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(54) **METHOD OF OPERATING A PROCESSING SYSTEM FOR TREATING A SUBSTRATE**

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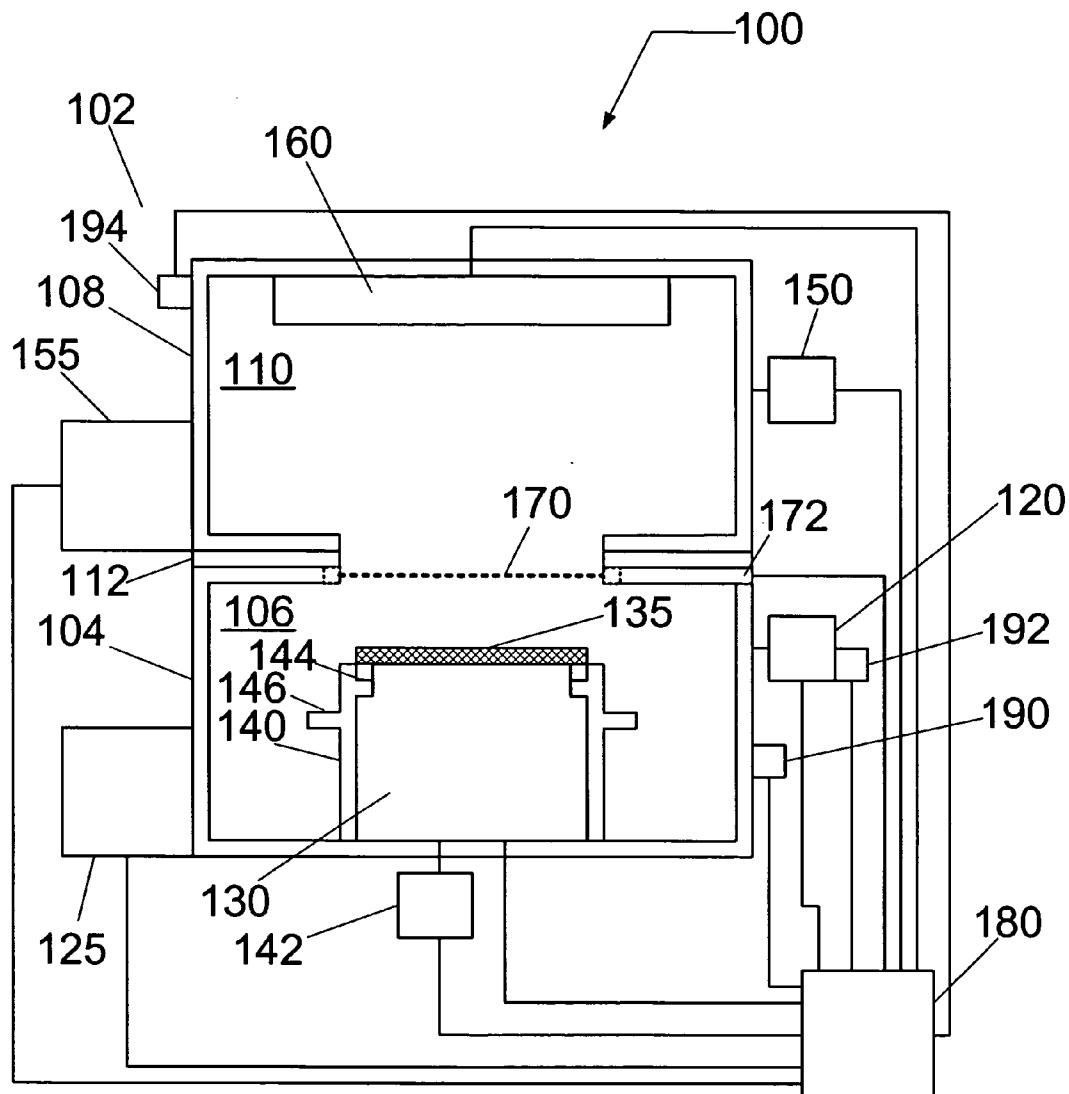
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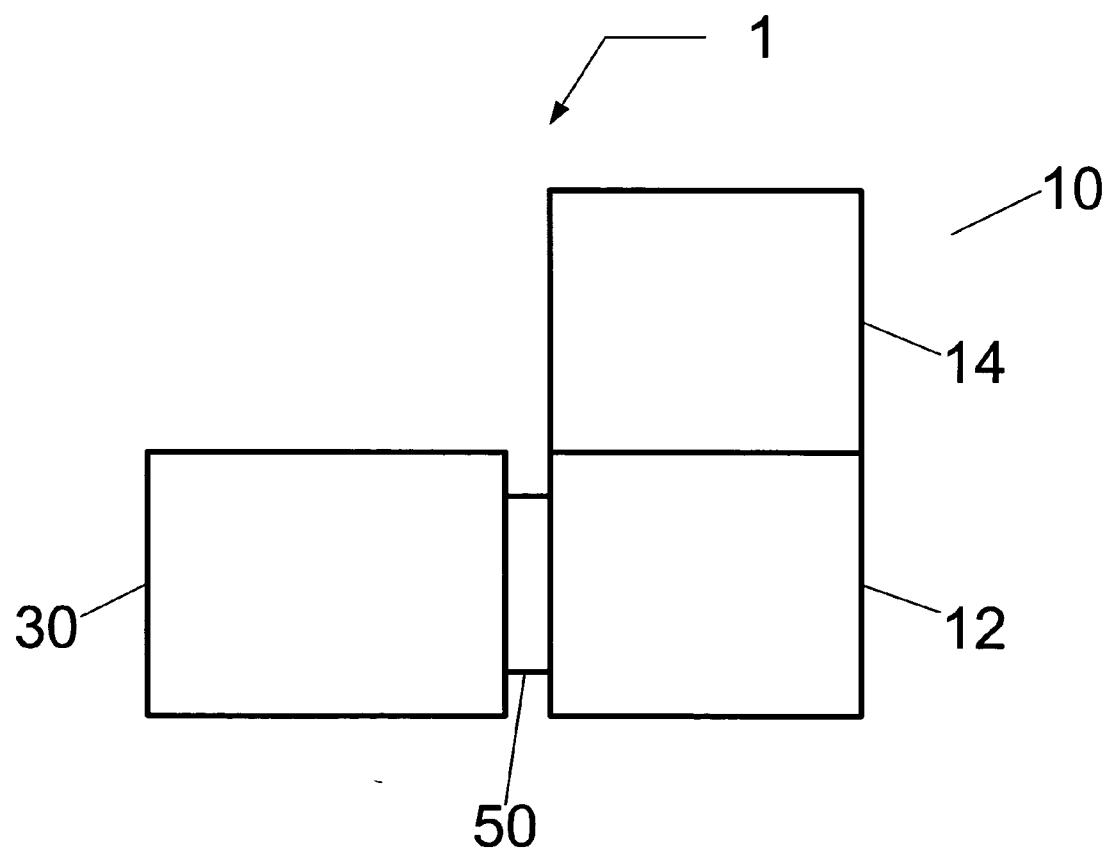
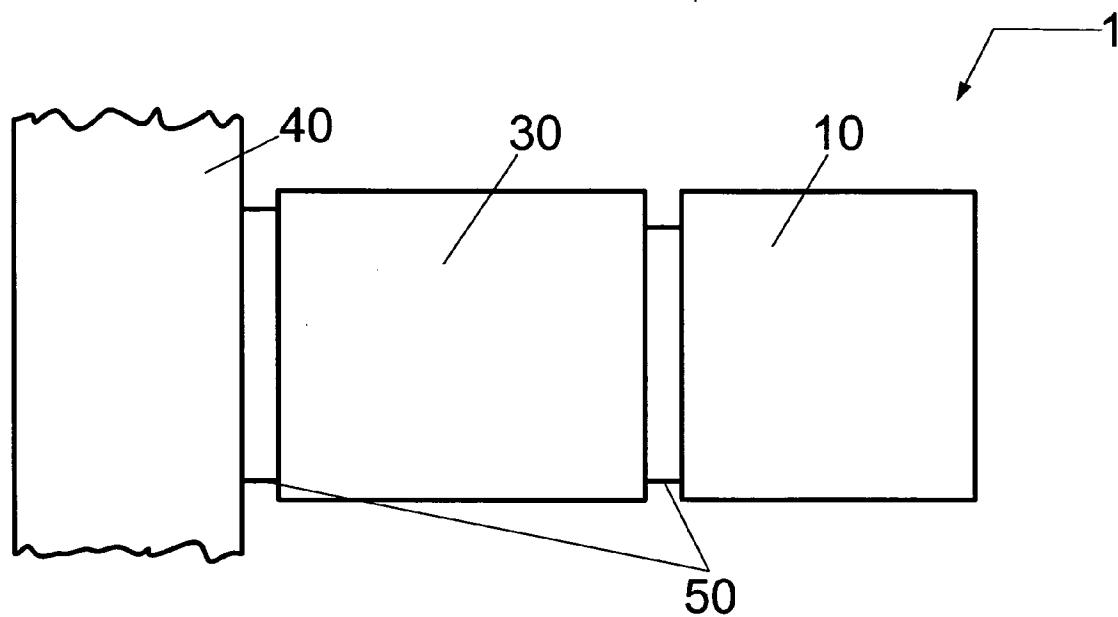
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ABSTRACT

A method and system are described for operating a processing system in order to optimize throughput. The processing system includes a process chamber having a lower chamber portion configured to chemically treat a substrate and an upper chamber portion configured to thermally treat the substrate, and a substrate lifting assembly configured to transport the substrate between the lower chamber portion and the upper chamber portion.





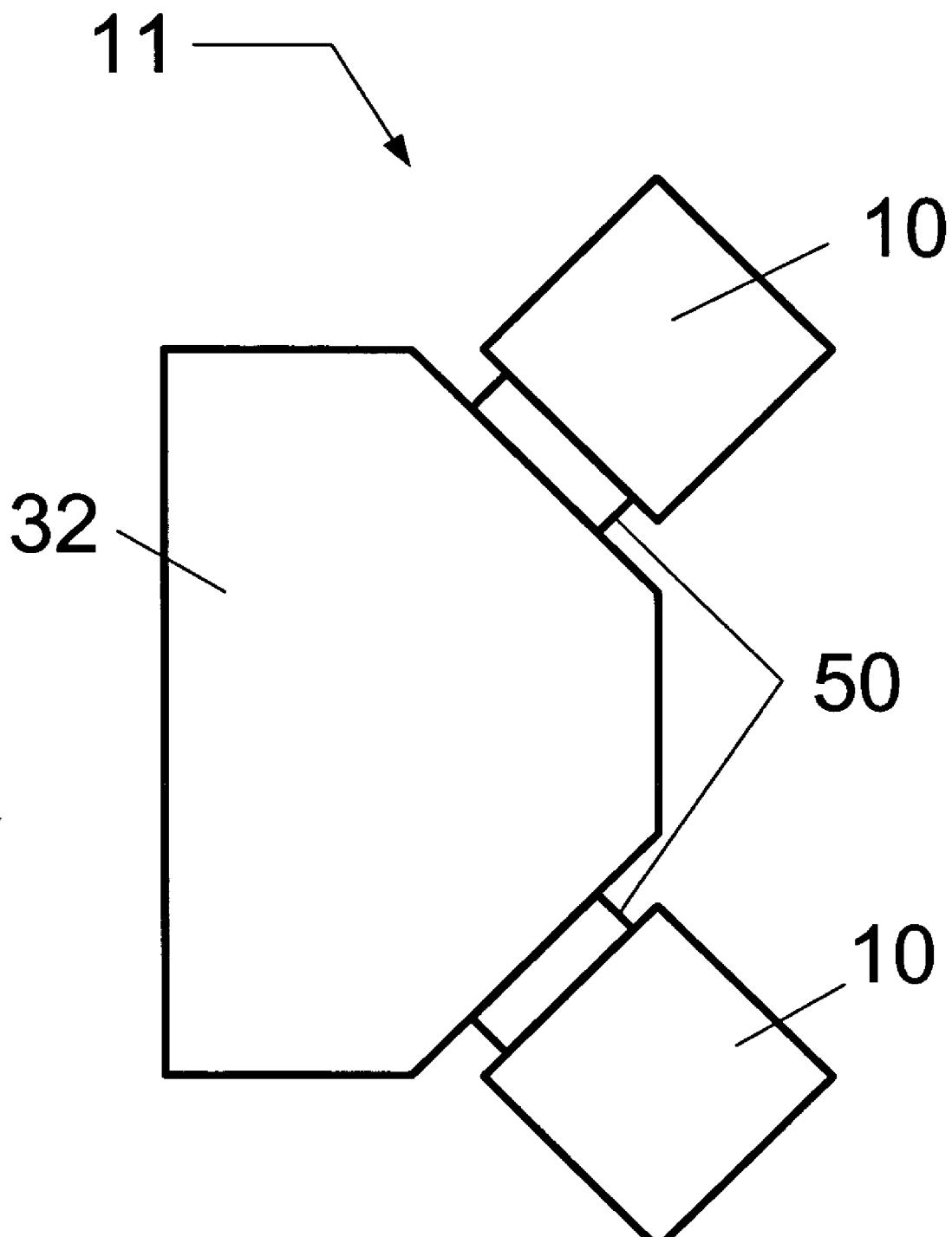


FIG. 1C

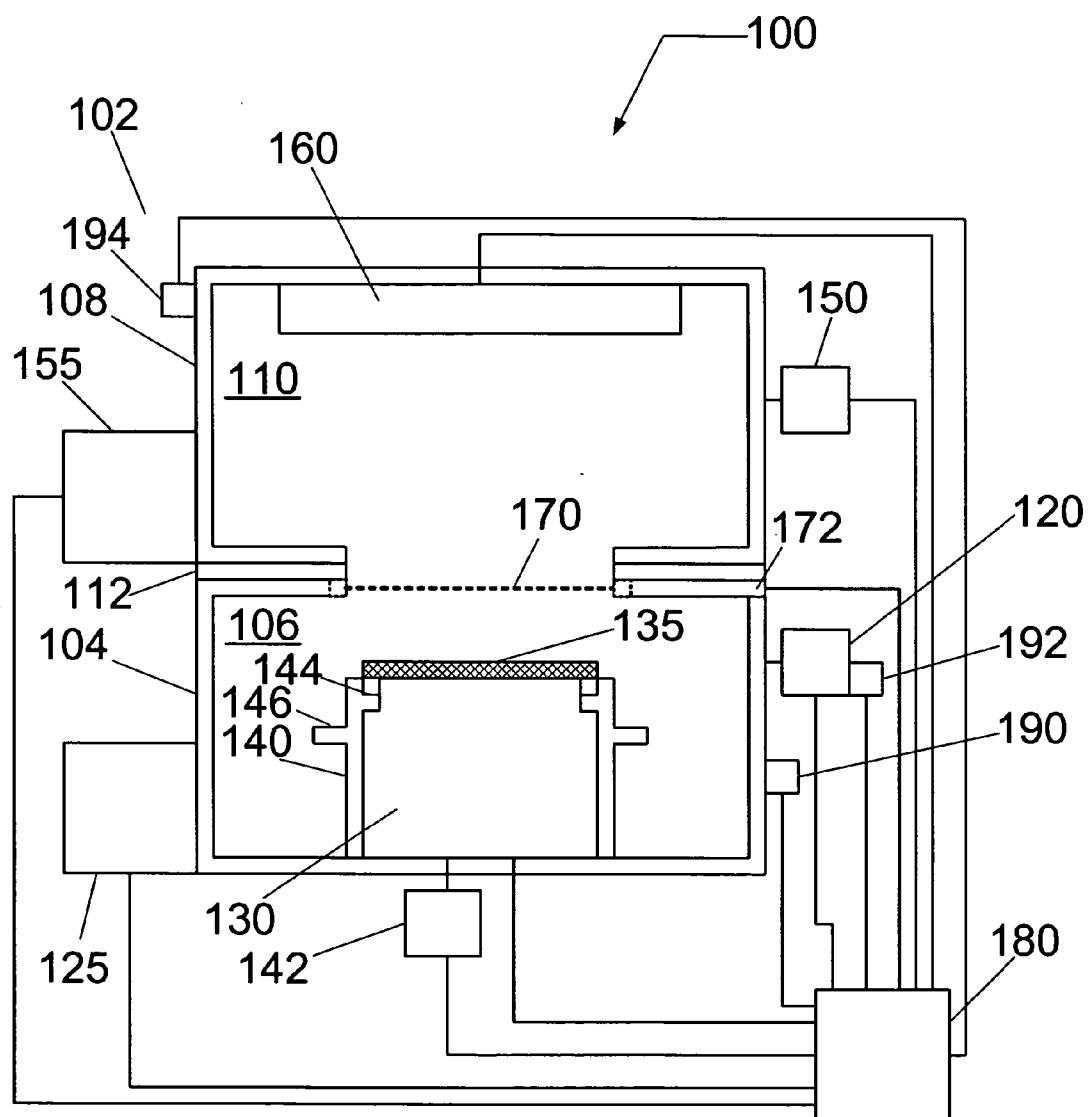


FIG. 2A

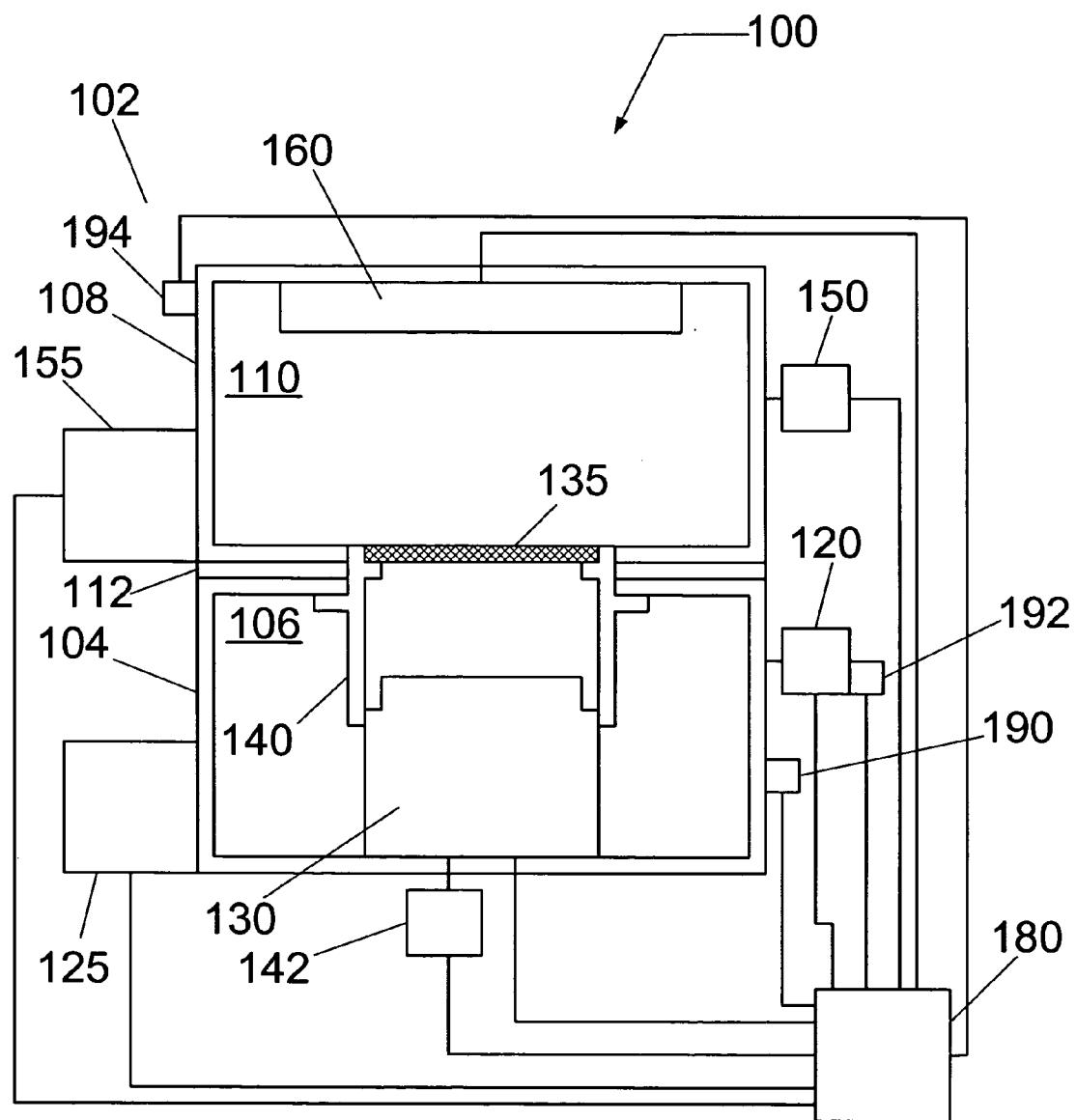


FIG. 2B

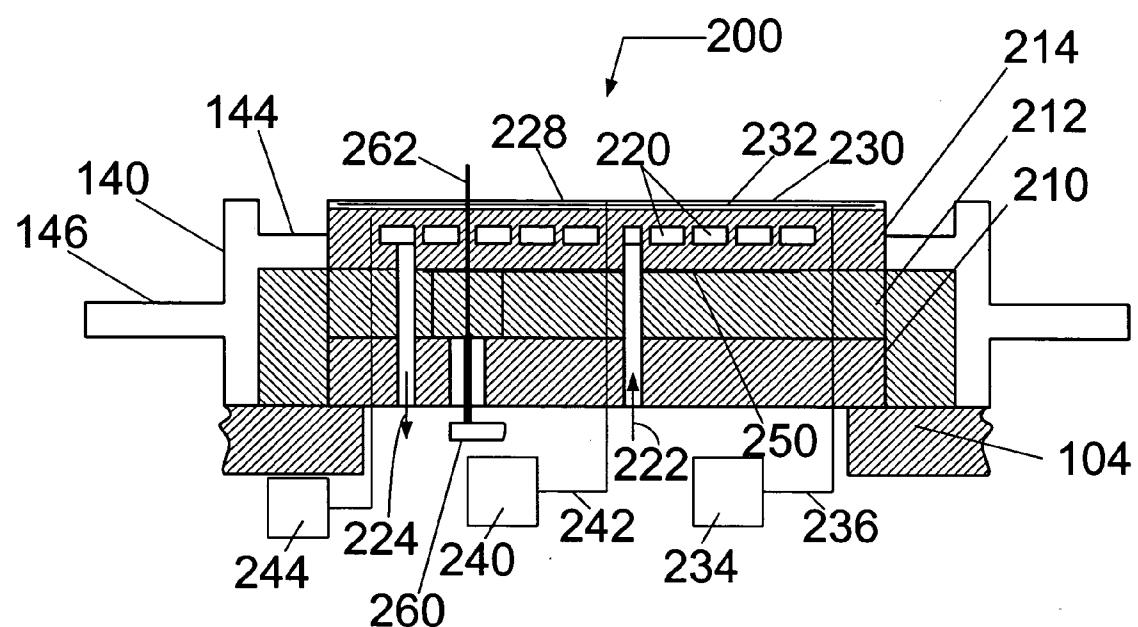


FIG. 3

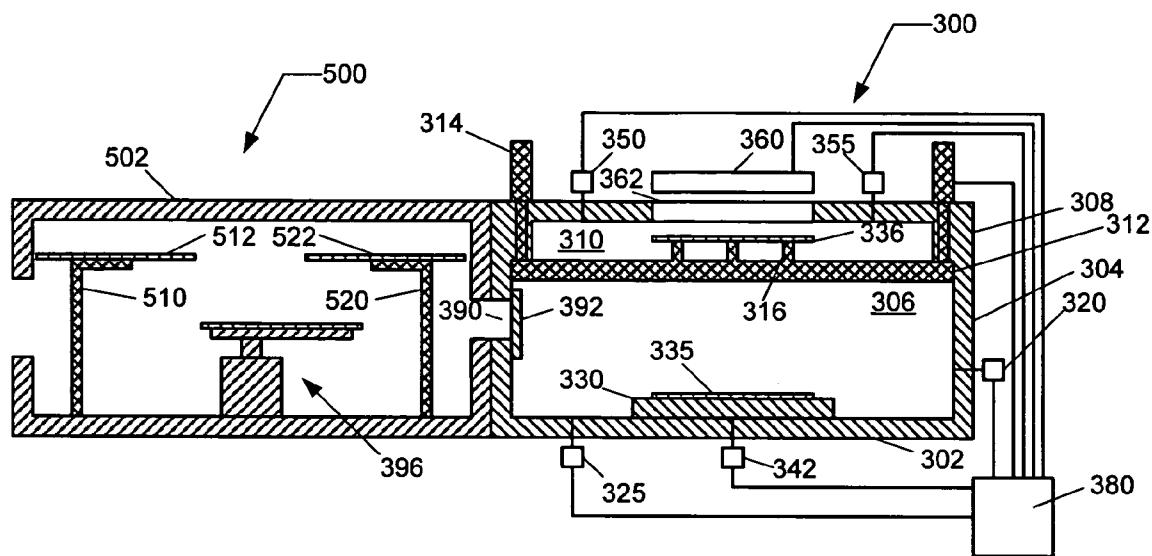


FIG. 4A

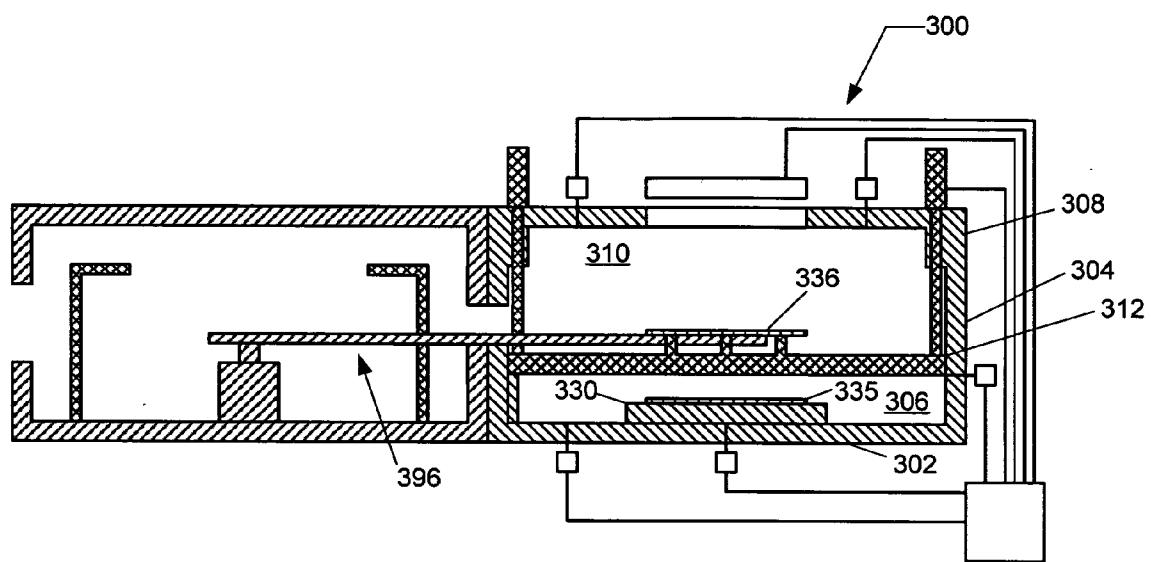


FIG. 4B

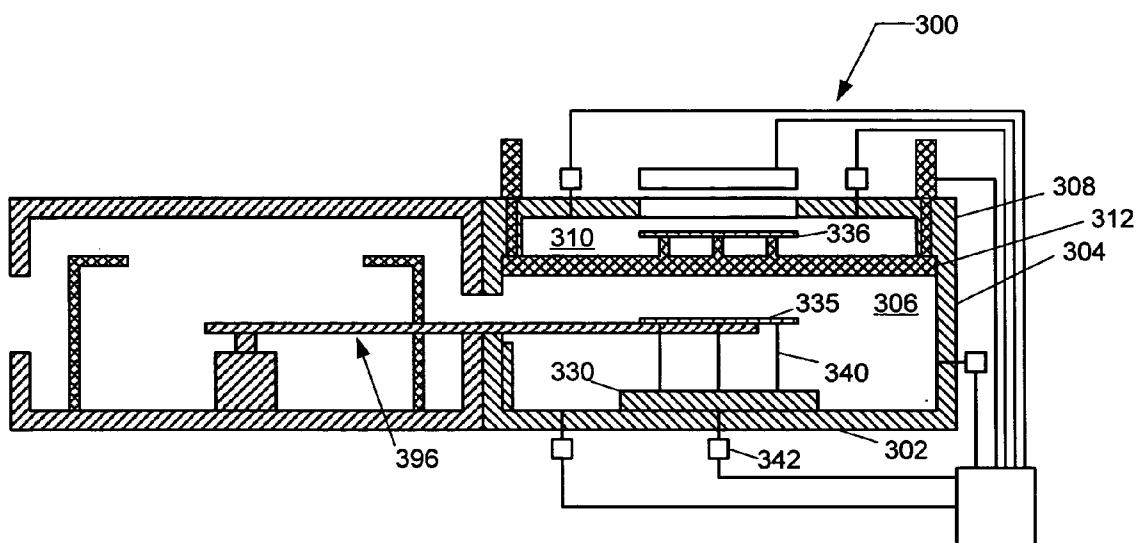


FIG. 4C

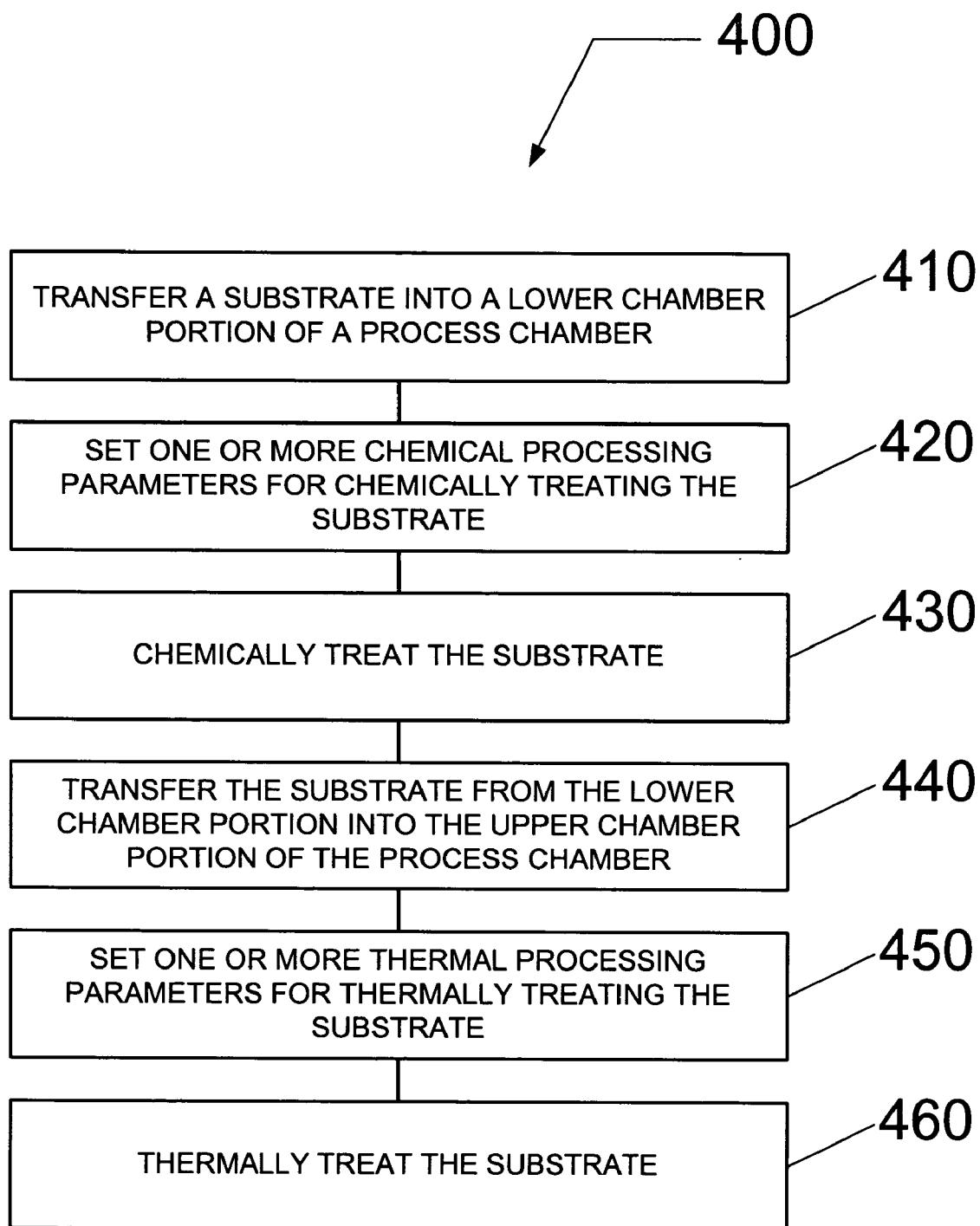


FIG. 5

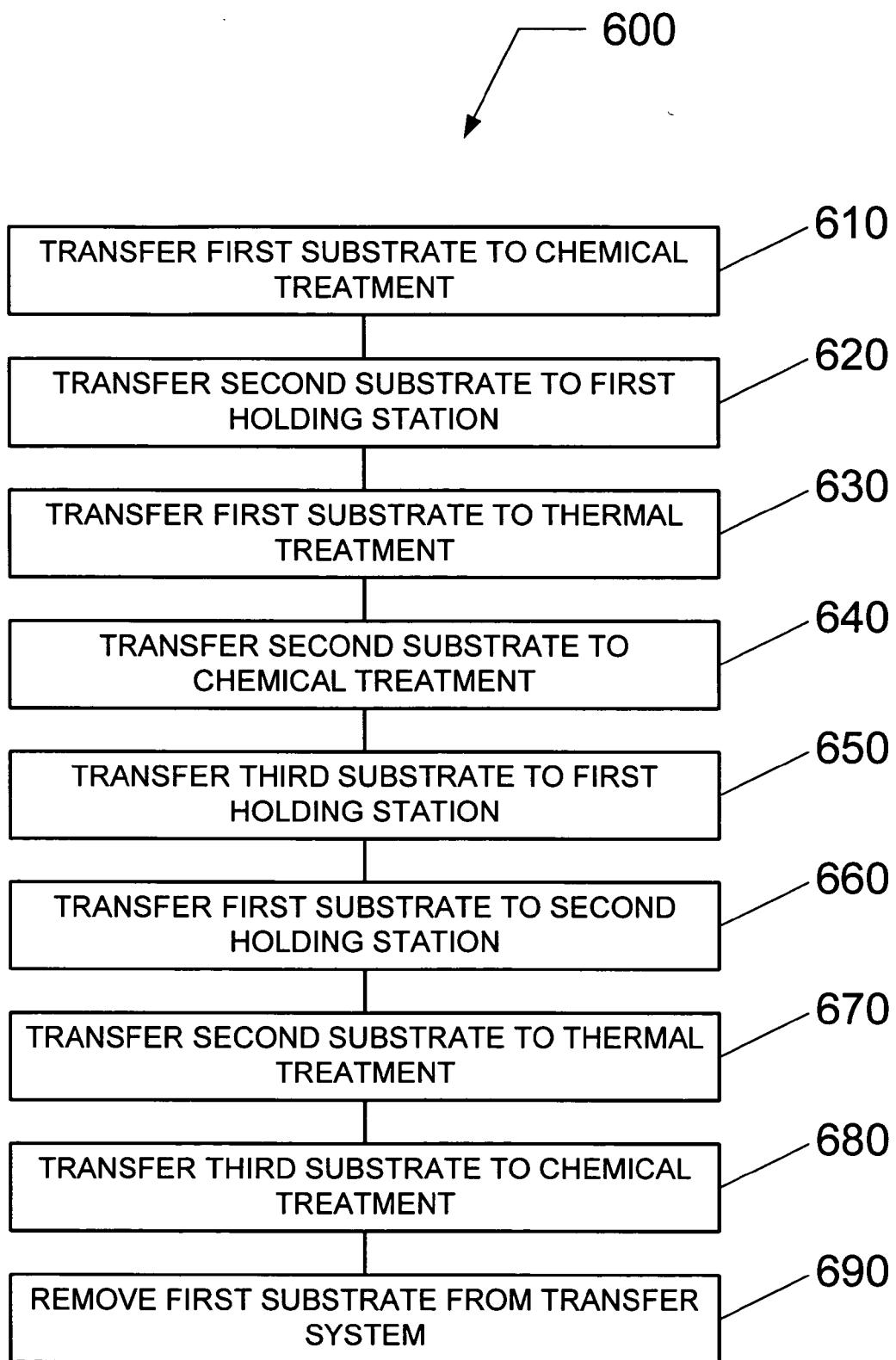


FIG. 6

METHOD OF OPERATING A PROCESSING SYSTEM FOR TREATING A SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to pending U.S. patent application Ser. No. 10/705,201, entitled "Processing System and Method For Treating a Substrate", filed on Nov. 12, 2003; pending U.S. patent application Ser. No. 10/705,200, entitled "Processing System and Method For Chemically Treating a Substrate", filed on Nov. 12, 2003; pending U.S. patent application Ser. No. 10/704,969, entitled "Processing System and Method For Thermally Treating a Substrate", filed on Nov. 12, 2003; pending U.S. patent application Ser. No. 10/705,397, entitled "Method and Apparatus For Thermally Insulating Adjacent Temperature Controlled Chambers", filed on Nov. 12, 2003; pending U.S. patent application Ser. No. 10/812,347, entitled "Processing System and Method For Treating a Substrate", filed on Mar. 30, 2004; and co-pending U.S. patent application Ser. No. 10/_____, entitled "Processing System and Method for Treating a Substrate", filed on even date herewith. The entire contents of all of those applications are herein incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a method of operating a processing system for treating a substrate, and more particularly to a method of operating a processing system configured for chemical and thermal treatment of a substrate.

[0004] 2. Description of the Related Art

[0005] During semiconductor processing, a (dry) plasma etch process can be utilized to remove or etch material along fine lines or within vias or contacts patterned on a silicon substrate. The plasma etch process generally involves positioning a semiconductor substrate with an overlying patterned, protective layer, for example a photoresist layer, in a processing chamber. Once the substrate is positioned within the chamber, an ionizable, dissociative gas mixture is introduced within the chamber at a pre-specified flow rate, while a vacuum pump is throttled to achieve an ambient process pressure. Thereafter, a plasma is formed when a fraction of the gas species present are ionized by electrons heated via the transfer of radio frequency (RF) power either inductively or capacitively, or microwave power using, for example, electron cyclotron resonance (ECR).

[0006] Moreover, the heated electrons serve to dissociate some species of the ambient gas species and create reactant specie(s) suitable for the exposed surface etch chemistry. Once the plasma is formed, selected surfaces of the substrate are etched by the plasma. The process is adjusted to achieve appropriate conditions, including an appropriate concentration of desirable reactant and ion populations to etch various features (e.g., trenches, vias, contacts, gates, etc.) in the selected regions of the substrate. Such substrate materials where etching is required include silicon dioxide (SiO_2), low-k dielectric materials, poly-silicon, and silicon nitride.

[0007] During material processing, etching such features generally comprises the transfer of a pattern formed within a mask layer to the underlying film within which the

respective features are formed. The mask can, for example, comprise a light-sensitive material such as (negative or positive) photo-resist, multiple layers including such layers as photo-resist and an anti-reflective coating (ARC), or a hard mask formed from the transfer of a pattern in a first layer, such as photo-resist, to the underlying hard mask layer.

SUMMARY OF THE INVENTION

[0008] The present invention relates to a system and method for treating a substrate, and to a system and method for chemically and thermally treating a substrate.

[0009] In one embodiment, a method of operating a processing system for treating substrates is described comprising: transferring a first substrate into a lower portion of a processing system configured to perform a chemical treatment using a transfer system coupled to the processing system; transferring the first substrate from the lower portion of the processing system to an upper portion of the processing system configured to perform a thermal treatment using the transfer system; and removing the first substrate from the processing system and the transfer system.

[0010] In another embodiment, a method of operating a processing system for treating substrates is described comprising: transferring a first substrate into a lower portion of the processing system using a transfer system coupled to the processing system; processing the first substrate in the lower portion; while processing the first substrate in the lower portion, transferring a second substrate to a first holding station in the transfer system; transferring the first substrate using the transfer system from the lower portion to an upper portion of the processing system; processing the first substrate in the upper portion; while processing the first substrate in the upper portion, transferring the second substrate into the lower portion; processing the second substrate in the lower portion; while processing the second substrate in the lower portion, transferring a third substrate to the first holding station; while processing the second substrate in the lower portion, transferring the first substrate to a second holding station in the transfer system; transferring the second substrate using the transfer system from the lower portion to the upper portion of the processing system; processing the second substrate in the upper portion; transferring the third substrate into the lower portion; processing the third substrate in the lower portion; and removing the first substrate from the processing system and the transfer system.

[0011] In another embodiment, a system for chemically treating and thermally treating a substrate is described comprising: a processing system having a process chamber including a lower chamber portion that chemically alters exposed surface layers on the substrate, and an upper chamber portion that thermally treats the chemically altered surface layers on the substrate; a substrate lifting assembly coupled to the process chamber, configured to transport the substrate between the lower chamber portion and the upper portion; and a controller coupled to the processing system and the substrate lifting assembly, and configured to optimize the throughput of a plurality of substrates through the upper portion and the lower portion of the processing system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

[0013] **FIG. 1A** illustrates a schematic representation of a plan view of a transfer system for a processing system according to an embodiment of the invention;

[0014] **FIG. 1B** illustrates a schematic representation of a side view of a transfer system for a processing system according to another embodiment of the invention;

[0015] **FIG. 1C** illustrates a schematic representation of a plan view of a transfer system for a processing system according to another embodiment of the invention;

[0016] **FIGS. 2A and 2B** show a schematic cross-sectional view of a processing system according to an embodiment of the invention;

[0017] **FIG. 3** shows a schematic cross-sectional view of a substrate holder according to an embodiment of the invention;

[0018] **FIGS. 4A, 4B, and 4C** show a schematic cross-sectional view of a processing system according to another embodiment of the invention;

[0019] **FIG. 5** shows a flow diagram for processing a substrate; and

[0020] **FIG. 6** illustrates a method of operating a processing system according to an embodiment of the invention.

DETAILED DESCRIPTION OF SEVERAL EMBODIMENTS

[0021] In material processing methodologies, pattern etching comprises the application of a thin layer of light-sensitive material, such as photoresist, to an upper surface of a substrate, that is subsequently patterned in order to provide a mask for transferring this pattern to the underlying thin film during etching. The patterning of the light-sensitive material generally involves exposure by a radiation source through a reticle (and associated optics) of the light-sensitive material using, for example, a micro-lithography system, followed by the removal of the irradiated regions of the light-sensitive material (as in the case of positive photoresist), or non-irradiated regions (as in the case of negative resist) using a developing solvent.

[0022] Additionally, multi-layer and hard masks can be implemented for etching features in a thin film. For example, when etching features in a thin film using a hard mask, the mask pattern in the light-sensitive layer is transferred to the hard mask layer using a separate etch step preceding the main etch step for the thin film. The hard mask can, for example, be selected from several materials for silicon processing, including, but not limited to, silicon dioxide (SiO_2), silicon nitride (Si_3N_4), or carbon.

[0023] In order to reduce the feature size formed in the thin film, the hard mask can be trimmed laterally using, for example, a two-step process involving a chemical treatment of the exposed surfaces of the hard mask layer in order to alter the surface chemistry of the hard mask layer, and a post

treatment of the exposed surfaces of the hard mask layer in order to desorb the altered surface chemistry.

[0024] According to one embodiment, **FIGS. 1A and 1B** present a plan view and a side view, respectively, of a processing system **1** for processing a substrate using, for example, mask layer trimming. The processing system **1** comprises a treatment system **10** having a lower chamber portion **12** and an upper chamber portion **14** (see **FIG. 1B**). For example, the treatment system **10** can be configured to perform a chemical treatment of a substrate in the lower chamber portion **12**, and a thermal treatment of the substrate in the upper chamber portion **14**. Also, as illustrated in **FIG. 1A**, a transfer system **30** can be coupled to the treatment system **10** in order to transfer substrates into and out of the treatment system **10**, and exchange substrates with a multi-element manufacturing system **40**.

[0025] The treatment system **10**, and the transfer system **30** can, for example, comprise a processing element within the multi-element manufacturing system **40**. For example, the multi-element manufacturing system **40** can permit the transfer of substrates to and from processing elements including such devices as etch systems, deposition systems, coating systems, patterning systems, metrology systems, etc. In order to isolate the processes occurring in the treatment system from the transfer system **30**, an isolation assembly **50** can be utilized to couple each system. For instance, the isolation assembly **50** can comprise at least one of a thermal insulation assembly to provide thermal isolation, and a gate valve assembly to provide vacuum isolation.

[0026] Alternately, in another embodiment, **FIG. 1C** presents a processing system **11** for processing a substrate using a process such as mask layer trimming. The processing system **11** comprises one or more treatment systems **10** having a lower chamber portion **12** and an upper chamber portion **14** (see **FIG. 1B**). However, the treatment systems **10** are coupled to a transfer system **32** in a cluster-tool arrangement. In order to isolate the processes occurring in the treatment system from the transfer system **32**, an isolation assembly **50** can be utilized to couple each system. For instance, the isolation assembly **50** can comprise at least one of a thermal insulation assembly to provide thermal isolation, and a gate valve assembly to provide vacuum isolation.

[0027] Referring now to **FIGS. 2A and 2B**, a processing system **100** for performing chemical treatment and thermal treatment of a substrate is presented. Processing system **100** comprises a process chamber **102** having a lower chamber portion **104** for chemically treating a substrate **135** in a chemical treatment space **106**, and an upper chamber portion **108** for thermally treating the substrate **135** in a thermal treatment space **110**. The lower chamber portion **104** can be temperature-controlled, and the upper chamber portion **108** can be temperature-controlled. The lower chamber portion **104** and upper chamber portion **108** can be thermally insulated from one another using a thermal insulation assembly **112**. Additionally, the lower chamber portion **104** and the upper chamber portion **108** can be vacuum isolated from one another using an optional vacuum isolation assembly, such as gate valve **170** and valve drive system **172** (as shown in **FIG. 2A**).

[0028] Referring now to **FIG. 2A**, the lower chamber portion **104** includes a substrate holder **130** configured to support substrate **135**. The substrate holder **130** can be

configured to heat, cool, or control the temperature of substrate 135. Coupled to substrate holder 130, a substrate lifting assembly 140 is configured to raise and lower substrate 135 from the upper surface of substrate holder 130 using translation drive system 142. Additionally, the lower chamber portion 104 further includes a gas injection system 120 for introducing one or more process gases to the chemical treatment space 106 in the lower chamber portion 104 in order to chemically treat substrate 135, and a pumping system 125 for evacuating the lower chamber portion 104.

[0029] Referring still to FIG. 2A, the upper chamber portion 108 includes a heating assembly 160, such as a radiant heating assembly to be discussed in greater detail below, for elevating the temperature of substrate 135. Additionally, the upper chamber portion 108 further includes a gas purge system 150 for introducing purge gas to the thermal treatment space 110 in the upper chamber portion 108, and a pumping system 155 for evacuating the upper chamber portion 108.

[0030] Additionally, as shown in FIGS. 2A and 2B, the processing system 100 further includes a controller 180 coupled to the processing system, and configured to control the processing system.

[0031] Additionally, the processing system 100 further includes a transfer opening (not shown) through which a substrate can be transferred. During processing, the transfer opening can be sealed closed using a gate valve assembly in order to prevent, for example, contamination between the processing system and other systems, such as a transfer system. For example, although not shown, the transfer opening can be formed in the lower chamber portion 104 of process chamber 102.

[0032] As described above, a film layer on substrate 135 can be trimmed using, for example, a two-step process involving a chemical treatment of the exposed surfaces of the film layer in order to alter the surface chemistry of the film layer, and a thermal treatment of the exposed surfaces of the film layer in order to desorb the altered surface chemistry. As illustrated in FIG. 1A, substrate lifting assembly 140 can be lowered to its chemical treatment position, wherein substrate 135 is coupled to the upper surface of substrate holder 130. During this period of time, the lower chamber portion 104 can be thermally insulated from the upper chamber portion 108 via thermal insulation assembly 112, and it can optionally be vacuum isolated from the upper chamber portion 108 via gate valve 170. One or more process gases can be introduced for chemically treating substrate 135 using gas injection system 120, and the lower chamber portion 104 can be evacuated using pumping system 125. Once the chemical treatment process is complete, the substrate lifting assembly 140 can be elevated to its thermal treatment position as shown in FIG. 2B. Therein, the substrate lifting assembly captures substrate 135 with substrate lip 144, raises substrate 135 from the lower chamber portion 104 to the upper chamber portion 108, and isolates the lower chamber portion 104 from the upper chamber portion 108 via chamber lip 146.

[0033] As illustrated in FIG. 3, the lower chamber portion 104 comprises a substrate holder 130 configured to provide several operational functions for thermally controlling and processing substrate 135. The substrate holder 130 can

comprise an electrostatic clamping system (or mechanical clamping system) in order to electrically (or mechanically) clamp substrate 135 to the substrate holder 130. Furthermore, substrate holder 130 can, for example, further include a cooling system having a re-circulating coolant flow that receives heat from substrate holder 130 and transfers heat to a heat exchanger system (not shown), or when heating, transfers heat from the heat exchanger system.

[0034] Moreover, a heat transfer gas can, for example, be delivered to the back-side of substrate 135 via a backside gas system to improve the gas-gap thermal conductance between substrate 135 and substrate holder 130. For instance, the heat transfer gas supplied to the back-side of substrate 135 can comprise an inert gas such as helium, argon, xenon, krypton, a process gas, or other gas such as oxygen, nitrogen, or hydrogen. Such a system can be utilized when temperature control of the substrate is required at elevated or reduced temperatures. For example, the backside gas system can comprise a multi-zone gas distribution system such as a two-zone (center-edge) system, wherein the back-side gas gap pressure can be independently varied between the center and the edge of substrate 135. In other embodiments, heating/cooling elements, such as resistive heating elements, or thermo-electric heaters/coolers can be included in the substrate holder 130, as well as the chamber wall of the lower chamber portion 104 of process chamber 102.

[0035] For example, FIG. 3 presents a temperature controlled substrate holder 200 for performing several of the above-identified functions. Substrate holder 200 comprises a chamber mating component 210 coupled to a lower wall of the lower chamber portion 104 of process chamber 102, an insulating component 212 coupled to the chamber mating component 210, and a temperature control component 214 coupled to the insulating component 212. The chamber mating and temperature control components 210, 214 can, for example, be fabricated from an electrically and thermally conducting material such as aluminum, stainless steel, nickel, etc. The insulating component 212 can, for example, be fabricated from a thermally-resistant material having a relatively lower thermal conductivity such as quartz, alumina, Teflon, etc.

[0036] The temperature control component 214 can comprise temperature control elements such as cooling channels, heating channels, resistive heating elements, or thermoelectric elements. For example, as illustrated in FIG. 3, the temperature control component 214 comprises a coolant channel 220 having a coolant inlet 222 and a coolant outlet 224. The coolant channel 220 can, for example, be a spiral passage within the temperature control component 214 that permits a flow rate of coolant, such as water, Fluorinert, Galden HT-135, etc., in order to provide conductive-convective cooling of the temperature control component 214. Alternately, the coolant channel 220 can be zoned into two or more coolant zones, wherein each zone is independently controlled.

[0037] Moreover, the temperature control component 214 can comprise an array of thermo-electric elements capable of heating or cooling a substrate depending upon the direction of electrical current flow through the respective elements. An exemplary thermo-electric element is one commercially available from Advanced Thermoelectric, Model

ST-127-1.4-8.5M (a 40 mm by 40 mm by 3.4 mm thermoelectric device capable of a maximum heat transfer power of 72 W).

[0038] Additionally, the substrate holder 200 can further comprise an electrostatic clamp (ESC) 228 comprising a ceramic layer 230, a clamping electrode 232 embedded therein, and a high-voltage (HV) DC voltage supply 234 coupled to the clamping electrode 232 using an electrical connection 236. The ESC 228 can, for example, be monopolar, or bi-polar. The design and implementation of such a clamp is well known to those skilled in the art of electrostatic clamping systems.

[0039] Additionally, the substrate holder 200 can further comprise a back-side gas supply system 240 for supplying a heat transfer gas, such as an inert gas including, but not limited to, helium, argon, xenon, krypton, a process gas, or other gas including oxygen, nitrogen, or hydrogen, to the backside of substrate 135 through at least one gas supply line 242, and at least one of a plurality of orifices and channels. The backside gas supply system 240 can, for example, be a multi-zone supply system such as a two-zone (center-edge) system, wherein the backside pressure can be varied radially from the center to the edge.

[0040] The insulating component 212 can further comprise a thermal insulation gap 250 in order to provide additional thermal insulation between the temperature control component 214 and the underlying mating component 210. The thermal insulation gap 250 can be evacuated using a pumping system (not shown) or a vacuum line as part of vacuum pumping system 250, and/or coupled to a gas supply (not shown) in order to vary its thermal conductivity. The gas supply can, for example, be the backside gas supply 340 utilized to couple heat transfer gas to the back-side of the substrate 135.

[0041] The mating component 210 can further comprise a lift pin assembly 260 capable of raising and lowering three or more lift pins 262 in order to vertically translate substrate 135 to and from an upper surface of the substrate holder 200 and a transfer plane in the processing system.

[0042] Each component 210, 212, and 214 further comprises fastening devices (such as bolts and tapped holes) in order to affix one component to another, and to affix the substrate holder 200 to the lower chamber portion 104. Furthermore, each component 210, 212, and 214 facilitates the passage of the above-described utilities to the respective component, and vacuum seals, such as elastomer O-rings, are utilized where necessary to preserve the vacuum integrity of the processing system.

[0043] The temperature of the temperature-controlled substrate holder 200 can be monitored using a temperature sensing device 244 such as a thermocouple (e.g. a K-type thermocouple, Pt sensor, etc.). Furthermore, a controller can utilize the temperature measurement as feedback to the chemical treatment process in order to control the temperature of substrate holder 200. For example, at least one of a fluid flow rate, fluid temperature, heat transfer gas type, heat transfer gas pressure, clamping force, resistive heater element current or voltage, and thermoelectric device current or polarity, etc. can be adjusted in order to affect a change in the temperature of substrate holder 200 and/or the temperature of the substrate 135.

[0044] Referring again to FIGS. 2A and 2B, the lower chamber portion 104 comprises gas injection system 120. The gas injection system 120 can include one or more gas injection orifices, one or more gas injection plenums for supplying process gas to the one or more gas injection orifices, and a gas supply system. For example, the gas injection system 120 can be configured to supply process gas comprising one or more gases. The process gas can, for example, comprise a variety of gases including, but not limited to, NH₃, HF, H₂, O₂, CO, CO₂, Ar, He, etc.

[0045] Referring again to FIGS. 2A and 2B, the lower chamber portion 104 can include a temperature controlled wall that is maintained at an elevated temperature. For example, a wall heating element can be coupled to a lower wall temperature control unit 190, and the wall heating element can be configured to couple to the lower chamber portion 104. The heating element can, for example, comprise a resistive heater element such as a tungsten filament, nickel-chromium alloy filament, aluminum-iron alloy filament, aluminum nitride filament, etc. Examples of commercially available materials to fabricate resistive heating elements include Kanthal, Nikrothal, and Akrothal, which are registered trademark names for metal alloys produced by Kanthal Corporation of Bethel, Conn. The Kanthal family includes ferritic alloys (FeCrAl) and the Nikrothal family includes austenitic alloys (NiCr, NiCrFe).

[0046] When an electrical current flows through the filament, power is dissipated as heat, and, therefore, the lower wall temperature control unit 190 can, for example, comprise a controllable DC power supply. For example, a wall heating element can comprise at least one Firerod cartridge heater commercially available from Watlow (1310 Kingsland Dr., Batavia, Ill., 60510). A cooling element can also be employed in the lower chamber portion. The temperature of the lower chamber portion 104 can be monitored using a temperature-sensing device such as a thermocouple (e.g., a K-type thermocouple, Pt sensor, etc.). Furthermore, a controller can utilize the temperature measurement as feedback to the lower wall temperature control unit 190 in order to control the temperature of the lower chamber portion 104.

[0047] Additionally, referring to FIGS. 2A and 2B, the gas injection system 120 of lower chamber portion 104 can further comprise a temperature controlled gas distribution system that can be maintained at any selected temperature. For example, a gas distribution heating element can be coupled to a gas distribution system temperature control unit 192, and the gas distribution heating element can be configured to couple to the gas distribution system 120. The heating element can, for example, comprise a resistive heater element such as a tungsten, nickel-chromium alloy, aluminum-iron alloy, aluminum nitride, etc., filament. Examples of commercially available materials to fabricate resistive heating elements include Kanthal, Nikrothal, and Akrothal, which are registered trademark names for metal alloys produced by Kanthal Corporation of Bethel, Conn. The Kanthal family includes ferritic alloys (FeCrAl) and the Nikrothal family includes austenitic alloys (NiCr, NiCrFe). When an electrical current flows through the filament, power is dissipated as heat, and, therefore, the gas distribution system temperature control unit 192 can, for example, comprise a controllable DC power supply. For example, gas distribution heating element can comprise a silicone rubber

heater (about 1 mm thick) capable of about 1400 W (or power density of about 5 W/in²). The temperature of the gas distribution system 120 can be monitored using a temperature-sensing device such as a thermocouple (e.g. a K-type thermocouple, Pt sensor, etc.). Furthermore, a controller can utilize the temperature measurement as feedback to the gas distribution system temperature control unit 192 in order to control the temperature of the gas distribution system 120. Alternatively, or in addition, cooling elements can be employed in any of the embodiments.

[0048] Additionally, referring to **FIGS. 2A and 2B**, processing system 100 includes heating assembly 160 coupled to the upper chamber portion 108, and configured to heat substrate 135 when it is in a raised position (thermal treatment position), as shown in **FIG. 2B**. As described earlier, the heating assembly 160 can include a radiant heating assembly and, more specifically, it can include an array of radiant lamps. For example, the array of lamps can include an array of tungsten-halogen lamps. When turned on, the array of radiant lamps can elevate the temperature of substrate 135 to a point (e.g., about 100 to about 150° C.) sufficient to desorb the altered surface chemistry.

[0049] Additionally, referring again to **FIGS. 2A and 2B**, the upper chamber portion 108 comprises gas purge system 150. The gas purge system 150 can include one or more gas injection orifices, one or more gas injection plenums for supplying purge gas to the one or more gas injection orifices, and a gas supply system. For example, the gas purge system 150 can be configured to supply purge gas comprising one or more gases. The purge gas can, for example, include N₂, or a noble gas (i.e., He, Ne, Ar, Kr, Xe, Rn). Furthermore, the gas purge system can be temperature controlled.

[0050] Additionally, referring to **FIGS. 2A and 2B**, the upper chamber portion 108 can include a temperature-controlled wall that is maintained at an elevated temperature. For example, a wall heating element can be coupled to an upper wall temperature control unit 194, and the wall heating element can be configured to couple to the upper chamber portion 108. The heating element can, for example, comprise a resistive heater element such as a tungsten, nickel-chromium alloy, aluminum-iron alloy, aluminum nitride, etc., filament. Examples of commercially available materials to fabricate resistive heating elements include Kanthal, Nikrothal, and Akrothal, which are registered trademark names for metal alloys produced by Kanthal Corporation of Bethel, Conn. The Kanthal family includes ferritic alloys (FeCrAl) and the Nikrothal family includes austenitic alloys (NiCr, NiCrFe).

[0051] When an electrical current flows through the filament, power is dissipated as heat, and, therefore, the upper wall temperature control unit 194 can, for example, comprise a controllable DC power supply. For example, a wall heating element can comprise at least one Firerod cartridge heater commercially available from Watlow (1310 Kingsland Dr., Batavia, Ill., 60510). A cooling element can also be employed in the lower chamber portion. The temperature of the upper chamber portion 108 can be monitored using a temperature-sensing device such as a thermocouple (e.g., a K-type thermocouple, Pt sensor, etc.). Furthermore, a controller can utilize the temperature measurement as feedback to the upper wall temperature control unit 194 in order to control the temperature of the upper chamber portion 108.

[0052] Referring still to **FIGS. 2A and 2B**, pumping systems 125 and 155 can, for example, include a turbo-molecular vacuum pumps (TMP) capable of a pumping speeds of up to about 5000 liters per second (and greater) and a gate valve for throttling the chamber pressure. In conventional vacuum processing devices, about 1000 to about 3000 liter per second TMP is generally employed. TMPs are useful for low pressure processing, typically less than about 50 mTorr. For high pressure processing (i.e., greater than about 100 mTorr), a mechanical booster pump and dry roughing pump can be used. Furthermore, a device for monitoring chamber pressure (not shown) can be coupled to process chamber 102. The pressure measuring device can be, for example, a Type 628B Baratron absolute capacitance manometer commercially available from MKS Instruments, Inc. (Andover, Mass.).

[0053] Referring again to **FIGS. 2A and 2B**, processing system 100 includes controller 180 having a microprocessor, memory, and a digital I/O port capable of generating control voltages sufficient to communicate and activate inputs to processing system 100 as well as monitor outputs from processing system 100 such as temperature and pressure sensing devices.

[0054] Moreover, controller 180 can be coupled to and can exchange information with substrate holder 130, translation drive system 142, gas injection system 120, pumping system 125, optional (gate) valve drive system 172, lower wall temperature control unit 190, gas distribution system temperature control unit 192, upper wall temperature control unit 194, gas purge system 150, pumping system 155, and heating assembly 160. For example, a program stored in the memory can be utilized to activate the inputs to the aforementioned components of processing system 100 according to a process recipe. One example of controller 180 is a DELL PRECISION WORKSTATION 610™, available from Dell Corporation, Austin, Tex.

[0055] Controller 180 can be located locally or remotely relative to the processing system 100. For example, controller 190 can exchange data with processing system 100 using at least one of a direct connection, an intranet, and the Internet. Controller 180 can be coupled to an intranet at, for example, a customer site (i.e., a device maker, etc.), or it can be coupled to an intranet at, for example, a vendor site (i.e., an equipment manufacturer). Additionally, for example, controller 180 can be coupled to the Internet. Furthermore, another computer (i.e., controller, server, etc.) can, for example, access controller 180 to exchange data via at least one of a direct connection, an intranet, the Internet, or a combination thereof.

[0056] Furthermore, one or more surfaces of the components comprising the lower chamber portion 104 and the upper chamber portion 108 can be coated with a protective barrier. The protective barrier can comprise at least one of Kapton, Teflon, surface anodization, ceramic spray coating such as alumina, yttria, etc., plasma electrolytic oxidation, etc.

[0057] Referring now to **FIGS. 4A, 4B, and 4C**, a processing system 300 for performing chemical treatment and thermal treatment of a substrate is presented according to another embodiment. Processing system 300 comprises a process chamber 302 having a lower chamber portion 304 for chemically treating a substrate 335 in a chemical treat-

ment space 306, and an upper chamber portion 308 for thermally treating a substrate 336 in a thermal treatment space 310. The lower chamber portion 304 can be temperature-controlled, and the upper chamber portion 308 can be temperature-controlled. The lower chamber portion 304 and upper chamber portion 308 can be isolated from one another using an isolation assembly 312. Isolation assembly 312 is configured to translate vertically upward and downward using translation drive assembly 314. The isolation assembly 312 further includes support elements 316 for supporting substrate 336.

[0058] Referring now to **FIG. 4A**, the lower chamber portion 304 includes a substrate holder 330 configured to support substrate 335. The substrate holder 330 can be configured to heat, cool, or control the temperature of substrate 335. Coupled to substrate holder 330, a substrate lift-pin assembly 340 (see **FIG. 4C**) is configured to raise and lower substrate 335 from the upper surface of substrate holder 330 using translation drive system 342. Additionally, the lower chamber portion 304 further includes a gas injection system 320 for introducing one or more process gases to the chemical treatment space 306 in the lower chamber portion 304 in order to chemically treat substrate 335, and a pumping system 325 for evacuating the lower chamber portion 304.

[0059] Referring still to **FIG. 4A**, the upper chamber portion 308 includes a heating assembly 360 and thermal window 362, such as a radiant heating assembly, for elevating the temperature of substrate 336. Additionally, the upper chamber portion 308 further includes a gas purge system 350 for introducing purge gas to the thermal treatment space 310 in the upper chamber portion 308, and a pumping system 355 for evacuating the upper chamber portion 308.

[0060] Additionally, as shown in **FIGS. 4A, 4B**, and 4C, the processing system 300 further includes a controller 380 coupled to the processing system, and configured to control the processing system. The controller can be similar to that described above.

[0061] Additionally, the processing system 300 further includes a transfer opening 390 through which a substrate can be transferred via a substrate transfer assembly 396, when a gate valve assembly 392 is open. During processing, the transfer opening 390 is sealed closed using gate valve assembly 392 in order to prevent, for example, contamination between the processing system and other systems, such as a transfer system.

[0062] As shown in **FIGS. 4A and 4B**, isolation assembly 312 is configured to receive substrate 336 at a transfer plane (**FIG. 4B**), translate substrate 336 vertically upward in order to position substrate 336 proximate heating assembly 360, and seal with the upper portion 308 of process chamber 302. As shown in **FIGS. 4A and 4C**, substrate lift-pin assembly 340 is configured to receive substrate 335 at the transfer plane and translate substrate 335 vertically downward in order to position the substrate 335 on substrate holder 330.

[0063] As described above, a film layer on substrate 335 can be trimmed using, for example, a two-step process involving a chemical treatment of the exposed surfaces of the film layer in order to alter the surface chemistry of the film layer, and a thermal treatment of the exposed surfaces of the film layer in order to desorb the altered surface

chemistry. As illustrated in **FIG. 4C**, substrate lift-pin assembly 340 can receive substrate 335 and lower it to substrate holder 330 (in its chemical treatment position), wherein substrate 335 is coupled to the upper surface of substrate holder 330. During this period of time, the lower chamber portion 304 is isolated from the upper chamber portion 308. One or more process gases can be introduced for chemically treating substrate 335 using gas injection system 320, and the lower chamber portion 304 can be evacuated using pumping system 325. Once the chemical treatment process is complete, the substrate lifting assembly 340 can be elevated to the transfer plane, and substrate 335 can be removed for subsequent processing in the upper chamber portion 308. As illustrated in **FIG. 4B**, the isolation assembly 312 can receive substrate 336 and raise it to its thermal treatment position. Therein, substrate 336 is translated proximate heating assembly 360, wherein it is thermally treated in, for example, an inert atmosphere provided by gas purge system 350 and pumping system 355.

[0064] **FIG. 5** presents a method of operating the processing system 100 comprising lower chamber portion 104 and upper chamber portion 108. The method is illustrated as a flowchart 400 beginning with 410 wherein a substrate is transferred to the lower chamber portion 104 using the substrate transfer system. The substrate is received by lift pins that are housed within the substrate holder, and the substrate is lowered to the substrate holder. Thereafter, the substrate is secured to the substrate holder using a clamping system, such as an electrostatic clamping system, and a heat transfer gas is supplied to the backside of the substrate. Additionally, for example, an optional gate valve can be utilized to provide vacuum isolation between the lower chamber portion 104 and the upper chamber portion 108.

[0065] In task 420, one or more chemical processing parameters for chemical treatment of the substrate are set. For example, the one or more chemical processing parameters comprise at least one of a chemical treatment processing pressure, a chemical treatment wall temperature, a chemical treatment substrate holder temperature, a chemical treatment gas distribution system temperature, and a chemical treatment gas flow rate.

[0066] For example, one or more of the following processes may occur: 1) a controller coupled to a lower wall temperature control unit and a first temperature-sensing device is utilized to set a chemical treatment chamber temperature for the chemical treatment chamber; 2) a controller coupled to a gas injection system temperature control unit and a second temperature-sensing device is utilized to set a chemical treatment gas distribution system temperature for the chemical treatment chamber; 3) a controller coupled to at least one temperature control element and a third temperature-sensing device is utilized to set a chemical treatment substrate holder temperature; 4) a controller coupled to at least one of a temperature control element, a backside gas supply system, and a clamping system, and a fourth temperature sensing device in the substrate holder is utilized to set a chemical treatment substrate temperature; 5) a controller coupled to at least one of a vacuum pumping system, and a gas distribution system, and a pressure-sensing device is utilized to set a processing pressure within the chemical treatment chamber; and/or 6) the mass flow

rates of the one or more process gases are set by a controller coupled to the one or more mass flow controllers within the gas distribution system.

[0067] In task 430, the substrate is chemically treated under the conditions set forth in task 420 for a first period of time. The first period of time can range from about 10 to about 480 seconds, for example.

[0068] In task 440, the substrate is transferred from the lower chamber portion 104 to the upper chamber portion 108 via a substrate lifting assembly. For example, the substrate lifting assembly can be as shown in FIGS. 2A and 2B, or as shown in FIGS. 4A, 4B and 4C wherein it includes motions associated with a combination of a substrate lift-pin assembly, a substrate transfer assembly, and an isolation assembly.

[0069] In task 450, thermal processing parameters for thermal treatment of the substrate are set. For example, the one or more thermal processing parameters comprise at least one of a thermal treatment wall temperature, a thermal treatment upper assembly temperature, a thermal treatment substrate temperature, a thermal treatment substrate holder temperature, a thermal treatment substrate temperature, and a thermal treatment processing pressure.

[0070] For example, one or more of the following processes may occur: 1) a controller coupled to a thermal wall temperature control unit and a first temperature-sensing device in the thermal treatment chamber is utilized to set a thermal treatment wall temperature; 2) a controller coupled to an upper assembly temperature control unit and a second temperature-sensing device in the upper assembly is utilized to set a thermal treatment upper assembly temperature; 3) a controller coupled to a substrate holder temperature control unit and a third temperature-sensing device in the heated substrate holder is utilized to set a thermal treatment substrate holder temperature; 4) a controller coupled to a substrate holder temperature control unit and a fourth temperature-sensing device in the heated substrate holder and coupled to the substrate is utilized to set a thermal treatment substrate temperature; and/or 5) a controller coupled to a vacuum pumping system, a gas distribution system, and a pressure sensing device is utilized to set a thermal treatment processing pressure within the thermal treatment chamber.

[0071] In task 460, the substrate is thermally treated under the conditions set forth in 450 for a second period of time. The second period of time can range from about 10 to about 480 seconds, for example.

[0072] In an example, the processing system 100, as depicted in FIGS. 2A and 2B, or FIGS. 4A and 4B, can be a chemical oxide removal system for trimming an oxide hard mask. The processing system 100, 300 comprises lower chamber portion 104, 304 for chemically treating exposed surface layers, such as oxide surface layers, on a substrate, whereby adsorption of the process chemistry on the exposed surfaces affects chemical alteration of the surface layers. Additionally, the processing system 100, 300 comprises upper chamber portion 108, 308 for thermally treating the substrate, whereby the substrate temperature is elevated in order to desorb (or evaporate) the chemically altered exposed surface layers on the substrate.

[0073] In the lower chamber portion 104, 304, the chemical treatment space 106, 306 (see FIG. 2A, or 4A) is

evacuated, and a process gas comprising HF and NH₃ is introduced. Alternately, the process gas can further comprise a carrier gas. The carrier gas can, for example, comprise an inert gas such as argon, xenon, helium, etc. The processing pressure can range from about 1 to about 1000 mTorr and, for example, can typically range from about 2 to about 25 mTorr. The process gas flow rates can range from about 1 to about 2000 sccm for each specie and, for example, typically range from about 10 to about 100 sccm.

[0074] Additionally, the lower chamber portion 104, 304 can be heated to a temperature ranging from about 10 to about 200° C. and, for example, the temperature can typically be about 35 to about 55° C. Additionally, the gas injection system can be heated to a temperature ranging from about 10 to about 200° C. and, for example, the temperature can typically be about 40 to about 60° C. The substrate can be maintained at a temperature ranging from about 10 to about 50° C. and, for example, the substrate temperature can typically be about 25 to about 30° C.

[0075] In the upper chamber portion 108, 308, the thermal treatment space 110, 310 (see FIG. 2B, or 4B) is evacuated, and a purge gas comprising N₂ is introduced. The processing pressure can range from about 1 to about 1000 mTorr and, for example, can typically range from about 2 to about 25 mTorr. The purge gas flow rates can range from about 1 to about 2000 sccm for each specie and, for example, typically range from about 10 to about 100 sccm.

[0076] In the upper chamber portion 108, 308, the wall can be heated to a temperature ranging from about 20 to about 200° C. and, for example, the temperature can typically be about 75 to about 100° C. Additionally, the gas purge system can be heated to a temperature ranging from 20 to about 200° C. and, for example, the temperature can typically be about 75 to about 100° C. The substrate can be heated to a temperature in excess of about 100° C. ranging from about 100 to about 200° C., and, for example, the temperature can typically be about 100 to about 150° C.

[0077] As described above, the processing system illustrated in FIGS. 2A and 2B, and FIGS. 4A, 4B and 4C can be configured to facilitate the trimming of a hard mask using a two-step process involving a chemical treatment of the exposed surfaces of the hard mask layer in order to alter the surface chemistry of the hard mask layer, followed by a post treatment of the exposed surfaces of the hard mask layer in order to desorb the altered surface chemistry. As shown in FIGS. 2A, 2B, 4A, 4B and 4C, the chemical treatment of a substrate can be performed in a lower portion of the processing system, while the thermal treatment of the substrate can be performed in the upper portion of the processing system.

[0078] Due in part to the sequential nature of the two-step trimming process, as well as the difference in respective treatment times, the throughput of substrates may be compromised. For example, the total treatment time for a single substrate can comprise chemical treatment for approximately 200 seconds (including loading the substrate into the chemical treatment chamber, evacuating the chamber, purging the chamber, and chemically treating the substrate), thermal treatment for approximately 100 seconds (including loading the substrate into the thermal treatment chamber, evacuating the chamber, purging the chamber and thermally treating the substrate), and substrate transfer through a

transfer system for approximately 60 seconds (including introducing a substrate, purging the transfer system, and evacuating the transfer system). Thus, for the examples given above, the total time in sequence can be 360 seconds per substrate, leading to a throughput of ten substrates per hour.

[0079] To overcome such processing inefficiencies, an embodiment of the present invention provides for overlapping the chemical treatment and the thermal treatment times between adjacent substrates in a substrate lot and performing a number of substrate transfer movements in the transfer system with the thermal treatment. Since the chemical treatment is the limiting process, this ensures that a substrate is in the chemical treatment chamber at all times. This embodiment makes efficient use of the processing and transfer systems and can achieve an improvement in throughput by nearly a factor of two.

[0080] Referring again to **FIG. 4A**, a transfer system **500** is depicted comprising a transfer chamber **502**, and a substrate transfer assembly **396** configured to transfer substrates **335, 336** to and from the lower portion **304** of processing system **300** and the upper portion **308** of processing system **300**. Additionally, transfer system **500** includes a first holding station **510** coupled to the transfer system **500** and configured to hold a first substrate **512**, and a second holding station **520** coupled to the transfer system and configured to hold a second substrate **522**.

[0081] Referring now to **FIG. 6**, a method of operating a processing system for chemically treating and thermally treating a substrate is presented. The processing system can be the system depicted in **FIGS. 2A and 2B**, or the system depicted in **FIGS. 4A, 4B and 4C**. The method includes a flow chart **600** beginning with task **610** with transferring a first substrate into the lower portion of the processing system for chemical treatment. In task **620**, while the first substrate is processed in the lower portion, a second substrate is introduced to the transfer system, and stored at a first holding station in the transfer system.

[0082] Upon completion of the chemical processing the first substrate, the first substrate, in task **630**, is transferred from the lower portion to the upper portion for thermal treatment. In task **640**, the second substrate is transferred into the lower portion for chemical treatment.

[0083] While the second substrate is processed in the lower portion, a third substrate is introduced to the transfer system in task **650**, and stored at the first holding station in the transfer system. In task **660**, while the second substrate is processed in the lower portion, the first substrate is removed from the upper portion upon completion of the thermal processing and transferred to a second holding station in the transfer system.

[0084] In task **670**, upon completion of the chemical processing the second substrate, the second substrate is transferred from the lower portion to the upper portion for thermal treatment. In task **680**, the third substrate is transferred into the lower portion for chemical treatment.

[0085] The first substrate is then removed from the transfer system in task **690**, and the preceding substrate flow pattern is continued, i.e., while the third substrate is processed in the lower portion, a fourth substrate is introduced to the transfer system and stored at the first holding station

in the transfer system, the second substrate is removed from the upper portion upon completion of thermal processing and stored at the second holding station, etc.

[0086] Although only certain embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention.

[0087] Thus, the description is not intended to limit the invention and the configuration, operation, and behavior of the present invention has been described with the understanding that modifications and variations of the embodiments are possible, given the level of detail present herein. Accordingly, the preceding detailed description is meant or intended to, in any way, limit the invention—rather the scope of the invention is defined by the appended claims.

What is claimed is:

1. A method of operating a processing system for treating substrates comprising:

transferring a first substrate into a lower portion of a processing system configured to perform a chemical treatment using a transfer system coupled to said processing system;

transferring said first substrate from said lower portion of said processing system to an upper portion of said processing system configured to perform a thermal treatment using said transfer system; and

removing said first substrate from said processing system and said transfer system.

2. The method of claim 1, further comprising:

storing a second substrate at a first holding station in said transfer system while said first substrate is processed in said lower portion of said processing system.

3. The method of claim 2, further comprising:

transferring said second substrate to said lower portion of said processing system while said first substrate is processed in said upper portion of said processing system.

4. The method of claim 3, further comprising:

transferring said second substrate from said lower portion of said processing system to said upper portion of said processing system while said first substrate is stored at a second holding station in said transfer system.

5. The method of claim 4, further comprising:

storing a third substrate at said first storage station in said transfer system while said second substrate is processed in said lower portion of said processing system.

6. The method of claim 5, further comprising:

transferring said third substrate to said lower portion of said processing system while said second substrate is processed in said upper portion of said processing system.

7. The method of claim 1, wherein said removing said first substrate from said processing system and said transfer system includes storing said first substrate at a second storage station in said transfer system.

8. The method of claim 1, wherein said transferring said first substrate into said lower portion of said processing system is followed by chemically treating said first substrate in said lower portion in order to alter surface layers on said first substrate.

9. The method of claim 8, wherein said transferring said first substrate from said lower portion to said upper portion of said processing system is followed by thermally treating said first substrate in order to remove said chemically altered surface layers on said first substrate.

10. A method of operating a processing system for treating substrates comprising:

transferring a first substrate into a lower portion of said processing system using a transfer system coupled to said processing system;

processing said first substrate in said lower portion;

while processing said first substrate in said lower portion, transferring a second substrate to a first holding station in said transfer system;

transferring said first substrate using said transfer system from said lower portion to an upper portion of said processing system;

processing said first substrate in said upper portion;

while processing said first substrate in said upper portion, transferring said second substrate into said lower portion;

processing said second substrate in said lower portion;

while processing said second substrate in said lower portion, transferring a third substrate to said first holding station;

while processing said second substrate in said lower portion, transferring said first substrate to a second holding station in said transfer system;

transferring said second substrate using said transfer system from said lower portion to said upper portion of said processing system;

processing said second substrate in said upper portion;

transferring said third substrate into said lower portion;

processing said third substrate in said lower portion; and removing said first substrate from said processing system and said transfer system.

11. A system for chemically treating and thermally treating a substrate comprising:

a processing system having a process chamber including a lower chamber portion that chemically alters exposed surface layers on said substrate, and an upper chamber portion that thermally treats said chemically altered surface layers on said substrate;

a substrate lifting assembly coupled to said process chamber, configured to transport said substrate between said lower chamber portion and said upper portion; and

a controller coupled to said processing system and said substrate lifting assembly, and configured to optimize the throughput of a plurality of substrates through said upper portion and said lower portion of said processing system.

12. The system of claim 11, wherein at least one of said lower chamber portion and said upper chamber portion is temperature-controlled.

13. The system of claim 11, wherein said lower chamber portion is thermally insulated from said upper chamber portion.

14. The system of claim 13, wherein said thermal insulation comprises a thermal insulation plate.

15. The system of claim 14, wherein said thermal insulation plate provides a thermal barrier between said chemical treatment chamber and said thermal treatment chamber.

16. The system of claim 15, wherein said thermal insulation plate comprises at least one of Teflon, alumina, sapphire, and quartz.

17. The system of claim 11, wherein said lower chamber portion is vacuum isolated from said upper chamber portion.

18. The system of claim 17, wherein said vacuum isolation includes a gate valve for opening and closing an opening between said lower chamber portion and said upper chamber portion.

19. The system of claim 11, wherein said lower chamber portion comprises a temperature controlled substrate holder mounted within said lower chamber portion and configured to be substantially thermally insulated from said lower chamber portion, a pumping system coupled to said lower chamber portion, and a gas injection system configured to introduce one or more process gases to said lower chamber portion.

20. The system of claim 19, wherein said temperature controlled substrate holder comprises at least one of an electrostatic clamping system, a back-side gas supply system, and one or more temperature control elements.

21. The system of claim 19, wherein said temperature controlled substrate holder in said chemical treatment chamber includes one or more temperature control elements and said one or more temperature control elements comprise at least one of a cooling channel, a heating channel, a resistive heating element, a radiant lamp, and a thermo-electric device.

22. The system of claim 19, wherein said gas injection system comprises at least one gas distribution plenum.

23. The system of claim 19, wherein said gas injection system comprises one or more gas injection orifices.

24. The system of claim 19, wherein said one or more process gases comprises a first gas and a second gas different from said first gas.

25. The system of claim 19, wherein said one or more process gases comprise at least one of HF and NH₃.

26. The system of claim 25, wherein said one or more process gases further includes an inert gas.

27. The system of claim 26, wherein said inert gas includes a Noble gas.

28. The system of claim 11, wherein said upper chamber portion comprises:

a heating assembly configured to elevate the temperature of said substrate,

a pumping system coupled to said upper chamber portion, and

a gas purge system configured to introduce a purge gas to said upper chamber portion.

29. The system of claim 28, wherein said heating assembly includes a radiant heating assembly.

30. The system of claim 29, wherein said radiant heating assembly includes an array of radiant lamps.

31. The system of claim 28, wherein said purge gas includes N₂.

32. The system of claim 11, wherein said substrate lifting assembly locates said substrate on a temperature-controlled substrate holder in said lower chamber portion for exposure

to one or more process gases when in a lowered position, and locates said substrate proximate a heating assembly in said upper chamber portion when in a raised position.

33. The system of in claim 11, wherein said process chamber is coupled to a manufacturing system.

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