processing chamber **100** and facilitate movement of the substrate support assembly **138** in the z-direction.

The lid assembly **110** may optionally include an inlet **180** through which gases provided by the supply sources **104** may enter the processing chamber **100**. The supply sources **104** may optionally controllably pressurize the processing volume **112** with a gas, such as nitrogen, argon, helium, hydrogen, neon, chlorine, other gases, or combinations thereof. The gases from the supply sources **104** may create a controlled environment within the processing chamber **100**. In other embodiments, the gases from the supply sources **104** may be used to generate a plasma. For example, the plasma may be generated in a remote plasma source **160**.

The supply sources **104** may couple directly to the processing volume **112** through a supply conduit **105**. In some embodiments, such as shown, the one or more source compounds may indirectly flow into the processing volume **112**. As shown, the one or more source compounds first flow through the remote plasma source **160** before flowing into the processing volume **112**.

The remote plasma source **160** may be configured to provide charged species, such as electrons, into the processing volume **112**. The remote plasma source may be, for example, a capacitively coupled plasma source or an inductively coupled source. The remote plasma source **160** is coupled to a power supply **176**. The power supply **176** may be, for example, an RF power supply. The power supply **176** may be configured to deliver power at a frequency of 10 Hz and about 1 MHz, such as about 5 kHz. In other embodiments, the power supply **176** may be configured to deliver power at 13.56 MHz. The power supply **176** and the remote plasma source **160** may be configured to generate a "soft" plasma. For example, the generated plasma may contain charged species having an ion energy of between about 1 eV and about 1000 eV, such as between about 5 eV and about 50 eV. In some embodiments, the ion energy may be between about 1 eV and about 5 eV. Electrons in the soft plasma may be used to drive the charged species **255** (shown in FIGS. **2**A and **2**B) generated from the photoacid generator in the direction perpendicular to the plane of the first surface **134**. Driving the charged species in the z-direction may increase resist sensitivity.

In a representative example using a 300 mm substrate, the soft plasma may be generated as follows. It is contemplated that the gas flows may be scaled proportionately to the substrate diameter. Hydrogen gas may be provided into the remote plasma source **160** at a flow rate of between about 10 sccm and about 1000 sccm. Argon may optionally be flowed into the remote plasma source **160** at a flow rate of up to about 1000 sccm. A plasma may be generated in an inductively coupled remote plasma source **160** from an RF power of between about 400 W and about 800 W. The pressure of the processing volume **112** may reduced to at least 10^{-5} Torr. For example, the pressure may be reduced to between about 10^{-6} Torr and about 10^{-8} Torr. The temperature of the substrate support assembly **138** may be maintained from room temperature to about 200° C., such as between about 70° C. and about 160° C., for example between about 90° C. and 140° C. as needed.

An actuator **190** may be coupled between the lid assembly **110** and the electrode assembly **116** to provide relative motion between the electrode assembly **116** and the substrate support assembly **138**. The actuator **190** may be configured to move the electrode assembly **116** in one or more of the x, y, and z directions. The x and y directions are referred to herein as the lateral directions or dimensions. The actuator **190** enables the electrode assembly **116** to scan the surface of the substrate **140**. The actuator **190** also enables the distance d to be adjusted. In some embodiments the electrode assembly **116** is coupled to the lid assembly **110** by a fixed stem (not shown). In some embodiments, the actuator **190** is configured to rotate the electrode assembly **116** about z-axis. In other embodiments, the electrode assembly **116** may be coupled to the inside of the bottom **108** of the processing chamber **100**, to the second surface **126** of the substrate support assembly **138**, or to the stem **142**.

The electrode assembly **116** includes one or more electrodes. The electrode assembly **116** is coupled to the power supply **170**. In embodiments where the electrode assembly **116** includes more than one electrode, each electrode may be connected to a power supply. In some embodiments, the electrode assembly **116** is configured to generate an electric field parallel to the x-y plane defined by the first surface **134** of the substrate support assembly **138**. For example, the electrode assembly **116** may be configured to generate an electric field in one of the y direction, x direction or other direction in the x-y plane. In one embodiment, the electrode assembly **116** is configured to generate an electric field in the x-y plane and in the direction of the latent image lines **155**. In another embodiment, the electrode assembly **116** is configured to generate an electric field in the x-y plane and perpendicular to the direction of the latent image lines **155**. The electrode assembly **116** may additionally or alternatively be configured to generate an electric field in the z-direction, such as, for example, perpendicular to the first surface **134**.

The power supply **170** and/or the power supply **174** may be configured to supply, for example, between about 500 V and about 100 kV to one or more electrodes of the electrode assembly **116** and/or the electrode assembly **118**. In some embodiments, the power supply **170** and/or the power supply **174** are a continuous or pulsed direct current (DC) power supply or a continuous or pulsed AC power. The pulsed DC wave or AC wave may be from a half-wave rectifier or a full-wave rectifier. The power supply **170** and/or the power supply **174** may be configured to provide power at a frequency of between about 10 Hz and about 1 MHz, such as about 5 kHz. The duty cycle of the pulsed DC power or AC power may be between about 5% and about 95%, such as between about 20% and about 60%. In some embodiments, the duty cycle of the pulsed DC power or AC power may be between about 20% and about 40%. In other embodiments, the duty cycle of the pulsed DC power or AC power may be about 60%. The rise and fall time of the pulsed DC power or AC power may be between about 1 ns and about 1000 ns, such as between about 10 ns and about 500 ns. In other embodiments, the rise and fall time of the pulsed DC power or AC power may be between about 10 ns and about 100 ns. In some embodiments, the rise and fall time of the pulsed DC power or AC power may be about 500 ns. In some embodiments, the power supply **170** and/or the power supply **174** is an alternating current power supply. In other embodiments, the power supply **170** and/or the power supply **174** is a direct current power supply.

As shown, the electrode assembly **116** spans approximately the width of the substrate support assembly **138**. In other embodiments, the width of the electrode assembly **116** may be less than that of the substrate support assembly **138**. For example, the electrode assembly **116** may span between about 10% to about 80%, such as about 20% and about 40%, the width of the substrate support assembly **138**. In embodiments where the width of the electrode assembly **116** is shorter than the width of the substrate support assembly **138**, the actuator **190** may scan the electrode assembly **116** across the surface of the substrate **140** positioned on the first surface **134** of the substrate support assembly **138**. For example, the actuator **190** may scan such that the electrode assembly **116** scans the entire surface of the substrate **140**. In other embodiments, the actuator **190** may scan only certain portions of the substrate **140**. Alternatively, the substrate support assembly **138** may scan underneath the electrode assembly **116**.

In some embodiments, one or more magnets **196** may be positioned in the processing chamber **100**. In the embodiment shown in FIG. **1**, the magnets **196** are coupled to the inside surface of the sidewalls **106**. In other embodiments, the magnets **196** may be positioned in other locations within the processing chamber **100** or outside the processing chamber **100**. For example, the magnets **196** may be positioned within the processing chamber **100** and adjacent to the bottom **108** and/or the lid assembly **110**. The magnets **196** may be, for example, permanent magnets or electromagnets. Representative permanent magnets include ceramic magnets and rare earth magnets. In embodiments where the magnets **196** include electromagnets, the magnets **196** may be coupled to a power supply (not shown). The magnets **196** are configured to generate a magnetic field in a parallel direction, a perpendicular direction, or other direction relative to the electric field generated by electrode assembly **116** and/or the electrode assembly **118**. The magnets **196** may be configured to generate a field strength across the first surface **134** of between about 0.1 Tesla (T) and about 10 T, such as between about 1 T and about 5 T. In embodiments including a magnetic field, the magnets **196** may remain stationary or move relative to the first surface **134**.

FIG. **2** is a top view of embodiments of the electrode assembly **116** of FIG. **1**. In the embodiment shown in FIG. **2**, the electrode assembly **116** includes at least a first electrode **258** and a second electrode **260**. The first electrode **258** includes a first terminal **210**, a support structure **230**, and one or more antennas **220**. The second electrode **260** includes a second terminal **211**, a support structure **230**, and one or more antennas **221**. The first terminal **210**, the support structure **230**, and the one or more antennas **220** of the first electrode **258** may form a unitary body. Alternatively, the first electrode **258** may include separate portions that may be coupled together. For example, the one or more antennas **220** may be detachable from the support structure **230**. The second electrode **260** may similarly be a unitary body or be comprised of separate detachable components. The first electrode **258** and the second electrode **260** may be prepared by any suitable methods. For example, the first electrode **258** and the second electrode **260** may be fabricated by machining, casting, or additive manufacturing.

The support structure **230** may be made from a conductive material, such as metal. For example, the support structure **230** may be made of one or more of silicon, polysilicon, silicon carbide, molybdenum, aluminum, copper, graphite, silver, platinum, gold, palladium, zinc, other materials, or mixtures thereof. The support structure **230** may have any desired dimensions. For example, the length L_S of the support structure **230** may be between about 25 mm and about 450 mm, for example, between about 100 mm and about 300 mm. In some embodiments, the support structure **230** has a length L_S approximately equal to a diameter of a standard semiconductor substrate. In other embodiments, the support structure **230** has a length L_S that is larger or smaller than the diameter of a standard semiconductor substrate. For example, in different representative embodiments, the length L_S of the support structure **230** may be about 25 mm, about 51 mm, about 76 mm, about 100 mm, about 150 mm, about 200 mm, about 300 mm, or about 450 mm. The width W_S of the support structure **230** may be between about 2 mm and about 25 mm. In other embodiments, the width W_S of the support structure **230** is less than about 2 mm or greater than about 25 mm. The thickness of the support structure **230** may be between about 1 mm and about 10 mm, such as between about 2 mm and about 8 mm, such as about 5 mm. In other embodiments the support structure may have a thickness of less than about 1 mm or greater than about 10 mm. In some embodiments, the support structure **230** may have a cross-section that is square, cylindrical, rectangular, oval, rods, or other shapes. Embodiments having round exterior surfaces may avoid arcing.

The support structure **231** may be made of the same materials as the support structure **230**. The support structure **230** and the support structure **231** are made of different materials. The lengths L_S, widths W_S, and thicknesses of the support structure **230** and the support structure **231** may be the same or different. The one or more antennas **220** of the first electrode **258** may also be made from a conductive material. The one or more antennas **220** may be made from the same materials as the support structure **230**. Each of the antennas **220** may have the same dimensions. Alternatively, some of the one or more antennas **220** may have different dimensions than one or more of the other antennas **220**. The antennas **221** may be made of the same range of materials as the antennas **220**. The range of dimensions suitable for the antennas **220** is also suitable for the antennas **221**.

The number of the antennas **220** may be between about 1 and about 40 antennas. For example, the number of the antennas **220** may include between about 4 and about 40, such as between about 10 and about 20. Each of the antennas **220** may be substantially parallel to each of the other antennas **220**. Each of the antennas **221** may be similarly positioned with respect to the support structure **231** and each other antenna **221**. In one example, the support structure **230** and the support structure **231** are straight. In other example, the support structure **230** and the support structure **231** may not be straight, such as curved, jagged, or have other profiles or shapes. In these embodiments, each of the antennas **220** may still be substantially parallel to each of the other antennas **220**.

Each of the antennas **220** has a terminal end **223**. Each of the antennas **221** has a terminal end **225**. A distance C is defined between the support structure **230** and the terminal end **225**. A distance C' is defined between the support structure **231** and the terminal end **223**. Each of the distances C and C' may be between about 1 mm and about 10 mm. A distance A is defined between facing surfaces of one of the antennas **221** and an adjacent one of the antennas **221**. The distance A' is defined between facing surfaces of one antenna **220** and an adjacent one the antennas **220**. The distances A and A' may be greater than about 6 mm. A distance B is defined between facing surfaces of one of the antennas **220** and an adjacent one of the antennas **221**. The distance B may be, for example, greater than about 1 mm. The strength of an electric field generated between an antenna **220** and an adjacent antenna correlates with the distance B. For example, a smaller distance B correlates with a stronger electric field. Accordingly, in embodiments where a stronger electric field is desired, a smaller distance B may be advantageous.

In operation, the power supply **170** may supply a voltage to the first terminal **210** and/or a power supply **170'** may provide a voltage to the second terminal **211**. The power supply **170'** may be substantially similar to the power supply **170**. The supplied voltage creates an electric field between each antenna of the one or more antennas **220** and each antenna of the one or more antennas **221**. The electric field will be strongest between an antenna of the one or more antennas **220** and an adjacent antenna of the one or more antennas **221**. The interleaved and aligned spatial relationship of the antennas **220**, **221** produces an electric field in a direction parallel to the plane defined by the first surface **134**. The substrate **140** is positioned on the first surface **134** such that the latent image lines **155** are parallel to the electric field lines generated by the electrode assembly **116**. Since the charged species **255** are charged, the charged species **255** are affected by the electric field. The electric field drives the charged species **255** generated by the photoacid generators in the photoresist layer **150** in the direction of the electric field. By driving the charged species **255** in a direction parallel with the latent image lines **155**, line edge roughness may be reduced. The uniform directional movement is shown by the double headed arrow **270**. In contrast, when a voltage is not applied to the first terminal **210** or the second terminal **211**, an electric field is not created to drive the charged species **255** in any particular direction. As a result, the charged species **255** may move randomly, as shown by the arrows **270'**. In other embodiments, the substrate **140** may be oriented differently relative to the antennas **220**, **221**. For example, the antennas **220**, **221** may be parallel to the latent image lines **155**.

FIG. **3** are schematic side cross-sectional view of an embodiment of the substrate support assembly **138** of FIG. **1** having one embodiment of the electrode assembly **118** embedded therein. The electrode assembly **118** is embedded between the first surface **134** and the second surface **126** of the body **124**. The electrode assembly **118** has a first surface **334** and a second surface **326**. The first surface **334** and the second surface **326** are opposite each other and substantially parallel to the first surface **134** of the substrate support assembly. The first surface **334** of the electrode assembly **118** is closer than the second surface **326** to the first surface **134** of the substrate support assembly **138**. The distance D represents the distance separating the first surface **134** of the substrate support assembly **138** from the first surface **334** of the electrode assembly. The distance D may be between about 0.1 mm and about 100 mm. For example, the distance D may be between about 8 mm and about 14 mm. The distance D may control the strength of the electric field provided by the electrode assembly **118** to the first surface **134** and/or the photoresist layer **150**. The strength of the electric field controls the rate of diffusion of the charged species **255**.

The substrate support assembly **138** has outer side surfaces **348**. The electrode assembly **118** has outer side surfaces **328**. The distance E represents a rim between the outer side surfaces **328** and the outer side surfaces **348**. The distance E may be, for example, any distance suitable for the distance D. The distance E may be constant around the electrode assembly **118**, or the distance E may vary. The thickness of the electrode assembly **118** is represented by the distance T_A. The distance T_A may be any suitable thickness for the antennas **220**, **221** discussed above. As shown, the electrode assembly **118** is coupled to the power supply **174**. The properties of the power supplied by the power supply **174** to the electrode assembly **118** may be as described above in relation to the power supply **170** of FIG. **1**.

FIG. **4**A depicts one example of the substrate support assembly **138** with an intermediate medium **402** disposed in the processing volume **112** and retained by the confinement ring **154** above the substrate **140**. Without the intermediate medium **402** positioned in the processing volume **112**, an air gap is typically defined in the processing volume **112** between the substrate **140** and the electrode assembly **116**. The dimension of the air gap defined in the processing volume **112** may be determined by the distance where the electrode assembly **116** is positioned approximate to the substrate **140**. For example, when the electrode assembly **116** is positioned close to the photoresist layer **150** disposed on the substrate **140**, a smaller dimension of the air gap may be defined in the processing volume **112**. In contrast, when the electrode assembly **116** is positioned relatively far and distanced away from the substrate **140**, a larger dimension of the air gap may be defined in the processing volume **112**.

It is believed that air medium (i.e., air gap) formed in the processing volume **112** may adversely result in a voltage drop when a voltage power is applied to the electrode assemblies **116**, **118**. As the dielectric constant in the substrate **140** and in the air are very different, e.g., approximately 11.7 for the substrate **140** and 1 for air, when the voltage supplied to the electric assembly **116** to generated an electric field to the substrate **140**, a significant voltage drop is often observed when voltage is transmitting through the air gap formed in the processing volume **112** prior to reaching to the photoresist layer **150** disposed on the substrate **140**. It is believed the low dielectric constant in air, e.g., dielectric constant of 1, significantly changes the voltage level applied from the electrode assembly **116**. Thus, by inserting a material with relatively high dielectric constant, such as greater than 10, to replace the air gap defined in the processing volume **112**, the voltage applied to form the electric field therein may be maintained at a desired level without significant loss until reaching to the photoresist layer **150** disposed on the substrate **140**. In one example, intermediate medium **402** placed in the processing volume may be liquid solution, such as DI water, organic gel, inorganic solution, or other suitable medium that has high dielectric constant that can assist maintaining the voltage level transmitting therethrough without significant voltage drop. In one example, DI water, e.g., a material having a dielectric constant about 80, is disposed and placed in the processing volume **112** above the substrate support assembly **138** confined by the confinement ring **154**.

In one example, the intermediate medium **402** may be supplied from the intermediate medium source **172** through the intermediate medium dispensing tool **173** to substantially fill the processing volume **112**. The intermediate medium **402** disposed in the processing volume **112** may create an interface **404** in a close approximation to a downward surface **406** of the electrode assembly **116**. After the intermediate medium source **172** is filled in the processing volume **112**, the electrode assembly **116** may be lowered down to keep a minimum or negligible distance **407** between the electrode assembly **116** and the intermediate medium source **172**. By doing so, the likelihood of voltage drop caused by the low dielectric constant air gap may be mostly eliminated.

Different materials other than DI water may also be utilized as the intermediate medium source **172** to be filled in the region of the processing volume **112** confined by the confinement ring **154**, as shown in FIG. **4**B. In the example depicted in FIG. **4**B, a gel or flowable organic droplets **410** with a dielectric constant greater than 9 may also be used to fill in the processing volume **112**. The gel or flowable organic droplets **410** may be spun-on to the substrate **140** until an interface **412** of the gel or flowable organic droplets **410** is defined in a close approximation to the downward surface **406** of the electrode assembly **116** with minimum and/or negligible room for an air gap. Quantity of the gel or flowable organic droplets **410** needed to fill the processing volume **112** defined above the substrate support assembly **138** confined by the confinement ring **154** depends on the geometry of those components. It is noted that the gel or flowable organic droplets **410** may be continuously added until the processing volume **112** above the substrate is substantially full without leaving an undesired air gap touching the surface of the substrate **140**.

FIG. **5**A depicts another embodiment of the electrode assembly **116** with a confinement ring **502** disposed on an edge of the electrode assembly **116** from its downward surface **406**. Instead of liquid medium, a solid state medium **504** may be utilized to be positioned below and in contact with the downward surface **406** of the electrode assembly **116** within the area confined by the confinement ring **502**. After the solid state medium **504** is in place, the electrode assembly **116** may then be lowered down by the actuator **190** to have the solid state medium **504** in contact with the photoresist layer **150** disposed on the substrate **140**, as shown in FIG. 5B. By carefully selecting the qualities and properties of the solid state medium **504**, e.g., with desired dielectric constant, the solid state medium **504** serves as a good medium between the electrode assembly **116** and the electrode assembly **118** disposed in the substrate support assembly **138** to maintain the voltage level applied thereto at a desired range for electric field generation. In one example, the solid state medium **504** may be a solid disk having a size that may covers an entire surface of the photoresist layer **150** disposed on the substrate **140**. The solid state medium **504** may be attached to the electrode assembly **116** by any suitable techniques, including mechanical bonding or chemical bonding. The solid state medium **504**, when positioned above the photoresist layer **150**, may be placed in a position confined by the confinement ring **502** in close approximation to the photoresist layer **150** with minimum and/or negligible room for an air gap. It is noted that the phrase "negligible room" as described here may be a space less than 10 micrometer in dimension. In one example, the solid state medium **504** may be fabricated from a material with high dielectric constant greater than 10. Suitable examples of the solid state medium **504** include quartz or TiO_2.

FIG. **6** depicts illustrates one representative processing system **600** that may be used to process a substrate according to embodiments disclosed herein. As shown, the processing system **600** includes a load port **610**, a coating chamber **620**, a processing chamber **100**, an exposure chamber **630** (such as a scanner), a second processing chamber **100**, a development chamber **640**, and a post-processing chamber **650**. Each chamber of the processing system **600** is coupled to each adjacent chamber by a transfer chamber **605** or a transfer chamber **615**. The transfer chambers **605** and the transfer chamber **615** may be substantially similar or different.

The load port **610** may be used to introduce or remove substrates into or out of the processing system **600**. The coating chamber **620** may be used, for example, for applying a photoresist to a substrate. The coating chamber **620** may be, for example, a spin coater. The exposure chamber **630** may be used for exposing the substrate to electromagnetic energy in order to form a latent acid image in a photoresist layer on a substrate. The development chamber **640** may be used, for example, for removing portions of the photoresist layer. The post-processing chamber **650** may be used, for example, to perform a variety of post-processing steps on a substrate. The processing chamber **100** may be used for a pre-exposure bake, a post-exposure bake, and/or other processing steps. As described above, the processing chamber **100** may include one or more electrode assemblies **118**, a remote plasma source **160**, and magnets **196**. However, it is to be understood that the coating chamber **620**, the exposure chamber **630**, and the development chamber **640** may also be similarly equipped.

FIG. **7** is a flow diagram of a representative method **700** for processing a substrate, such as the substrate **140**. The method **700** for processing the substrate **140** has multiple stages. The stages can be carried out in any order or simultaneously (except where the context excludes that possibility), and the method can include one or more other stages which are carried out before any of the defined stages, between two of the defined stages, or after all the defined stages (except where the context excludes that possibility). Not all embodiments may include all the stages.

In general, the method **700** starts at operation **710** by applying a photoresist containing a photoacid generator to the substrate **140**. At operation **710**, a photoresist is applied to the substrate **140** to form a photoresist layer **150**. The photoresist layer **150** may be applied by, for example, by spin coating inside a spin coating apparatus, such as the coating chamber **620** included in the processing system **600**. In such an embodiment, the substrate **140** may enter the processing system **600** through the load port **610** and thereafter be transferred to the coating chamber **620** through a transfer chamber **605**.

The photoresist may include a solvent, a photoresist resin, and a photoacid generator. The photoresist resin may be any positive photoresist resin or any negative photoresist resin. Representative photoresist resins include acrylates, Novolac resins, poly(methylmethacrylates), and poly(olefin sulfones). Other photoresist resins may also be used.

Prior to the photoresist layer **150** exposed to electromagnetic radiation, the photoacid generator generates charged species **255**, such as an acid cation and an anion. The photoacid generator may also generate polarized species. The photoacid generator sensitizes the resin to electromagnetic radiation. Representative photoacid generators include sulfonate compounds, such as, for example, sulfonated salts, sulfonated esters, and sulfonyloxy ketones. Other suitable photoacid generators include onium salts, such as aryldiazonium salts, halonium salts, aromatic sulfonium salts and sulfoxonium salts or selenium salts. Other representative photoacid generators include nitrobenzyl esters, s-triazine derivatives, ionic iodonium sulfonates, perfluoroalkanesulfonates, aryl triflates and derivatives and analogs thereof, pyrogallol derivatives, and alkyl disulfones. Other photoacid generators may also be used.

At operation **720**, the substrate **140** is then heated by a pre-exposure baking process. During the pre-exposure baking process, the substrate is heated to partially evaporate the photoresist solvents. The pre-exposure bake at operation **720** and the photoresist application at operation **710** may occur in the same chamber or different chambers. For example, both operations **710**, **720** may occur in a spin coater or the substrate **140** may be transferred to a different processing chamber. For example, in an embodiment using the processing system **600**, the substrate **140** may be transferred from the coating chamber **620** to the processing chamber **100** through the transfer chamber **605**.

At operation **730**, the substrate **140** then transferred to the exposure chamber **630** to expose substrate **140** to electromagnetic radiation for a lithographic exposure process. The substrate **140** and portions of the photoresist layer **150** are exposed to electromagnetic radiation. During exposure, portions of the photoresist layer **150** are selectively exposed and portions of the photoresist layer **150** are selectively unexposed. Portions of the photoresist layer **150** exposed to electromagnetic radiation may have different chemical properties than the portions of the photoresist layer **150** not exposed to the electromagnetic radiation. The charged species **255** generated by the photoacid generator results in a latent acid image in the resist resin. In some embodiments, a photomask or reticle may be positioned between the photoresist layer **150**, and the photoresist layer **150** may be exposed to electromagnetic radiation through the mask or reticle. The mask or reticle may be configured to transfer a pattern containing lines to the photoresist layer **150**. In other embodiments, a pattern containing lines may be transferred to the photoresist layer **150** using maskless lithography techniques. The transferred latent image lines **155** may have any desired length, width, and spacing between latent image lines **155**. For example, in some embodiments, the line widths and line spacings may be between about 10 nm and about 16 nm. In other embodiments the line widths and spacings may be less than about 10 nm or greater than about 16 nm. In some embodiments, the length of the latent image line **155** is about 150% of the width of the latent image line **155**. In other embodiments, the length of the latent image line **155** is greater than about 200% of the width of the latent image line **155**, such as for example, greater than about 1000% of the width of the latent image line **155**.

The electromagnetic radiation generally has a wavelength suitable for exposing the photoresist layer **150**. For example, the electromagnetic radiation may have a wavelength in the extreme ultra violet (EUV) range, such as between about 10 nm and about 124 nm. In other embodiments, the electromagnetic radiation may be generated by an argon fluoride laser. In such an embodiment, the electromagnetic radiation may have a wavelength of about 193 nm. In some embodiments, the wavelength may be 248 nm. Other embodiments may use different wavelengths. In some embodiments, the electromagnetic radiation is from an electron beam or an ion beam.

After exposure, at operation **740**, the substrate **140** is heated in a post-exposure bake stage for a post-exposure baking process to change the film properties exposed under electromagnetic radiation at operation **740**. The substrate **140** may be transferred from the exposure chamber **630** to the processing chamber **100** through the transfer chamber **615** for the post-exposure baking process. The substrate **140** may be positioned on the first surface **134** of the substrate support assembly **138**. The power supply **174** may provide power to the embedded heater **132** to heat the substrate **140**. The embedded heater **132** may quickly heat the substrate **140** and the photoresist layer **150**. For example, the embedded heater **132** may raise the temperature of the photoresist layer **150** from ambient temperature to between about 70° C. and about 160° C., such as between about 90° C. and 140° C., in less than about 2 seconds.

During the post-exposure bake at operation **740**, photoacid generators in the photoresist layer **150** may continue to alter the chemical properties of the exposed portions of the photoresist layer **150**. In addition to the baking process, an electrical field may be generated to the photoresist layer **150**, as described at operation **701**, while performing the post-exposure baking process at operation **740**. While applying the electric field between the electrode assembly **116** and/or the electrode assembly **118**, the charged species **255** may be guided in a desired direction by at least one of an electric field, a magnetic field, and a plasma. The magnetic field may be generated by, for example, the magnets **196**. The plasma may be generated by, for example, the remote plasma source **160**. With the utilization of intermediate medium **402**, gel or flowable organic droplets **410** or the solid state medium **504** in the processing volume **112**, the likelihood of voltage drop/loss applying to the electrode assemblies **116**, **118** for electric field generation may be significantly reduced or eliminated. While generating the electric field to the photoresist layer **150**, the substrate **140** may or may not have a relative motion to the electrode assemblies **116**, **118** as needed to alter the electric field strength at different locations of the photoresist layer **150**.

As noted above, the charged species **255** may be guided in any operation or in any combination of operations. In some embodiments, the charged species **255** are guided in one direction relative to the latent image lines **155** in one operation and guided in another direction relative to the latent image lines **155** in another operation. For example, during the exposure operation **730**, the charged species **255** may be guided in a direction perpendicular to the first surface **134**, and during the post-exposure bake operation **740**, the charged species **255** may be guided in the direction of the latent image lines **155** or both in the direction of the latent image lines **155** and in a direction perpendicular to the first surface **134**. In another embodiment, the charged species may be guided in the direction of the latent image lines **155** or both in the direction of the latent image lines **155** and in a direction perpendicular to the first surface **134** during the exposure operation **730** and guided in a direction perpendicular to the first surface **134** during the post-exposure bake at operation **740**. In some embodiments, the charged species **255** may be guided in different directions within a single phase. For example, in an exposure operation or during a post-exposure bake operation, the charged species **255** may be guided in a direction perpendicular to the first surface **134** for a portion of the stage and guided in a direction perpendicular to the first surface **134** and in a direction along the direction of the latent image lines for a portion of the stage. Such a variation in guided direction may be achieved by toggling the magnetic field on and off while applying a vertical magnetic field.

Subsequently, at operation **750**, a development process is performed to the areas exposed or not exposed to electromagnetic radiation from the substrate **140** to develop the photoresist layer. In one embodiment, after operation **740**, the substrate **140** is transferred to a develop chamber, such as the develop chamber **640** depicted in FIG. **6**. In embodiments using the processing system **600**, the substrate **140** may be transferred from the processing chamber **100** to the development chamber **640** through the transfer chamber **605**. The development chamber **640** may also include the electrode assembly **116** coupled to one or more power supplies and/or the actuator **190** and magnets **196**. The substrate **140** may be positioned in the development chamber **640** relative to the electrode assembly **116** and magnets **196** as described in relation to the coating chamber **620**.

During operation **750**, the photoresist layer **150** may be developed by, for example, exposing the photoresist layer **150** to a developer, such as a sodium hydroxide solution, a tetramethylammonium hydroxide solution, xylene, or Stoddard solvent. The substrate **140** may be rinsed with, for example, water or n-butylacetate. After the development process at operation **750**, the latent image lines **155** may no longer be latent. The lines **155** on the substrate **140** will have less line edge/width roughness compared to conventional techniques.

Subsequently, at operation **760**, a post-treatment process may be performed on the substrate **140** to post-treat the substrate after the development process. The post-processing process may be performed, for example, in the post-processing chamber **650** depicted in FIG. **6**. In an embodiment using the processing system **600**, the substrate **140** may be transferred from the development chamber **640** through the transfer chamber **605** to the post-processing chamber **650** for post-processing. For example, after rinsing, the substrate **140** may be hard baked and inspected. After inspection, an etching process may be performed on the substrate **140**. The etching process uses the features of photoresist layer **150**, such as the lines **155**, to transfer a pattern to the layer **145**.

While performing the processes of applying the photoresist layer on the substrate at operation **710**, heating the substrate at operation **720**, exposing the substrate to electromagnetic radiation at operation **730**, heating the substrate at operation **740**, developing the substrate at operation **750**, and post-treating the substrate at operation **760**, a voltage may be applied to generate an electric field, as indicated at operation **701**, to guild the charged species **255** generated by the photoacid generator in a desired direction, such as a direction parallel to the x-y plane and in the direction of the latent image lines **155**, a direction parallel to the x-y plane and perpendicular to the latent image lines **155**, a different direction, or combinations thereof. With the intermediate medium **402**, the gel or flowable organic droplets **410** or the solid state medium **504** placed in between the electrode assembly **116** and the substrate **140** to avoid possible air gap defined therebetween, voltage applied thereto to generate the electric field may then be maintained at a desired level without undesired voltage drop or loss.

The previously described embodiments have many advantages, including the following. For example, the embodiments disclosed herein may reduce or eliminate voltage drop/loss while applying an electric field between an electrode assembly and a photoresist layer disposed on a substrate for line edge/width roughness reduction. The reduction or elimination of voltage drop/loss may be obtained by utilizing intermediate medium **402**, a gel or flowable organic droplets **410** or a solid state medium **504** placed in between the electrode assembly **116** and the substrate **140** to avoid possible air gap defined therebetween. The aforementioned advantages are illustrative and not limiting. It is not necessary for all embodiments to have all the advantages.

While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An apparatus for processing a substrate, the apparatus comprising:

a processing chamber, the processing chamber comprising:

a substrate support having a substrate supporting surface;

a heat source embedded in the substrate support configured to heat a substrate positioned on the substrate supporting surface;

an electrode assembly configured to generate an electric field in a direction substantially perpendicular to the substrate supporting surface, wherein the electrode assembly is positioned opposite the substrate supporting surface having a downward surface facing the substrate supporting surface, wherein the electrode assembly is spaced apart from substrate support defining a processing volume between the electrode assembly and the substrate supporting surface; and

a confinement ring disposed on an edge of the substrate support or the electrode assembly configured to retain an intermediate medium, wherein the intermediate medium has a dielectric constant greater than 10.

2. The apparatus of claim **1**, wherein the intermediate medium is configured to be disposed in the processing volume.

3. The apparatus of claim **1**, wherein the intermediate medium positioned in the processing volume is in close approximation to the substrate supporting surface and the downward surface of the electrode assembly.

4. The apparatus of claim **1**, wherein the processing chamber is coupled to a remote plasma source.

5. The apparatus of claim **1**, further comprising:

an intermediate medium dispensing tool disposed in the processing chamber configured to dispense the intermediate medium in the processing volume.

6. The apparatus of claim **1**, wherein the intermediate medium is DI water.

7. The apparatus of claim **1**, wherein the intermediate medium is a solid state medium.

8. The apparatus of claim **1**, wherein the intermediate medium is quartz.

9. The apparatus of claim **1**, wherein the intermediate medium is substantially filled in the processing volume defined between the electrode assembly and the substrate supporting surface without air gap.

10. The apparatus of claim **1**, wherein the confinement ring disposed on the edge of the electrode assembly is configured to retain the intermediate medium when the electrode assembly is actuated to a processing position.

11. An apparatus for processing a substrate, the apparatus comprising:

a processing chamber, the processing chamber comprising:

a substrate support comprising a substrate supporting surface;

an electrode assembly comprising a first electrode disposed in the substrate support and a second electrode positioned opposite the substrate supporting surface, the first and the second electrodes defining a processing volume inbetween configured to generate an electric field in a direction substantially perpendicular to the substrate supporting surface; and

an intermediate medium positioned in the processing volume, wherein the intermediate medium has a dielectric constant greater than 10.

12. The apparatus of claim **11**, further comprising:

a heating element disposed in the substrate support.

13. The apparatus of claim **11**, further comprising:

an intermediate medium dispensing tool disposed in the processing chamber configured to dispense the substance or liquid medium in the processing volume.

14. The apparatus of claim **11**, further comprising:

a confinement ring disposed on an edge of the substrate support or an edge of the second electrode configured to retain the intermediate medium.

15. The apparatus of claim **11**, wherein the intermediate medium is DI water.

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