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(54) ELECTROSTATIC CHUCK FOR ION BEAM DEPOSITION SYSTEMS

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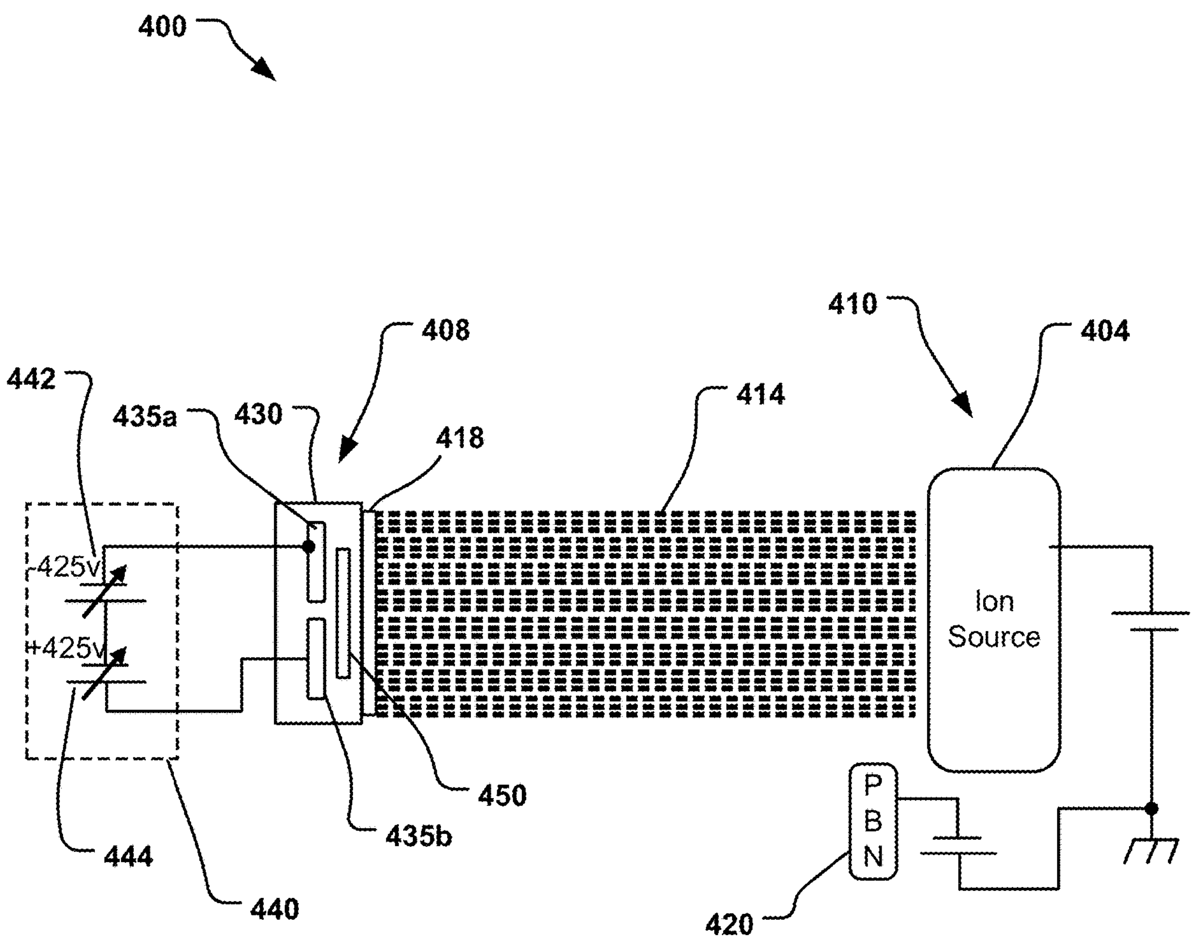
(57) ABSTRACT

An electrostatic chuck for ion beam deposition systems having an assist beam and that can be operated at elevated temperature. The electrostatic chuck includes or is operably connected to a power source capable of outputting at least 1 milliAmp of current, to provide a nominal voltage of at least 150V (+150V or −150V) and a total voltage differential, whether for a monopolar source or across multiple power sources, of at least 300V. The power source is isolated or floating with respect to ground.



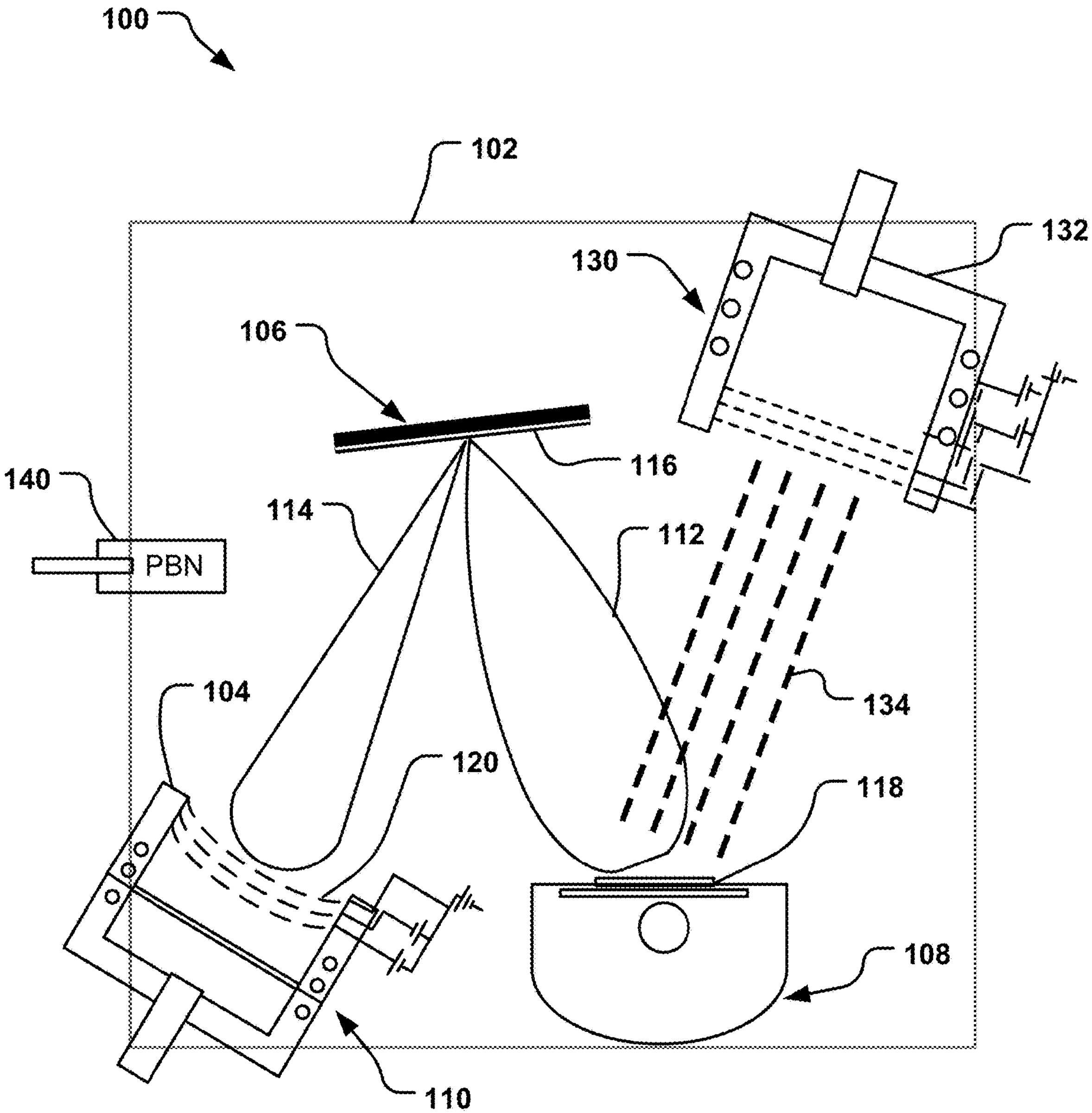


FIG. 1

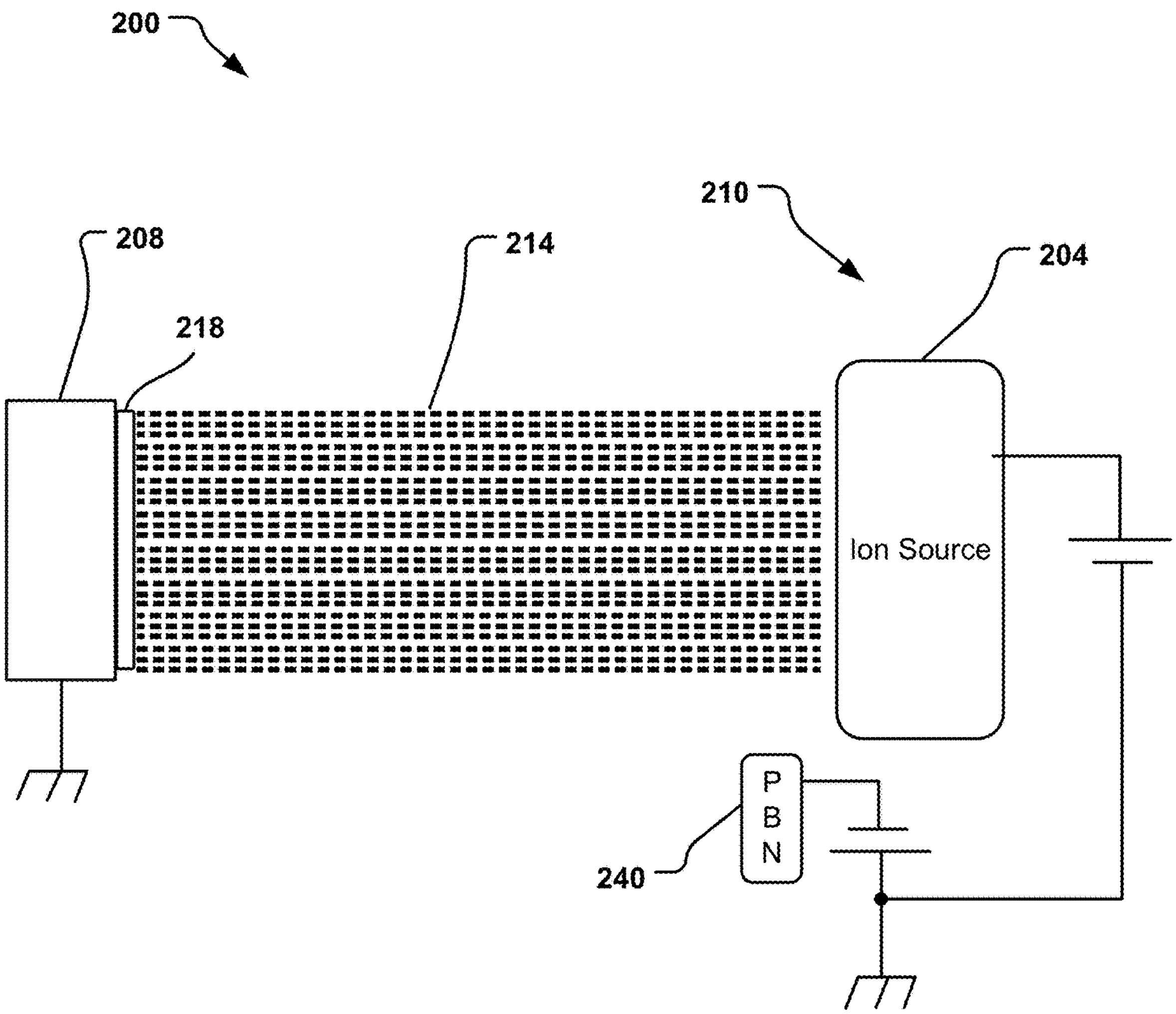


FIG. 2

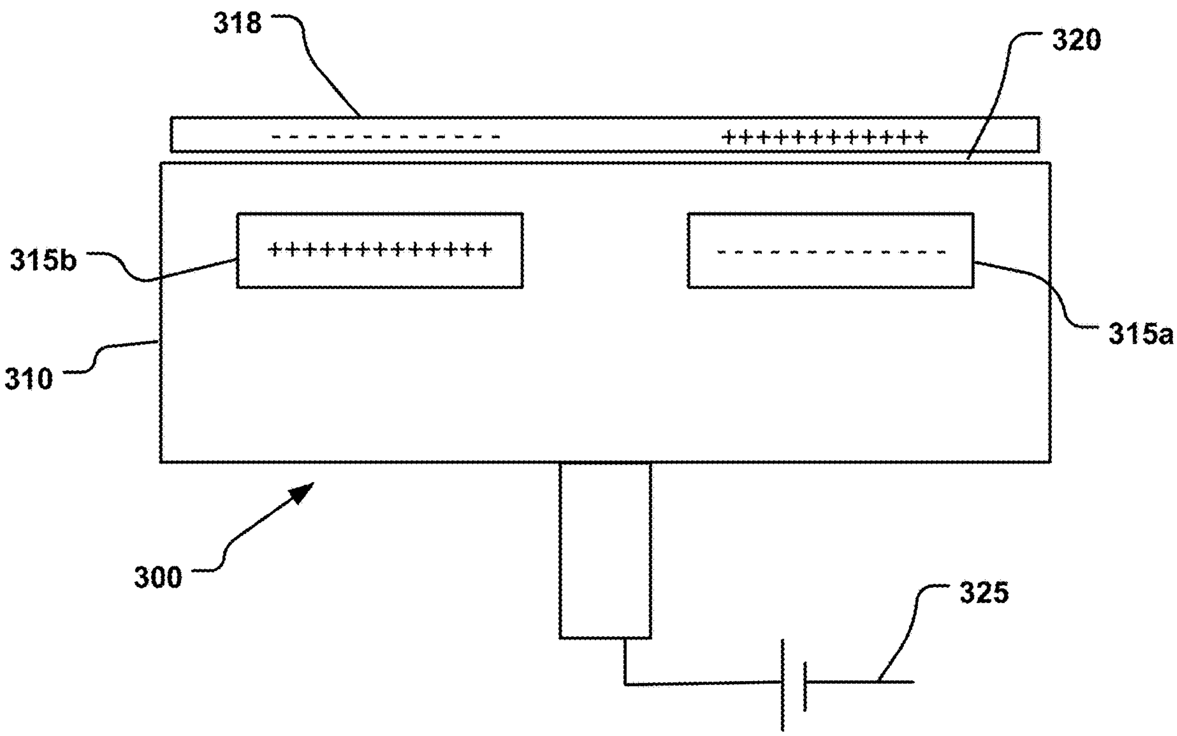


FIG. 3

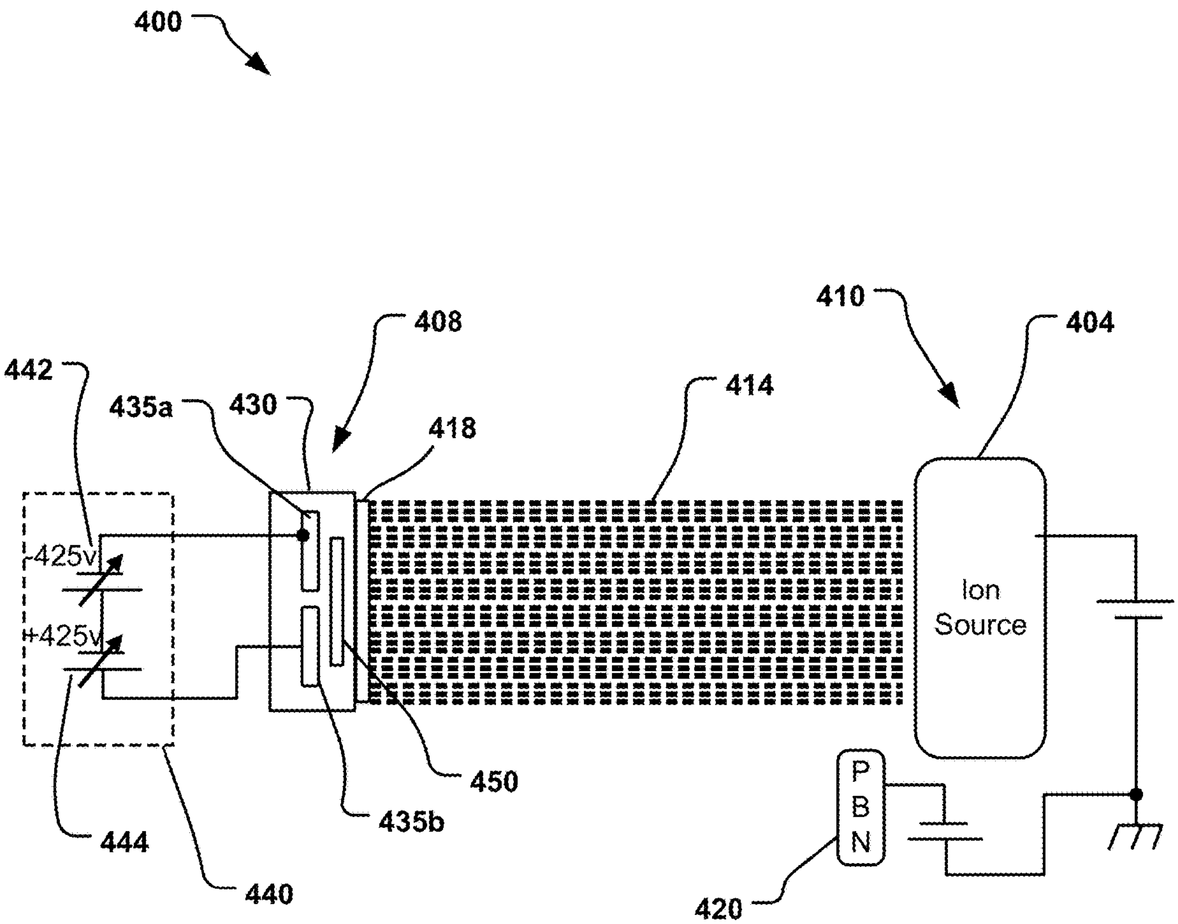

400
408
410
404
442
435a
430
418
414
-425v
+425v
Ion
Source
450
435b
444
440
P
B
N
420

FIG. 4

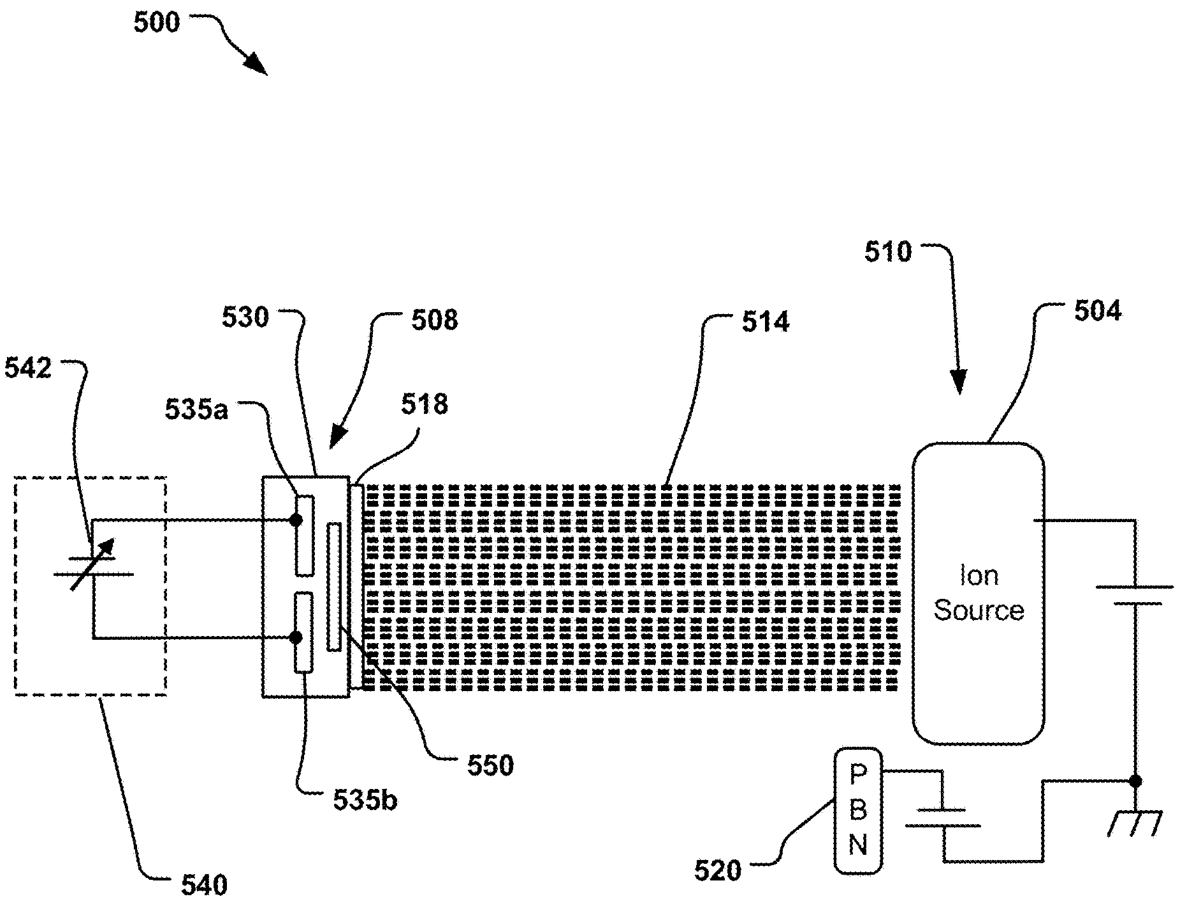

500
510
504
530
508
514
542
535a
518
Ion
Source
550
535b
P
B
N
520
540

FIG. 5

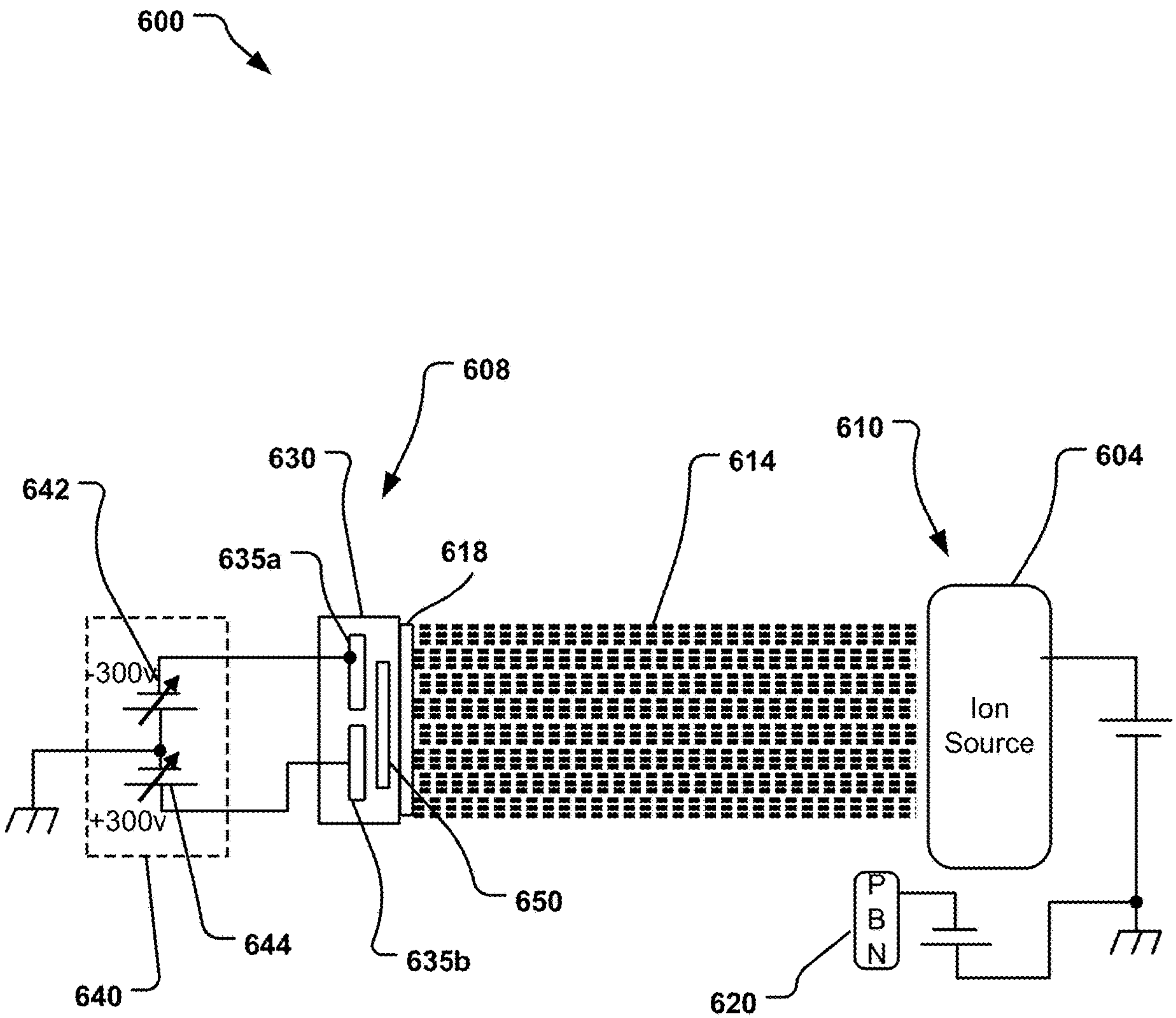

600
608
610
630
614
604
642
635a
618
-300v
Ion
Source
+300v
650
644
635b
P
B
N
640
620

FIG. 6

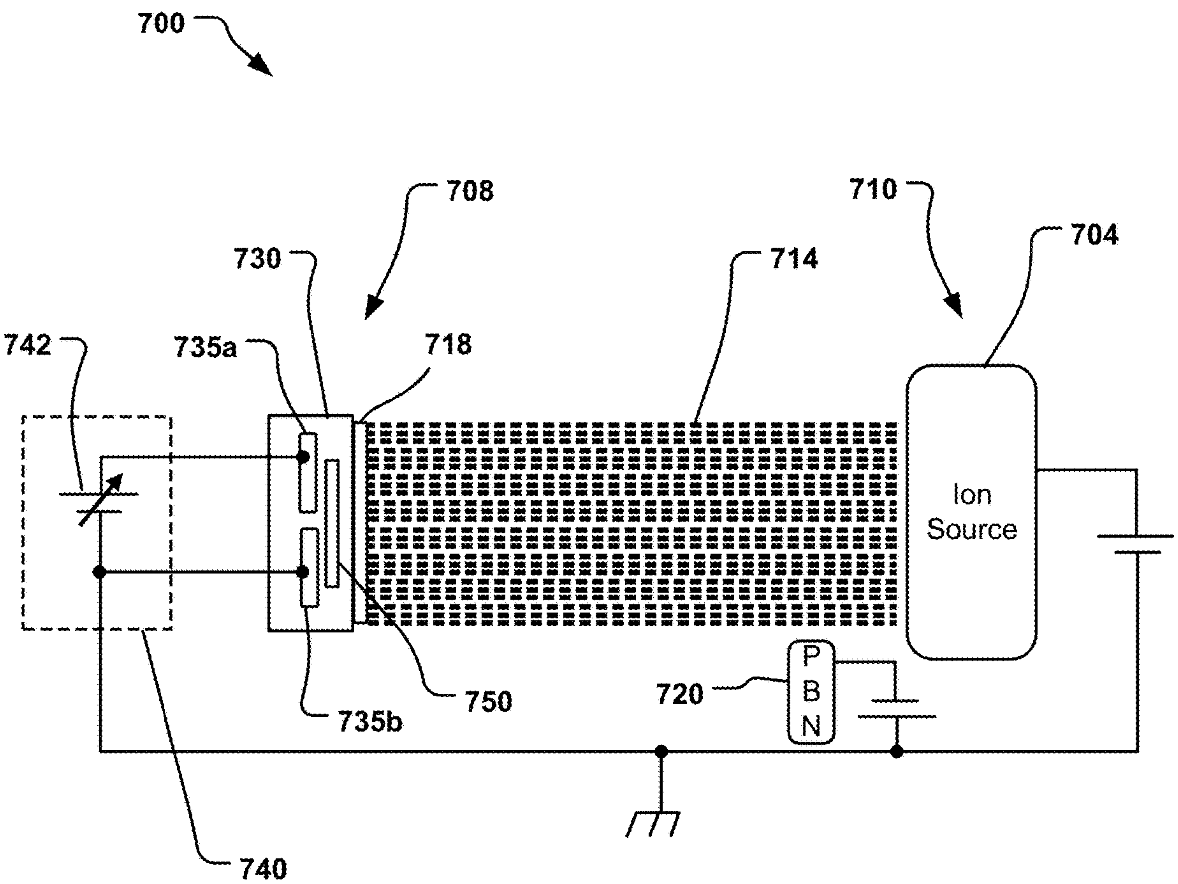

700
708
710
704
730
714
742
735a
718
Ion
Source
P
B
N
720
750
735b
740

FIG. 7

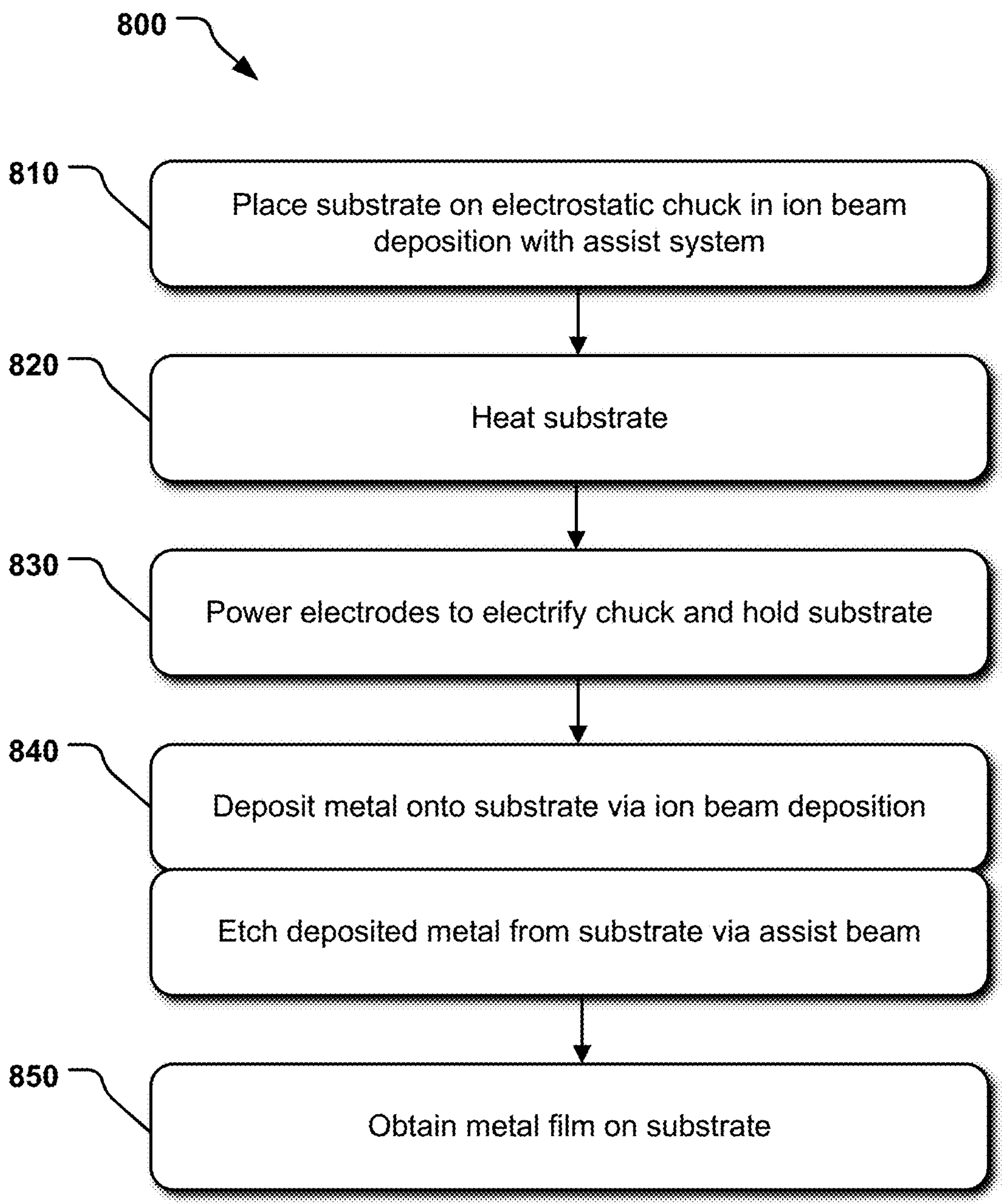

800
810
Place substrate on electrostatic chuck in ion beam deposition with assist system
820
Heat substrate
830
Power electrodes to electrify chuck and hold substrate
840
Deposit metal onto substrate via ion beam deposition
Etch deposited metal from substrate via assist beam
850
Obtain metal film on substrate

FIG. 8

ELECTROSTATIC CHUCK FOR ION BEAM DEPOSITION SYSTEMS

CROSS REFERENCE

[0001] This application claims priority to U.S. provisional application No. 63/555,557 filed Feb. 20, 2024, the entire disclosure of which is incorporated herein by reference for all purposes.

BACKGROUND

[0002] Ion beam deposition (IBD) is one of many methods suitable for forming metallic films, such as for semiconductor processing; the other methods include (but are not limited to) plasma vapor deposition (PVD), chemical vapor deposition (CVD), and molecular beam epitaxy (MBE). MBE is useful for depositing layers at very low energy, which can produce pseudo epitaxial layers. PVD is useful for depositing layers at a higher energy, which can produce layers that have, e.g., good electrical conductivity capabilities. IBD is useful for depositing layers at still higher energy and reduced pressures and with control of deposition geometry, which can produce layers with higher crystallinity and with controlled microstructures. Some IBD systems combine both material deposition and etch (or assist).

[0003] For IBD, the substrate on which the layer is being formed is typically held by a clamp or chuck; these clamps or chucks are commonly either mechanical or electrostatic. The selection of the clamp or chuck is highly dependent on the deposition system and the processing conditions.

SUMMARY

[0004] The present disclosure is directed to electrostatic chucks for ion deposition systems having both deposition and etch (assist) capabilities, with available heating of the substrate to an elevated temperature of at least 250° C. during processing. The support surface of the chuck is a high temperature resistant material, such as a high temperature ceramic.

[0005] The electrostatic chuck includes or is operably connected to a power source capable of outputting at least 1 mA of current, to provide a nominal voltage of at least 150V (+150V or −150V) and a total voltage differential, whether for a monopolar source or across multiple power sources, of at least 300V.

[0006] A particular embodiment described herein is an AlN heated electrostatic chuck powered with a DC power supply capable of driving high a voltage (up to about 1000V) at high currents (e.g., up to 100 mA), with the output isolated or floating with respect to ground.

[0007] Another particular embodiment described herein is an AlN heated electrostatic chuck powered with a power supply that includes two DC power sources capable of driving high a voltage (up to about 1000V) at high currents (e.g., up to 100 mA) with both outputs isolated or floating with respect to ground.

[0008] Yet another particular embodiment described herein is an electrostatic chuck for holding a substrate, the chuck having a support assembly having two electrodes therein and an electrically insulating support surface for receiving the substrate, a heating element operably connected to the support surface, and a high current, high voltage power supply having two outputs operably connected to the electrodes, with each of the power supply outlets isolated or floating with respect to ground. The high current, high voltage power supply can be configured to provide 1 to 100 mA.

[0009] Another particular embodiment of an electrostatic chuck for holding a substrate has a high current, high voltage power supply for operating the electrostatic chuck, the power supplying having two outlets isolated or floating with respect to ground, a support assembly with a heating element for heating an electrically insulating support surface of the support assembly, and at least two electrodes within the support assembly and electrically connected to the outlets of the power supply for charging the electrodes to electrostatically hold the substrate to the electrostatic chuck.

[0010] Any of the electrostatic chucks can be part of a system, such as a deposition system for applying material onto a substrate.

[0011] One particular embodiment of a system has an ion deposition beam system, an assist ion system, and an electrostatic chuck having two electrodes within a heated support assembly, the electrodes electrically connected to outlets of a high current, high voltage power supply for charging the electrodes to electrostatically hold a substrate to the electrostatic chuck, wherein the power supply outlets are isolated or floating with respect to ground

[0012] Also described herein is a method of holding a substrate in a process chamber. The method includes providing an electrostatic chuck having a heated support assembly with an electrically insulative support surface in the process chamber, the support assembly having two electrodes therein electrically connected to outlets of a power supply for charging the electrodes, the outlets isolated or floating with respect to ground; placing a substrate on the support surface; and applying a current of at least 1 milliAmp via the power supply to the at least two electrodes to produce a voltage differential of at least 300V. Heating the substrate may be to a temperature of at least 250° C.

[0013] Another method of holding a substrate in a process chamber includes providing an electrostatic chuck comprising a heated support assembly having an electrically insulative support surface in the process chamber, the support assembly having two electrodes therein electrically connected to outlets of a power supply for charging the electrodes, the outlets isolated or floating with respect to ground; placing a substrate on the support surface; and applying a current of at least 1 milliAmp via the power supply to the at least two electrodes to produce a voltage differential of at least 150V.

[0014] Yet another method includes providing an electrostatic chuck comprising a support assembly having an insulative support surface in the process chamber, the support assembly having two electrodes therein electrically connected to outlets of a high current, high voltage power supply for charging the electrodes, the outlets isolated or floating with respect to ground; placing a substrate on the support surface; and electrostatically holding the substrate to the support surface by applying power to the electrodes with the power supply in an isolated or floating state.

[0015] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. These and various other

features and advantages will be apparent from a reading of the following Detailed Description.

BRIEF DESCRIPTION OF THE DRAWING

[0016] FIG. **1** is a schematic side view of an ion beam deposition system with an assist ion beam system.

[0017] FIG. **2** is a schematic rendering of a mechanical chuck.

[0018] FIG. **3** is a schematic diagram of a generic electrostatic chuck with a substrate.

[0019] FIG. **4** is a schematic rendering of an ion beam deposition system with a first example of an electrostatic chuck.

[0020] FIG. **5** is a schematic rendering of an ion beam deposition system with a second example of an electrostatic chuck.

[0021] FIG. **6** is a schematic rendering of an ion beam deposition system with another example of an electrostatic chuck.

[0022] FIG. **7** is a schematic rendering of an ion beam deposition system with another example of an electrostatic chuck.

[0023] FIG. **8** is a stepwise method for forming a thin layer metal film in an ion beam deposition system with assist.

DETAILED DESCRIPTION

[0024] Semiconductor devices are used extensively, from computers and printers, to cars, to appliances, and even in toys. The manufacturing process for a semiconductor chip involves many steps, typically starting with a bare semiconductor substrate, or wafer. The semiconductor substrate material historically has been silicon, but materials now include silicide(s), nitride(s), oxide(s), metal(s) including alloys, and ceramic(s).

[0025] During processing, both in transfer between various pieces of machinery and during the actual processing step, the substrate must be held in place; this is typically done using a chuck. There are different types of chucks, including a mechanical chuck (which uses pins to hold the substrate in place), a vacuum chuck (which uses a vacuum force to hold the substrate in place), or an electrostatic chuck (which uses electrostatics to hold the substrate in place). As indicated above, this disclosure is directed to electrostatic chucks.

[0026] In the following description, reference is made to the accompanying drawing that forms a part hereof and in which is shown by way of illustration at least one specific implementation. The following description provides additional specific implementations. It is to be understood that other implementations are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples, including the figures, provided below. In some instances, a reference numeral may have an associated sub-label consisting of a lower-case letter to denote one of multiple similar components. When reference is made to a reference numeral without specification of a sub-label, the reference is intended to refer to all such multiple similar components.

[0027] Turning to the figures, FIG. **1** illustrates a system **100** according to the present disclosure, the system **100** including an ion beam deposition (IBD) system and an assist ion or ion beam etch system. The system **100** also has one or more ion beam neutralizers and their associated gas distribution systems. The system **100** may have an apparatus for introduction of reactive gas species into the process chamber.

[0028] The system **100** includes a chamber **102** having therein a, ion beam deposition system **110** that includes an ion beam source **104**, and also a target assembly **106**, and a substrate assembly **108** for supporting a substrate **118** that may be formed of, for example, one or multiple layers of silicide(s), nitride(s), oxide(s), metal(s) including alloys, or ceramic(s). Incorporated into the substrate assembly **108** is a chuck to hold the substrate **118**.

[0029] The ion beam source **104** generates an ion beam **114**, which can include a plurality of ion beamlets targeted or directed toward the target assembly **106**, which includes at least one target **116** composed of the material to be deposited. The system **100** may include one or more grids **120** proximate the ion beam source **104** for directing the ion beam **114** from the ion beam source **104** to the target **116**. A source gas is used in the ion source **104** to help generate the ion beam **114**.

[0030] Also present in the system **100** may be a heat source (not shown), such as heating element(s) present within the chamber **102** or heating element(s) as part of or connected to the substrate assembly **108**.

[0031] The ion beam **114**, upon striking the target **116**, generates a sputter plume **112** of material from the target **116**. The ion beam **114** strikes the target **116** at such an angle so that the sputter plume **112** generated from the target **116** travels towards the substrate **118**. The sputter plume **112** may be made more or less concentrated so that its resulting deposition of material on the substrate **118** is more effectively distributed over a particular area of the substrate **118**.

[0032] The system **100** also includes an assist ion beam system **130** that provides a source of ions that bombards the substrate **118** so that material on the substrate **118** is removed or modified. The assist ion beam system **130** may be referred to an ion beam etching system, or the like.

[0033] The assist ion beam system **130** includes an ion beam source **132** that generates an assist ion beam **134**, that can include a plurality of ion beamlets, targeted or directed toward the substrate assembly **108**, particularly toward the substrate **118**. The assist ion beam **134** controls the net amount of material deposited on the substrate **118**. In some implementations, the assist ion beam **134** modifies the material that is being deposited by the sputter plume **112**.

[0034] The target assembly **106** is positioned so that the ion beam **114** strikes the target **116** at a predetermined desired angle and also so that the sputter plume **112** strikes the substrate **118** at a predetermined desired angle. Any or all of the ion beam source **104**, the target assembly **106** and the substrate assembly **108** may be pivotable, rotatable, movable, etc. Those skilled in the art will appreciate that the relative positions of the sputter plume **112** and the assist ion beam **134** can be such that the deposition angle and the etch angle can be adjusted over a range of angles.

[0035] The deposition ion beam system **110** may be, for example, a broad ion beam system, e.g., having a plasma bridge neutralizer (PBN) **140** for generating low energy electrons via the introduction of reactive gases into the chamber **102**.

[0036] Such a system **100**, having an IBD system **110** and an assist ion beam system **130**, may be referred to as an ion beam deposition system with assist. When using reactive gases in the process chamber **102** (introduced via various manners), the system **100** may be referred to as a reactive ion beam deposition system.

[0037] The system **100**, having ion beam deposition with an assist ion beam, can be used to deposit, deposit and modify, and/or deposit and etch, with or without reactive gases, either simultaneously or sequentially or interpedently. By adjusting the net deposition rate of material onto the substrate **118**, not only is the thickness of the deposited material controlled, but the physical properties of the deposited material, including microstructure and grain growth, can be controlled. The net deposition can be adjusted, e.g., by adjusting the rate of deposition by the IBD system **110** and the rate of modification by the assist ion beam system **130**, by adjusting the net deposition rate of target material onto the substrate **118**, by adjusting the rate of reaction between the gas species introduced into the chamber and the material in the target **116** and/or the sputter plume **112**, and by the rate of dissociation of the reacted metal compounds to form the desired material.

[0038] During the processing (e.g., the depositing, depositing and modifying, and/or depositing and etching), the substrate **118** is securely held in or to the substate assembly **108**. FIG. **2** provides a simplified schematic of an ion beam deposition system with a generic mechanical chuck holding a substrate.

[0039] In FIG. **2**, an ion beam deposition system **200** has an ion deposition assembly **210** that includes an ion source **204** and a PBN **240**. Each of the ion source **204** and the PBN **240** has a power source (not numbered) which are grounded; although shown connected, the sources may be individually grounded. The ion source **204** produces an ion beam **214** toward a substrate **218** retained on a substrate assembly **208**. The particular substrate assembly **208** is a mechanical chuck that is grounded in order to have the ion beam **214** deposit material onto the substrate **218**.

[0040] Although a mechanical chuck is a good system for retaining the substrate **218** during a deposition process (no arcing is typically observed), a problem with a mechanical chuck is that it may damage the edges of the substrate and prevent deposition on the complete surface of the substrate, including the bevel of the substrate, which is desirable in many applications. Additionally, a mechanical chuck does not readily allow for direct heating of the substrate **218** during the process, as the physical dimensions of the substrate **218** will change with temperature, possibly further damaging the substrate.

[0041] As indicated above, this disclosure is directed to electrostatic chucks for ion deposition systems having both deposition and etch (assist) capabilities and heating of the substrate.

[0042] FIG. **3** illustrates an example, generic electrostatic chuck **300**. The electrostatic chuck **300** includes a body **310** having at least two electrodes **315***a*, **315***b* embedded therein, and a support surface **320** for receiving a semiconductor substrate **318** thereon. The support surface **320** can be any number of materials, depending on the application; for room temperature deposition processes, the support surface **320** is often a dielectric material such as alumina, quartz, sapphire, or polyimide. The support surface **320** may be a layer on the body **310** or the support surface **320** may be integral with the body **310**, the body **310** and the support surface **320** being the same material.

[0043] The electrostatic chuck **300**, particularly the electrodes **315**, are connected to outputs of a high-voltage power supply **325** to provide a current, at a voltage, to the electrodes **315**.

[0044] In use, the substrate **318** is placed on the chuck **300**, against the support surface **320**. Once the semiconductor substrate **318** is in contact with the chuck **300**, the power supply **325** is activated. Activation of the power supply **325** induces a strong electric field in the electrodes **315**. For the two-electrode design of FIG. **3**, this results in regions of positive and negative charges in the electrodes **315**. This also results in induced regions of positive and negative charge in the substrate **318** opposite the chuck electrodes **315** (the charges in the substrate **318** of opposite sign of that of the electrodes **315**), resulting in a positive grip pressure due to the opposing charges. The substrate **318** is thus held in place.

[0045] The voltage is typically applied to the chuck electrodes **315** via a direct current (DC) but could be via an alternating current (AC).

[0046] FIGS. **4** through **7** provide specific electrostatic chucks for use with ion deposition systems having both deposition and etch (assist) capabilities and heating of the substrate.

[0047] Turning to FIG. **4**, a system **400** is shown having an ion beam deposition assembly **410** that includes an ion source **404** and a PBN **420**. Each of the ion source **404** and the PBN **420** has a power source (not numbered) which are grounded; although shown connected, the sources may be individually grounded. The ion source **404** produces an ion beam **414** aimed toward a semiconductor substrate **418** retained on a substrate assembly **408** that includes an electrostatic chuck **430**. The electrostatic chuck **430** has at least two electrodes **435***a*, **435***b* embedded therein, and a support surface for receiving the substrate **418** thereon. The electrostatic chuck **430**, particularly the electrodes **435**, are connected to a high-voltage, high-current power supply **440** to provide a current, at a voltage, to the electrodes **435**. One example of a power supply **440** provides a 1 to 100 milliAmp (mA) current to produce the voltage (e.g., up to about 1000V) to the retain the substrate on the support surface.

[0048] Also present in the system **400** is a heating element **450** for heating the substrate **418**, e.g., to a temperature of at least 250° C., e.g., 250° C.-650° C. The heating element **450** is shown within the substrate assembly **408** of the system **400** but can be operably connected to the substrate assembly **408**. In some embodiments, the heating element **450** may be present within the chamber of the system **400** (e.g., on an interior surface or wall), however, due to the system **400** being a vacuum environment during use, heating the chamber air/environment may not be practical. Although not shown in the figure, the substrate assembly **408** may include gas outlets through the support surface to provide heated gas to the substrate **418**.

[0049] In this chuck **430**, the power supply **440** is a bipolar, dual power source having isolated outputs from two power sources **442**, **444** at opposite voltages. The power supply **440**, particularly the power sources **442**, **444**, are DC power sources that are not grounded in this design, but are isolated. In some embodiments, the isolated outputs may be referred to as floating.

[0050] In one example, the power sources **442**, **444** provide equal, offsetting voltages; for example, one power source **442** provides −425V and the other power source **444** provides +425, or vice versa. In other examples, the offsetting voltages are not equal, but either the negative or positive voltage is greater than the other. Either of the power supplies could be set to 0V.

[0051] In FIG. **5**, a system **500** is shown having an ion beam deposition assembly **510** that includes an ion source **504** and a PBN **520**. Each of the ion source **504** and the PBN **520** has a power source (not numbered) which are grounded; although shown connected, the sources may be individually grounded. The ion source **504** produces an ion beam **514** aimed toward a semiconductor substrate **518** retained on a substrate assembly **508** that includes an electrostatic chuck **530**. The electrostatic chuck **530** has at least two electrodes **535***a*, **535***b* embedded therein, and a support surface for receiving the substrate **518** thereon. The electrostatic chuck **530**, particularly the electrodes **535**, are connected to a high-voltage power supply **540** to provide a current, at a voltage, to the electrodes **535**. Also present in the system **500** is a heating element **550** for heating the substrate **518**, e.g., to a temperature of at least 250° C., e.g., 250° C.-650° C.

[0052] In this chuck **530**, the power supply **540** has a single power source **542** having isolated outputs. The power supply **540**, particularly the power source **542**, is monopolar and is not grounded in this design.

[0053] In one example, the power sources **542** provides a negative voltage; in a specific example, the power source **542** provides −600V.

[0054] In FIG. **6**, another system **600** is shown having an ion beam deposition assembly **610** that includes an ion source **604** and a PBN **620**. Each of the ion source **604** and the PBN **620** has a power source (not numbered) which are grounded; although shown connected, the sources may be individually grounded. The ion source **604** produces an ion beam **614** aimed toward a semiconductor substrate **618** retained on a substrate assembly **608** that includes an electrostatic chuck **630**. The electrostatic chuck **630** has at least two electrodes **635***a*, **635***b* embedded therein, and a support surface for receiving the substrate **618** thereon. The electrostatic chuck **630**, particularly the electrodes **635**, are connected to a high-voltage power supply **640** to provide a current, at a voltage, to the electrodes **635**. Also present in the system **600** is a heating element **650** for heating the substrate **618**, e.g., to a temperature of at least 250° C., e.g., 250° C.-650° C.

[0055] In this chuck **630**, the power supply **640** has dual DC power sources **642**, **644** with a central tap ground, with isolated outputs that are used to power both electrodes **635**.

[0056] In one example, the power sources **643**, **644** provide opposite, equal voltages, such as −300V and +300V. In other examples, the two voltages may be unequal.

[0057] In FIG. **7**, another system **700** is shown having an ion beam deposition assembly **710** that includes an ion source **704** and a PBN **720**. Each of the ion source **704** and the PBN **720** has a power source (not numbered) which are grounded; although shown connected, the sources may be individually grounded. The ion source **704** produces an ion beam **714** aimed toward a semiconductor substrate **718** retained on a substrate assembly **708** that includes an electrostatic chuck **730**. The electrostatic chuck **730** has at least two electrodes **735***a*, **735***b* embedded therein, and a support surface for receiving the substrate **718** thereon. The electrostatic chuck **730**, particularly the electrodes **735**, are connected to a high-voltage power supply **740** to provide a current, at a voltage, to the electrodes **735**. Also present in the system **700** is a heating element **750** for heating the substrate **718**, e.g., to a temperature of at least 250° C., e.g., 250° C.-650° C.

[0058] In this chuck **730**, the power supply **740** has a single or monopolar power source **742** that has a negative grounded outlet and a single or monopolar outlet. The electrode **735***a* is powered positively and the other electrode **735***b* is grounded through the negative side of the power source **742**. The power supply **740**, particularly the power source **742**, is grounded in this design; in the figure, the power source **742** is connected to the ground of the ion source **704** and the PBN **720**, although any could be grounded individually.

[0059] In one example, the power source **742** provides a positive voltage differential; in a specific example, the power source **742** provides +850V.

[0060] Thus, multiple examples and embodiments of electrostatic chucks have been provided in FIGS. **4** through **7**, described above. It is to be understood that any features or details of one design may be utilized for or with any other design, unless contrary to the process, construction or configuration.

[0061] Although specific examples of voltages have been provided (e.g., −425V and +425V for FIG. **4**, −600V for FIG. **5**, 300V and +300V for FIG. **6**, and +850V for FIG. **7**) other voltages can be used for every and any of the chucks described.

[0062] Typically for bipolar voltage sources, if the voltage is different for the two sources (e.g., +300V and −425V), the negative voltage is greater.

[0063] The nominal voltage, for any power source, is at least 150V (+150V or −150V), in other embodiments at least 325V. The total voltage differential, whether for a monopolar source or across multiple power sources, is at least 300V, in some embodiments, at least 650V. In some embodiments, the voltage differential is 450V-1000V, in other embodiments 550V-850V.

[0064] The electrostatic chucks described above can all be used in any process under any conditions; the chucks are, however, especially configured to be used at elevated temperature, i.e., at least at 250° C., e.g., at 250° C.-650° C. Typically at these temperatures, ceramic materials are used as the support surface.

[0065] However, at these temperatures, ceramic materials tend to be leaky dielectrics, requiring higher currents for the high voltages needed to obtain the electrostatic engaging force in the electrostatic chuck. In general, the chucks described herein, when operating at elevated temperature, utilize 100×-1000× more current than a chuck operating at room temperature. Thus, the power supply (e.g., the power supply **440**, **540**, **640**, **740**, and variation thereof) is capable of providing high current, measured in milliAmps, to provide the voltage levels needed. The current needed for the electrostatic chucks of these designs is at least 1 milliAmp, and no more than 100 milliAmps, in some embodiments no more than 60 milliAmps, and in other embodiment no more than 30 milliAmps. The power supply may be a commercially available power supply or one that is custom made.

[0066] Additionally because of the high voltage needed due to the elevated temperature, the support plate for the substrate (e.g., the support surface **320** of FIG. **3**) includes a high temperature electrically insulative or dielectric material, such as a high temperature ceramic, particularly if the heating element of the system is incorporated into the substrate assembly, e.g., so that the backside of the substrate is heated. The entire engagement plate or merely the surface may be the high temperature material.

[0067] Examples of suitable high temperature ceramics include carbides, nitrides, oxides, and borides of metals, e.g., transition metals; specific examples include aluminum nitride, boron nitride, silicon nitride, hafnium nitride, and hafnium carbide. The ceramic material may be doped to adjust the electrical conductivity properties of the material.

[0068] The electrostatic chucks described herein (e.g., chucks **430**, **530**, **630**, **730**, and variations thereof) are particularly conducive for elevated temperature ion deposition process.

[0069] Turning to FIG. **8**, an example method **800** for forming a thin layer metal film, such as ruthenium, is described.

[0070] In a first step **810**, a semiconductor wafer substrate is placed on an engagement plate of an electrostatic chuck in an ion beam deposition with assist system. The engagement plate may be, for example, aluminum nitride. The substrate is heated in a step **820** to at least 250° C. Power is supplied to electrodes in the chuck in step **830** to produce a voltage differential of at least 300V, the power being supplied by a current of at least 1 milliAmp and less than 100 milliAmps. Due to the electrified chuck, an opposite charge forms in the wafer, thus attracting and adhering the wafer to the chuck. In a next step **840**, a metal is deposited onto the substrate via ion beam deposition and, at least partially simultaneously, metal is etched from the substrate via assist beam, providing a net deposition rate.

[0071] The resulting metal film obtain in step **850** may be a thin layer (e.g., no more than 50 nm), low resistivity, pure (e.g., at least 99%), dense (e.g., at least 99% of theoretical density) film. If a ruthenium target is used in the system, the film with be a ruthenium film.

[0072] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

[0073] Although the technology has been described in language that is specific to certain structures and materials, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific structures and materials described. Rather, the specific aspects are described as forms of implementing the claimed invention. Because many embodiments of the invention can be practiced without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

[0074] Various features and details have been provided in the multiple designs described above. It is to be understood that any features or details of one design may be utilized for or with any other design, unless contrary to the process, construction or configuration. Any variations may be made. For example, processing time, pressure, temperature, etc. may be varied.

[0075] The above specification and examples provide a complete description of the structure and use of exemplary implementations of the invention. The above description provides specific implementations. It is to be understood that other implementations are contemplated and may be made without departing from the scope or spirit of the present disclosure. The above detailed description, therefore, is not to be taken in a limiting sense. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided.

[0076] Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties are to be understood as being modified by the term "about," whether or not the term "about" is immediately present. Accordingly, unless indicated to the contrary, the numerical parameters set forth are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

[0077] As used herein, the singular forms "a", "an", and "the" encompass implementations having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

[0078] Spatially related terms, including but not limited to, "bottom," "lower", "top", "upper", "beneath", "below", "above", "on top", "on," etc., if used herein, are utilized for ease of description to describe spatial relationships of an element(s) to another. Such spatially related terms encompass different orientations of the device in addition to the particular orientations depicted in the figures and described herein. For example, if a structure depicted in the figures is turned over or flipped over, portions previously described as below or beneath other elements would then be above or over those other elements.

What is claimed is:

1. An electrostatic chuck for holding a substrate, the chuck comprising:

a support assembly having two electrodes therein and an electrically insulating support surface for receiving the substrate;

a heating element operably connected to the support surface; and

a high current, high voltage power supply adapted to provide a voltage differential of at least 300V and having two outlets operably connected to the electrodes, with each of the power supply outlets isolated or floating with respect to ground.

2. The electrostatic chuck of claim **1**, wherein the high current, high voltage power supply is configured to provide 1 to 100 milliAmps.

3. The electrostatic chuck of claim **2**, wherein the power supply is adapted to provide a nominal voltage of at least +/−150V.

4. The electrostatic chuck of claim **1**, wherein the heating element is adapted to heat the substrate to at least 250° C.

5. The electrostatic chuck of claim **1**, wherein the power supply is a monopolar power supply.

6. The electrostatic chuck of claim **5**, wherein the monopolar power supply provides a negative voltage.

7. The electrostatic chuck of claim **1**, wherein the power supply has a first power source providing a positive voltage and a second power source providing a negative voltage.

8. The electrostatic chuck of claim **1**, wherein the power supply has a bipolar power source providing a positive voltage and a negative voltage.

9. An electrostatic chuck for holding a substrate, the chuck comprising:

a high current, high voltage power supply adapted to provide a voltage differential of at least 300 for operating the electrostatic chuck, the power supplying having two outlets isolated or floating with respect to ground;

a support assembly with a heating element operably connected to an electrically insulating support surface of the support assembly; and

at least two electrodes within the support assembly and electrically connected to the outlets of the power supply for charging the electrodes to electrostatically hold the substrate to the electrostatic chuck.

10. The electrostatic chuck of claim **9**, wherein the high current, high voltage power supply is adapted to provide 1 to 100 milliamps.

11. The electrostatic chuck of claim **10**, wherein the power supply is adapted to provide a nominal voltage of at least +/−150V.

12. The electrostatic chuck of claim **9**, wherein the heating element is adapted to heat the substrate to at least 250° C.

13. The electrostatic chuck of claim **9**, wherein the power supply is a monopolar power supply.

14. The electrostatic chuck of claim **13**, wherein the monopolar power supply provides a negative voltage.

15. The electrostatic chuck of claim **9**, wherein the power supply has a first power source providing a positive voltage and a second power source providing a negative voltage.

16. The electrostatic chuck of claim **9**, wherein the power supply has a bipolar power source providing a positive voltage and a negative voltage.

17. A method of holding a substrate in a process chamber, the method comprising:

providing an electrostatic chuck comprising a support assembly having an electrically insulative support surface in the process chamber, the support assembly having two electrodes therein electrically connected to outlets of a power supply for charging the electrodes, the outlets isolated or floating with respect to ground;

placing a substrate on the support surface; and

applying a current of at least 1 milliAmp via the power supply to the at least two electrodes to produce a voltage differential of at least 300V.

18. The method of claim **17**, further comprising:

heating the substrate to at least 250° C.

19. The method of clam **17**, wherein applying a current of at least 1 milliAmp comprises applying a current of 1 milliAmp to 100 milliAmp.

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