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(54) **INTEGRATED PRECLEAN-DEPOSITION SYSTEM FOR OPTICAL FILMS**

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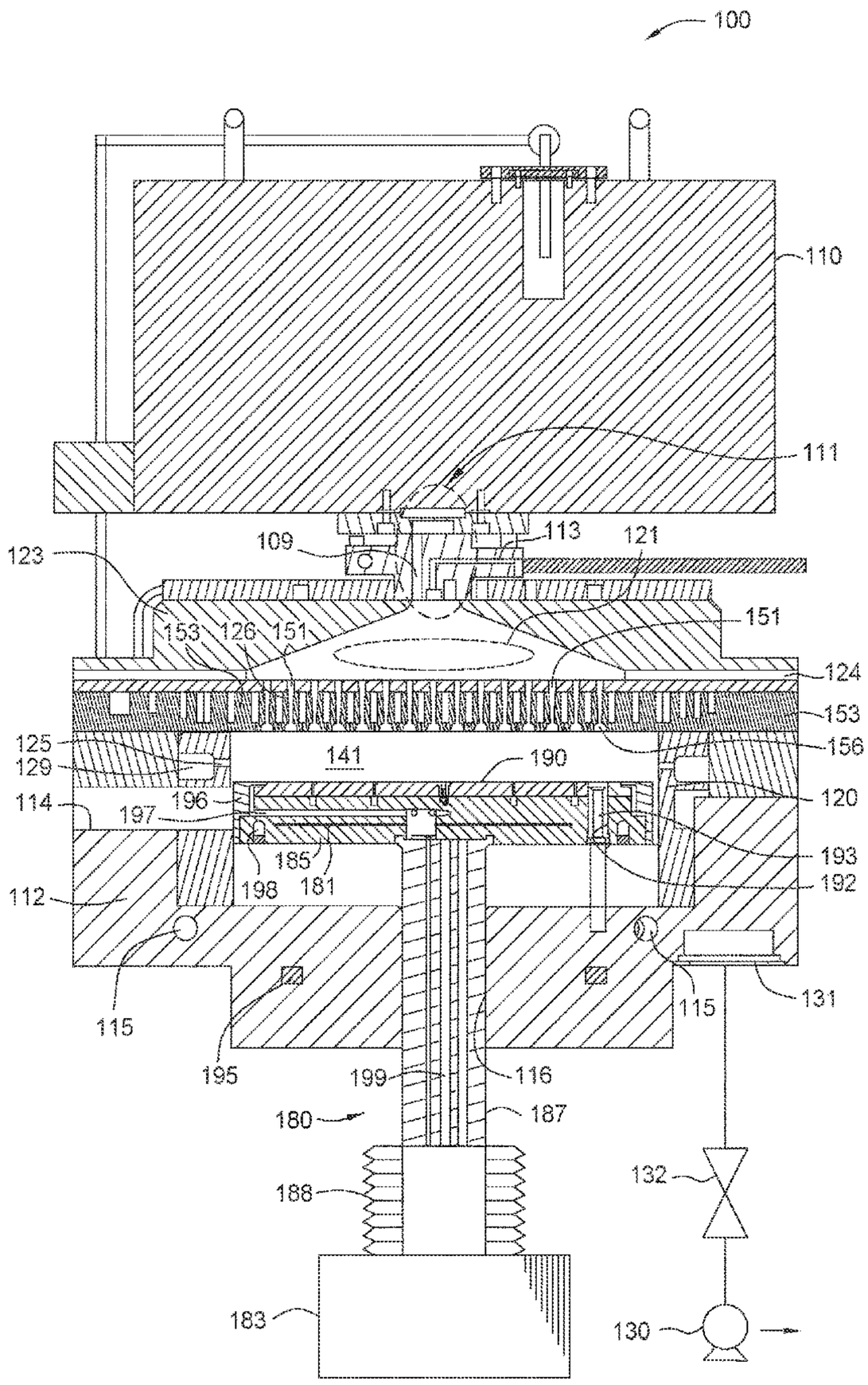
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CPC ***C23C 14/564*** (2013.01); ***C23C 14/24*** (2013.01); *H01J 37/32357* (2013.01)

(57) **ABSTRACT**

Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments described herein relate to a system and method of forming an optical device film. In an embodiment, a method is provided for positioning a substrate in a pre-cleaning chamber disposed in a cluster processing system and pre-cleaning the substrate to remove a native oxide layer from one or more surfaces of the substrate. The substrate is then transferred in an air free state to a deposition chamber disposed in the cluster processing system for forming an optical device film layer on the substrate.



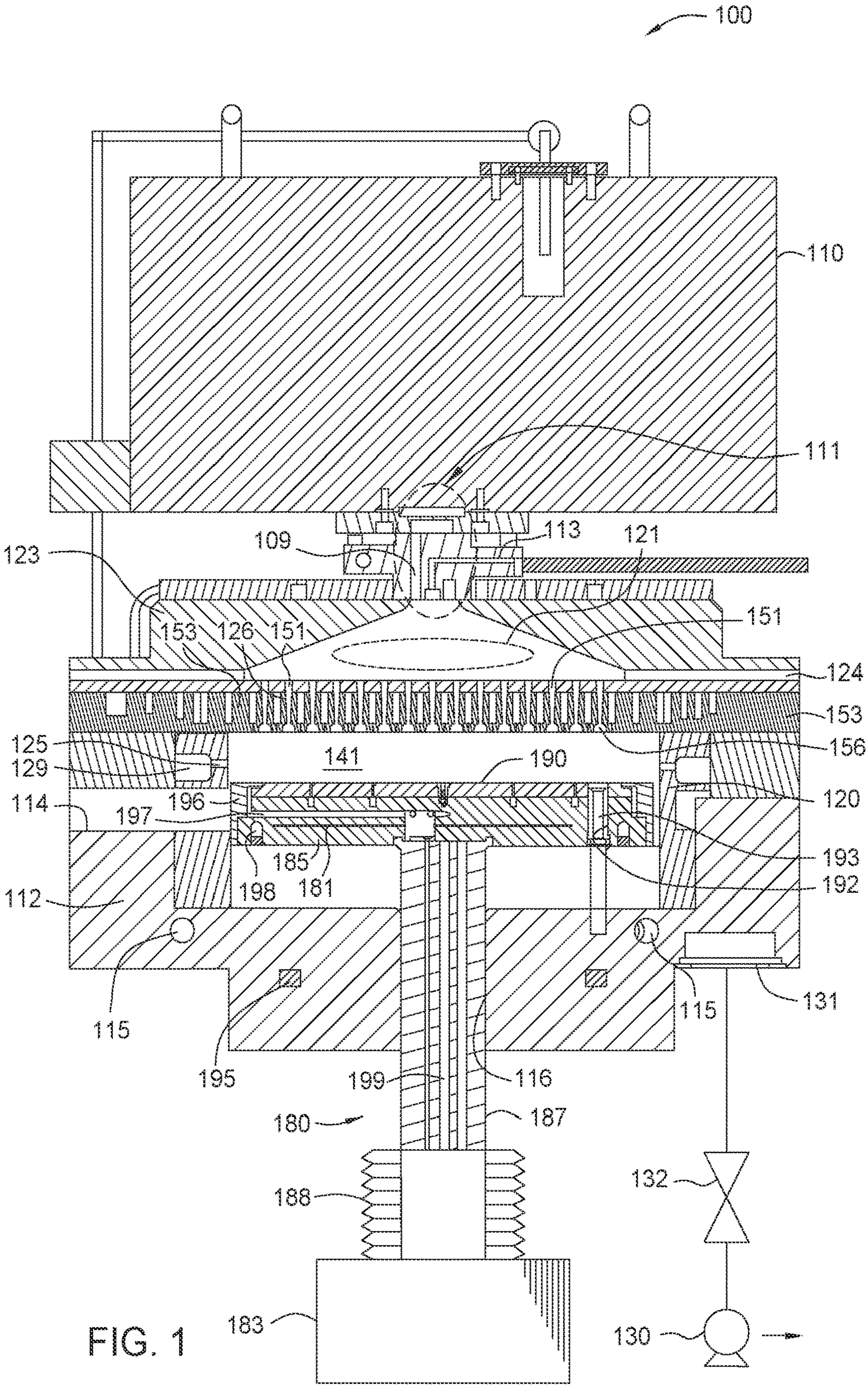

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FIG. 1

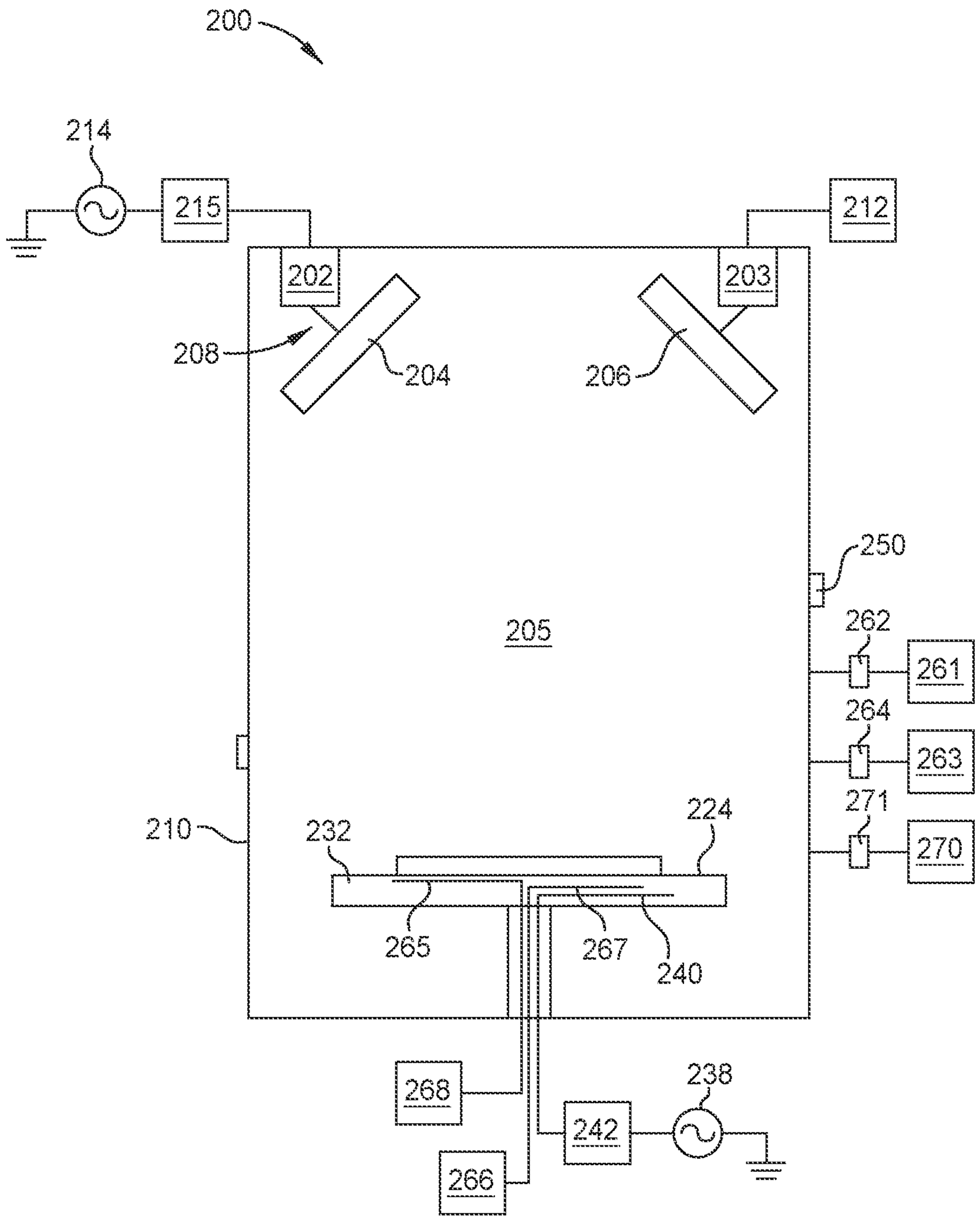

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FIG. 2

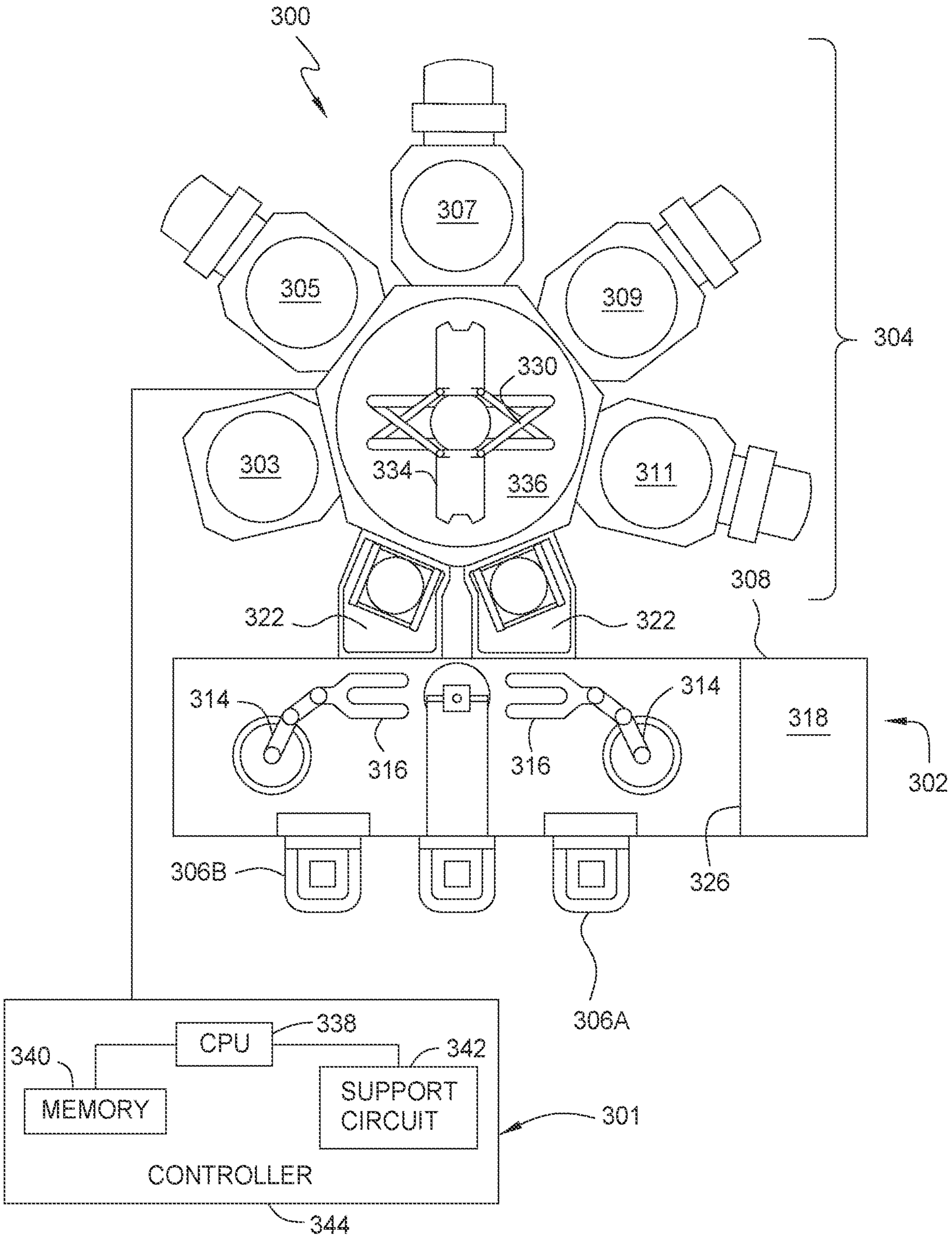

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SUPPORT CIRCUIT
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CONTROLLER
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FIG. 3

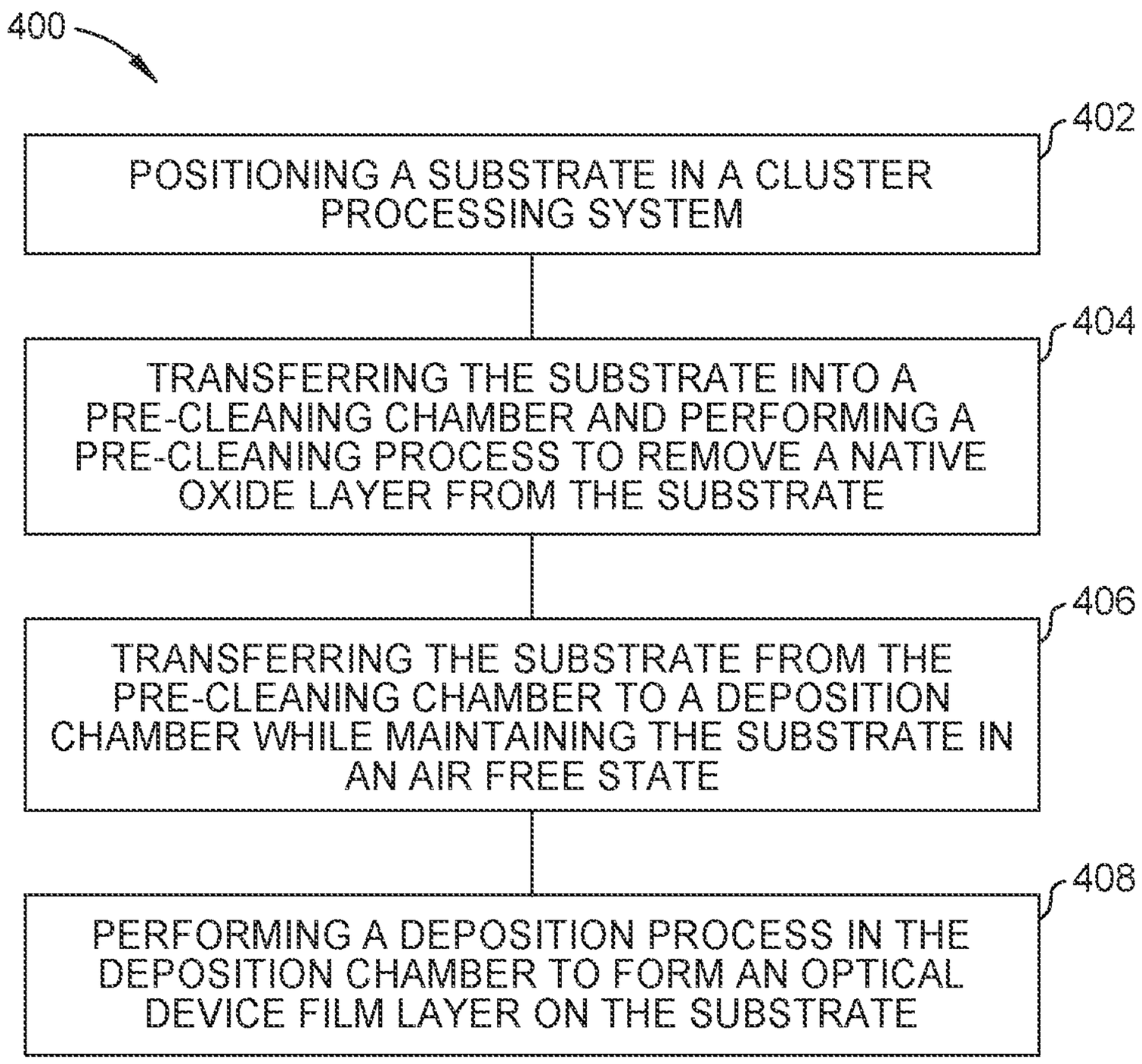


FIG. 4

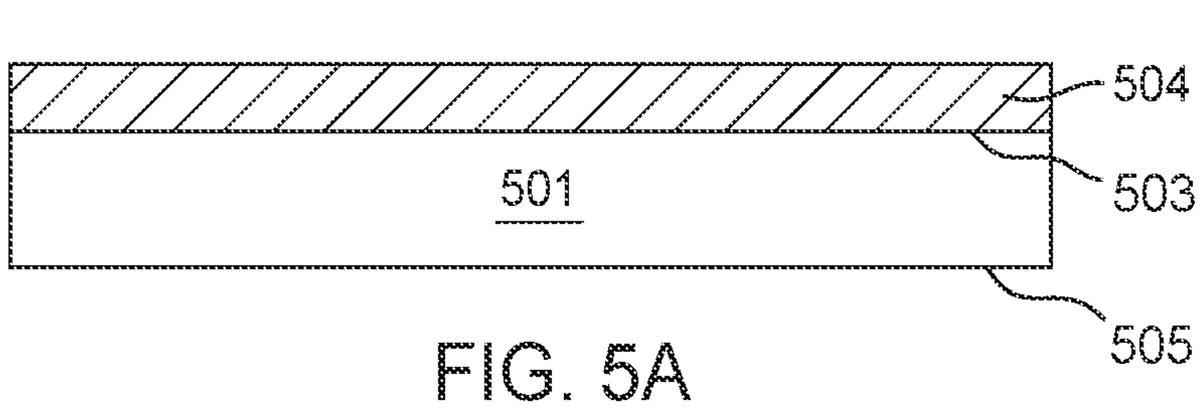


FIG. 5A

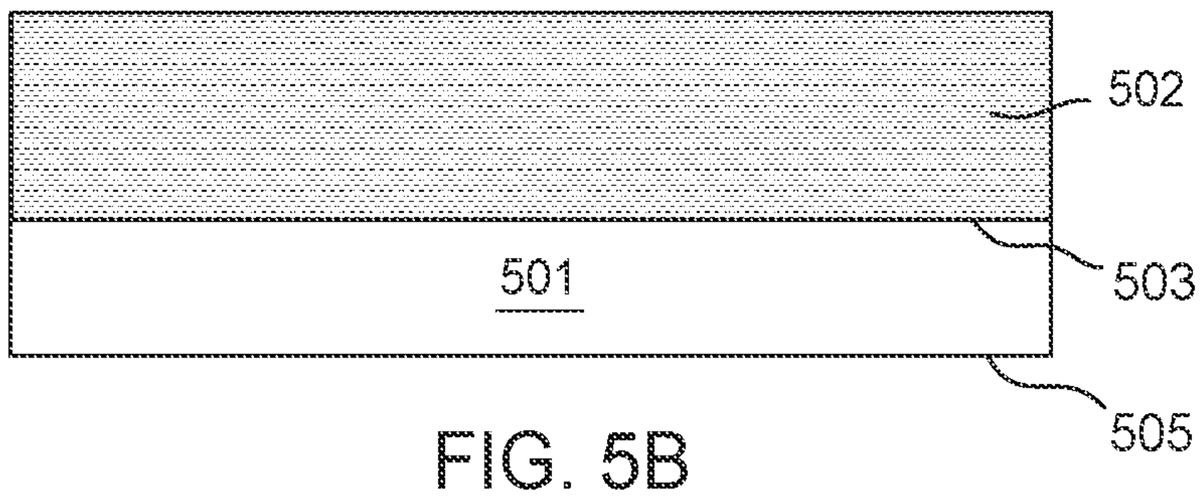


FIG. 5B

INTEGRATED PRECLEAN-DEPOSITION SYSTEM FOR OPTICAL FILMS

RELATED APPLICATIONS

[0001] This application claims benefit of and priority to U.S. Provisional Patent Application No. 63/253,695, filed Oct. 8, 2021, which is herein incorporated in its entirety by reference for all purposes.

BACKGROUND

Field

[0002] Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments described herein relate to a deposition system and a method forming an optical device film with the deposition system.

Description of the Related Art

[0003] Virtual reality is generally considered to be a computer generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment.

[0004] Augmented reality, however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated to appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhances or augments the environment that the user experiences. As an emerging technology, there are many challenges and design constraints with augmented reality.

[0005] One such challenge is displaying a virtual image overlaid on an ambient environment. Optical devices including waveguide combiners, such as augmented reality waveguide combiners, and flat optical devices, such as metasurfaces, are used to assist in overlaying images. Generated light is propagated through an optical device until the light exits the optical device and is overlaid on the ambient environment.

[0006] Accordingly, what is needed in the art is a deposition system and a method of forming an optical device film with the deposition system.

SUMMARY

[0007] In one embodiment, a method for forming an optical device film layer on a substrate is provided. The method includes pre-cleaning a substrate in a pre-cleaning chamber disposed in a cluster processing system to remove a native oxide layer from a top surface of the substrate. When the native oxide layer is removed from the substrate, the substrate is transferred to a deposition chamber disposed in the cluster processing system. The substrate is transferred to the deposition chamber while being maintained in an air free state to prevent regrowth of the native oxide layer. Then, an optical device film layer is formed on the top surface of the substrate in the deposition chamber disposed in the cluster processing system.

[0008] In another embodiment, a method for forming an optical device film layer on a silicon carbide (SiC) substrate is provided. The method includes positioning a SiC substrate in a pre-cleaning chamber of a cluster processing system and pre-cleaning the SiC substrate in the pre-cleaning chamber disposed in a cluster processing system to remove a native SiOC layer from one or more surfaces of the SiC substrate.

[0009] When the native SiOC layer is removed from the SiC substrate, the Sic substrate is transferred to a deposition chamber disposed in the cluster processing system. The SiC substrate is transferred to the deposition chamber while being maintained in an air free state to prevent growth of SiOC on the one or more surfaces of the SiC substrate. Then, an optical device film layer on the one or more surfaces of the SiC substrate in the deposition chamber disposed in the cluster processing system.

[0010] In yet another embodiment, cluster processing system for forming an optical device film layer on a substrate is provided. The system includes a pre-cleaning chamber configured to remove a native oxide layer, a deposition chamber configured to form an optical device film layer, and a transfer chamber configured to maintain an air free environment when transitioning between the pre-cleaning chamber and the first deposition chamber. The system may also include a computer readable media that when executed by a controller of the cluster processing system, causes the cluster processing system to pre-clean a substrate in a pre-cleaning chamber disposed in the cluster processing system to remove the native oxide layer from one or more surfaces of the substrate, transfer the substrate to a deposition chamber disposed in the cluster processing system while maintaining the substrate in an air free state, and form an optical device film layer on the substrate in the deposition chamber disposed in the cluster processing system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0012] FIG. **1** is a schematic view of a pre-clean processing chamber which may be utilized to perform a pre-clean process on a substrate, according to certain embodiments described herein.

[0013] FIG. **2** is a schematic view of an apparatus that may be utilized to perform a physical vapor deposition (PVD) processing process, according to certain embodiments described herein.

[0014] FIG. **3** is a schematic view of a cluster processing system that may have the processing chambers from FIGS. **1-2** incorporated thereto for practice of the example method in FIG. **4**, according to certain embodiments described herein.

[0015] FIG. **4** is a flow diagram of an example method for forming an optical device film, according to certain embodiments described herein.

[0016] FIG. **5**A is a schematic, cross-sectional view of an optical device substrate having a surface with an oxidized layer, according to certain embodiments described herein.

[0017] FIG. **5**B is a schematic, cross-sectional view of an optical device substrate after a method of forming an optical device film, according to certain embodiments described herein.

[0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0019] Embodiments of the present disclosure generally relate to optical devices. More specifically, embodiments described herein relate to a deposition system and a method of forming an optical device film with the deposition system. A deposition system as shown and described herein is provided. A method as shown and described herein is also provided.

[0020] FIG. **1** is a cross sectional view of an illustrative processing chamber **100** suitable for performing a substrate pre-cleaning process as further described below. The processing chamber **100** may be configured to remove native oxide, or surface contamination from a substrate surface. The processing chamber **100** is particularly useful for performing the remote plasma surface cleaning process. The processing chamber **100** may be a Frontier™, PCxT Reactive Preclean™ (RPC), AKTIV Pre-Clean™, Siconi™ or Capa™ chamber, which is available from Applied Materials, Santa Clara, Calif. It is noted that other vacuum processing chambers available from other manufactures may also be adapted to practice the present disclosure.

[0021] The processing chamber **100** includes a chamber body **112**, a lid assembly **123**, and a support assembly **180**. The lid assembly **123** is disposed at an upper end of the chamber body **112**, and the support assembly **180** is at least partially disposed within the chamber body **112**.

[0022] The chamber body **112** includes a slit valve opening **114** formed in a sidewall thereof to provide access to the interior of the processing chamber **100**. The slit valve opening **114** is selectively opened and closed to allow access to the interior of the chamber body **112** by a wafer handling robot (not shown).

[0023] In one or more implementations, the chamber body **112** includes a channel **115** formed therein for flowing a heat transfer fluid therethrough. The chamber body **112** can further include a liner **120** that surrounds the support assembly **180**. The liner **120** is removable for servicing and cleaning. In one or more embodiments, the liner **120** includes one or more apertures **125** and a pumping channel **129** formed therein that is in fluid communication with a vacuum system. The apertures **125** provide a flow path for gases into the pumping channel **129**, which provides an egress for the gases within the processing chamber **100**.

[0024] The vacuum system can include a vacuum pump **130** and a throttle valve **132** to regulate flow of gases through the processing chamber **100**. The vacuum pump **130** is coupled to a vacuum port **131** disposed in the chamber body **112** and therefore, in fluid communication with the pumping channel **129** formed within the liner **120**.

[0025] A remote plasma system **110** may process a halogen containing precursor, for example fluorine-containing precursor, which then travels through a gas inlet assembly **111**. Two distinct gas supply channels (a first channel **109** and a second channel **113**) are visible within the gas inlet assembly **111**. The first channel **109** carries a gas that passes through the remote plasma system **110** (RPS), while the second channel **113** bypasses the remote plasma system **110**. Either channel **109**, **113** may be used for the halogen-containing precursor. On the other hand, the first channel **109** may be used for the process gas and the second channel **113** may be used for a treatment gas. A lid assembly (or conductive top portion) **123** and a perforated partition **153** (or called a showerhead) are shown with an insulating ring **124** in between, which allows an AC potential to be applied to the lid assembly **123** relative to the perforated partition **153**. The AC potential strikes a plasma in a chamber plasma region **121**. The process gas may travel through the first channel **109** into the chamber plasma region **121** and may be excited by a plasma in the chamber plasma region **121** alone or in combination with the remote plasma system **110**. If the process gas flows through the second channel **113**, then only the chamber plasma region **121** is used for excitation. The combination of the chamber plasma region **121** and/or the remote plasma system **110** may be referred to as a remote plasma system herein. The perforated partition (also referred to as a showerhead) **153** separates the chamber plasma region **121** from a substrate processing region **141** beneath the perforated partition **153**. The perforated partition **153** allows a plasma present in the chamber plasma region **121** to avoid directly exciting gases in the substrate processing region **141**, while still allowing excited species to travel from the chamber plasma region **121** into the substrate processing region **141**.

[0026] The perforated partition **153** is positioned between the chamber plasma region **121** and the substrate processing region **141** and allows plasma effluents (excited derivatives of precursors or other gases) created within remote plasma system **110** and/or the chamber plasma region **121** to pass through a plurality of through-holes **156**. The perforated partition **153** also has one or more hollow volumes **151** which can be filled with a precursor in the form of a vapor or gas and pass through the through-holes **156** into the substrate processing region **141** but not directly into the chamber plasma region **121**. In order to maintain a significant concentration of excited species penetrating from the chamber plasma region **121** to the substrate processing region **141**, the length **126** of the through-holes **156** may be restricted and configured in different configurations as needed.

[0027] The perforated partition **153** may be configured to serve the purpose of an ion suppressor as shown in FIG. **1**. Alternatively, a separate processing chamber element may be included (not shown) which suppresses the ion concentration traveling into the substrate processing region **141**. The lid assembly **123** and the perforated partition **153** may function as a first electrode and second electrode, respectively, so that the lid assembly **123** and the perforated partition **153** may receive different electric voltages. In these configurations, electrical power (e.g., RF power) may be applied to the lid **123**, the perforated partition **153**, or both. For example, the electrical power may be applied to the lid assembly **123** while the perforated partition **153** (serving as ion suppressor) is grounded. The substrate processing chamber **100** may include a RF generator that provides the electrical power to the lid assembly **123** and/or the perforated partition **153** as needed. The voltage applied to the lid assembly **123** may facilitate a uniform distribution of plasma

(i.e., reduce localized plasma) within the chamber plasma region **121**. To enable the formation of a plasma in the chamber plasma region **121**, the insulating ring **124** may electrically insulate the lid assembly **123** from the perforated partition **153**. The insulating ring **124** may be made from a ceramic and may have a high breakdown voltage to avoid sparking. Portions of substrate processing chamber **100** near the capacitively-coupled plasma components just described may further include a cooling unit (not shown) that includes one or more cooling fluid channels to cool surfaces exposed to the plasma with a circulating coolant (e.g., water).

[0028] In the embodiment shown, the perforated partition **153** may distribute (via through-holes **156**) process gases which contain hydrogen, fluorine and/or plasma effluents of such process gases upon excitation by a plasma in the chamber plasma region **121**. In embodiments, the process gas introduced into the remote plasma system **110** and/or the chamber plasma region **121** may contain fluorine (such as F2 or HF). The process gas may also include a carrier gas such as helium, argon, hydrogen (H2), etc. Plasma effluents may include ionized or neutral derivatives of the process gas and may also be referred to herein as radical-fluorine referring to the atomic constituent of the process gas introduced.

[0029] The through-holes **156** are configured to suppress the migration of ionically-charged species out of the chamber plasma region **121** while allowing uncharged neutral or radical species to pass through the perforated partition **153** into the substrate processing region **141**. These uncharged species may include highly reactive species that are transported with less-reactive carrier gas by the through-holes **156**. As noted above, the migration of ionic species by the through-holes **156** may be reduced, and in some instances completely suppressed. Controlling the amount of ionic species passing through the perforated partition **153** provides increased control over the gas mixture brought into contact with the underlying wafer substrate, which in turn increases control of the deposition and/or etch characteristics of the gas mixture. For example, adjustments in the ion concentration of the gas mixture can significantly alter its etch selectivity (e.g., silicon nitride/oxide: silicon etch ratios).

[0030] In embodiments, the number of the through-holes **156** may be between about 60 and about 2000. The through-holes **156** may have a variety of shapes but are most easily made round. There is also latitude in choosing the cross-sectional shape of through-holes, which may be made conical, cylindrical or combinations of the two shapes. The through-holes **156** may be configured to control the passage of the plasma-activated gas (i.e., the ionic, radical, and/or neutral species) through the perforated partition **153**. For example, the aspect ratio of the holes (i.e., the whole diameter to length) and/or the geometry of the holes may be controlled so that the flow of ionically-charged species in the activated gas passing through the perforated partition **153** is reduced. The through-holes **156** in the perforated partition **153** may include a tapered portion that faces the chamber plasma region **121**, and a cylindrical portion that faces the substrate processing region **141**. The cylindrical portion may be proportioned and dimensioned to control the flow of ionic species passing into the substrate processing region **141**. An adjustable electrical bias may also be applied to the perforated partition **153** as an additional means to control the flow of ionic species through the perforated partition **153**.

[0031] Alternatively, the through-holes **156** may have a smaller inner diameter (ID) toward the top surface of the perforated partition **153** and a larger ID toward the bottom surface. In addition, the bottom edge of the through-holes **156** may be chamfered to help evenly distribute the plasma effluents in the substrate processing region **141** as the plasma effluents exit the showerhead and promote even distribution of the plasma effluents and precursor gases. The smaller ID may be placed at a variety of locations along the through-holes **156** and still allow the perforated partition **153** to reduce the ion density within the substrate processing region **141**. The reduction in ion density results from an increase in the number of collisions with walls prior to entry into the substrate processing region **141**. Each collision increases the probability that an ion is neutralized by the acquisition or loss of an electron from the wall. Generally speaking, the smaller ID of the through-holes **156** may be between about 0.2 mm and about 20 mm. In other embodiments, the smaller ID may be between about 1 mm and 6 mm or between about 0.2 mm and about 5 mm. Further, aspect ratios of the through-holes **156** (i.e., the smaller ID to hole length) may be approximately 1 to 20. The smaller ID of the through-holes **156** may be the minimum ID found along the length of the through-holes. The cross sectional shape of through-holes **156** may be generally cylindrical, conical, or any combination thereof.

[0032] The support assembly **180** can include a support member **185** to support a substrate (not shown in FIG. **1**) for processing within the chamber body **112**. The support member **185** can be coupled to a lift mechanism **183** through a shaft **187** which extends through a centrally-located opening **116** formed in a bottom surface of the chamber body **112**. The lift mechanism **183** can be flexibly sealed to the chamber body **112** by a bellows **188** that prevents vacuum leakage from around the shaft **187**.

[0033] The support member **185** can include bores **192** formed therethrough to accommodate lift pins **193**, one of which is shown in FIG. **1**. Each lift pin **193** is constructed of ceramic or ceramic-containing materials, and are used for substrate-handling and transport. The lift pin **193** is moveable within its respective bore **192** when engaging an annular lift ring **195** disposed within the chamber body **112**. The support assembly **180** can further include an edge ring **196** disposed about the support member **185**.

[0034] The temperature of the support assembly **180** can be controlled by a fluid circulated through a fluid channel **198** embedded in the body of the support member **185**. In one or more implementations, the fluid channel **198** is in fluid communication with a heat transfer conduit **199** disposed through the shaft **187** of the support assembly **180**. The fluid channel **198** is positioned about the support member **185** to provide a uniform heat transfer to the substrate receiving surface of the support member **185**. The fluid channel **198** and heat transfer conduit **199** can flow heat transfer fluids to either heat or cool the support member **185**. Any suitable heat transfer fluid may be used, such as water, nitrogen, ethylene glycol, or mixtures thereof. The support assembly **180** can further include an embedded thermocouple (not shown) for monitoring the temperature of the support surface of the support member **185**. For example, a signal from the thermocouple may be used in a feedback loop to control the temperature or flow rate of the fluid circulated through the fluid channel **198**.

[0035] The support member **185** can be moved vertically within the chamber body **112** so that a distance between support member **185** and the lid assembly **140** can be controlled. A sensor (not shown) can provide information concerning the position of support member **185** within processing chamber **100**.

[0036] A system controller (not shown) can be used to regulate the operations of the processing chamber **100**. The system controller can operate under the control of a computer program stored on a memory of a computer. The computer program may include instructions that enable the preclean process described below to be performed in the processing chamber **100**. For example, the computer program can dictate the process sequencing and timing, mixture of gases, chamber pressures, RF power levels, susceptor positioning, slit valve opening and closing, wafer cooling and other parameters of a particular process.

[0037] FIG. **2** is a schematic cross-sectional view of a processing chamber **200** according to one embodiment described herein. The processing chamber **200** may be a deposition chamber, such as a PVD chamber **200**. The processing chamber **200** may be used to perform the methods described herein and configured at least to deposit a thin film on a substrate surface. It is to be understood that the chamber **200** is an exemplary physical vapor deposition (PVD) chamber and other PVD chambers, including PVD chambers from other manufacturers, may be used with or modified to accomplish the methods of the present disclosure. While PVD is discussed in this disclosure, various deposition techniques, such as chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), atomic layer deposition (ALD), plasma enhanced atomic layer deposition (PEALD), low pressure chemical vapor deposition (LPCVD), etc., are also contemplated.

[0038] The processing chamber **200** includes one or more cathodes **202**, **203** that have a corresponding single target or a plurality of targets, attached to the chamber body **210** (e.g., via a chamber body adapter). In the implementation shown in FIG. **2**, the processing chamber **200** includes at least one first target **204** and at least one second target **206**. The first target **204** includes at least one first material described herein and the second target **206** includes at least one second material described herein. Each cathode (e.g., the first target **204** and second target **206**) may be coupled to a DC power source **212** and/or an RF power source **214** and matching network **216**.

[0039] The processing chamber **200** is configured to include a substrate support **232** having a support surface **234** to support the substrate. The processing chamber **200** includes an opening **250** (e.g., a slit valve) through which an end effector (not shown) extends to place a substrate onto lift pins (not shown) for lowering the substrate onto the support surface **234**.

[0040] The processing chamber **200** includes a sputter gas source **261** operable to supply a sputter gas to a process volume **205**. A plasma **198** can be generated in the processing volume **205** from a non-reactive sputter gas (such as argon (Ar), krypton (Kr), etc., and/or from a process gas including an oxygen-containing gas (e.g., O_2) for oxide deposition or a nitrogen-containing gas (e.g., N_2) for nitride deposition, according to some embodiments. The present disclosure contemplates that other sputter gas(es) may also be used.

[0041] A gas flow controller **262** is disposed between the sputter gas source **261** and the process volume **205** to control a flow of the sputter gas from the sputter gas source **261** to the process volume **205**. The processing chamber **200** also includes a reactive gas source **263** operable to supply a reactive gas, such as an oxygen-containing gas or nitrogen-containing gas to the process volume **205**. A gas flow controller **264** is disposed between the reactive gas source **263** and the process volume **205** to control a flow of the reactive gas from the reactive gas source **263** to the process volume **205**. The processing chamber **200** may include a precursor gas source **270** operable to supply a precursor gas to the process volume **205**. In one embodiment, which can be combined with other embodiments, a gas flow controller **271** is disposed between the precursor gas source **270** and the process volume **205** to control a flow of the precursor gas from the precursor gas source **270** to the process volume **205**. Sputter gases, reactive gases, and precursor gases may each be referred to as process gases herein. During processing, the process volume **205** can be maintained at a process pressure using a vacuum device and/or the gas flow controllers **262**, **264**, **271**.

[0042] The substrate support **232** includes an RF bias power source **238** coupled to a bias electrode **240** disposed in the substrate support **232** via a matching network **242**. The substrate support **232** includes a mechanism (not shown) that retains the substrate on the support surface **234** of the substrate support **232**, such as an electrostatic chuck, a vacuum chuck, a substrate retaining clamp, or the like. The substrate support **232** includes a cooling conduit **265** disposed in the substrate support **232** where the cooling conduit **265** controllably cools the substrate support **232** and the substrate positioned thereon to a predetermined temperature, for example between about −20° C. to about 300° C. The cooling conduit **265** is coupled to a cooling fluid source **268** to provide cooling fluid (not shown). The substrate support **232** also includes a heater **267** embedded therein. The heater **267**, such as a resistive element, disposed in the substrate support **232** is coupled to an optional heater power source **266** and controllably heats the substrate support **232** and the substrate positioned thereon to a predetermined temperature, for example between about −150° C. to about 500° C.

[0043] While FIG. **2** depicts one first target **204** and one second target **206**, the processing chamber **200** may include one or more first targets **204** and/or one or more second targets **206**. For example, 3-5 targets selected from at least one of the first targets **204** and/or the second targets **206** may be included in the processing chamber **200**. Each first target **204** is operable to deposit a different material. For example, 3-5 second targets **206** may be included in the processing chamber **200**. Each second target **206** is operable to deposit a different material. In one or more embodiments with the one or more first targets **204** and the one or more second target **206**, each first target **204** is operable to deposit a different first material and/or each second target **206** is operable to deposit a different second material on the substrate.

[0044] FIG. **3** is a schematic, top plan view of a cluster processing system **300**, according to certain embodiments described herein. The cluster tool **300** features at least one or more of the processing chambers **100**, **200** that are incorporated and integrated therein. In one embodiment, the cluster processing system **300** may be a Centura® or Endura® integrated processing system, commercially avail-

able from Applied Materials, Inc., located in Santa Clara, Calif. It is contemplated that other processing systems (including those from other manufacturers) may be adapted to benefit from the disclosure.

[0045] The cluster processing system **300** includes a vacuum-tight processing platform **304**, a factory interface **302**, and a system controller **344**. The platform **304** includes a plurality of processing chambers **303**, **305**, **307**, **309**, **311** and at least one load-lock chamber **322** that is coupled to a vacuum substrate transfer chamber **336**. Although FIG. **3** shows an embodiment of the cluster processing system **300** having five (5) processing chambers **303**, **305**, **307**, **309**, **311**, in an embodiment, the processing system **300** may be configured with only two (2) processing chambers incorporating processing chambers **100** and **200** described herein. Two load lock chambers **322** are shown in FIG. **3**. The factory interface **302** is coupled to the transfer chamber **336** by the load lock chambers **322**.

[0046] In one embodiment, the factory interface **302** comprises at least one docking station **308** and at least one factory interface robot **314** to facilitate transfer of substrates. The docking station **308** is configured to accept one or more front opening unified pod (FOUP). Two FOUPS **306**A, **306**B are shown in the embodiment of FIG. **3**. The factory interface robot **314** having a blade **316** disposed on one end of the robot **314** is configured to transfer the substrate from the factory interface **302** to the processing platform **304** for processing through the load lock chambers **322**. Optionally, one or more metrology stations **318** may be connected to a terminal **326** of the factory interface **302** to facilitate measurement of the substrate from the FOUPS **306**A-B.

[0047] Each of the load lock chambers **322** have a first port coupled to the factory interface **302** and a second port coupled to the transfer chamber **336**. The load lock chambers **322** are coupled to a pressure control system (not shown) which pumps down and vents the load lock chambers **322** to facilitate passing the substrate between the vacuum environment of the transfer chamber **336** and the substantially ambient (e.g., atmospheric) environment of the factory interface **302**.

[0048] The transfer chamber **336** has a vacuum robot **330** disposed therein. The vacuum robot **330** has a blade **334** capable of transferring substrates among the load lock chambers **322**, a metrology system, and the processing chambers **303**, **305**, **307**, **309**, **311**. In an embodiment, which can be combined with other embodiments described herein, the transfer chamber **336** prevents oxide growth or regrowth on substrates by maintaining a high vacuum, such as about 100 mT or less than about 100 mT. In another embodiment, which can be combined with other embodiments described herein, the transfer chamber **336** prevents oxide growth or regrowth on substrates by being filled with an inert gas, such as N2, Ar, and the like.

[0049] In one embodiment of the cluster processing system **300**, the cluster processing system **300** may include one or more processing chambers **303**, **305**, **307**, **309**, **311**, which may be a deposition chamber (e.g., physical vapor deposition chamber, chemical vapor deposition, atomic layer deposition or other deposition chambers), annealing chamber (e.g., high pressure annealing chamber, RTP chamber, laser anneal chamber), etch chamber, cleaning chamber, pre-cleaning chamber, curing chamber, lithographic exposure chamber, or other similar type of semiconductor processing chambers. In one embodiment, processing chamber **303** may be a pre-cleaning chamber, such as processing chamber **100** described herein, configured to clean the substrate prior to deposition of an optical device film. The pre-clean chamber may be configured to perform the Applied Materials SICONI™ Pre-clean process. Processing chambers **305**, **307**, **309** and/or **311** may be additional material deposition chambers, including processing chamber **200** described herein, or other chambers that enable interface treatment, interfacial layer deposition, and multiple-layer film stack deposition. The cluster processing system **300** may also include facets (not shown) for connecting additional chambers to the cluster processing system **300** for one or more of interface treatment, interfacial layer deposition, and multiple-layer film stack deposition.

[0050] The system controller **344** is coupled to the cluster processing system **300**. The system controller **344**, which may include the computing device **301** or be included within the computing device **301**, controls the operation of the cluster processing system **300** using a direct control of the process chambers **303**, **305**, **307**, **309**, **311** of the cluster processing system **300**. Alternatively, the system controller **344** may control the computers (or controllers) associated with the process chambers **303**, **305**, **307**, **309**, **311** and the cluster processing system **300**. In operation, the system controller **344** also enables data collection and feedback from the respective chambers to optimize performance of the cluster processing system **300**.

[0051] The system controller **344**, much like the computing device **301** described above, generally includes a central processing unit (CPU) **338**, a memory **340**, and support circuits **342**. The CPU **338** may be one of any form of a general purpose computer processor that can be used in an industrial setting. The support circuits **342** are conventionally coupled to the CPU **338** and may comprise cache, clock circuits, input/output subsystems, power supplies, and the like. Processes may generally be stored in the memory **340** of the system controller **344** as a software routine that, when executed by the CPU **338**, causes the process chamber to perform processes of the present disclosure. The software routines transform the CPU **338** into a specific purpose computer (controller) **344**. The software routines may also be stored and/or executed by a second controller (not shown) that is located remotely from the cluster processing system **300**. Some or all of the method of the present disclosure may also be performed in hardware. As such, the process may be implemented in software and executed using a computer system, in hardware as, e.g., an application specific integrated circuit or other type of hardware embodiment, or as a combination of software and hardware.

[0052] FIG. **4** is a flow diagram of an example method **400** for forming an optical device film on a substrate, according to certain embodiments described herein. FIGS. **5**A and **5**B are schematic cross-sectional views of a portion of a substrate **501** corresponding to various stages of the method **400**.

[0053] Method **400** begins at operation **402** by positioning a substrate, such as the substrate **501** shown in FIGS. **5**A, in a cluster processing system for processing. In an embodiment, the cluster processing system used to perform the method **400** described herein may be the cluster processing system **300** described in FIG. **3**. In an embodiment, the substrate **501** that is to be processed may arrive to the cluster processing system **300** in a pod (not shown). The substrate **501** is transferred from the pod to one of the vacuum

compatible load-lock chambers **322** by the factory interface robot **314**. The substrate is then picked by the vacuum robot **330** in the transfer chamber **336** which is generally kept in a vacuum state, for transfer from one of the load-lock chambers **322** to one of the processing chambers **303**, **305**, **307**, **309**, **311** for processing.

[0054] In one embodiment, the substrate **501** is a silicon carbide (SiC) substrate. As shown in FIG. **5**A, the substrate **101** includes a first surface **503** with an oxidized layer **504** disposed thereon. In embodiments described herein, the first surface **503** and a second surface **505** may both include the oxidized layer **504** disposed thereon. In embodiments of the SiC substrate, the oxidized layer **504** is a silicon oxycarbide (SiOC). The oxidized layer **504** of SiOC may have a refractive index of about 1.46 or less and the optical device substrate **501** may have a refractive index of about 2.67. The oxidized layer **504** may have a thickness of 2 nanometers (nm) or less. The difference in refractive index between the oxidized layer **504** and the optical device substrate **501** creates optical interference and leads to optical loss if an optical device film (such as an optical device film layer **502** of FIG. **5**B) is deposited thereover.

[0055] At operation **404**, the substrate **501** is transferred into a processing chamber, such as the pre-cleaning chamber **100** as depicted in FIG. **1**, which may be incorporated into the cluster processing system **300** depicted in FIG. **3**, to perform a pre-cleaning process on the substrate **501**. In an embodiment, the vacuum robot **330** of the cluster processing system **300** loads the substrate **501** into the processing chamber **303** for pre-cleaning as described in operation **404**.

[0056] In one embodiment, the pre-cleaning process performed at operation **404** removes a native oxide layer (such as the oxidized layer **504** of FIG. **5**A) from the substrate **501**. In another embodiment, the pre-cleaning process at operation **404** can remove the native oxide layer from both surfaces **503**, **505** of the substrate **501**.

[0057] In one embodiment, the pre-cleaning process may be performed by supplying a pre-cleaning gas mixture including hydrogen etchants. The pre-cleaning gas mixture includes at least a hydrogen containing gas. While supplying the hydrogen containing gas in the pre-cleaning gas mixture, an inert gas may also be optionally supplied during the pre-cleaning process. Suitable examples of the hydrogen containing gas include H2, NH3, H2O, H2O2, and the like. Suitable examples of the inert gas may also be supplied into the pre-cleaning gas mixture as needed. Examples of the inert gas supplied in the gas mixture include Ar, He, Ne, Kr, Xe and the like. In one particular example, the pre-cleaning gas mixture includes H2, N2, NH3, H2O, O2, NF3, CF4, Ar, and combinations thereof.

[0058] The pre-cleaning gas mixture is supplied through the chamber plasma region **121** into the substrate processing region **141** to form a remote plasma source in the chamber plasma region **121** from the pre-cleaning gas mixture for removing surface contaminants and native oxide. The amount of gases introduced into the processing chamber **100** from the pre-cleaning gas mixture may be varied and adjusted to accommodate, for example, the thickness of the native oxide or the amount of the surface contaminates to be removed.

[0059] A remote plasma power from the power source **152** is generated to form a plasma in the chamber plasma region **121** from the pre-cleaning gas mixture supplied at operation **404**. The plasma generated remotely in the chamber plasma region **121** during the pre-cleaning process at operation **404** may have the etchants dissociated to form a relatively mild and gentle etchants, so as to slowly, gently and gradually etch the surface contaminants and native oxide, e.g., an isotropic etching process. The remote plasma process provides good control for the interface cleaning and promotes high etching selectivity.

[0060] In an embodiment, which can be combined with other embodiments herein, the support assembly **180** of the pre-cleaning chamber **100** is operable to heat the substrate **501** to between about 400 degrees Celsius and about 1500 degrees Celsius during the pre-cleaning process.

[0061] In another embodiment, which can be combined with other embodiments herein, the pre-cleaning chamber **100** maintains a pressure of about 100 mT to atmospheric pressure in the processing region **141** during the pre-cleaning process.

[0062] At operation **406**, the substrate **501** is transferred from the pre-cleaning chamber **100** to a deposition chamber while maintaining the substrate **501** in an air free state. In an embodiment, which can be combined with other embodiments described herein, the substrate **501** is maintained in a high vacuum environment, such as about 100 mT or less, during transfer to prevent oxide growth on the substrate **501**. In another embodiment, which can be combined with other embodiments described herein, the substrate **501** is maintained in a space filled with an inert gas, such as N2, Ar, and the like, during transfer to prevent oxide growth on the substrate **501**.

[0063] In an embodiment, when the pre-cleaning chamber **100** is incorporated into the cluster processing system **300** depicted in FIG. **3**, the substrate **501** in the pre-cleaning chamber **100** is picked by the vacuum robot **330** in operation **406** for transfer to a deposition chamber in the cluster processing system **300**. The vacuum robot **330** in the transfer chamber **336** is kept in a vacuum state to facilitate passing the substrate **501** in an air free environment between the pre-cleaning chamber **100** and one of the processing chambers **303**, **305**, **307**, **309**, **311** configured for performing a deposition process.

[0064] At operation **408**, a deposition process is performed to form an optical device film layer **502** on the substrate **501**, as shown in FIG. **5**B. The deposition process may be a PVD process performed at the PVD processing chamber **200** depicted in FIG. **2**, which may be incorporated into the cluster processing system **300** depicted in FIG. **3**, to perform the deposition process on the substrate **501**. Alternatively, other deposition process techniques may be performed, such as chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), atomic layer deposition (ALD), plasma enhanced atomic layer deposition (PEALD), low pressure chemical vapor deposition (LPCVD), etc. in a corresponding deposition chamber.

[0065] The optical device film layer **502** deposited on the substrate **501** in operation **408** includes, but is not limited to, materials containing germanium, silicon, titanium oxide, niobium oxide, silicon nitride, hafnium oxide, tantalum oxide, scandium oxide, or combinations thereof. In one embodiment, the optical device film **102** may be disposed over the first surface **503** and the second surface **505** of the substrate **501** opposite of the first surface **503**.

[0066] In summation, using aspects described herein, it has been found that by removing native oxides having a low refractive index from a substrate, such as a SiC substrate, to

form an oxide free surface and maintaining such oxide free surface in an air free state prior to depositing an optical device film on the substrate, optical interference and loss usually caused by interfacial oxide layers, such as by an SiOC interfacial layer between an optical device film layer and a SiC substrate, can be minimized and/or removed altogether. In certain embodiments, a system and method is provided to remove native oxides layer from a substrate and form an optical device film on the substrate all while maintaining the substrate in an air free state. In one embodiment, the method includes positioning the substrate in a pre-cleaning chamber incorporated into a cluster processing system to remove native oxides from the substrate and transferring the substrate to a deposition chamber also incorporated into the cluster processing system to deposit an optical device film, all while maintaining the substrate in an air free environment to prevent oxide growth on the substrate.

[0067] While the foregoing is directed to examples of the present disclosure, other and further examples of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A method for forming an optical device film, comprising:

pre-cleaning a substrate in a pre-cleaning chamber disposed in a cluster processing system to remove a native oxide layer from a top surface of the substrate;

transferring the substrate to a deposition chamber disposed in the cluster processing system while maintaining the substrate in an air free state; and

forming an optical device film layer on the top surface of the substrate in the deposition chamber disposed in the cluster processing system.

2. The method of claim **1**, wherein the substrate comprises a silicon carbide (SiC) substrate.

3. The method of claim **1**, wherein the native oxide layer comprises a silicon oxycarbide (SiOC) layer.

4. The method of claim **2**, wherein pre-cleaning the silicon carbide substrate further comprises heating and maintaining the silicon carbide substrate temperature between about 400 degrees Celsius and about 1500 degrees Celsius.

5. The method of claim **1**, wherein pre-cleaning the substrate further comprises maintaining a pressure of about 100 mT to atmospheric pressure in the pre-cleaning chamber disposed in the cluster processing system.

6. The method of claim **1**, wherein pre-cleaning the substrate further comprises removing a second native oxide layer from a bottom surface of the substrate.

7. The method of claim **1**, wherein maintaining the substrate in an air free state comprises maintaining the substrate in an high vacuum environment at a pressure of about 100 mT or less.

8. The method of claim **1**, wherein maintaining the substrate in the air free state comprises flowing an inert gas when transferring the substrate between the pre-cleaning chamber and the deposition chamber.

9. The method of claim **1**, wherein maintaining the substrate in the air free state when transferring the substrate between the pre-cleaning chamber and the deposition chamber prevents oxide growth on the top surface of the substrate.

10. A method for forming an optical device film, comprising:

positioning a SiC substrate in a pre-cleaning chamber of a cluster processing system;

pre-cleaning the SiC substrate in the pre-cleaning chamber disposed in a cluster processing system to remove a native SiOC layer from one or more surfaces of the SiC substrate;

transferring the SiC substrate to a deposition chamber disposed in the cluster processing system while maintaining the SiC substrate in an air free state to prevent oxide growth on the one or more surfaces of the SiC substrate; and

forming an optical device film layer on the one or more surfaces of the SiC substrate in the deposition chamber disposed in the cluster processing system.

11. The method of claim **10**, wherein pre-cleaning the SiC substrate further comprises heating and maintaining the SiC substrate temperature between about 400 degrees Celsius and about 1500 degrees Celsius.

12. The method of claim **10**, wherein maintaining the SiC substrate in an air free state comprises maintaining the SiC substrate in an high vacuum environment at a pressure of about 100 mT or less.

13. The method of claim **10**, wherein maintaining the SiC substrate in an air free state comprises flowing an inert gas when transferring the substrate between the pre-cleaning chamber and the deposition chamber.

14. A cluster processing system, comprising:

a pre-cleaning chamber configured to remove a native oxide layer;

a deposition chamber configured to form an optical device film layer; and

a transfer chamber configured to maintain an air free environment when transitioning between the pre-cleaning chamber and the first deposition chamber.

15. The cluster processing system of claim **14**, further comprising a computer readable media, when executed by a controller of the cluster processing system, causes the cluster processing system to:

pre-clean a substrate in a pre-cleaning chamber disposed in the cluster processing system to remove the native oxide layer from one or more surfaces of the substrate;

transfer the substrate to a deposition chamber disposed in the cluster processing system while maintaining the substrate in an air free state; and

form an optical device film layer on the substrate in the deposition chamber disposed in the cluster processing system.

16. The cluster processing system of claim **15**, wherein the substrate comprises a silicon carbide substrate and the native oxide layer comprises a silicon oxycarbide layer.

17. The cluster processing system of claim **16**, wherein the pre-cleaning chamber is configured to heat and maintain the silicon carbide substrate temperature between about 400 degrees Celsius and about 1500 degrees Celsius.

18. The cluster processing system of claim **15**, wherein the pre-cleaning chamber is configured to maintain the substrate in a pressure of about 100 mT to atmospheric pressure.

19. The cluster processing system of claim **15**, wherein the transfer chamber is configured to maintain the substrate in an high vacuum environment at a pressure of about 100 mT or less.

20. The cluster processing system of claim **14**, wherein the transfer chamber is configured to flow an inert gas to maintain an air free environment when transitioning between the pre-cleaning chamber and the first deposition chamber in the cluster processing system.

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