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(54) SELECTIVE DEPOSITION USING DIFFERENTIAL SURFACE CHARGING

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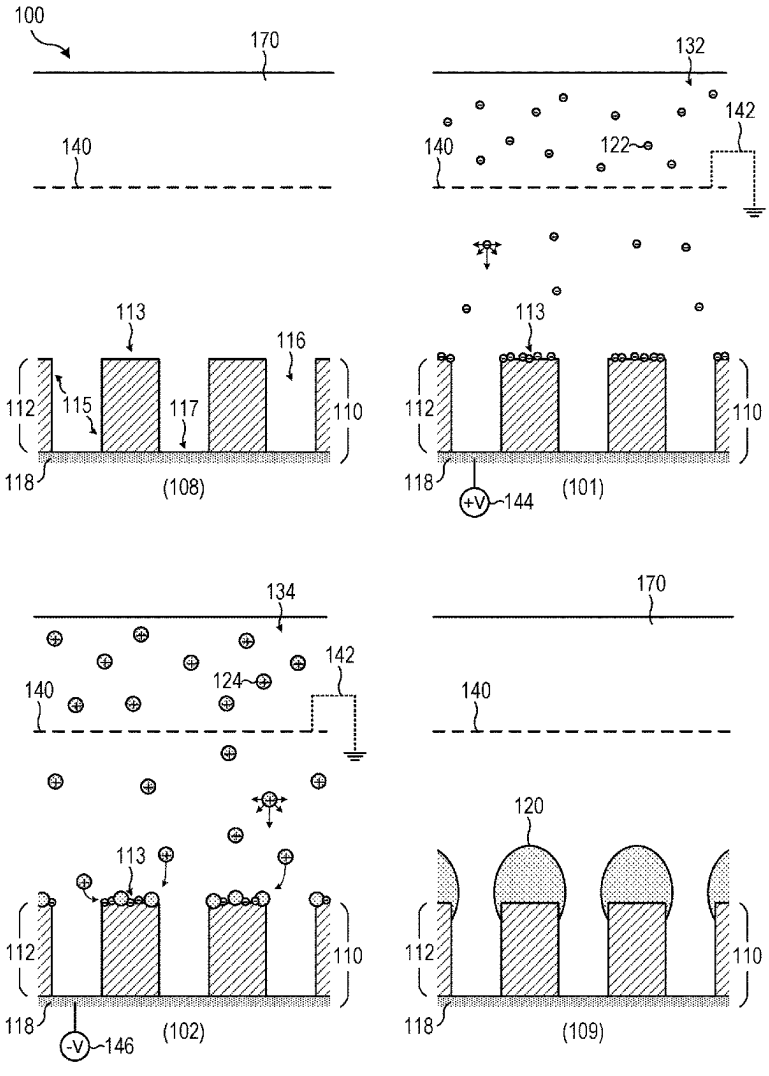
(57) **ABSTRACT**

A method includes extracting electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with the electrons, and extracting positive ions from a remote ion source to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces. The upper surfaces may be negatively charged by concurrently applying a positive bias at the patterned layer and applying source power with a lower power level to generate plasma. The material may be selectively deposited by concurrently applying a negative bias at the patterned layer and applying source power with a higher power level to plasma. An extraction grid may separate the patterned layer from the plasma. The extraction grid may be electrically floating or coupled to a ground potential during either of the electron extraction step or the ion extraction step.



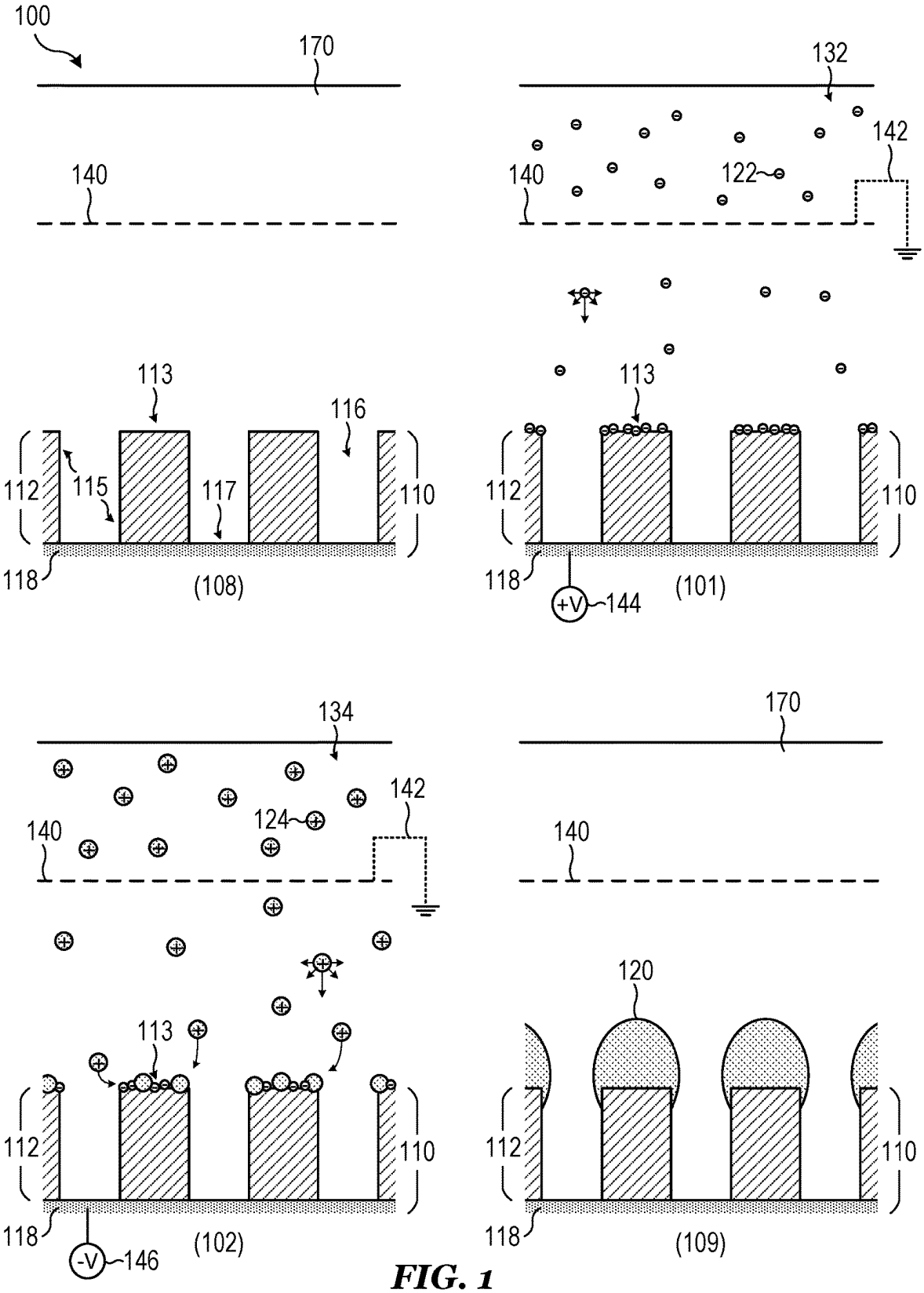
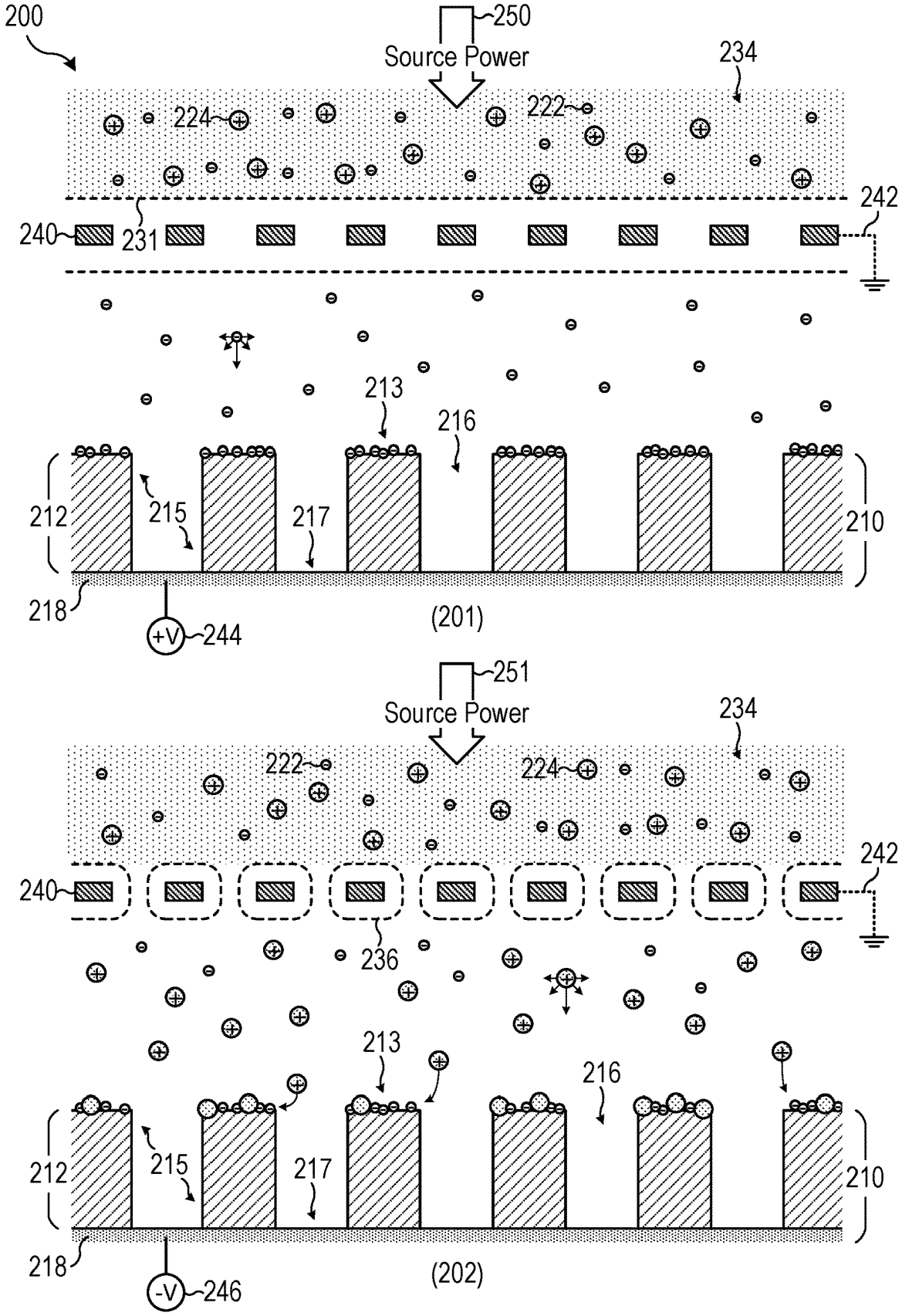

100
170
140
132
142
122
113
116
112
115
117
110
118
(108)
(101)
+V
144
134
124
-V
146
120
(102)
(109)

FIG. 1


200
250
Source Power
234
224
222
242
240
231
213
216
212
215
217
210
218
+V
244
(201)
251
Source Power
234
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224
242
240
236
213
216
212
215
217
210
218
-V
246
(202)

FIG. 2

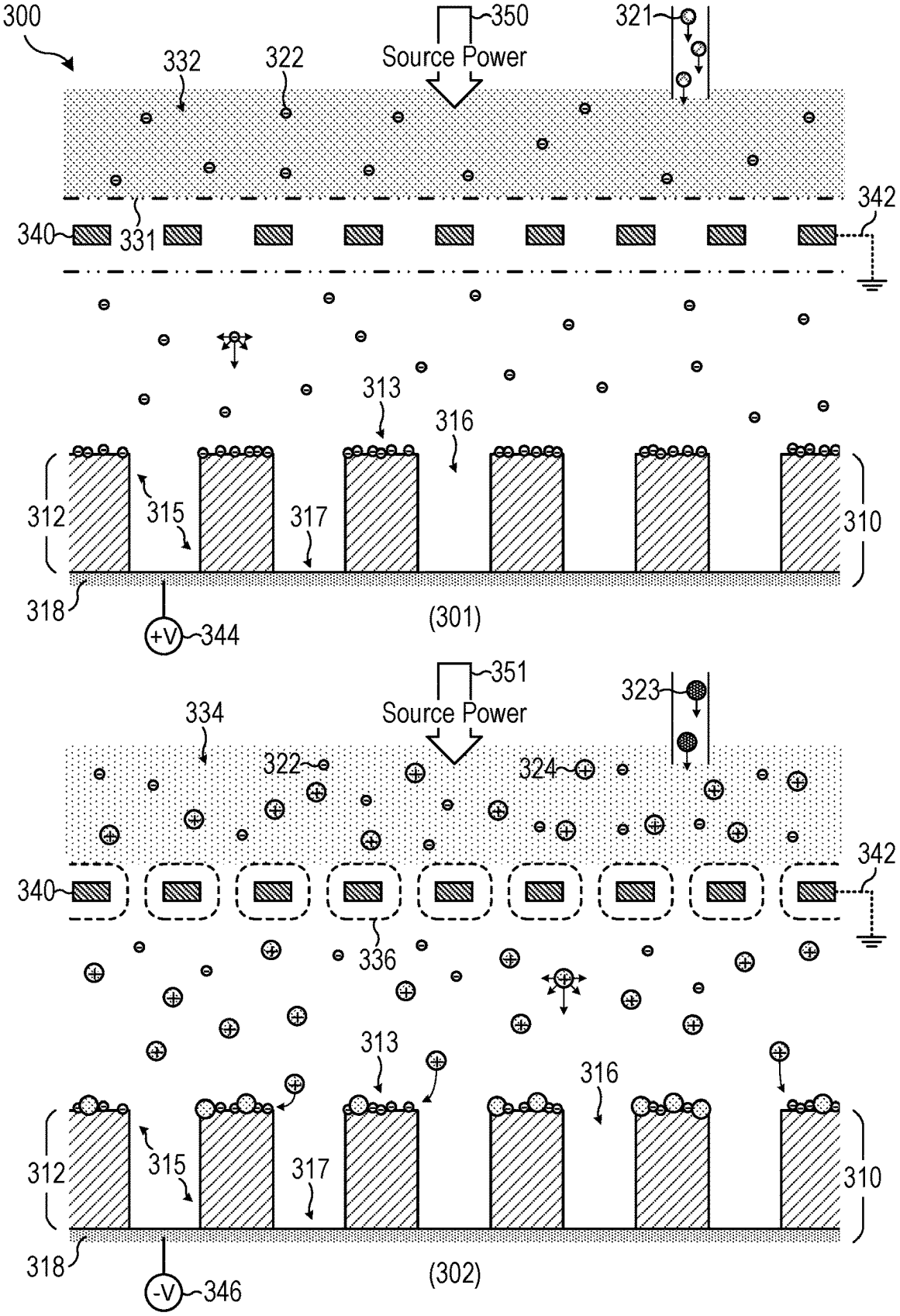
300
350
Source Power
321
332
322
342
340
331
313
316
312
315
317
310
318
+V
344
(301)
351
Source Power
323
334
322
324
342
340
336
313
316
312
315
317
310
318
-V
346
(302)

FIG. 3

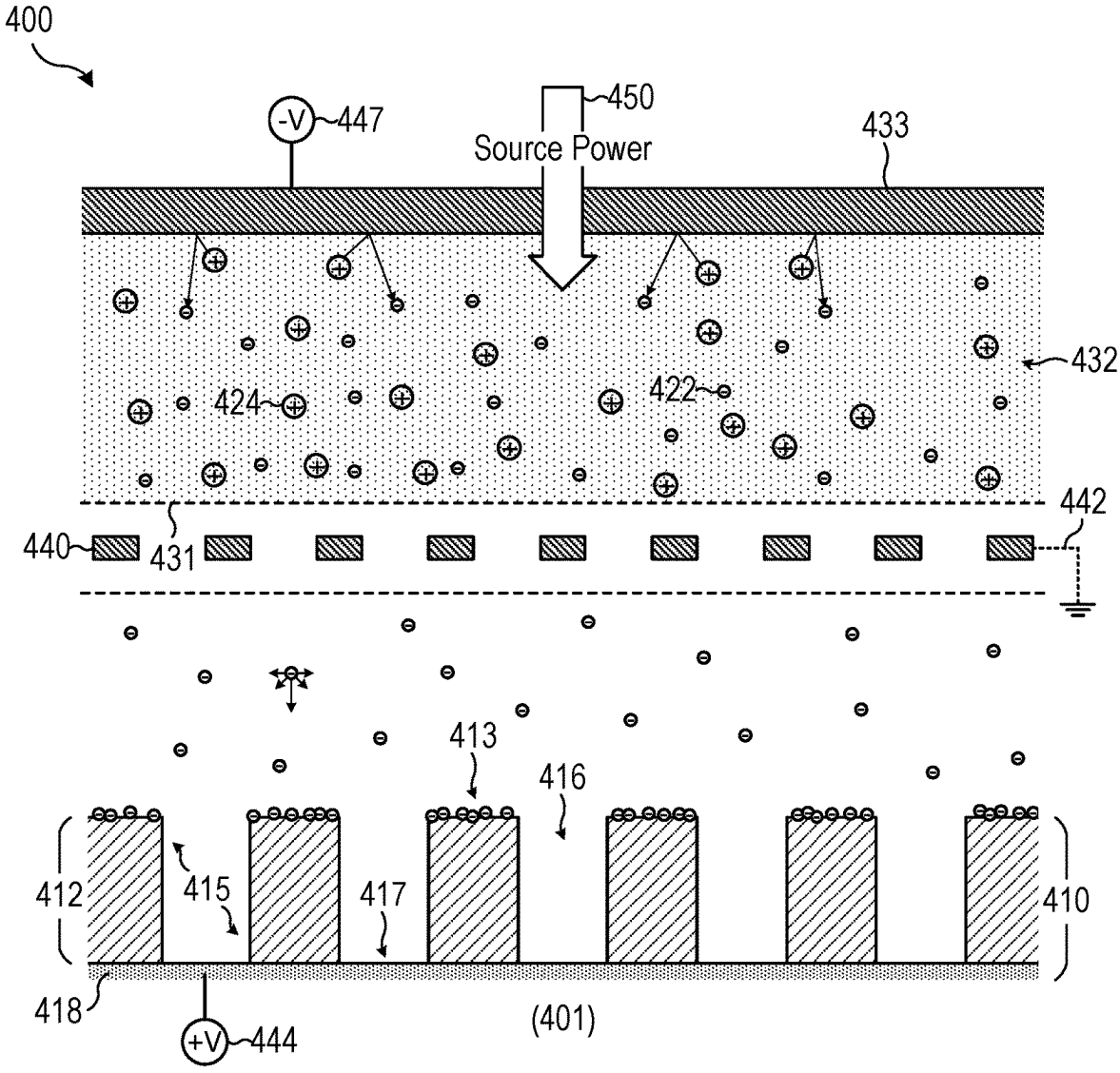
400
-V
447
450
Source Power
433
432
424
422
442
440
431
413
416
412
415
417
410
418
(401)
+V
444

FIG. 4

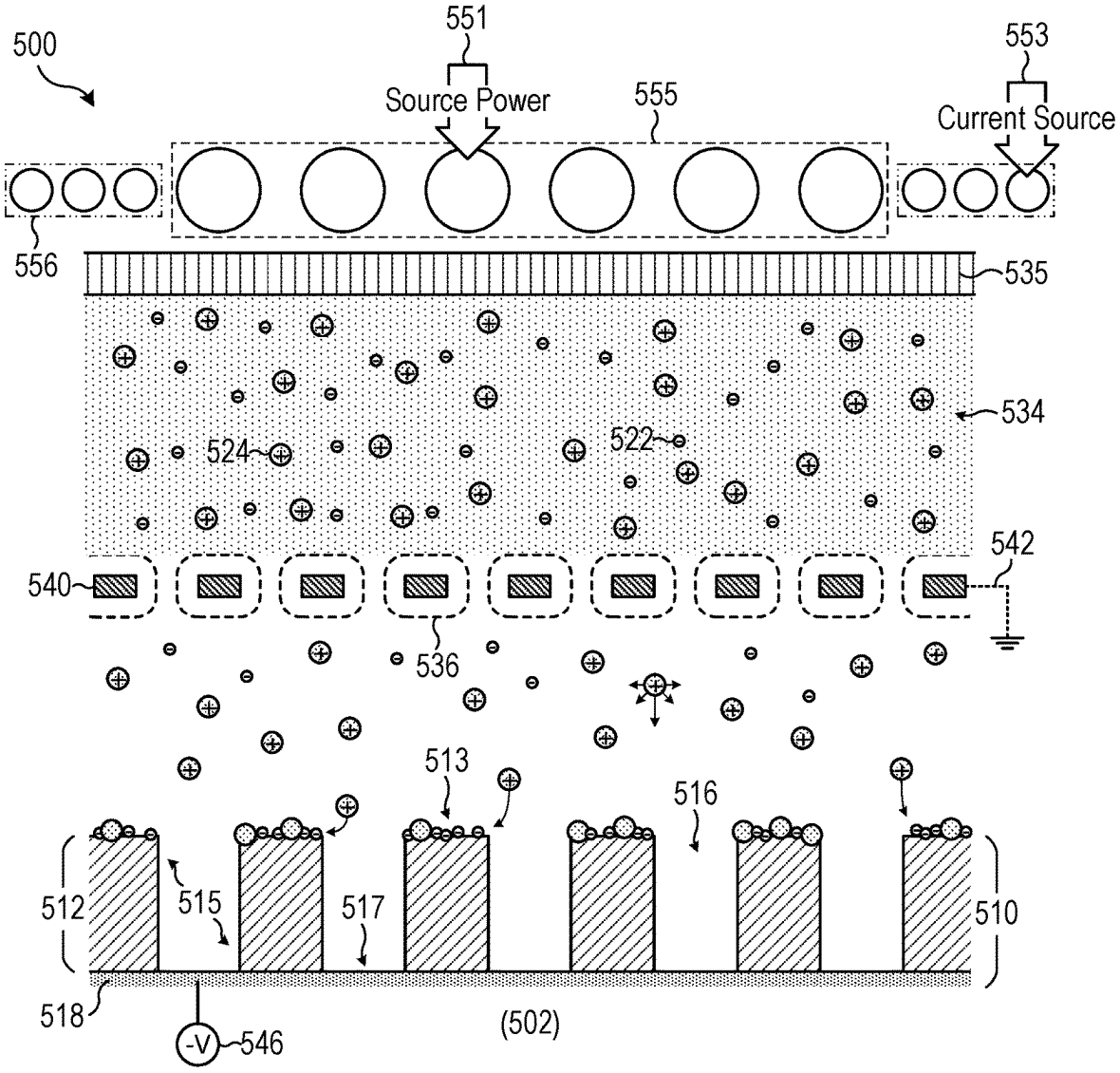
500
551
Source Power
555
553
Current Source
556
535
534
524
522
542
540
536
513
516
512
515
517
510
518
-V
546
(502)

FIG. 5

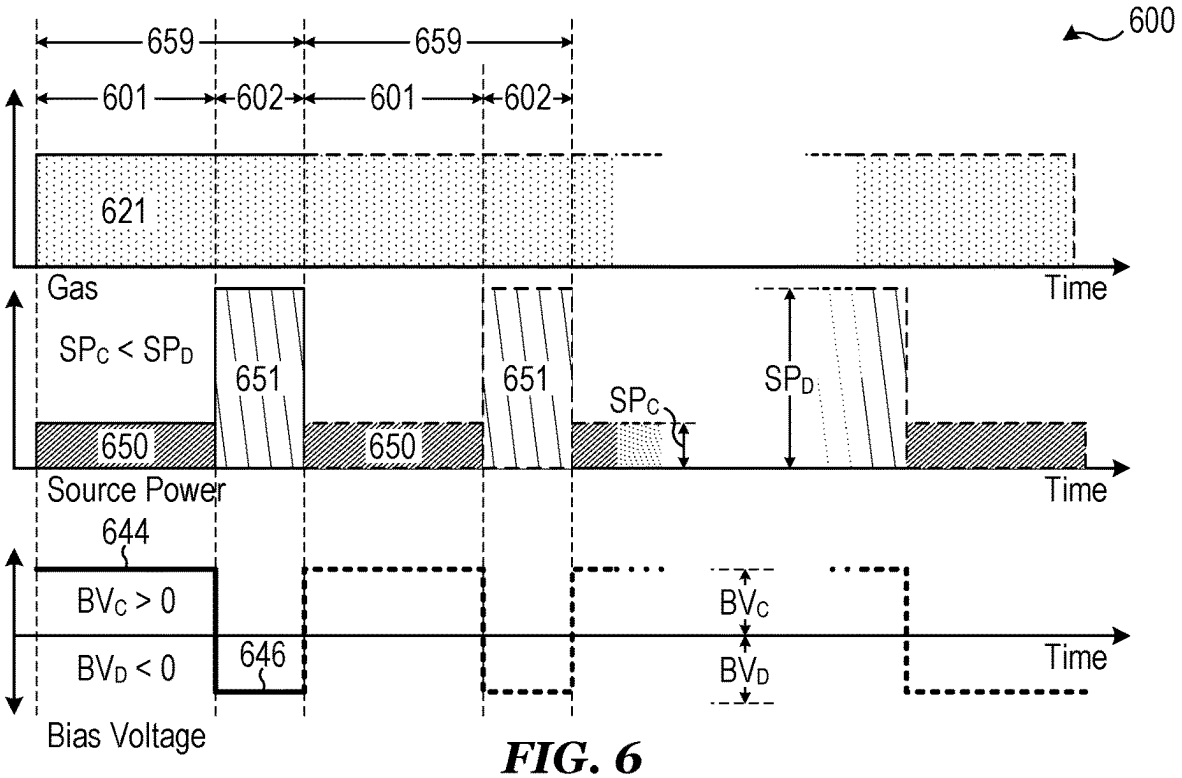
600
659
659
601
602
601
602
621
Gas
Time
SPC < SPD
651
651
SPC
SPD
650
650
Source Power
Time
644
BVC > 0
BVC
BVD < 0
646
BVD
Time
Bias Voltage

FIG. 6

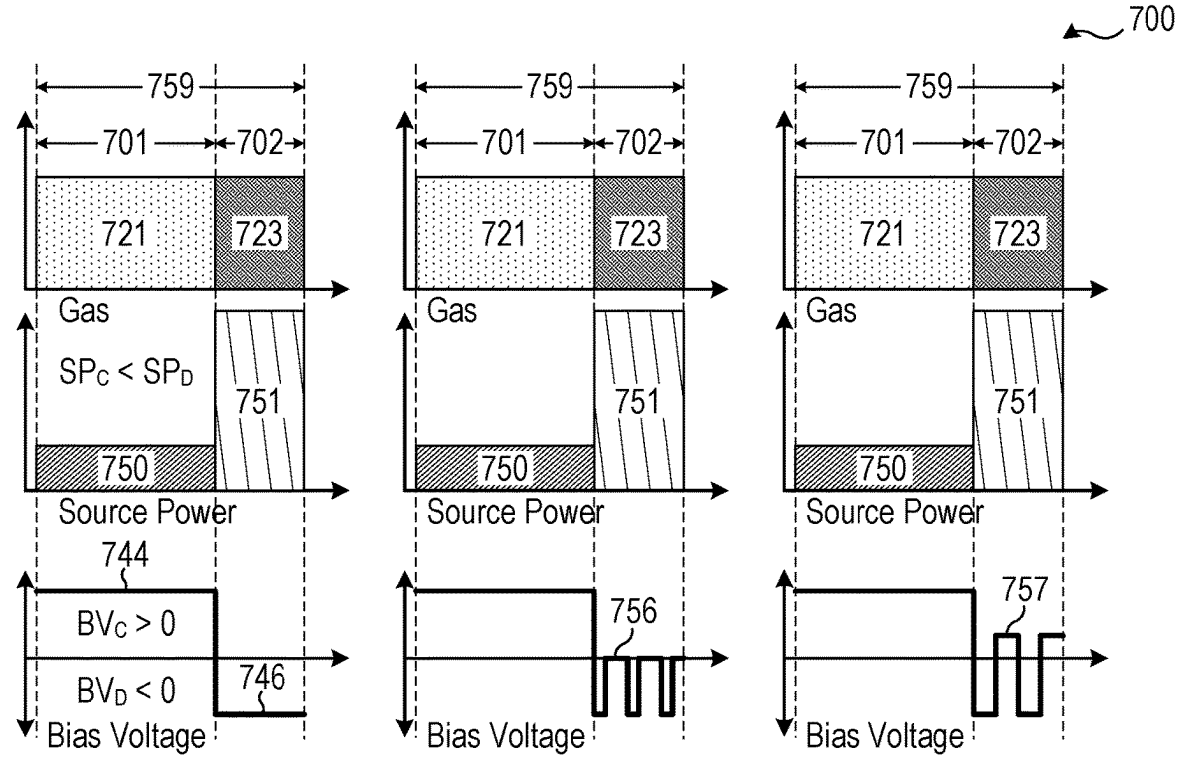
700
759
759
759
701
702
701
702
701
702
721
723
721
723
721
723
Gas
Gas
Gas
SPC < SPD
751
751
751
750
750
750
Source Power
Source Power
Source Power
744
BVC > 0
BVD < 0
746
756
757
Bias Voltage
Bias Voltage
Bias Voltage

FIG. 7

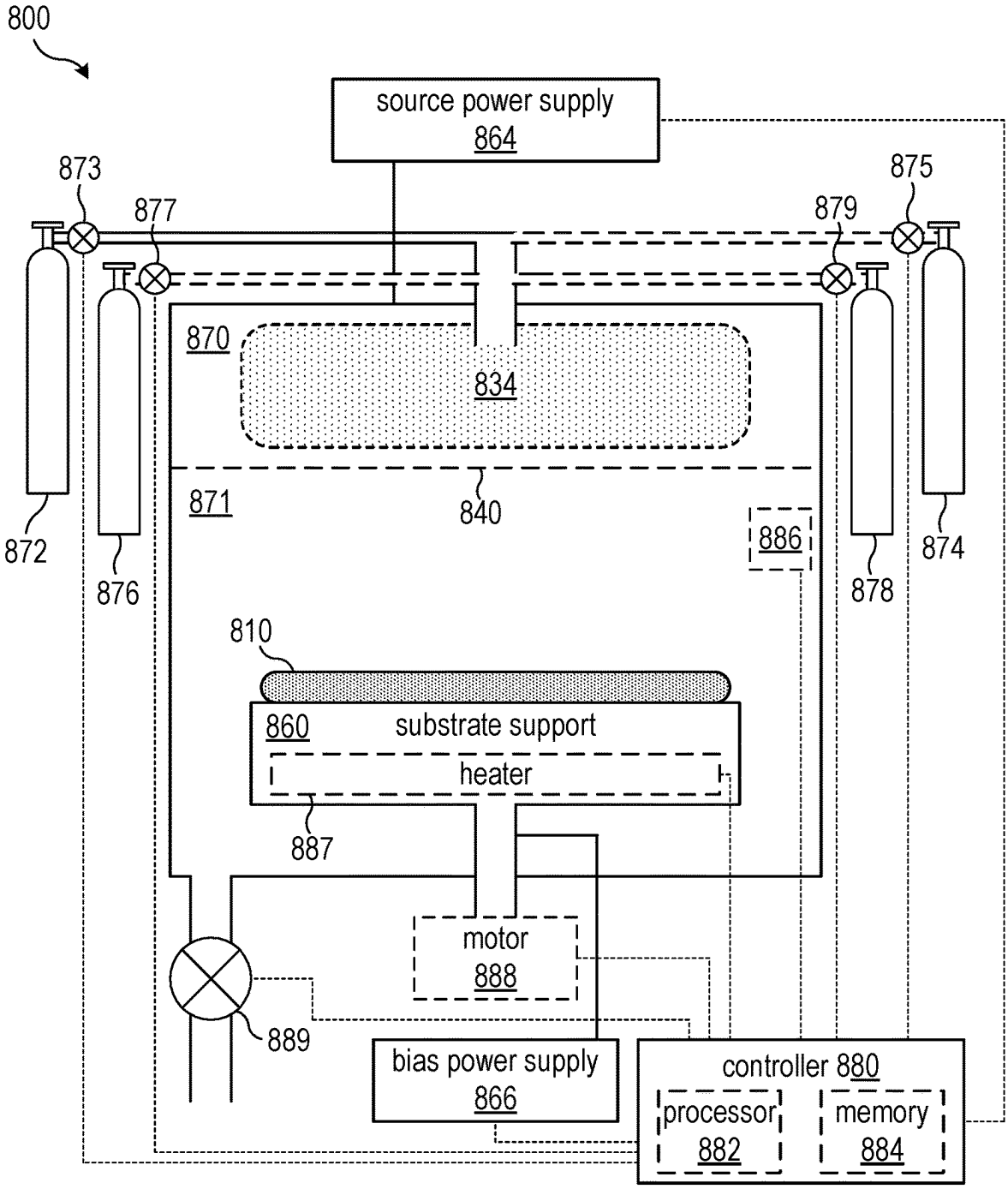
800
source power supply
864
873
877
875
879
870
834
871
840
872
876
886
878
874
810
860
substrate support
heater
887
motor
888
889
bias power supply
866
controller 880
processor
882
memory
884

FIG. 8

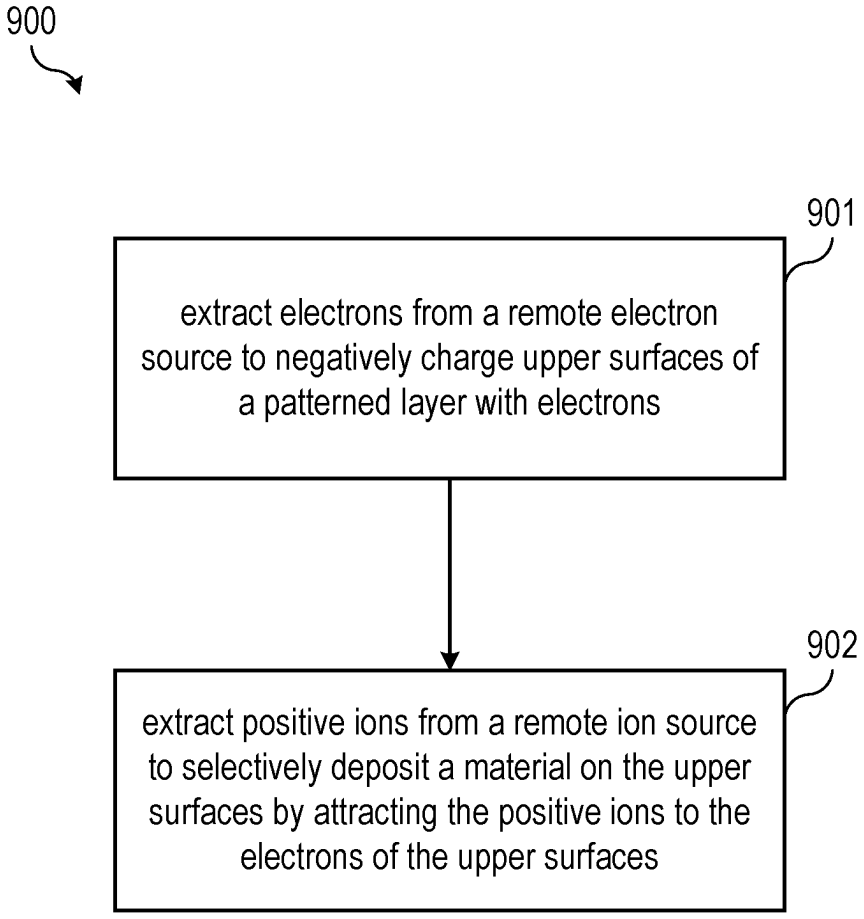
900
901
extract electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with electrons
902
extract positive ions from a remote ion source to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces

FIG. 9

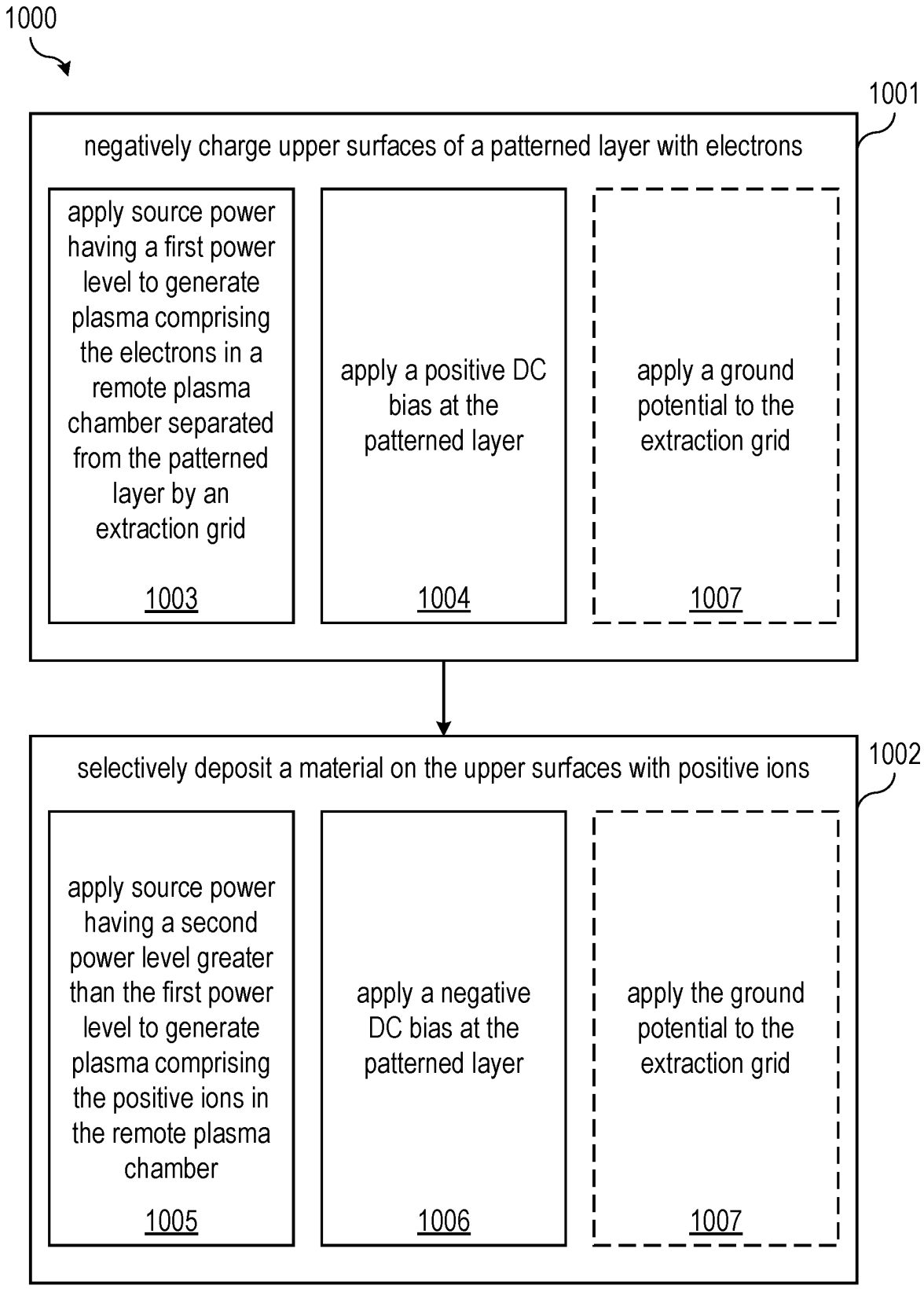
1000
1001
negatively charge upper surfaces of a patterned layer with electrons
apply source power having a first power level to generate plasma comprising the electrons in a remote plasma chamber separated from the patterned layer by an extraction grid
1003
apply a positive DC bias at the patterned layer
1004
apply a ground potential to the extraction grid
1007
1002
selectively deposit a material on the upper surfaces with positive ions
apply source power having a second power level greater than the first power level to generate plasma comprising the positive ions in the remote plasma chamber
1005
apply a negative DC bias at the patterned layer
1006
apply the ground potential to the extraction grid
1007

FIG. 10

SELECTIVE DEPOSITION USING DIFFERENTIAL SURFACE CHARGING

TECHNICAL FIELD

[0001] The present invention relates generally to selective deposition processes, and, in particular embodiments, to systems and methods for selectively depositing material using differential surface charging.

BACKGROUND

[0002] Microelectronic device fabrication typically involves a series of manufacturing techniques that include formation, patterning, and removal of a number of layers of material on a substrate. Etch masks may be formed (e.g., deposited, grown, patterned) to protect regions of the substrate and allow for pattern transfer via etching. Wet or dry etching processes may be used, with plasma etching processes being an example of a dry etching process. Etching processes are used extensively to form networks of electronic components and interconnect elements (e.g., transistors, resistors, capacitors, metal lines, contacts, and vias) that are integrated in a monolithic structure (i.e., an integrated circuit).

[0003] Photolithographic processes are often utilized to form etch masks by exposing a photoresist layer to structured actinic radiation and developing the photoresist to form a relief pattern. The relief pattern can then be transferred to an underlying layer of the photoresist layer (e.g., an etch target layer or an underlying hard mask layer formed over an etch target layer). The minimum feature size of photolithographic techniques is limited by the resolution of the optical system (e.g., because of diffraction limitations that depend on the wavelength of the actinic radiation used for the exposure).

[0004] As technology advances, feature sizes (i.e., critical dimensions) are reduced and device density increases. Since shorter wavelengths are less hindered by diffraction limitations, extreme ultraviolet (EUV) lithography has become widely used, for sub-10 nm technology nodes (e.g., 13.5 nm EUV lithography for 7 nm and 5 nm technology nodes). However, with the improved optical resolution, EUV photoresists present significant engineering challenges for meeting stringent cost and/or quality requirements. For instance, smaller dimensionality decreases feature stability and exacerbates interactions between the features of the mask, which can lead to photoresist line or pillar collapse. To account for this and other issues such as the depth of focus of the optics, low aspect ratio photoresist patterns (e.g., having a film thickness<15 nm) may be used. However, during the subsequent etch process, thinner photoresist films may be excessively damaged or etched away entirely destroying the integrity of the pattern transfer (i.e., there is a low resist budget). Moreover, stochastically-driven irregularities (such as line roughness, resist height thinning, line thinning, line edge roughness (LER), line width roughness (LWR), resist wiggling, etc.) are amplified by the reduced size and increased density of the features.

[0005] Selective deposition processes (also referred to as area selective deposition (ASD) processes) can be used to selectively deposit (i.e., grow) a material on desired surfaces (e.g., a patterned mask surface) while depositing less of the material (or even none of the material) on other surfaces (e.g., exposed underlying materials). Selective deposition can be difficult, such as when the material being deposited interacts similarly with both the desired surfaces and the undesired surfaces. Even worse, some systems exhibit reverse selectivity to certain materials (e.g., the material selectively deposits on the undesired surfaces relative to the desired surfaces).

[0006] Selective deposition processes have been used to mitigate problems associated with reduced mask material (such as those mentioned above). Unfortunately, the typical methods and chemistries to date depend on lengthy multi-step processes that depend on the material composition and surface structure of the photoresist. For example, conventional selective deposition processes may form a passivating layer on a target area while avoiding deposition on an area with a different composition, structure and topography. Another conventional method uses cyclic deposition-etch cycles which are time-consuming and require etching, which imposes additional limitations. Therefore, improved selective deposition methods that efficiently and selectively deposit material without etching and independent of material composition and surface structure may be desirable.

SUMMARY

[0007] In accordance with an embodiment of the invention, a method includes extracting electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with the electrons, and extracting positive ions from a remote ion source to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces.

[0008] In accordance with another embodiment of the invention, a method includes negatively charging upper surfaces of a patterned layer with electrons by concurrently applying source power having a first power level to generate plasma including the electrons in a remote plasma chamber separated from the patterned layer by an extraction grid and applying a positive direct current (DC) bias at the patterned layer. The method further includes selectively depositing a material on the upper surfaces with positive ions by concurrently applying source power having a second power level greater than the first power level to generate plasma including the positive ions in the remote plasma chamber and applying a negative DC bias at the patterned layer.

[0009] In accordance with still another embodiment of the invention, a plasma system includes a processing chamber, a remote plasma chamber configured to contain plasma including electrons and positive ions, an extraction grid separating the processing chamber and the remote plasma chamber, a substrate support disposed in the processing chamber and configured to support a substrate including a patterned layer fluidically coupled to the remote plasma chamber through the extraction grid, an electron source gas fluidically coupled to the remote plasma chamber through one or more valves, an ion source gas fluidically coupled to the remote plasma chamber through the one or more valves, a source power supply configured to generate the plasma in the remote plasma chamber, a DC bias power supply electrically coupled to the substrate support, and a controller operatively coupled to the one or more valves, the DC bias power supply, and the source power supply. The controller includes a processor and a non-transitory computer-readable medium storing a program including instructions that, when executed by the processor, performs a method including negatively charging upper surfaces of a patterned layer with

the electrons by concurrently applying source power from the source power supply to generate plasma including the electrons in a remote plasma chamber separated from the patterned layer and applying a positive DC bias from the DC bias power supply to the substrate holder. The method further includes selectively depositing a material on the upper surfaces with positive ions by concurrently applying source power from the source power supply to generate plasma including the positive ions in the remote plasma chamber and applying a negative DC bias from the DC bias power supply to the substrate holder.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0011] FIG. **1** illustrates an example selective deposition process that includes a surface charging step to negatively charge upper surfaces of a patterned layer and a deposition step to selectively deposit a material on the upper surfaces in accordance with embodiments of the invention;

[0012] FIG. **2** illustrates an example selective deposition process that includes a surface charging step and a selective deposition step, where the remote electron source and the remote ion source are remote plasmas in accordance with embodiments of the invention;

[0013] FIG. **3** illustrates an example selective deposition process that includes a surface charging step and a selective deposition step, where the remote electron source and the remote ion source are different remote plasmas in accordance with embodiments of the invention;

[0014] FIG. **4** illustrates a surface charging step of an example selective deposition process, where the remote electron source is a direct current superposition plasma in accordance with embodiments of the invention;

[0015] FIG. **5** illustrates a selective deposition step of an example selective deposition process, where the remote ion source is a magnetized plasma in accordance with embodiments of the invention;

[0016] FIG. **6** illustrates a timing diagram of an example selective deposition process in accordance with embodiments of the invention;

[0017] FIG. **7** illustrates several timing diagrams of example selective deposition processes in accordance with embodiments of the invention;

[0018] FIG. **8** illustrates an example plasma system that includes a remote plasma chamber and a process chamber within which selective deposition processes including surface charging step and a selective deposition step may be performed in accordance with embodiments of the invention;

[0019] FIG. **9** illustrates an example method of selectively depositing a material on upper surfaces of a patterned layer in accordance with embodiments of the invention; and

[0020] FIG. **10** illustrates another example method of selectively depositing a material on upper surfaces of a patterned layer in accordance with embodiments of the invention.

[0021] Corresponding numerals and symbols in the different figures generally refer to corresponding parts unless otherwise indicated. The figures are drawn to clearly illustrate the relevant aspects of the embodiments and are not necessarily drawn to scale. The edges of features drawn in the figures do not necessarily indicate the termination of the extent of the feature.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0022] The making and using of various embodiments are discussed in detail below. It should be appreciated, however, that the various embodiments described herein are applicable in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use various embodiments, and should not be construed in a limited scope. Unless specified otherwise, the expressions "around", "approximately", and "substantially" signify within 10%, and preferably within 5% of the given value or, such as in the case of substantially zero, less than 10% and preferably less than 5% of a comparable quantity.

[0023] With high-NA (numerical aperture) EUV lithography on the horizon, resist thickness continues to shrink and problems with stochastically driven roughness become more detrimental. These problems are transferred to underlying layers during the etching process, leading to problems with etch profile and uniformity, ultimately reducing yield, or in some cases rendering the processes completely intractable. Shrinking resist thickness (i.e., lower resist budget) may also cause issues that require higher selectivity during etches.

[0024] At the processing stage that these problems manifest, the mask has already been formed so that an underlayer is exposed through openings in the mask. For this reason, selective deposition is potentially attractive for mitigating these issues without adversely affecting the process of transferring the pattern to the underlayer. For example, materials selectively deposited on the mask surfaces may "heal" defects (e.g., smooth, fix breaks) in the mask pattern while depositing little or no material on the underlayer.

[0025] Additionally, selective deposition methods may be used to improve the resist budget during an etching process. The resist budget can be thought of as the effective selectivity of the mask layer relative to an underlying layer (i.e., the target layer being etched). For example, as a pattern is being transferred from a mask layer to an underlying layer, the mask layer is being etched (e.g., at a slower rate) than the underlying layer. Selectively increasing the height of the pattern features during the etching process can increase the amount of time it takes to etch away the features and thereby increase the effective selectivity (resist budget) of the mask layer relative to the underlying layer.

[0026] However, conventional direct selective deposition on many materials is only possible for a narrow selection of deposition materials. Further, conventional indirect selective deposition methods require the formation of an intermediate layer that is then reacted with a different compound to from the deposited material in a subsequent step. Consequently, such conventional methods are highly chemistry-dependent and still often have the drawback of requiring chemical compatibility of the intermediate layer with the patterned layer.

[0027] In accordance with embodiments herein described, the invention proposes a selective deposition process that selectively deposits a material (e.g., polymer) on upper surfaces of a patterned layer by charging the upper surfaces relative to other surfaces. The embodiment selective deposition processes described herein may advantageously selec-

tively deposit any desired material on the patterned layer as long as the material can be deposited using positive ions. Additionally, the upper surfaces are charged using electrons, which has the benefit of facilitating direct selective deposition of the material (as opposed to conventional methods that use multiple compounds to form the deposited material).

[0028] Specifically, the selective deposition process includes two steps: a surface charging step and a selective deposition step. During the surface charging step, a remote electron source is used to provide electrons (e.g., low-energy substantially directionless electrons) at upper surfaces of a patterned layer. For example, the electrons may be extracted from the remote electron source to negatively charge the upper surfaces with the electrons. Positive ions (e.g., polymerizing ions such as carbon-containing ions like fluorocarbons, hydrofluorocarbons, etc.) are then extracted from a remote ion source (e.g., low-energy substantially directionless ions) to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons collected on the upper surfaces.

[0029] The remote electron source may be a remote plasma source. Electrons may be generated in a remote plasma chamber that is separated from the patterned layer by an extraction grid. Source power at a low power level may applied to generate plasma in the remote plasma chamber (e.g., source power that is high enough to generate a plasma, but low enough to maintain a continuous plasma sheath at the extraction grid). A positive direct current (DC) bias may also be applied at the patterned layer to attract electrons that pass through the plasma sheath to the upper surfaces. The positive DC bias has a low enough voltage to maintain the substantially directionless quality of the electrons while still collecting the electrons at the upper surfaces.

[0030] Similarly, the remote ion source may also be a remote plasma source (either using the same plasma or different plasmas). Source power at a higher power level may be applied to generate plasma in the remote plasma chamber (e.g., source power that is high enough to promote plasma molding around the extraction grid and allow positive ions to pass through the extraction grid). A negative DC bias may also be applied at the patterned layer to form a potential gradient accelerating positive ions towards the patterned layer. However, similar to the negative DC bias, the positive DC bias also has a low enough voltage to avoid imparting significant directionality to the positive ions (i.e., so that the negatively charged upper surfaces exert a meaningful attractive force on the positive ions). The positive ions collect at the upper surfaces and the material is selectively deposited.

[0031] The embodiment selective deposition processes described herein may afford various potential benefits, such as increasing resist budget, which may be particularly important when resist height is small, such as in EUV processes where the resist height may be on the order of 20 nm. Selective deposition on a wide variety of resists (including metal-containing resists) may advantageously help with mask budget in addition to possibly addressing roughness concerns during pattern transfer. The selective deposition may also facilitate improved process transfer for smaller features by smoothing mask features. That is, the selectively deposited material may mitigate stochastically-driven irregularities, such as line roughness, resist height thinning, line thinning, LER, LWR, resist wiggling, line breaks, and others.

[0032] The advantages of selective deposition may also be achieved for a larger variety of materials than conventional methods. Additionally, the selective deposition process is a direct process, capable of selectively depositing the using a species of positive ion. The selective deposition processes may also be advantageously implemented without having to remove the substrate from the processing chamber, such as in situ during an etching process. For example, the selective deposition processes described herein, may be performed in an etching system, such as a plasma etching system. Additionally, the deposition processes may have the advantage of being capable of integration into current process flows, such as etch processes.

[0033] Embodiments provided below describe various systems and methods for selective deposition processes, and in particular, to systems and methods for selectively depositing a material on upper surfaces of a patterned layer using differential surface charging. The following description describes the embodiments. FIG. **1** is used to describe an example selective deposition process. Two more example selective deposition processes are described using FIGS. **2** and **3**. A surface charging step of an example selective deposition process is described using FIG. **4**. A selective deposition step of a selective deposition process is described using FIG. **5**. Various timing diagrams of example selective deposition processes are described using FIGS. **6** and **7**. An example plasma system that can be used to perform selective deposition processes is described using FIG. **8**. Two example methods of selectively depositing a material on upper surfaces of a patterned layer are described using FIGS. **9** and **10**.

[0034] FIG. **1** illustrates an example selective deposition process that includes a surface charging step to negatively charge upper surfaces of a patterned layer and a deposition step to selectively deposit a material on the upper surfaces in accordance with embodiments of the invention.

[0035] Referring to FIG. **1**, a selective deposition process **100** begins with a substrate **110** that includes a patterned layer **112** overlying an underlying layer **118**. The patterned layer **112** has been formed such that it has various recesses **116** with upper surfaces **113** and sidewalls **115** revealing bottom surfaces **117** below (i.e., exposed surfaces of the underlying layer **118**). The underlying layer **118** may be any suitable material (e.g., a dielectric material, such as an oxide or a nitride, but any material is possible including metal materials, semiconductor materials, etc.). Of course, the substrate **110** may (and very often does) include various other layers below the underlying layer **118**. An extraction grid **140** separates the patterned layer **112** from a remote chamber **170**. At an initial state **108** of the selective deposition process **100**, the patterned layer **112** has been formed on the underlying layer **118**.

[0036] During a surface charging step **101** of the selective deposition process **100**, the entire patterned layer **112** (including the upper surfaces **113**, sidewalls **115**, and the bottom surfaces **117**) is exposed to electrons **122** extracted from a remote electron source **132** in the remote chamber **170**. For example, the electrons **122** may be generated using any suitable method (e.g., in a plasma, thermionic, field emission, etc.). The electrons **122** are extracted through the extraction grid **140** (which may be coupled to an optional

ground potential **142** or left electrically floating). For example, the extraction grid **140** is configured to keep the electrons **122** of the remote electron source **132** separate from the patterned layer **112** while they are being generated (e.g., while they potentially have high energy or directionality). The remote electron source **132** and the extraction grid **140** are configured to provide the electrons at the patterned layer **112** with low energy and substantially directionless motion (e.g., substantially random thermal motion).

[0037] A positive DC bias **144** may be applied at the substrate **110** during the surface charging step **101** (e.g., to a substrate holder supporting the substrate). The positive DC bias **144** is configured to be a charging potential (e.g., low positive voltage that imparts little downward velocity to the electrons) that is sufficient to collect the electrons **122** as surface charge at the upper surfaces **113**, as shown. In various embodiments, the positive DC bias **144** is less than about 50 V, and is less than about 30 V in some embodiments. In on embodiment, the positive DC bias **144** is between about 10 V and about 30 V.

[0038] The electrons **122** may diffuse through the extraction grid **140** and then experience the low positive potential from the positive DC bias **144**. The electrons **122** collect preferentially at the upper surfaces **113** relative to other surfaces (i.e., the sidewalls **115** and the bottom surfaces **117**). For example, various factors may play a role in achieving this differential charging of the upper surfaces **113**, such as the geometry of the patterned layer **112** (e.g., shading effects), the location of the upper surfaces **113** at the top of the patterned layer **112**, the low energy of the electrons **122**, the low voltage of the positive DC bias **144**, collected charge in the bottom regions of the recesses **116**, and others.

[0039] During a selective deposition step **102** of the selective deposition process **100**, the entire patterned layer **112** (including the charged upper surfaces **113**, the sidewalls **115**, and the bottom surfaces **117**) is exposed to positive ions **124** extracted from a remote ion source **134** in the remote chamber **170**. The selective deposition process **100** is not limited by the type of remote ion source as long as the positive ions **124** are capable of being extracted through extraction grid **140** with the desired properties. In one embodiment, the remote ion source **134** is a remote plasma. Further, when the remote electron source **132** is also a remote plasma, the remote ion source **134** may be the same remote plasma as the remote electron source **132** in various embodiments. In other embodiments, two different plasma may be generated for the remote electron source **132** and the remote ion source **134**. Additional details of these options are discussed in further detail in the following.

[0040] A negative DC bias **146** may be applied at the substrate **110** during the selective deposition step **102** (again, to a substrate holder supporting the substrate, for example). The negative DC bias **146** is configured to extract the positive ions **124**, but is a low negative voltage configured to avoid accelerating the positive ions **124** past the charged upper surfaces **113** and to the sidewalls **115** and bottom surfaces **117** of the recesses **116**. That is, whatever downward velocity is acquired by the positive ions **124** from the negative DC bias **146** is low enough to allow the positive ions **124** to be attracted by the electrons **122** of the charged upper surfaces **113** resulting in selective deposition of a deposited material **120** at the upper surfaces **113**, as shown in a post deposition state **109**. In various embodiments, the magnitude of the negative DC bias **146** is less than about 50 V, and is less than about 30 V in some embodiments. In one embodiment, the magnitude of the negative DC bias **146** is between about 10 V and about 30 V.

[0041] In some cases, it may be desirable to provide the negative DC bias **146** as a series of pulses (e.g., to control surface charging from the positive ions **124**, control the flux of the positive ions **124**, etc.). Additionally, positive pulses may also be included, such as by interspersing the positive bias pulses between the negative bias pulses to form a bipolar pulse train.

[0042] The deposited material **120** may be any desired material as long as it may be deposited using positive ions that can be generated by a remote ion source **134**. Advantageously, the deposited material **120** may be a polymeric material that is compatible with a corresponding etching process. In various embodiments, the deposited material **120** is a carbon-based material. In one embodiment, the deposited material **120** is a fluorocarbon polymer. In another embodiment, the deposited material **120** is a hydrofluorocarbon polymer. Of course, many materials suitable for use as the deposited material **120** may be combinations of many elements, and may include carbon. Further, carbon is by no means required as a component of the deposited material **120**, as other elements may also make up or be included in the positive ions **124** and/or the deposited material **120**, such as silicon, boron, nitrogen, oxygen, halogens (chlorine, iodine, and others), metals (aluminum, magnesium, and others), just to name a few.

[0043] The surface charging step **101** and the selective deposition step **102** may be perform on any timescale appropriate for the desired amount of charge (during the surface charging step **101**) and the desired amount of the deposited material (during the selective deposition step **102**). In some cases, the timescales may be influenced by considerations such as the flux of the electrons **122** in the surface charging step **101** and the flux of the positive ions **124** in the selective deposition step **102**. For example, the surface charging step **101** may be made longer or shorter to accumulate the desired amount of charge on the upper surfaces **113** (which may have a practical upper limit after which no additional charge accumulates or charge begins to undesirably accumulate on the sidewalls **115** or the bottom surfaces **117**. If the amount of positive charge accumulated during the selective deposition step **102** is higher than that of the surface charging step **101** then the desired effects of selective deposition using differential charging may be lost. Therefore, the duration of the selective deposition step **102** may be chosen to ensure that the positive charge at the upper surfaces **113** is limited to a desired percentage of the negative charge collected during the surface charging step **101**.

[0044] Another practical consideration related to the timescales of the surface charging step **101** and the selective deposition step **102** are the speed that the remote electron source **132** and the remote ion source **134** can generate the electrons **122** and the positive ions **124**, respectively. In some cases, additional time may be required to generate the electrons **122** and the positive ions **124** with the desired properties. One example, might be if the remote electron source **132** and the remote ion source **134** are different remote plasmas. The duration of the surface charging step **101** and the selective deposition step **102** may then be

influenced by the gas switching speed, which may be slower than the charging and deposition processes.

[0045] The patterned layer **112** may be formed by patterning a resist such as a photoresist. In various embodiments, the patterned layer **112** is a metal oxide resist (MOR) photoresist. In one embodiment, the patterned layer **112** is a tin oxide-based mask formed by patterning a tin oxide-based photoresist (e.g., using EUV lithography). The substrate **110** may include various layers ranging from amorphous silicon (aSi) to organic layers (e.g., an OPL) to oxides (e.g., silicon dioxide (SiO_2) such as low temperature oxide (LTO), tetraethyl orthosilicate (TEOS), aluminum oxide (Al_2O_3), etc.) to nitrides (e.g., silicon nitride (Si_3N_4)) and metals. Moreover, the substrate **110** may be any suitable substrate, such as an insulating, conducting, or semiconducting substrate with one or more layers disposed thereon. For example, the substrate **110** may be a semiconductor wafer, such as a silicon wafer, and include various layers, structures, and devices (e.g., forming integrated circuits). In one embodiment, the substrate **110** includes silicon. In another embodiment, the substrate **110** includes silicon germanium (SiGe). In still another embodiment, the substrate **110** includes gallium arsenide (GaAs). Of course, many other suitable materials, semiconductor or otherwise, may be included in the substrate **110** as may be apparent to those of skill in the art.

[0046] FIG. **2** illustrates an example selective deposition process that includes a surface charging step and a selective deposition step, where the remote electron source and the remote ion source are remote plasmas in accordance with embodiments of the invention. The selective deposition process of FIG. **2** may be a specific implementation of other selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0047] Referring to FIG. **2**, a selective deposition process **200** includes a surface charging step **201** and a selective deposition step **202**. It should be noted that here and in the following a convention has been adopted for brevity and clarity wherein elements adhering to the pattern [x01] where 'x' is the figure number may be related implementations of a surface charging step in various embodiments. For example, the surface charging step **201** may be similar to the surface charging step **101** except as otherwise stated. An analogous convention has also been adopted for other elements as made clear by the use of similar terms in conjunction with the aforementioned numbering system.

[0048] During the surface charging step **201**, a patterned layer **212** including upper surfaces **213**, sidewalls **215**, and bottom surfaces **217** is exposed to electrons **222** extracted from a remote plasma **234**. The patterned layer **212** is disposed over an underlying layer **218** of a substrate **210**. A charging source power **250** is applied to the remote plasma **234** and the electrons **222** are extracted through an extraction grid **240**, which again may be coupled to an optional ground potential **242** or left electrically floating. As shown, the charging source power **250** is configured to generate the remote plasma **234** and form a plasma sheath **231** at the interface between the remote plasma **234** and the extraction grid **240**. The charging source power **250** is applied at a power level that results in a plasma sheath **231** is substantially continuous which may repel positive ions **224** that may be present in the remote plasma **234**. A positive DC bias **244** is applied at the substrate **210** during the surface charging step **201** and is configured to be a charging potential sufficient to collect the electrons **222** as surface charge at the upper surfaces **213**.

[0049] During the selective deposition step **202**, the patterned layer **212** is exposed the positive ions **224** extracted from remote plasma **234**. A deposition source power **251** is now applied to the remote plasma **234**, which differs from the charging source power **250** in that it is higher than the charging source power **250**. Specifically, the deposition source power **251** results in a molded plasma sheath **236** that conforms around the structure of the extraction grid **240** (due to reduced thickness compared to the plasma sheath **231** of the surface charging step **201**). The molded plasma sheath **236** allows the positive ions **224** to be extracted through the extraction grid **240**. A negative DC bias **246** is applied at the substrate **210** during the selective deposition step **202** and is configured to extract the positive ions **224** while avoiding accelerating the positive ions **224** past the charged upper surfaces **213** to the sidewalls **215** and bottom surfaces **217** of the recesses **216**. As shown, the molded plasma sheath **236** also allows some of the electrons **222** to pass through the extraction grid **240**, but the negative DC bias **246** may advantageously repel them away from the upper surfaces **213**.

[0050] The size of the extraction grid **240** may be selected to allow the formation of the plasma sheath **231** and the molded plasma sheath **236** respectively. For this reason, the size of the openings on the extraction grid **240** may depend on a variety of factors. As an example, the size of the openings of the extraction grid **240** may be on the order of a millimeter. For example, the opening size of the extraction grid **240** is greater than about 500 μm in some embodiments, and is about 900 μm in one embodiment.

[0051] The remote plasma **234** may be any suitable type of plasma. In various embodiments, the remote plasma **234** is a polymer generating plasma, and may be a plasma used for etching the underlying layer **218** in some embodiments. In one embodiment, the remote plasma **234** is a fluorocarbon plasma, including fluorocarbon species (e.g., CF species, CHF species, etc.) In some implementations, the remote plasma **234** in the surface charging step **201** and the selective deposition step **202** are different plasmas (i.e., generated using different source gases). This option will be discussed more fully in reference to FIG. **3** below.

[0052] Additional gases may be included along with the source gas used to produce the electrons **222** and/or the positive ions **224**. Specifically, the remote plasma **234** may include one or more carrier gases, stabilizing gases, supporting gases, and others. For example, a noble gas such as argon may be included as a carrier gas (or may also be used as a part of the source gas, such as to produce the electrons **222**, for example). Relatively inert gases such as nitrogen may also be used as a carrier gas (or for another purpose). Reactive gases may also be included, such as hydrogen or oxygen. Indeed, as long as the electrons **222** and the positive ions **224** are generated with appropriate properties within the remote plasma **234**, any desired gas may be included, as may be apparent to those of skill in the art.

[0053] FIG. **3** illustrates an example selective deposition process that includes a surface charging step and a selective deposition step, where the remote electron source and the remote ion source are different remote plasmas in accordance with embodiments of the invention. The selective deposition process of FIG. **3** may be a specific implemen-

tation of other selective deposition processes described herein such as the selective deposition process of FIG. **2**, for example. Similarly labeled elements may be as previously described.

[0054] Referring to FIG. **3**, a selective deposition process **300** includes a surface charging step **301** and a selective deposition step **302**. As before, during the surface charging step **301**, a patterned layer **312** including upper surfaces **313**, sidewalls **315**, and bottom surfaces **317** is exposed to electrons **322** extracted from a remote electropositive plasma **332** that is generated by applying a charging source power **350** to an electron source gas **321**. The patterned layer **312** is disposed over an underlying layer **318** of a substrate **310**. The electrons **322** are extracted through a plasma sheath **331** and an extraction grid **340** (coupled to an optional ground potential **342** or left electrically floating). A positive DC bias **344** is applied at the substrate **310** during the surface charging step **301** and is configured to be a charging potential sufficient to collect the electrons **322** as surface charge at the upper surfaces **313**.

[0055] During the selective deposition step **302**, the patterned layer **312** is exposed to positive ions **324** extracted from a remote polymerizing plasma **334** (e.g., a fluorocarbon plasma). A deposition source power **351** is applied to an ion source gas **323** to generate the remote polymerizing plasma **334** resulting in a molded plasma sheath **336** at the extraction grid **340**. A negative DC bias **346** is applied at the substrate **310** during the selective deposition step **302** and is configured to extract the positive ions **324** while avoiding accelerating the positive ions **324** past the charged upper surfaces **313**. It should be noted that the remote electropositive plasma **332** includes positive ions (as well as potentially other plasma species) that were not shown to avoid confusion with the positive ions **324**. That is, ions in the remote electropositive plasma **332** remain above the extraction grid **340** and are not the same as the positive ions **324**.

[0056] In contrast the to the selective deposition process **200** of FIG. **2**, the surface charging step **301** and the selective deposition step **302** utilize different plasmas (i.e., plasmas generated using different source gases). Specifically, the remote electropositive plasma **332** is generated using the electron source gas **321**, which may comprise argon, such as pure argon gas. Meanwhile, the remote polymerizing plasma **334** may be any suitable type of plasma with the positive ions **324** that are used to selectively deposit a material on the upper surfaces **313**.

[0057] FIG. **4** illustrates a surface charging step of an example selective deposition process, where the remote electron source is a direct current superposition plasma in accordance with embodiments of the invention. The surface charging step of FIG. **4** may be included in other selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0058] Referring to FIG. **4**, a surface charging step **401** of a selective deposition process **400** is similar to the surface charging step **201** of FIG. **2**, except that in this specific implementation, direct current superposition (DCS) is used to generate all or some of the electrons by applying a DCS potential **447** to a DCS electrode **433**. A patterned layer **412** including upper surfaces **413**, sidewalls **415**, and bottom surfaces **417** is exposed to electrons **422** extracted from the resulting remote DCS plasma **432** (including the electrons **422** and positive ions **424**) that is generated by applying a charging source power **450** (e.g., to the DCS electrode **433** or coupled through other means such as to another electrode or to a resonant structure, radio frequency (RF) antenna, etc.). The patterned layer **412** is disposed over an underlying layer **418** of a substrate **410**. The electrons **422** are extracted through a plasma sheath **431** and an extraction grid **440** (coupled to an optional ground potential **442** or left electrically floating). A positive DC bias **444** is applied at the substrate **410** during the surface charging step **401** and is configured to be a charging potential sufficient to collect the electrons **422** as surface charge at the upper surfaces **413**.

[0059] FIG. **5** illustrates a selective deposition step of an example selective deposition process, where the remote ion source is a magnetized plasma in accordance with embodiments of the invention. The selective deposition step of FIG. **5** may be included in other selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0060] Referring to FIG. **5**, a selective deposition step **502** of a selective deposition process **500** is similar to the selective deposition step **202** of FIG. **2**, except that in this specific implementation, a remote magnetized plasma **534** is generated by applying deposition source power **551** to a source electrode **555** while applying a pulsed current source **553** to an electromagnet **556**. For example, the electromagnet **556** may be a planar coil (as shown), a helical coil surrounding the remote magnetized plasma **534**, or other configurations. While the source electrode **555** is shown as an inductive source electrode (a planar coil), other configurations are also possible, such as helical coil, or even a capacitive source electrode such as an upper electrode (for example if the electromagnet **556** is implemented as a helical coil).

[0061] A patterned layer **512** including upper surfaces **513**, sidewalls **515**, and bottom surfaces **517** is exposed to positive ions **524** extracted from the remote magnetized plasma **534** The patterned layer **512** is disposed over an underlying layer **518** of a substrate **510**. The positive ions **524** are extracted through molded plasma sheath **536** and an extraction grid **540** (coupled to an optional ground potential **542** or left electrically floating). A negative DC bias **546** is applied at the substrate **510** during the selective deposition step **502** and is configured to extract the positive ions **524** while avoiding accelerating the positive ions **524** past the charged upper surfaces **513**.

[0062] FIG. **6** illustrates a timing diagram of an example selective deposition process in accordance with embodiments of the invention. The timing diagram of FIG. **6** may correspond with any of the selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0063] Referring to FIG. **6**, a timing diagram **600** of an example selective deposition process shows timing for a source gas **621**, charging source power **650**, deposition source power **651**, positive DC bias **644**, and negative DC bias **646**. As before, the selective deposition process includes a surface charging step **601** and a selective deposition step **602**. In some embodiments, the surface charging step **601** and the selective deposition step **602** may be repeated as part of a cycle **659** (e.g., when the amount of the selectively deposited material exceeds the amount of mate-

rial that can be selectively deposited during a single combination of the surface charging step **601** and the selective deposition step **602** steps.

[0064] In this embodiment, the source gas **621** remains the same throughout the both the surface charging step **601** and the selective deposition step **602**. The charging source power **650** (SP_C) is less than the deposition source power **651** (SP_D), which may advantageously result in the desired sheath effects at the extraction grid. In one embodiment, the charging source power **650** is less than 200 W and the deposition source power **651** is greater than 200 W. The charging source power **650** may be in the range of about 10 W and about 200 W. The deposition source power **651** may be in the range of about 500 W to about 2000 W.

[0065] During the surface charging step **601**, the DC bias voltage is positive ($BV_C>0$) while the DC bias voltage is negative (BV_D) during the selective deposition step **602**. In some applications, the timescale of the cycle **659** may be faster because the same source gas **621** is used for both the surface charging step **601** and the selective deposition step **602**. For example, the timescale of the cycle **659** may be on the order of milliseconds or even microseconds. However, longer timescales are also possible and will depend on the details of a given application.

[0066] As previously mentioned, the duration of the selective deposition step **602** may be shorter than that of the surface charging step **601**. This may be because of the relative fluxes of the electrons and the positive ions during the respective steps. For example, it may be desirable to limit the amount of positive charge in the selective deposition step **602** relative to the amount of negative charge in the surface charging step **601**. In various embodiments, the duration of the selective deposition step **602** may be selected to be between about 10% and about 50% of the duration of the surface charging step **601**.

[0067] FIG. **7** illustrates several timing diagrams of example selective deposition processes in accordance with embodiments of the invention. The timing diagram of FIG. **7** may correspond with any of the selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0068] Referring to FIG. **7**, timing diagrams **700** of example selective deposition processes show timing for source gas, charging source power **750**, deposition source power **751**, positive DC bias **744**, and negative DC bias **746**. In contrast to the timing diagram **600**, the source gas is different between a surface charging step **701** (an electron source gas **721**) and a selective deposition step **702** (an ion source gas **723**). In addition to the specific implementation of different source gases, two alternative negative DC bias implementations are also qualitatively illustrated in the timing diagrams **700**. For example, the negative DC bias **746** may be applied as a series of negative bias pulses **756**. Additionally, the series of negative bias pulses **756** may be further modified to include positive pulses (e.g., to mitigate charging even further) so that the negative DC bias **746** is applied as a series of bipolar pulses **757**.

[0069] FIG. **8** illustrates an example plasma system that includes a remote plasma chamber and a process chamber within which selective deposition processes including surface charging step and a selective deposition step may be performed in accordance with embodiments of the invention. The deposition system of FIG. **8** may be used to perform any of the example selective deposition processes described herein such as the selective deposition process of FIG. **1**, for example. Similarly labeled elements may be as previously described.

[0070] Referring to FIG. **8**, a plasma system **800** (e.g., a plasma deposition system, and may also be an etching system, such as a plasma etching system like an RIE etching system) includes a substrate support **860** disposed within a processing chamber **871**, such as a plasma etching chamber, and configured to support a substrate **810**. The processing chamber **871** is separated from a remote plasma chamber **870** by an extraction grid **840** (which may be grounded or electrically floating). A deposition gas source **872** and an optional charging gas source **874** are fluidically coupled to the remote plasma chamber **870** through a deposition valve **873** and an optional charging valve **875** respectively. Additional gas sources and valves may also be included in the plasma system **800**. For example, an optional additional gas source **876** may be fluidically coupled to the remote plasma chamber **870** through an optional additional gas valve **877** (an additional gas may be any type of gas, such as a carrier gas, and multiple additional gases may be included) while an optional etch gas source **878** may be fluidically coupled to the remote plasma chamber **870** through an optional etch gas valve **879**. An exhaust valve **889** is included to evacuate the processing chamber **871** (and or the remote plasma chamber **870**) during the plasma process.

[0071] The plasma system **800** is configured to generate a remote plasma **834** during any or all of the steps of a plasma process (e.g., during a surface charging step, a selective deposition step, a plasma etching process, such as an RIE process, etc.). A source power supply **864** is configured to couple source power to the remote plasma chamber **870** in order to generate the remote plasma **834**. Additionally, a bias power supply **866** is also included that is configured to supply bias power to the substrate support **860** (and the substrate **810**). The processing chamber **871** may be any suitable processing chamber, such as an etching chamber (e.g., an RIE chamber, a capacitively couple plasma (CCP) etching chamber, an inductively coupled plasma (ICP) etching chamber), a deposition chamber (e.g., a CVD chamber, ALD chamber, MLD, chamber), and others.

[0072] An optional temperature monitor **886** may be included to monitor and/or aid in controlling the temperature of the substrate **810** and the environment in the processing chamber **871**. An optional heater **887** may be included to elevate the temperature of the substrate **810** above the equilibrium temperature at the substrate **810** during the deposition process. Alternatively, the optional heater **887** may optionally be a cooler to decrease the temperature of the substrate **810** below equilibrium. An optional motor **888** may also be included to improve process uniformity.

[0073] A controller **880** is operationally coupled to the valves (deposition valve **873**, the optional charging valve **875**, the optional additional gas valve **877**, the optional etch gas valve **879**, etc.), and may be operationally coupled to any of the optional temperature monitor **886**, the optional heater **887**, the optional motor **888**, and the exhaust valve **889**. The controller **880** may include a processor **882** and a memory **884** (i.e., a non-transitory computer-readable medium) that stores a program including instructions that, when executed by the processor **882**, perform a selective deposition process. For example, the memory **884** may have volatile memory (e.g., random access memory (RAM)) and

non-volatile memory (e.g., flash memory). Alternatively, the program may be stored in physical memory at a remote location, such as in cloud storage. The processor **882** may be any suitable processor, such as the processor of a microcontroller, a general-purpose processor (such as a central processing unit (CPU), a microprocessor, a field-programmable gate array (FPGA), an application-specific integrated circuit (ASIC), and others.

[0074] FIG. **9** illustrates an example method of selectively depositing a material on upper surfaces of a patterned layer in accordance with embodiments of the invention. The method of FIG. **9** may be combined with other methods and performed using the systems and apparatuses as described herein. For example, the method of FIG. **9** may be combined with any of the embodiments of FIGS. **1-8** and **10**.

[0075] Referring to FIG. **9**, a method **900** of selectively depositing a material on upper surfaces of a patterned layer includes a surface charging step **901** of extracting electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with the electrons. For example, the electrons may be extracted from the remote electron source (e.g., a remote plasma source) by applying a positive DC bias at a substrate that includes the patterned layer (such as applied to a substrate support supporting the substrate). Positive ions are then extracted from a remote ion source in a selective deposition step **902** to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces. A negative DC bias may be applied at the substrate to extract the positive ions from the remote ion source (e.g., a remote plasma source, which may be the same or different than the remote electron source).

[0076] FIG. **10** illustrates another example method of selectively depositing a material on upper surfaces of a patterned layer in accordance with embodiments of the invention. The method of FIG. **10** may be combined with other methods and performed using the systems and apparatuses as described herein. For example, the method of FIG. **10** may be combined with any of the embodiments of FIGS. **1-9**. Although shown in a logical order, the arrangement and numbering of the steps of FIG. **10** are not intended to be limited. The method steps of FIG. **10** may be performed in any suitable order or concurrently with one another as may be apparent to a person of skill in the art.

[0077] Referring to FIG. **10**, a method **1000** of selectively depositing a material on upper surfaces of a patterned layer includes a surface charging step **1001** of negatively charging upper surfaces of a patterned layer with electrons. During the surface charging step **1001**, a plasma generation step **1003** of applying source power to generate plasma comprising the electrons in a remote plasma chamber and an electron extraction step **1004** of applying a positive direct current (DC) bias at the patterned layer are performed concurrently. The remote plasma chamber is separated from the patterned layer by an extraction grid.

[0078] The method **1000** further includes a selective deposition step **1002** of selectively depositing a material on the upper surfaces with positive ions. During the selective deposition step **1002**, a plasma generation step **1005** of applying source power to generate plasma comprising the positive ions in the remote plasma chamber and an ion extraction step **1006** of applying a negative DC bias at the patterned layer are performed concurrently. The power level of the source power during the surface charging step **1001** is lower than the power level of the source power during the selective deposition step **1002**.

[0079] The extraction grid may be grounded or electrically floating. For example, in one or both of the surface charging step **1001** and the selective deposition step **1002**, an optional grounding step **1007** of applying a ground potential to the extraction grid may be performed concurrently with the other respective steps. The ground potential may be continuously coupled to the extraction grid (e.g., permanently) or may be applied during desired steps of the method **1000**.

[0080] Example embodiments of the invention are summarized here. Other embodiments can also be understood from the entirety of the specification as well as the claims filed herein.

[0081] Example 1. A method including: extracting electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with the electrons; and extracting positive ions from a remote ion source to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces.

[0082] Example 2. The method of example 1, where the remote electron source is a remote plasma including the electrons.

[0083] Example 3. The method of example 2, where the remote plasma is an electropositive plasma generated from pure argon gas.

[0084] Example 4. The method of one of examples 1 to 3, where the remote ion source is a remote plasma including the positive ions.

[0085] Example 5. The method of example 4, where the remote electron source is the same remote plasma as the remote ion source, the remote plasma further including the electrons.

[0086] Example 6. The method of example 4, where the remote plasma is a fluorocarbon plasma, and where the material selectively deposited on the upper surfaces is a carbon-based polymer.

[0087] Example 7. The method of one of examples 1 to 6, where: extracting the electrons from the remote electron source includes applying a ground potential to an extraction grid separating the remote electron source from the patterned layer, and applying a positive direct current (DC) bias at the patterned layer; and extracting the positive ions from the remote ion source includes applying the ground potential to the extraction grid, and applying a negative DC bias at the patterned layer.

[0088] Example 8. A method including: negatively charging upper surfaces of a patterned layer with electrons by concurrently applying source power having a first power level to generate plasma including the electrons in a remote plasma chamber separated from the patterned layer by an extraction grid, and applying a positive direct current (DC) bias at the patterned layer; and selectively depositing a material on the upper surfaces with positive ions by concurrently applying source power having a second power level greater than the first power level to generate plasma including the positive ions in the remote plasma chamber, and applying a negative DC bias at the patterned layer.

[0089] Example 9. The method of example 8, where applying the negative DC bias includes pulsing the negative DC bias as a series of negative bias pulses.

[0090] Example 10. The method of example 9, where each bias pulse of the series of negative bias pulses includes a pulse width less than about 5 ns.

[0091] Example 11. The method of one of examples 9 and 10, where the series of negative bias pulses is a bipolar pulse train, the series of negative bias pulses including positive bias pulses separating adjacent negative bias pulses.

[0092] Example 12. The method of one of examples 8 to 11, where the magnitude of both the positive DC bias and the negative DC bias is less than about 50 V.

[0093] Example 13. The method of example 12, where the negative DC bias is substantially the same as the plasma potential of the plasma.

[0094] Example 14. The method of one of examples 8 to 13, where the first power level is less than 200 W, and where the second power level is greater than 200 W.

[0095] Example 15. A plasma system including: a processing chamber; a remote plasma chamber configured to contain plasma including electrons and positive ions; an extraction grid separating the processing chamber and the remote plasma chamber; a substrate support disposed in the processing chamber and configured to support a substrate including a patterned layer fluidically coupled to the remote plasma chamber through the extraction grid; an electron source gas fluidically coupled to the remote plasma chamber through one or more valves; an ion source gas fluidically coupled to the remote plasma chamber through the one or more valves; a source power supply configured to generate the plasma in the remote plasma chamber; a direct current (DC) bias power supply electrically coupled to the substrate support; and a controller operatively coupled to the one or more valves, the DC bias power supply, and the source power supply, the controller including a processor and a non-transitory computer-readable medium storing a program including instructions that, when executed by the processor, perform a method including: negatively charging upper surfaces of a patterned layer with the electrons by concurrently applying source power from the source power supply to generate plasma including the electrons in a remote plasma chamber separated from the patterned layer, and applying a positive DC bias from the DC bias power supply to the substrate holder; and selectively depositing a material on the upper surfaces with positive ions by concurrently applying source power from the source power supply to generate plasma including the positive ions in the remote plasma chamber, and applying a negative DC bias from the DC bias power supply to the substrate holder.

[0096] Example 16. The plasma system of example 15, where negatively charging the upper surfaces further includes concurrently applying a ground potential to the extraction grid while applying the source power and the positive DC bias, and where selectively depositing the material further includes concurrently applying the ground potential to the extraction grid while applying the source power and the negative DC bias.

[0097] Example 17. The plasma system of example 15, where the extraction grid is electrically floating while negatively charging the upper surfaces and while selectively depositing the material.

[0098] Example 18. The plasma system of one of examples 15 to 17, where electron source gas and the ion source gas are the same gas.

[0099] Example 19. The plasma system of one of examples 15 to 18, further including: an electrode disposed in the remote plasma chamber, where negatively charging the upper surfaces further includes concurrently applying a negative DC superposition potential as a continuous wave potential or a series or negative DC pulses.

[0100] Example 20. The plasma system of one of examples 15 to 19, where selectively depositing the material further includes applying a magnetic field to the plasma in the remote plasma chamber while applying the source power and the negative DC bias.

[0101] While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A method comprising:
- extracting electrons from a remote electron source to negatively charge upper surfaces of a patterned layer with the electrons; and
- extracting positive ions from a remote ion source to selectively deposit a material on the upper surfaces by attracting the positive ions to the electrons of the upper surfaces.

2. The method of claim **1**, wherein the remote electron source is a remote plasma comprising the electrons.

3. The method of claim **2**, wherein the remote plasma is an electropositive plasma generated from pure argon gas.

4. The method of claim **1**, wherein the remote ion source is a remote plasma comprising the positive ions.

5. The method of claim **4**, wherein the remote electron source is the same remote plasma as the remote ion source, the remote plasma further comprising the electrons.

6. The method of claim **4**, wherein the remote plasma is a fluorocarbon plasma, and wherein the material selectively deposited on the upper surfaces is a carbon-based polymer.

7. The method of claim **1**, wherein:
- extracting the electrons from the remote electron source comprises
  - applying a ground potential to an extraction grid separating the remote electron source from the patterned layer, and
  - applying a positive direct current (DC) bias at the patterned layer; and
- extracting the positive ions from the remote ion source comprises
  - applying the ground potential to the extraction grid, and
  - applying a negative DC bias at the patterned layer.

8. A method comprising:
- negatively charging upper surfaces of a patterned layer with electrons by concurrently
  - applying source power having a first power level to generate plasma comprising the electrons in a remote plasma chamber separated from the patterned layer by an extraction grid, and
  - applying a positive direct current (DC) bias at the patterned layer; and
- selectively depositing a material on the upper surfaces with positive ions by concurrently
  - applying source power having a second power level greater than the first power level to generate plasma comprising the positive ions in the remote plasma chamber, and
  - applying a negative DC bias at the patterned layer.

9. The method of claim 8, wherein applying the negative DC bias comprises pulsing the negative DC bias as a series of negative bias pulses.

10. The method of claim 9, wherein each bias pulse of the series of negative bias pulses comprises a pulse width less than about 5 ns.

11. The method of claim 9, wherein the series of negative bias pulses is a bipolar pulse train, the series of negative bias pulses comprising positive bias pulses separating adjacent negative bias pulses.

12. The method of claim 8, wherein the magnitude of both the positive DC bias and the negative DC bias is less than about 50 V.

13. The method of claim 12, wherein the negative DC bias is substantially the same as the plasma potential of the plasma.

14. The method of claim 8, wherein the first power level is less than 200 W, and wherein the second power level is greater than 200 W.

15. A plasma system comprising:

a processing chamber;

a remote plasma chamber configured to contain plasma comprising electrons and positive ions;

an extraction grid separating the processing chamber and the remote plasma chamber;

a substrate support disposed in the processing chamber and configured to support a substrate comprising a patterned layer fluidically coupled to the remote plasma chamber through the extraction grid;

an electron source gas fluidically coupled to the remote plasma chamber through one or more valves;

an ion source gas fluidically coupled to the remote plasma chamber through the one or more valves;

a source power supply configured to generate the plasma in the remote plasma chamber;

a direct current (DC) bias power supply electrically coupled to the substrate support; and

a controller operatively coupled to the one or more valves, the DC bias power supply, and the source power supply, the controller comprising a processor and a non-transitory computer-readable medium storing a program including instructions that, when executed by the processor, perform a method comprising:

negatively charging upper surfaces of a patterned layer with the electrons by concurrently

applying source power from the source power supply to generate plasma comprising the electrons in a remote plasma chamber separated from the patterned layer, and

applying a positive DC bias from the DC bias power supply to the substrate holder; and

selectively depositing a material on the upper surfaces with positive ions by concurrently

applying source power from the source power supply to generate plasma comprising the positive ions in the remote plasma chamber, and

applying a negative DC bias from the DC bias power supply to the substrate holder.

16. The plasma system of claim 15,

wherein negatively charging the upper surfaces further comprises concurrently applying a ground potential to the extraction grid while applying the source power and the positive DC bias, and

wherein selectively depositing the material further comprises concurrently applying the ground potential to the extraction grid while applying the source power and the negative DC bias.

17. The plasma system of claim 15, wherein the extraction grid is electrically floating while negatively charging the upper surfaces and while selectively depositing the material.

18. The plasma system of claim 15, wherein electron source gas and the ion source gas are the same gas.

19. The plasma system of claim 15, further comprising:

an electrode disposed in the remote plasma chamber, wherein negatively charging the upper surfaces further comprises concurrently applying a negative DC superposition potential as a continuous wave potential or a series or negative DC pulses.

20. The plasma system of claim 15, wherein selectively depositing the material further comprises applying a magnetic field to the plasma in the remote plasma chamber while applying the source power and the negative DC bias.

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