

INTEGRATED CAPACITIVELY COUPLED PLASMA AND REMOTE INDUCTIVELY COUPLED PLASMA

INCORPORATION BY REFERENCE

5 [0001] A PCT Request Form is filed concurrently with this specification as part of the present application. Each application that the present application claims benefit of or priority to as identified in the concurrently filed PCT Request Form is incorporated by reference herein in its entirety and for all purposes.

FIELD

10 [0002] The present disclosure relates to plasma processing apparatuses and tools used in semiconductor manufacturing operations.

BACKGROUND

[0003] Plasma has long been employed for processing substrates. Plasma processes are commonly used in the fabrication of semiconductor devices. Plasma is generated by supplying a plasma-generation chamber with reactant gases and applying an electromagnetic field. For example, plasma generation may employ capacitively-coupled plasma (CCP) technology, inductively-coupled plasma (ICP) technology, transformer-coupled plasma (TCP) technology, electron-cyclotron technology, or microwave technology. High-energy ions and/or radicals from the plasma are delivered to a substrate surface to react with materials on the substrate surface.

15 [0004] The background description provided herein is for the purpose of generally presenting the context of the present technology. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present technology.

SUMMARY

25 [0005] Provided herein is a plasma processing apparatus. The plasma processing apparatus includes an inductively-coupled plasma (ICP) generating chamber, a capacitively-coupled plasma (CCP) generating chamber separate from the ICP generating chamber, a showerhead between the CCP generating chamber and the ICP generating chamber, where the CCP generating chamber and the ICP generating chamber are in fluid communication with one another via the showerhead, and a pedestal configured to support a substrate in the CCP generating chamber.

30 [0006] In some implementations, the ICP generating chamber is configured to generate inductively-coupled plasma comprising radicals and ions of one or more first gases, where the CCP generating chamber is configured to generate capacitively-coupled plasma comprising radicals and ions of one or more second gases, and where the showerhead is configured to filter

out ions of the inductively-coupled plasma. In some implementations, the capacitively-coupled plasma modifies the substrate in a first step and the inductively-coupled plasma modifies the substrate in a second step. In some implementations, the inductively-coupled plasma modifies the substrate in a first step and the capacitively-coupled plasma modifies the substrate in a second step. In some implementations, the pedestal is powered by an RF generator and the showerhead is grounded for generation of the capacitively-coupled plasma in the CCP generating chamber. In some implementations, the showerhead includes: a planar base portion, and a downwardly protruding portion having an inner wall and an outer wall and positioned along a periphery of the planar base portion, where the inner wall of the downwardly protruding portion and the planar base portion define a bore of the showerhead. In some implementations, the showerhead further includes a plurality of through-holes configured to filter out ions from the inductively-coupled plasma generated in the ICP generating chamber. In some implementations, the showerhead includes grooves configured to circulate coolant through the showerhead. In some implementations, the CCP generating chamber is configured to generate and confine the capacitively-coupled plasma in the bore of the showerhead. In some implementations, the pedestal is configured to tilt so that a major surface of the pedestal is parallel with a major surface of the planar base portion of the showerhead. In some implementations, the plasma processing apparatus further includes: a first RF generator coupled to the ICP generating chamber, and a second RF generator coupled to the CCP generating chamber, where the first RF generator is configured to deliver higher RF power and higher frequency than the second RF generator. In some implementations, the plasma processing apparatus further includes: an RF generator, and a power splitter coupled to the RF generator, where the power splitter is configured to deliver RF power via the RF generator to either the ICP generating chamber or the CCP generating chamber. In some implementations, the plasma processing apparatus further includes: a gas injector in fluid communication with the ICP generating chamber for delivering one or more first gases to the ICP generating chamber, and one or more gas ports in fluid communication with the showerhead without being in fluid communication with the ICP generating chamber for delivering one or more second gases to the CCP generating chamber. In some implementations, the plasma processing apparatus further includes a controller configured with instructions for performing the following operations: generate an inductively-coupled plasma in the ICP generating chamber to assist in deposition of a dielectric layer on the substrate, and generate a capacitively-coupled plasma in the CCP generating chamber to assist in etch or partial etch of the dielectric layer on the substrate. In some implementations, the controller is further configured with instructions to perform the following operations: flow one or more precursor gases towards the substrate, where radicals of

one or more first gases are provided from the inductively-coupled plasma from the ICP generating chamber, where the one or more precursor gases reacts with the radicals of the one or more first gases to deposit the dielectric layer on the substrate. In some implementations, the controller is further configured with instructions to perform the following operations: flow one or more second
5 gases towards the substrate, where the capacitively-coupled plasma comprises ions of the one or more second gases to etch or partially etch the dielectric layer on the substrate. In some implementations, the plasma processing apparatus further includes a controller configured with instructions to perform the following operations: generate an inductively-coupled plasma in the
10 ICP generating chamber to assist in deposition of a tensile film on the substrate, and generate a capacitively-coupled plasma in the CCP generating chamber to assist in deposition of a compressive film on the substrate. In some implementations, the plasma processing apparatus further includes a controller configured with instructions to perform the following operations: generate an inductively-coupled plasma in the ICP generating chamber to assist in deposition of a
15 film on the substrate, and generate a capacitively-coupled plasma in the CCP generating chamber to assist in treatment of the film on the substrate.

[0007] Also provided herein is a multi-station processing apparatus. The multi-station processing apparatus includes a plurality of processing stations each comprising: an inductively-coupled plasma (ICP) generating chamber, a capacitively-coupled plasma (CCP) generating chamber separate from the ICP generating chamber, a showerhead between the CCP generating
20 chamber and the ICP generating chamber, where the CCP generating chamber and the ICP generating chamber are in fluid communication with one another via the showerhead, and a pedestal configured to support a substrate in the CCP generating chamber.

[0008] In some implementations, the ICP generating chamber is configured to generate inductively-coupled plasma including radicals and ions of one or more first gases, where the CCP
25 generating chamber is configured to generate capacitively-coupled plasma including radicals and ions of one or more second gases, where the showerhead is configured to filter out ions of the inductively-coupled plasma. In some implementations, the multi-station processing apparatus further includes a controller configured with instructions to perform the following operations: generate an inductively-coupled plasma in the ICP generating chamber for depositing a first layer
30 on the substrate, and generate a capacitively-coupled plasma in the CCP generating chamber for etching the first layer or treating the first layer, or depositing a second layer on the first layer of the substrate.

[0009] Also provided herein is a method of processing a substrate. The method includes generating an inductively-coupled plasma in a remote plasma chamber to assist in deposition of a

first layer on the substrate in a processing chamber, and generating a capacitively-coupled plasma in the processing chamber to assist in etch or treatment of the first layer, or in deposition of a second layer on the substrate.

[0010] In some implementations, the remote plasma chamber and the processing chamber are in fluid communication with one another via a showerhead, where the showerhead is positioned between the remote plasma chamber and the processing chamber. In some implementations, the method further includes: flowing a precursor gas into the processing chamber, where the precursor gas reacts with radicals of the inductively-coupled plasma to deposit the first layer on the substrate.

BRIEF DESCRIPTION OF DRAWINGS

[0011] Figure 1 shows a schematic illustration of an example capacitively-coupled plasma apparatus for generating a plasma between a showerhead and a pedestal in a processing chamber.

[0012] Figure 2 shows a schematic illustration of an example inductively-coupled plasma apparatus for generating a plasma in a remote plasma source that is fluidly coupled to a processing chamber via a showerhead.

[0013] Figure 3 shows a detailed schematic illustration of a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of a remote plasma and a capacitively-coupled plasma chamber for generation of a direct plasma according to some implementations.

[0014] Figure 4 shows a simplified schematic illustration of a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of a remote plasma and a capacitively-coupled plasma chamber for generation of a direct plasma according to some implementations.

[0015] Figure 5A shows a simplified schematic illustration of the plasma apparatus of Figure 4 using the inductively-coupled plasma chamber for generation of the remote plasma during substrate processing according to some implementations.

[0016] Figure 5B shows a simplified schematic illustration of the plasma apparatus of Figure 4 using the capacitively-coupled plasma chamber for generation of the direct plasma during substrate processing according to some implementations.

[0017] Figure 6 shows a schematic illustration of a showerhead in relation to a pedestal used in a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of remote plasma and a capacitively-coupled plasma chamber for generation of direct plasma according to some implementations.

[0018] Figure 7 shows a flow diagram of an example method for processing a substrate using an inductively-coupled plasma and capacitively-coupled plasma according to some implementations.

[0019] Figure 8 shows a schematic diagram of an example process tool including multiple stations, where one or more stations are each configured to generate an inductively-coupled plasma and a capacitively-coupled plasma according to some implementations.

DETAILED DESCRIPTION

5 [0020] The implementations disclosed below may describe processing of a material on a substrate such as a wafer, substrate, or other work piece. The work piece may be of various shapes, sizes, and materials. In this application, the terms “semiconductor wafer,” “wafer,” “substrate,” “wafer substrate,” and “partially fabricated integrated circuit” are used interchangeably. One of ordinary skill in the art would understand that the term “partially fabricated integrated circuit” can
10 refer to a silicon wafer during any of many stages of integrated circuit fabrication thereon. A wafer or substrate used in the semiconductor device industry typically has a diameter of 200 mm, or 300 mm, or 450 mm. Unless otherwise stated, the processing details recited herein (e.g., flow rates, power levels, etc.) are relevant for processing 300 mm diameter substrates, or for treating chambers that are configured to process 300 mm diameter substrates and can be scaled as
15 appropriate for substrates or chambers of other sizes. In addition to semiconductor wafers, other work pieces that may be used implementations disclosed herein include various articles such as printed circuit boards and the like. The processes and apparatuses can be used in the fabrication of semiconductor devices, displays, LEDs, photovoltaic panels and the like.

20 Introduction

[0021] A capacitively coupled plasma (CCP) system is one of the most common types of plasma sources. Generally, such a system includes a first electrode and a second electrode arranged in a parallel plate configuration. At least one of the electrodes is powered by an RF generator, typically operating at a frequency around 13.56 MHz. During operation, a capacitor is formed between the
25 powered electrode and the grounded electrode. Process gas is introduced in a space between the electrodes. When an electric field is generated between the electrodes, atoms of the process gas are ionized and release electrons. Plasma of the process gas is formed when the gas is energized, leaving a mixture of charged and uncharged particles. CCP systems are widely used in the semiconductor processing industry for thin film deposition (e.g., sputtering) and etching.

30 [0022] An inductively coupled plasma (ICP) system can be used in a variety of microfabrication processes including substrate cleaning processes, surface conditioning processes, thin film deposition processes, etching processes, and cleaning processes, among other applications. In an ICP system, a generator supplies a radio frequency (RF) supply signal to an induction coil. The supply signal generates time-varying magnetic fields around the induction coil that then create

electric currents through a process gas by way of electromagnetic induction. The electric currents supply the energy to generate the plasma from the process gas. An impedance matching network can be used to facilitate the transfer of power from the supply signal generator to the induction coil of the ICP system and thereby facilitate the formation of the plasma while minimizing the wasted reflected power and potentially reducing the risk of damage to a device being fabricated in the ICP system as well as damage to the ICP system components themselves.

[0023] CCP processing and ICP processing are often performed in separate stations or modules in semiconductor manufacturing processing. The hardware components for CCP systems generally do not overlap with the hardware components for ICP systems such that CCP and ICP systems are not combined into a single station or module. As such, a semiconductor substrate processed by a CCP system would be subsequently transferred to a separate module or station for processing by an ICP system, or vice versa.

[0024] Figure 1 shows a schematic illustration of an example capacitively-coupled plasma apparatus for generating a plasma between a showerhead and a pedestal in a processing chamber. A process station 100 generates a capacitively coupled plasma in a space between a showerhead 106 and a pedestal 108 in a process chamber 102.

[0025] The process station 100 fluidly communicates with a reactant delivery system 101 for delivering process gases to the showerhead 106. Reactant delivery system 101 includes a mixing vessel 104 for blending and/or conditioning process gases for delivery to the showerhead 106. One or more inlet valves 120 may control introduction of process gases to the mixing vessel 104. Some reactants may be stored in liquid form prior to vaporization at and subsequent delivery to the process station 100. For example, the apparatus may include a vaporization point 103 for vaporizing liquid reactant to be supplied to the mixing vessel 104. In some embodiments, the vaporization point 103 may be a heated vaporizer.

[0026] Showerhead 106 distributes process gases toward substrate 112. In some embodiments, the substrate 112 is located beneath the showerhead 106, and is shown resting on a pedestal 108. It will be appreciated that the showerhead 106 may have any suitable shape, and may have any suitable number and arrangement of ports for distributing process gases to the substrate 112. In some implementations, the pedestal 108 may be raised or lowered to expose the substrate 112 to a volume between the substrate 112 and the showerhead 106. It will be appreciated that, in some implementations, the pedestal height may be adjusted programmatically by a suitable system controller 150. In another scenario, adjusting the height of the pedestal 108 may allow a plasma density to be varied during plasma activation cycles in the process. At the conclusion of a processing phase, the pedestal 108 may be lowered during another substrate transfer phase to allow

removal of the substrate 112 from the pedestal 108. In some implementations, a position of the showerhead 106 may be adjusted relative to the pedestal 108 to vary a volume between the substrate 112 and the showerhead 106. In some implementations, the pedestal 108 may include a rotational axis for rotating an orientation of the substrate 112. It will be appreciated that, in some implementations, one or more of these example adjustments may be performed programmatically by one or more suitable system controllers 150.

[0027] In some implementations, the pedestal 108 may be configured to be heated to an elevated temperature via a heater 110. In some implementations, pressure control for the process station 100 may be provided by a butterfly valve 118. The butterfly valve 118 throttles a vacuum provided by a downstream vacuum pump (not shown).

[0028] In some implementations, showerhead 106 and pedestal 108 electrically communicate with an RF power supply 114 and matching network 116 for powering a plasma in the process chamber 102. The showerhead 106 and pedestal 108 may serve as electrodes in generating a capacitively coupled plasma in the process chamber 102. In some implementations, the plasma energy may be controlled by controlling one or more of a process station pressure, a gas concentration, an RF source power, an RF source frequency, and a plasma power pulse timing. For example, RF power supply 114 and matching network 116 may be operated at any suitable power to form a plasma having a desired composition of radical and ionized species. In some implementations, the RF power supply 114 and matching network 116 may be operated to apply plasma power to the process chamber 102 to ignite plasma generated from reactant gases in the process chamber 102. Example plasma powers applied by the RF power supply 114 may be equal to or less than about 10000 W, equal to or less than about 5000 W, or between about 10 W and about 5000 W. Likewise, RF power supply 114 may provide RF power of any suitable frequency. In some implementations, RF power supply 114 may be configured to control high- and low-frequency RF power sources independently of one another. Example low-frequency RF frequencies may include, but are not limited to, frequencies between 0 kHz and 500 kHz. Example high-frequency RF frequencies may include, but are not limited to, frequencies between 1.8 MHz and 2.45 GHz, or at least about 13.56 MHz, at least about 27 MHz, at least about 40 MHz, or at least about 60 MHz.

[0029] Figure 2 shows a schematic illustration of an example inductively-coupled plasma apparatus for generating a plasma in a remote plasma source fluidly coupled to a processing chamber via a showerhead. A process station 200 generates an inductively coupled plasma in a plasma-generating chamber 202 that may be domed-shaped, where the plasma-generating chamber 202 is fluidly coupled to a processing chamber 204 via a gas distributor 206, which may

also be referred to as a showerhead.

[0030] A substrate 212 is supported on a substrate support or pedestal 214. The pedestal 214 may move within the processing chamber 204 to position the substrate 212 within the processing chamber 204. The pedestal 214 typically includes a chuck (sometimes referred to as a clamp) to
5 hold the substrate 212 during processing. The chuck may be an electrostatic chuck, a mechanical chuck, or various other types of chuck suitable for use in the industry. In some embodiments, the pedestal 214 may also adjust the temperature of the substrate 212 via one or more heaters.

[0031] The process station 200 includes the plasma-generating chamber 202 separated from the processing chamber 204. The plasma-generating chamber 202 may also be referred to as a remote
10 plasma source. The plasma-generating chamber 202 may be a hemispheric dome formed of a ceramic material. An induction coil 218 is wound outside the dome of the plasma-generating chamber 202. For example, the induction coil 218 can be formed of copper or another highly conductive material. Power through the induction coil 218 may be supplied by a generator 232. The generator 232 may generate an RF alternating current (AC) supply signal to the induction coil
15 218, where the signal may have a frequency between about 300 kHz and about 60 MHz, or at least about 1 MHz or at least about 13 MHz. The generator 232 may supply RF power in a range between about 100 W and about 10000 W, or between about 1000 W and about 8000 W.

[0032] During operation, one or more process gases are introduced into the plasma-generating chamber 202 via one or more inlets 216. It is the process gas or process gases that will be
20 transformed into plasma by the ICP system of the process station 200. In various applications, the process gases may or may not be premixed. In some implementations, the process gases can be introduced through a gas supply inlet including orifices. Some of the orifices can orient the process gas or gases along an axis of injection along the chamber walls of the plasma-generating chamber 202.

[0033] As the generator 232 supplies an RF supply signal to the induction coil 218, energy is
25 created in the plasma-generating chamber 202 to form and sustain plasma 224 within the plasma-generating chamber 202 via inductively coupled plasma generation. The plasma 224 contains a mixture of at least ions and neutral species (e.g., radicals). Ions and radicals of the process gas or process gases may be continuously generated in the plasma-generating chamber 202. Radical
30 species of the plasma 224 may flow from the plasma-generating chamber 202 to the processing chamber 204 via the gas distributor 206.

[0034] The gas distributor 206 may include or act as an ion filter. In some cases, the gas distributor 206 may also include or act as a photon filter. Filtering ions and/or photons may reduce substrate damage, undesirable re-excitation of molecules, and/or selective breakdown or

decomposition or precursors within the processing chamber 204. The gas distributor 206 may include a plurality of holes to diffuse the flow of gases into the processing chamber 204. The plurality of holes may be arranged as an array of regularly spaced apart channels or through-holes extending through a plate that separates the plasma-generating chamber 202 and the processing chamber 204.

[0035] In some implementations, excited state radical species exiting the gas distributor 206 may flow into an interior of the processing chamber 204. In some cases, the excited state radical species may transition into relaxed state or ground state radical species in the processing chamber 204. In some embodiments, precursor gases or other reactant gases may flow into the processing chamber 204 via gas outlets (not shown). The gas outlets may be located downstream from outlets of the gas distributor 206. That way, the precursor gases or other reactant gases do not interact with the radical species generated from the plasma-generating chamber 202 until entering the processing chamber 204. The radical species, which may be in a relaxed or ground state, react with the precursor gases or other reactant gases in an environment adjacent to the substrate 212 in the processing chamber 204. The reaction may cause CVD formation of a thin film (e.g., dielectric material) on the substrate 212.

[0036] Process gases may be removed from the processing chamber 204 via an outlet 248 that is fluidly coupled to a pump (not shown). Thus, excess precursor gases, reactant gases, radical species, diluent gases, displacement gases, purge gases, and other gases may be removed from the processing chamber 204.

[0037] In some implementations, a system controller 250 is in operative communication with the process station 200. The system controller 250 may include a processor system 252 (e.g., microprocessor) configured to execute instructions held in a data system 254 (e.g., memory). In some implementations, the system controller 250 may be in communication with the generator 232 to control plasma parameters and/or conditions. In some implementations, the system controller 250 may be in communication with the pedestal 214 to control pedestal elevation and temperature. In some implementations, the system controller 250 may control other processing conditions such as RF power settings, frequency settings, duty cycles, pulse times, pressure within the processing chamber 204, pressure within the plasma-generating chamber 202, gas flow rates, and temperature of the pedestal 214, among other processing conditions.

Integrated ICP and CCP System

[0038] The present disclosure integrates an ICP chamber and a CCP chamber into a single plasma apparatus or station for substrate processing. The ICP chamber is separate from and in

fluid communication with the CCP chamber via a showerhead. A remote plasma generated in the ICP chamber is used to deposit a first layer on a substrate, or otherwise process the substrate. A direct plasma generated in the CCP chamber is used to etch or treat the first layer of the substrate, used to deposit a second layer on the first layer of the substrate, or otherwise process the substrate.

5 [0039] With a remote plasma (e.g., ICP-based plasma), substrates may be exposed to fewer ions and high-energy species. With a direct plasma (e.g., CCP-based plasma), substrates may be exposed to more ions and high-energy species. Integration of the ICP chamber and the CCP chamber enables two different types of plasma-based processes to be performed without having to transfer to a separate module or station. This increases throughput, reduces queue time, provides
10 greater flexibility in plasma-based processing of substrates, and prevents exposure to ambient conditions that may otherwise damage or contaminate substrates during transfer.

[0040] Figure 3 shows a detailed schematic illustration of a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of a remote plasma and a capacitively-coupled plasma chamber for generation of a direct plasma according to some implementations.

15 [0041] The plasma apparatus 300 includes a remote plasma-generating chamber 302 and a processing chamber 303. A showerhead 304 separates the remote plasma-generating chamber 302 from the processing chamber 303. The showerhead 304 is arranged between the remote plasma-generating chamber 302 and the processing chamber 303. In some cases, the remote plasma-generating chamber 302 may also be referred to as a plasma source, remote plasma source, or ICP
20 system or ICP chamber. In some embodiments, the processing chamber 303 may also be referred to as a substrate processing chamber, reaction chamber, or CCP system or CCP chamber.

[0042] The showerhead 304 can include a base portion 305 and a cylindrical portion 307 that extends perpendicularly downward from the base portion 305. The cylindrical portion 307 has an outer wall 309-1 and an inner wall 309-2. The inner wall 309-2 of the cylindrical portion 307
25 defines a bore 306 of the showerhead 304. A diameter of the bore 306 is equal to a diameter of the inner wall 309-2 of the cylindrical portion 307 of the showerhead 304.

[0043] The processing chamber 303 has a sidewall 308 and a bottom wall 310. The sidewall 308 is attached to the bottom of the cylindrical portion 307 of the showerhead 304. The sidewall 308 is perpendicular to the base portion 305 and extends vertically downward from the bottom of
30 the outer wall 309-1 of the cylindrical portion 307. The bottom wall 310 of the processing chamber 303 is parallel to the base portion 305 of the showerhead 304 and perpendicular to the sidewall 308 of the processing chamber 303.

[0044] A pedestal 312 is arranged in the processing chamber 303 below the showerhead 304. A substrate 314 is arranged on a top surface 316 of the pedestal 312 during processing. The top

surface 316 of the pedestal 312 can be planar and parallel to the base portion 305 of the showerhead 304. The inner diameter of the cylindrical portion 307 of the showerhead 304 is greater than an outer diameter of the top surface 316 of the pedestal 312. Similarly, the inner diameter of the cylindrical portion 307 of the showerhead 304 is greater than an outer diameter of the substrate 314.

5 [0045] An actuator 320 driven by a motor 322 can move the pedestal 312 vertically up and down relative to the showerhead 304. As such, the substrate 314 and the top surface 316 of the pedestal 312 can move within the bore 306 of the showerhead 304. The remote plasma-generating chamber 302 and the showerhead 304 may be fixed relative to the pedestal 312. A gap between a bottom 10 of the base portion 305 of the showerhead 304 and the top surface 316 of the pedestal 312 may be adjusted by vertically moving the pedestal 312 within the cylindrical portion 307 of the showerhead 304. For example, the gap may be between about 0.01 inches and about 5 inches, between about 0.02 inches and about 3 inches, or between about 0.05 inches and about 2 inches, such as about 1 inch or about 2 inches.

15 [0046] In some implementations, the pedestal 312 may be configured to tilt. The top surface 316 of the pedestal 312 may be tilted with respect to a frame of reference, where the frame of reference may be a horizontal plane. The pedestal 312 may be configured to tilt so that a major surface of the pedestal 312 (i.e., the top surface 316) is parallel with a major surface of the base portion 305 of the showerhead 304 (i.e., a bottom surface 364). In some implementations, the 20 pedestal 312 may also be configured to rotate. The substrate 314 retained on the pedestal 312 may be moved in a vertical direction, tilted, and/or rotated during processing.

[0047] The remote plasma-generating chamber 302 may be dome-shaped as shown or may be any other suitable shape. A bottom end of the remote plasma-generating chamber 302 is open and is attached to a top end of a first cylindrical component 324. The first cylindrical component 324 25 has a first flange 326 that extends radially outwardly from about a center of the first cylindrical component 324. Accordingly, the first cylindrical component 324 has a shape of a letter “T” with the letter “T” rotated left by about 90 degrees. A second cylindrical component 328 surrounds the first cylindrical component 324. The second cylindrical component 328 has a second flange 329 that extends radially inwardly from a bottom end of the second cylindrical component 328. 30 Accordingly, the second cylindrical component 328 has a shape of the letter “L” with the letter “L” flipped horizontally. The first flange 326 of the first cylindrical component 324 overhangs the second flange 329 of the second cylindrical component 328. The bottom ends of the first and second cylindrical components 324, 328 are attached to the top of the base portion 305 of the showerhead 304 near the periphery of the base portion 305 of the showerhead 304.

[0048] The remote plasma-generating chamber 302 generates remote plasma (i.e., plasma outside the processing chamber 303) using ICP. The remote plasma-generating chamber 302 receives one or more first gases from a gas distribution system 330 via a gas injector 332 arranged at the top of the remote plasma-generating chamber 302. However, it will be understood that the one or more first gases may be introduced into the remote plasma-generating chamber 302 in other ways. A coil 334 is arranged around the remote plasma-generating chamber 302. In some embodiments, a first end of the coil 334 is grounded and a second end of the coil 334 is connected to an RF generating system 336.

[0049] The RF generating system 336 generates and outputs RF power to the coil 334. By way of an example, the RF generating system 336 may include an RF generator 338 that generates RF power. The RF power is delivered by a match network 340 to the coil 334. The RF power supplied to the coil 334 ignites the gases injected by the gas injector 332 into the remote plasma-generating chamber 302 and generates an inductively-coupled plasma 342. Since the remote plasma-generating chamber 302 generates the inductively-coupled plasma 342 remotely from (i.e., outside) the processing chamber 303, the inductively-coupled plasma 342 is also referred to as a remote plasma.

[0050] The base portion 305 of the showerhead 304 comprises a first set of holes 360. The first set of holes 360 may also be referred to as radical holes or through-holes. The first set of holes 360 extend from a top surface 362 of the base portion 305 of the showerhead 304 to a bottom surface 364 of the base portion 305 of the showerhead 304. In other words, the first set of holes 360 extend completely through a thickness of the showerhead 304.

[0051] In addition, the base portion 305 of the showerhead 304 may comprise a plenum 366 that is separate from and not in fluid communication with the first set of holes 360. The plenum 366 may receive one or more precursor gases from a gas delivery system 370. The base portion 305 of the showerhead 304 further comprises a second set of holes 372. The second set of holes 372 may also be referred to as precursor holes or ports. The second set of holes 372 extend from the plenum 366 to the bottom surface 364 of the base portion 305 of the showerhead 304. The first set of holes 360 are not in fluid communication with the plenum 366 and the second set of holes 372. In some embodiments, the first set of holes 360 are greater in diameter and length than the second set of holes 372. For example, each of the first set of holes 360 may have a diameter that is at least two times greater than each of the second set of holes 372. The plenum 366 represents a volume, space, or cavity defined in the base portion 305 in fluid communication with the second set of holes 372 but not in fluid communication with the first set of holes 360.

[0052] The base portion 305 of the showerhead 304 may further comprise a plurality of grooves

368. The grooves 368 may form a cooling channel through which a coolant flows. A fluid delivery system 380 supplies a coolant to the grooves 368 through an inlet in the base portion 305 of the showerhead 304. In some embodiments, the coolant may be water. In some embodiments, the coolant may be a fluorinated heat transfer fluid such as Galden®. By circulating coolant through the showerhead 304, the showerhead 304 may be cooled to maintain a consistent and uniform temperature during substrate processing. As such, the temperature across the bottom surface 364 of the base portion 305 of the showerhead 304 is spatially and temporally uniform during substrate processing.

[0053] One or more temperature sensors (not shown) may be disposed in the base portion 305 of the showerhead 304. The one or more temperature sensors may be connected to a temperature controller 382. The temperature controller 382 may control the supply of the coolant from the fluid delivery system 380 to the grooves 368 to control a temperature of the showerhead 304.

[0054] While not shown, the pedestal 312 may include one or more heaters, a cooling system that receives a coolant from the fluid delivery system 380, and/or one or more temperature sensors. The temperature controller 382 may be connected to the one or more temperature sensors in the pedestal 312. The temperature controller 382 may control power supply to the one or more heaters. Alternatively or additionally, the temperature controller 382 may control the supply of the coolant from the fluid delivery system 380 to the cooling system in the pedestal 312 to control the temperature of the pedestal 312.

[0055] A valve 386 and pump 388 may control pressure in the processing chamber 303 and to evacuate reactants from the processing chamber 303. A system controller 390 may control the components of the plasma apparatus 300 described above.

[0056] The showerhead 304 filters ions from the inductively-coupled plasma 342 and passes radicals from the inductively-coupled plasma 342 through the first set of holes 360 into the processing chamber 303. The total cross-sectional area of the first set of holes 360 may be optimized to filter ions from the inductively-coupled plasma 342, to pass only radicals from the inductively-coupled plasma 342 through the showerhead 304 into the processing chamber 303, and to limit back-diffusion of precursor gases through the showerhead 304 into the remote plasma-generating chamber 302. As discussed below, the total cross-sectional area of the first set of holes 360 may also be optimized to limit parasitic plasma formation in the showerhead from a capacitively-coupled plasma in the processing chamber 303.

[0057] In some embodiments, the inductively-coupled plasma 342 may be used for etch, treatment, or cleaning operations associated with processing the substrate 314. In some embodiments, the inductively-coupled plasma 342 may be used for deposition operations

associated with processing the substrate 314. For instance, the radicals of the inductively-coupled plasma 342 may react with precursor gases in the gap between the showerhead 304 and the pedestal 312, where a thin film may be deposited on the substrate 314 by way of a deposition process such as ALD or CVD. The open area provided by the first set of holes 360 for the radicals to pass through the showerhead 304, the density and pattern of the first set of holes 360 (radical holes) and the second set of holes 372 (precursor holes), and the structural and functional properties of the cylindrical portion 307 of the showerhead 304, may provide near-zero radial and azimuthal non-uniformity in films deposited using the showerhead 304.

[0058] The processing chamber 303 generates *in-situ* plasma (i.e., plasma inside the processing chamber 303) using CCP. The processing chamber 303 receives one or more second gases from either the gas delivery system 370 via the second set of holes 372 or the gas distribution system 330 via the first set of holes 360. However, it will be understood that the one or more second gases may be introduced into the processing chamber 303 in other ways. RF power may be supplied to either the showerhead 304 or to the pedestal 312. In some embodiments, RF power is supplied to the pedestal 312 to act as a powered electrode while the showerhead 304 is grounded to act as a grounded electrode. The pedestal 312 may be connected to an RF generating system 346.

[0059] The RF generating system 346 generates and outputs RF power to the pedestal 312. By way of an example, the RF generating system 346 may include an RF generator 348 that generates RF power. The RF power is delivered by a match network 350 to the pedestal 312. At sufficient power or when the electric field strength between the pedestal 312 and the showerhead 304 is sufficient, the one or more second gases provided into the processing chamber 303 are ionized and form the capacitively-coupled plasma 344. As RF power is coupled to the showerhead 304, the capacitively-coupled plasma 344 is ignited and sustained in the gap between the pedestal 312 and the showerhead 304 in the processing chamber 303. Since the processing chamber 303 generates the capacitively-coupled plasma 344 inside the processing chamber 303, the capacitively-coupled plasma 344 is also referred to as an *in-situ* or direct plasma.

[0060] In some embodiments, the capacitively-coupled plasma 344 may be used for deposition operations associated with processing the substrate 314. In some embodiments, the capacitively-coupled plasma 344 may be used for etch, treatment, or cleaning operations associated with processing the substrate 314. For example, ions of the capacitively-coupled plasma 344 may be generated in an environment adjacent to the substrate 314, and the substrate 314 may be exposed to the ions of the capacitively-coupled plasma 344 to cause one or more material layers of the substrate 314 to be etched. In some cases, the ions of the capacitively-coupled plasma 344 may

be directionally applied to non-conformally etch portions of the one or more material layers. The gap between the showerhead 304 and the pedestal 312, and the gap between the cylindrical portion 307 of the showerhead 304 and the edges of the pedestal 312, may be optimized to provide a micro-volume in the processing chamber 303 so that the capacitively-coupled plasma 344 does not form in regions outside the space between the showerhead 304 and the pedestal 312. In other words, the capacitively-coupled plasma 344 may be formed, sustained, and confined within the bore 306 of the showerhead 304.

[0061] Figure 4 shows a simplified schematic illustration of a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of a remote plasma and a capacitively-coupled plasma chamber for generation of a direct plasma according to some implementations.

[0062] The plasma apparatus 400 includes an ICP generating chamber 402 and a CCP generating chamber 403. The CCP generating chamber 403 is separate from the ICP generating chamber 402. The plasma apparatus 400 further includes a showerhead 404 between the ICP generating chamber 402 and the CCP generating chamber 403, where the showerhead 404 separates the ICP generating chamber 402 from the CCP generating chamber 403. The CCP generating chamber 403 and the ICP generating chamber 402 are in fluid communication with one another via the showerhead 404. The plasma apparatus 400 further includes a pedestal 412 in the CCP generating chamber 403, where the pedestal 412 is configured to support a substrate 414 in the CCP generating chamber 403. A controller 490 may control the various components of the plasma apparatus 400.

[0063] The showerhead 404 includes a planar base portion 405 and a downwardly protruding portion 407 that extends perpendicularly downward from the planar base portion 405. The downwardly protruding portion 407 is arranged along a periphery of the planar base portion 405 of the showerhead 404. The downwardly protruding portion 407 may have an inner wall and an outer wall, where the inner wall of the downwardly protruding portion 407 defines a bore 406 of the showerhead 404.

[0064] The showerhead 404 includes a plurality of through-holes 460. Gases flow from the ICP generating chamber 402 to the CCP generating chamber 403 via the through-holes 460 of the showerhead 404. The through-holes 460 may be arranged as an array of regularly spaced apart channels or through-holes that extend through a thickness of the planar base portion 405 of the showerhead 404. Plasma-activated species including radicals may exit from the ICP generating chamber 402 to the CCP generating chamber 403 through the through-holes 460 of the showerhead 404. In some implementations, the plurality of through-holes 460 may be configured to filter out ions.

[0065] The showerhead 404 also includes a plurality of gas ports 472. Gases flow from a plenum of the showerhead 404 to the CCP generating chamber 403 via the gas ports 472 of the showerhead 404. The plenum represents a volume, space, or cavity in the planar base portion 405 of the showerhead 404 that is in fluid communication with the CCP generating chamber 403 but not in fluid communication with the ICP generating chamber 402. More specifically, the plenum is in fluid communication with the gas ports 472 but not with the through-holes 460. Gases flowing in the through-holes 460 of the showerhead 404 are prevented from mixing with the gases flowing through the gas ports 472 of the showerhead 404 until reaching the CCP generating chamber 403. That way, gases in the through-holes 460 and gases in the gas ports 472 are provided by way of separate outlets/passages to avoid mixing in the showerhead 404.

[0066] The showerhead 404 may be cooled or otherwise maintained at a uniform temperature. In some embodiments, the planar base portion 405 of the showerhead 404 may include a plurality of grooves or channels through which a coolant flows. In other words, the showerhead 404 may include grooves configured to circulate coolant through the showerhead 404. The coolant may be water or fluorinated heat transfer fluid such as Galden®. The coolant may be used to control a temperature of the showerhead 404.

[0067] The pedestal 412 is arranged in the CCP generating chamber 403 below the showerhead 404. The pedestal 412 may include a chuck, a fork, and/or lift pins to hold the substrate 414 during and between processing. In some embodiments, the pedestal 412 is an electrostatic chuck. The pedestal 412 may include one or more electrodes for providing electrostatic clamping force configured to retain the substrate 414. Heating elements and/or a cooling system may be coupled to the pedestal 412 for controlling a temperature of the substrate 414.

[0068] The pedestal 412 may be configured to vertically move to adjust a gap distance between the showerhead 404 and the pedestal 412 via a pedestal lift assembly. That way, the substrate 414 may move with the bore 406 of the showerhead 404. In some embodiments, the pedestal 412 may be configured to tilt relative to a horizontal plane via a tilt adjustment system. A major surface of the pedestal 412 may be parallel with a major surface of the showerhead 404 during processing of the substrate 414.

[0069] The ICP generating chamber 402 is configured to generate an inductively-coupled plasma 442. The ICP generating chamber 402 may be dome-shaped as shown or some other suitable shape. A gas injector 432 may be located at the top of the ICP generating chamber 402 to supply process gases to the ICP generating chamber 402. A coil 434 may surround the ICP generating chamber 402. The coil 434 may be connected to an RF generator 436. One or more first gases are supplied to the ICP generating chamber 402. The one or more first gases may be

supplied via the gas injector 432 at the top of the ICP generating chamber 402.

[0070] In some implementations, the one or more first gases may comprise an oxygen-containing reactant, nitrogen-containing reactant, hydrogen-containing reactant, carbon-containing reactant, or combinations thereof. Example reactants include but are not limited to oxygen (O₂), ozone (O₃), carbon dioxide (CO₂), carbon monoxide (CO), nitrous oxide (N₂O), water (H₂O), methanol (CH₃OH), hydrazine (N₂H₄), nitrogen (N₂), ammonia (NH₃), silane (SiH₄), hydrogen (H₂), and the like. In some implementations, the one or more first gases may additionally comprise a diluent gas, carrier gas, or inert gas species. Non-limiting examples of inert gas species can include helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe).

[0071] The RF generator 436 generates and outputs RF power to the coil 434. In some embodiments, a frequency generated by the RF generator 436 is between about 2 MHz and about 60 MHz, such as 60 MHz, or between about 10 MHz and about 30 MHz, such as about 13 MHz or 27 MHz. However, in some embodiments, the frequency generated by the RF generator 436 may be in hundreds of kilohertz, such as between about 100 kHz and about 800 kHz, such as about 400 kHz. In some embodiments, a power supplied to the RF generator 436 is between about 10 W and about 20000 W, between about 100 W and about 10000 W, or between about 500 W and about 8000 W, such as about 6500 W. RF power supplied by the RF generator 436 to the coil 434 may ignite the one or more first gases to form the inductively-coupled plasma 442. The controller 490 may control delivery of RF power to the RF generator 436 for generation of the inductively-coupled plasma 442.

[0072] The inductively-coupled plasma 442 may comprise ions and radicals of the one or more first gases. The showerhead 404 may be configured to filter out ions to limit ion bombardment damage to the substrate 414. As such, radicals of the one or more first gases may pass through the through-holes of the showerhead 404 and delivered to the CCP generating chamber 403. The substrate 414 may be exposed to the radicals of the one or more first gases from the inductively-coupled plasma 442 during processing of the substrate 414.

[0073] The CCP generating chamber 403 is configured to generate a capacitively-coupled plasma 444. The showerhead 404 and the pedestal 412 may serve as electrodes in generating a capacitively-coupled plasma 444 in a space between the showerhead 404 and the pedestal 412.

The CCP generating chamber 403 may be configured to generate and confine the capacitively-coupled plasma 444 in the bore 406 of the showerhead 404. In some cases, the capacitively-coupled plasma 444 is generated by powering the showerhead 404 and grounding the pedestal 412. In some cases, the capacitively-coupled plasma 444 is generated by powering the pedestal 412 and grounding the showerhead 404. As shown in Figure 4, an RF generator 438 may be

electrically connected to the pedestal 412 for powering the pedestal 412 while the showerhead 404 may be grounded. This shows that the pedestal 412 is powered by the RF generator 438 and the showerhead 404 is grounded for generation of capacitively-coupled plasma 444 in the CCP generating chamber 403.

5 [0074] One or more second gases may be supplied to the CCP generating chamber 403. In some implementations, the one or more second gases are supplied via the showerhead 404 located above the pedestal 412. However, it will be understood that the one or more second gases may be supplied via other suitable manners into the CCP generating chamber 403. In some embodiments, the one or more second gases are supplied to the CCP generating chamber 403 via the gas ports
10 472. The gas ports 472 are in fluid communication with the showerhead 404 but not in fluid communication with the ICP generating chamber 402. Where the one or more second gases are delivered to the CCP generating chamber 403 via the gas ports 472, the one or more second gases may be provided to the plenum of the showerhead 404. In some embodiments, the one or more second gases are supplied to the CCP generating chamber 403 via the through-holes 460. In such
15 instances, the one or more second gases may be provided to the ICP generating chamber 402 and delivered through the showerhead 404.

[0075] In some implementations, the one or more second gases may comprise a fluorine-containing reactant or other halogen-containing reactant, a nitrogen-containing reactant, an oxygen-containing reactant, a hydrogen-containing reactant, a sulfur-containing reactant, a
20 carbon-containing reactant such as a hydrocarbon, a silicon-containing reactant such as a silane, an inert species, or combinations thereof. Example reactants include but are not limited to fluorine-based species such as carbon tetrafluoride (CF_4), nitrogen trifluoride (NF_3), sulfur hexafluoride (SF_6), fluoromethane (CH_3F), difluoromethane (CH_2F_2), silicon tetrafluoride (SiF_4), hexafluorobutadiene (C_4F_6), hexafluoroethane (C_2F_6), tetrafluoroethylene (C_2F_4), xenon difluoride
25 (XeF_2), or molecule fluorine (F_2). Example reactants may include but are not limited to chlorine-based species such as molecular chlorine (Cl_2), hydrogen chloride (HCl), or boron trichloride (BCl_3), or bromine-based species such as molecular bromine (Br_2) or hydrogen bromide (HBr). Example reactants may include oxygen-containing species such as oxygen (O_2), nitrous oxide (N_2O), carbonyl sulfide (COS), or carbon monoxide (CO), carbon-containing species such as
30 methane (CH_4), hydrogen-containing species such as molecular hydrogen (H_2) or ammonia (NH_3), nitrogen-containing species such as molecular nitrogen (N_2), sulfur-containing species such as hydrogen sulfide (H_2S), or inert species such as argon (Ar) or helium (He). In some embodiments, example reactants may include a silicon-containing species such as silane (SiH_4), disilane (Si_2H_6), trisilane (Si_3H_8), or aminosilane, where example aminosilanes may include but are not limited to

- bis(tert-butylamino)silane (BTBAS), N-(diethylaminosilyl)-N-ethylethanamine (SAM-24), tris(dimethylamino)silane (3DMAS), and tetrakis(dimethylamino)silane (4DMAS). Further examples of silicon-containing species include tetraethyl orthosilicate (TEOS), tetramethoxysilane (TMOS), methylsilane, trimethylsilane (3MS), ethylsilane, butasilane, pentasilane, octasilane, heptasilane, hexasilane, cyclobutasilane, cycloheptasilane, cyclohexasilane, cyclooctasilane, cyclopentasilane, 1,4-dioxo-2,3,5,6-tetrasilacyclohexane, diethoxymethylsilane (DEMS), diethoxysilane (DES), dimethoxymethylsilane, dimethoxysilane (DMOS), methyl-diethoxysilane (MDES), methyl-dimethoxysilane (MDMS), t-butoxydisilane, triethoxysilane (TES), trimethoxysilane (TMS), octamethylcyclotetrasiloxane (OMCTS), octamethoxydodecasiloxane (OMODDS), tetramethylcyclotetrasiloxane (TMCTS), triethoxysiloxane (TRIES), tetraoxymethylcyclotetrasiloxane (TOMCTS), dichlorosilane (DCS), hexachlorodisilane (HCDS), tetrachlorosilane (SiCl_4), trichlorosilane (SiHCl_3), and the like. Any of the aforementioned reactants may be used in combination with one another during processing with the capacitively-coupled plasma 444.
- 15 **[0076]** The RF generator 438 generates and outputs RF power to the pedestal 412. In some embodiments, a frequency generated by the RF generator 438 is between about 10 Hz and about 500 kHz, such as 3.5 kHz, or between about 50 kHz and about 500 kHz, such as about 400 kHz. In some embodiments, a power supplied to the RF generator 438 is between about 10 W and about 8000 W, between about 100 W and about 6000 W, or between about 100 W and about 5000 W, such as about 3500 W. The RF generator 436 for generating the inductively-coupled plasma 442 may be configured to deliver higher RF power and higher frequency than the RF generator 438 for generating the capacitively-coupled plasma 444. RF power supplied by the RF generator 438 to the pedestal 412 may generate a sufficient electromagnetic field with the showerhead 404 to ignite the one or more second gases to form the capacitively-coupled plasma 444. The controller 25 490 may control delivery of RF power to the RF generator 438 for generation of the capacitively-coupled plasma 444.
- 30 **[0077]** The capacitively-coupled plasma 444 may comprise ions and radicals of the one or more second gases. The capacitively-coupled plasma 444 may be confined within the bore 406 of the showerhead 404. The ions and radicals of the one or more second gases may be provided in the gap between the showerhead 404 and the pedestal 412. The substrate 414 may be exposed to the ions and radicals of the one or more second gases from the capacitively-coupled plasma 444 during processing of the substrate 414.
- [0078]** In some implementations, the capacitively-coupled plasma 444 modifies the substrate 414 in a first step and the inductively-coupled plasma 442 modifies the substrate 414 in a second

step. Or, the inductively-coupled plasma 442 modifies the substrate 414 in a first step and the capacitively-coupled plasma 444 modifies the substrate 414 in a second step. Regardless, integration of the CCP generating chamber 403 and the ICP generating chamber 402 enables processing of substrates using the capacitively-coupled plasma 444 and the inductively-coupled plasma 442 in a two-step process without having to transfer the substrates.

[0079] Though the plasma apparatus 400 illustrates the RF generator 436 and the RF generator 438 as separate plasma generators for generation of the inductively-coupled plasma 442 and the capacitively-coupled plasma 444, respectively, it is possible that the plasma apparatus 400 implements a single RF generator for generation of the inductively-coupled plasma 442 and the capacitively-coupled plasma 444. In such instances, a single RF generator can be provided to supply RF power to either the ICP generating chamber 402 (e.g., via the coil 434) for powering the inductively-coupled plasma 442 or the CCP generating chamber 403 (e.g., via the pedestal 412 or showerhead 404) for powering the capacitively-coupled plasma 444. For example, a split input RF (SiRF) or other power splitter can be used to deliver RF power from the single RF generator to either the ICP generating chamber 402 or the CCP generating chamber 403.

[0080] In some implementations, the controller 490 is in operative communication with the plasma apparatus 400. In some implementations, the controller 490 may be in communication with the RF generator 436 to control plasma parameters and/or conditions in the ICP generating chamber 402 and may be in communication with the RF generator 438 to control plasma parameters and/or conditions in the CCP generating chamber 403. In some implementations, the controller 490 may be in communication with the pedestal 412 to control pedestal elevation, pedestal tilt, pedestal rotation, electrostatic chucking and dechucking, and temperature. In some implementations, the controller 490 may be in communication with gas delivery systems to control delivery of the one or more first gases into the ICP generating chamber 402 and the one or more second gases into the CCP generating chamber 403. The controller 490 may control other processing conditions, such as RF power settings, frequency settings, duty cycles, pulse times, pressure within the ICP generating chamber 402, pressure within the CCP generating chamber 403, temperature of the pedestal 412, temperature of the ICP generating chamber 402, temperature of the CCP generating chamber 403, temperature of the showerhead 404, gas composition and mixture, and gas flow rates, among other processing conditions.

[0081] The controller 490 may contain instructions for controlling process conditions for the operation of the plasma apparatus 400. The controller 490 will typically include one or more memory devices and one or more processors. The processor may include a CPU or computer,

analog and/or digital input/output connections, stepper motor controller boards, etc. Instructions for implementing appropriate control operations are executed on the processor. These instructions may be stored on the memory devices associated with the controller 490 or they may be provided over a network.

5 **[0082]** In certain embodiments, the controller 490 controls all or most activities of the plasma apparatus 400 described herein. For example, the controller 490 may control all or most activities of the plasma apparatus 400 associated with depositing a first layer on the substrate 414, depositing a second layer on the first layer, treating the first layer, etching the first layer, and other substrate processing or chamber operations. The controller 490 may execute system control software
10 including sets of instructions for controlling the timing, gas composition, gas flow rates, chamber pressure, chamber temperature, RF power levels, substrate position, substrate temperature, DC chucking voltage, dechucking routines, and/or other parameters. Other computer programs, scripts, or routines stored on memory devices associated with the controller 490 may be employed in some embodiments. In a multi-station reactor, the controller 490 may comprise different or
15 identical instructions for different apparatus stations, thus allowing the apparatus stations to operate either independently or synchronously.

[0083] In some embodiments, the plasma apparatus 400 may include a user interface associated with controller 490. The user interface may include a display screen, graphical software displays of the plasma apparatus 400 and/or process conditions, and user input devices such as pointing
20 devices, keyboards, touch screens, microphones, etc.

[0084] The computer program code for controlling the above operations can be written in any conventional computer readable programming language: for example, assembly language, C, C++, Pascal, Fortran, or others. Compiled object code or script is executed by the processor to perform the tasks identified in the program.

25 **[0085]** Signals for monitoring the process may be provided by analog and/or digital input connections of the system controller. The signals for controlling the process are output on the analog and digital output connections of the processing system.

[0086] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control
30 operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software).

Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials (e.g., silicon nitride), surfaces, circuits, and/or dies of a wafer.

[0087] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0088] Figure 5A shows a simplified schematic illustration of the plasma apparatus of Figure 4 using the inductively-coupled plasma chamber for generation of the remote plasma during substrate processing according to some implementations. Figure 5B shows a simplified schematic illustration of the plasma apparatus of Figure 4 using the capacitively-coupled plasma chamber for generation of the direct plasma during substrate processing according to some implementations. The substrate 414 in the CCP generating chamber 403 can be processed by both the inductively-coupled plasma 442 and the capacitively-coupled plasma 444.

[0089] In Figure 5A, one or more first gases 452 may be supplied to the ICP generating chamber 402 via the gas injector 432. As discussed above, the one or more first gases 452 may include an oxygen-containing reactant, nitrogen-containing reactant, hydrogen-containing reactant, carbon-containing reactant, or combinations thereof. In one example, the one or more first gases 452 include molecular hydrogen mixed with an inert gas species such as helium or argon. In another example, the one or more first gases 452 include a gas mixture of nitrogen, ammonia, and hydrogen, where the gas mixture may further include an inert gas species such as helium or argon.

[0090] The ICP generating chamber 402 generates an inductively-coupled plasma 442 of the one or more first gases 452. The controller 490 may communicate with the RF generator 436 to deliver RF power to the coil 434 to ignite the inductively-coupled plasma 442. The inductively-coupled plasma 442 may include plasma-activated species (e.g., ions and radicals) of the one or more first gases 452. In some implementations, the plasma-activated species of the inductively-coupled plasma 442 include excited nitrogen radicals (N^*), hydrogen radicals (H^*), and/or amine radicals (NH^* or NH_2^*). In some implementations, the plasma-activated species of the inductively-coupled plasma 442 include excited hydrogen radicals (H^*). The showerhead 404 may filter out the ions of the inductively-coupled plasma 442 from reaching the CCP generating chamber 403. In particular, the plurality of through-holes 460 of the showerhead 404 are configured to filter ions from the inductively-coupled plasma 442.

[0091] Radicals of the inductively-coupled plasma 442, such as nitrogen radicals, hydrogen radicals, and/or amine radicals flow into the CCP generating chamber 403 towards the substrate 414. The radicals of the inductively-coupled plasma 442 are used to process the substrate 414. In one example, the inductively-coupled plasma 442 is used to assist in deposition of a dielectric layer on the substrate 414. By “assisting” in the deposition of the dielectric layer on the substrate 414, the charged and uncharged species of the inductively-coupled plasma 442 participates in a reaction for depositing the dielectric layer, such as by interacting directly with materials on the substrate surface or interacting with other gases (e.g., precursor gases) to deposit the dielectric layer on the substrate surface. In some embodiments, one or more precursor gases are supplied to the CCP generating chamber 403 for interacting with the radicals of the inductively-coupled plasma 442 in an environment adjacent to the substrate 414. For instance, the one or more precursor gases may be supplied to the CCP generating chamber 403 via the gas ports 472 of the showerhead 404. The one or more precursor gases may be delivered from a gas delivery system to the plenum of the showerhead 404 that is in fluid communication with the gas ports 472 but not in fluid communication with the through-holes 460.

[0092] In some implementations, the one or more precursor gases include a silicon-containing

precursor. The silicon-containing precursor may fall into a chemical class. In some embodiments, the silicon-containing precursor is a siloxane. Example siloxanes include but are not limited to 2,4,6,8-tetramethylcyclotetrasiloxane (TMCTS), octamethylcyclotetrasiloxane (OMCTS), heptamethylcyclotetrasiloxane (HMCTS), octamethoxydodecasiloxane (OMODDS), triethoxysiloxane (TRIES), tetraoxymethylcyclotetrasiloxane (TOMCTS), pentamethyldisiloxane (PMDSO), tetramethyldisiloxane (TMDSO), hexamethyltrisiloxane, and heptamethyltrisiloxane. In some embodiments, the silicon-containing precursor is an alkyl silane. Example alkyl silanes include but are not limited to tetraethyl orthosilicate (4MS), trimethylsilane (3MS), triethylsilane, pentamethyl disilamethane ((CH₃)₂Si-CH₂-Si(CH₃)₃), dimethylsilane (2MS), methylsilane, ethylsilane, hexamethyldisilane (HMDS), and pentamethyldisilane (PMDS). In some embodiments, the silicon-containing precursor is an alkoxy silane. Example alkoxy silanes include but are not limited to trimethoxysilane (TMOS), dimethoxysilane (DMOS), methoxysilane (MOS), diethoxysilane (DES), triethoxysilane (TES), trimethoxysilane (TMS), methyldimethoxysilane (MDMOS), diethoxymethylsilane (DEMS), dimethylethoxysilane (DMES), and dimethylmethoxysilane (DMMOS). In some embodiments, the silicon-containing precursor is a silazane. Examples of silazanes include but are not limited to methyl-substituted disilazanes and trisilazanes, such as tetramethyldisilazane and hexamethyl trisilazane. In some embodiments, the silicon-containing precursor is a silane, disilane, trisilane, butasilane, pentasilane, octasilane, heptasilane, hexasilane, or other polysilane. In some embodiments, the silicon-containing precursor is a cyclic silane such as cyclobutasilane, cycloheptasilane, cyclohexasilane, cyclooctasilane, cyclopentasilane. In some embodiments, the silicon-containing precursor is an aminosilane. Examples of aminosilanes include but are not limited to bis(tert-butylamino)silane, N-(diethylaminosilyl)-N-ethylethanamine, tris(dimethylamino)silane, and tetrakis(dimethylamino)silane. In some embodiments, the silicon-containing precursor is a halosilane. Examples of halosilanes include but are not limited to dichlorosilane, hexachlorodisilane, tetrachlorosilane, and trichlorosilane.

[0093] In some embodiments, one or more co-reactant gases may be flowed with the one or more precursor gases from the gas ports 472 into the CCP generating chamber 403. Examples of the co-reactant gases include but are not limited to oxygen, nitrogen, ammonia, carbon dioxide, carbon monoxide, water, methanol, ozone, methane, ethane (C₂H₆), acetylene (C₂H₂), ethylene (C₂H₄), and diborane (B₂H₆).

[0094] The radicals of the inductively-coupled plasma 442 may react with the one or more precursor gases in the environment adjacent to the substrate 414 in the CCP generating chamber 403. The reaction of the radicals with the one or more precursor gases may deposit a thin film

such as a dielectric layer on the substrate 414 by a vapor deposition process (e.g., ALD or CVD). In some embodiments, the radicals may transition from an excited energy state to a lower energy state or ground state upon reaction with the one or more precursor gases in the CCP generating chamber 403. In some embodiments, the radicals may react with one or more co-reactant gases along with the one or more precursor gases, where the co-reactant gases may influence a composition of the deposited thin film. In some embodiments, the reaction of the radicals with the one or more precursor gases deposits a silicon-containing film on the substrate 414. Examples of silicon-containing films include but are not limited to amorphous silicon (a-Si), silicon oxide (SiO_x), silicon carbide (SiC), silicon nitride (Si_xN_y), silicon oxycarbide (SiCO), silicon oxynitride (SiON), silicon carbonitride (SiCN), and silicon oxycarbonitride (SiOCN).

[0095] In some implementations, the radicals of the inductively-coupled plasma 442 are used to treat or etch a material layer on the substrate 414. In such instances, the radicals of the inductively-coupled plasma 442 do not interact with one or more precursor gases. Instead, the substrate 414 may be directly exposed to the radicals of the inductively-coupled plasma 442. Such radicals may include, for example, radicals of hydrogen (H^*), halides (e.g., F^* , Cl^*), hydrocarbons (e.g., CH^*), fluorocarbons (e.g., CF^*), amines (e.g., NH^*), or combinations thereof.

[0096] In Figure 5B, one or more second gases 454 may be supplied to the CCP generating chamber 403. As shown in Figure 5B, the one or more second gases 454 may be supplied to the CCP generating chamber 403 via the gas ports 472, though alternative methods of delivery may be implemented. As discussed above, the one or more second gases 454 may include a fluorine-containing reactant or other halogen-containing reactant, a nitrogen-containing reactant, an oxygen-containing reactant, a hydrogen-containing reactant, a sulfur-containing reactant, a carbon-containing reactant such as a hydrocarbon, a silicon-containing reactant such as a silane, an inert species, or combinations thereof. In one example, the one or more second gases 454 include nitrogen trifluoride or molecular hydrogen mixed with nitrogen trifluoride. In another example, the one or more second gases 454 include molecular oxygen and/or molecular chlorine. In another example, the one or more second gases 454 include a fluorocarbon such as fluoromethane.

[0097] The CCP generating chamber 403 generates a capacitively-coupled plasma 444 of the one or more second gases 454. The controller 490 may communicate with the RF generator 438 to deliver RF power to the pedestal 412 while the showerhead 404 is grounded to ignite the capacitively-coupled plasma 444. The capacitively-coupled plasma 444 may include plasma-activated species (e.g., ions and radicals) of the one or more second gases 454. Radicals, ions, and other reactive species of the capacitively-coupled plasma 444 may directly react with the substrate

414 to process the substrate 414.

[0098] In some embodiments, the radicals, ions, and other reactive species of the capacitively-coupled plasma 444 may react with the substrate 414 to deposit a thin film on the substrate 414. For instance, the material layer deposited by the capacitively-coupled plasma may be a dielectric film such as a silicon-containing film. In one example, the capacitively-coupled plasma 444 may deposit a tensile film and the inductively-coupled plasma 442 may assist in depositing a compressive film.

[0099] In some embodiments, the radicals, ions, and other reactive species of the capacitively-coupled plasma 444 may etch or treat a material layer on the substrate 414. The capacitively-coupled plasma 444 may provide a depth-controlled, directional etch/inhibition when etching or treating the substrate 414. In etching a material layer on the substrate 414, etchant chemistries such as oxygen-based etchant, hydrogen-based etchant, or fluorine-based etchant may be used to remove portions of the material layer using the capacitively-coupled plasma 444. In some embodiments, the capacitively-coupled plasma 444 is used to assist in etching or partially etching a dielectric layer on the substrate 414. By “assisting” in the etch or partial etch of the electric layer on the substrate, the charged and uncharged species of the capacitively-coupled plasma 444 participates in a reaction to remove material(s) from the substrate 414, such as by interacting directly with the dielectric layer on the substrate surface or by interacting with other gases that etches at least a portion of the dielectric layer from the substrate surface. The capacitively-coupled plasma 444 may include fluorine ions and/or radicals from a fluorine-based etchant such as nitrogen trifluoride. In some cases, the fluorine ions and/or radicals may provide a tapered or non-conformal etch of the material layer. In treating a material layer on the substrate 414, the capacitively-coupled plasma 444 may provide ion bombardment to densify the material layer. Ions in the capacitively-coupled plasma 444 may be able to densify layers such as oxide, nitride, or carbide layers in a manner that is more effective than using radicals in the inductively-coupled plasma 442. In some implementations, the capacitively-coupled plasma 444 may be used to tune film properties of the material layer using different active species than the inductively-coupled plasma 442. By way of an example, the capacitively-coupled plasma 444 may be used to tune a stress, composition, doping, dielectric constant, chemical resistance, thermal resistance, density, or in-feature profile of the material layer.

[0100] As shown in Figures 5A and 5B, the plasma apparatus 400 may operate in either an ICP mode or CCP mode. Processing the substrate 414 in the ICP mode in Figure 5A utilizes the inductively-coupled plasma 442 generated in the ICP generating chamber 402 without the capacitively-coupled plasma 444 in the CCP generating chamber 403. Processing the substrate

414 in the CCP mode in Figure 5B utilizes the capacitively-coupled plasma 444 generated in the CCP generating chamber 403 without the inductively-coupled plasma 442. It will be understood that processing the substrate 414 may involve the utilizing first the inductively-coupled plasma 442 followed by utilizing the capacitively-coupled plasma 444, or vice versa.

5 [0101] Figure 6 shows a schematic illustration of a showerhead in relation to a pedestal used in a plasma apparatus that integrates an inductively-coupled plasma chamber for generation of remote plasma and a capacitively-coupled plasma chamber for generation of direct plasma according to some implementations.

[0102] A micro-volume of gases in a gap between the showerhead 404 and the pedestal 412 is controllable. A gap height 470 between the showerhead 404 and the pedestal 412 is tunable by
10 adjusting a position of the pedestal 412 (or showerhead 404). This allows precise control of the micro-volume when processing the substrate 414 with either the capacitively-coupled plasma 444 or inductively-coupled plasma 442. A narrow gap for the gap height 470 between the showerhead 404 and the pedestal 412 prevents depletion of radicals and/or ions in the micro-volume. In some
15 implementations, the gap height 470 is between about 0.01 inches and about 5 inches, between about 0.02 inches and about 3 inches, or between about 0.05 inches and about 2 inches.

[0103] In addition, the downwardly protruding portion 407 of the showerhead 404 confines plasma generation of the capacitively-coupled plasma 444 to the micro-volume between the showerhead 404 and the pedestal 412. An inner wall of the downwardly protruding portion 407
20 provides a tight constriction with a top surface of the pedestal 412 to minimize gas flow around the edges of the pedestal 412. A gap distance 480 between the inner wall of the downwardly protruding portion 407 and the top surface of the pedestal 412 is configured to prevent or otherwise limit parasitic plasma from forming around the edges of the pedestal 412. That way, a capacitively-coupled plasma 444 is provided only in areas where it is desired in the CCP
25 generating chamber 403. In some implementations, the gap distance 480 is between about 0.001 inches and about 2 inches, between about 0.01 inches and about 1 inch, or between about 0.02 inches and about 0.5 inches.

[0104] Furthermore, the through-holes 460 are designed to filter out ions from the inductively-coupled plasma 442 while passing radicals from the inductively-coupled plasma 442. At the same
30 time, the through-holes 460 are designed to limit any charge buildup in the showerhead 404 from the capacitively-coupled plasma 444. In other words, the through-holes 460 prevent or otherwise limit parasitic plasma from forming in the through-holes 460 or at the edges of the through-holes 460.

[0105] Figure 7 shows a flow diagram of an example method for processing a substrate using

an inductively-coupled plasma and capacitively-coupled plasma according to some implementations. The operations of a process 700 may be performed in different orders and/or with different, fewer, or additional operations. One or more operations of the process 700 may be performed using a plasma apparatus described in any one of Figures 3, 4, 5A, 5B, and 6. In some implementations, the operations of the process 700 may be implemented, at least in part, according to software stored in one or more non-transitory computer readable media.

[0106] At block 710 of the process 700, an inductively-coupled plasma is generated in a remote plasma chamber to assist in deposition of a first layer on a substrate in a processing chamber. The remote plasma chamber and the processing chamber are in fluid communication with one another via a showerhead, where the showerhead is positioned between the remote plasma chamber and the processing chamber. An RF generator is electrically coupled to a coil that surrounds the remote plasma chamber. The RF generator is configured to provide RF power to the remote plasma chamber to ignite the inductively-coupled plasma.

[0107] One or more first gases are flowed into the remote plasma chamber. The one or more first gases may include an oxygen-containing reactant, nitrogen-containing reactant, hydrogen-containing reactant, carbon-containing reactant, or combinations thereof. For instance, the one or more first gases may include molecular hydrogen mixed with an inert gas such as argon or helium. The RF generator is configured to power the remote plasma chamber to ionize the one or more first gases, thereby forming radicals, ions, and other reactive species of the one or more first gases. The showerhead is configured to filter out ions while passing radicals of the inductively-coupled plasma to the processing chamber.

[0108] In some implementations, a precursor gas is flowed into the processing chamber towards the substrate. The precursor gas may be flowed into the processing chamber through gas outlets located downstream from the remote plasma source. The precursor gas may be flowed into the processing chamber through gas ports in the showerhead that are not in fluid communication with the remote plasma source. That way, the precursor gas avoids interaction with the radicals of the inductively-coupled plasma prior to entry into the processing chamber. In some implementations, the precursor gas includes a silicon-containing precursor. The precursor gas may react with the radicals of the inductively-coupled plasma in an environment adjacent to the substrate. The radicals of the inductively-coupled plasma may relax or transition from an excited energy state to a lower energy state (e.g., ground state) in the processing chamber. The precursor gas reacts with the radicals of the inductively-coupled plasma to deposit the first layer on the substrate. In some implementations, the first layer is a dielectric layer such as silicon oxide, doped or undoped silicon carbide, or doped or undoped silicon nitride.

[0109] At block 720 of the process 700, a capacitively-coupled plasma is generated in the processing chamber to assist in etch or treatment of the first layer, or in deposition of a second layer on the substrate. The capacitively-coupled plasma is formed in a micro-volume or space between the showerhead and a pedestal. The pedestal retains, holds, clamps, or otherwise supports the substrate. An RF generator is electrically coupled to the pedestal. The RF generator is configured to provide RF power to the pedestal while the showerhead is grounded, which forms an electric field between the powered electrode (i.e., pedestal) and the grounded electrode (i.e., showerhead) that ignites and sustains the capacitively-coupled plasma.

[0110] One or more second gases are flowed into the processing chamber. The one or more second gases may include a fluorine-containing reactant or other halogen-containing reactant, a nitrogen-containing reactant, an oxygen-containing reactant, a hydrogen-containing reactant, a sulfur-containing reactant, a carbon-containing reactant such as a hydrocarbon, silicon-containing reactant such as a silane, inert species, or combinations thereof. For instance, the one or more second gases may include nitrogen trifluoride or nitrogen trifluoride mixed with molecular hydrogen. The RF generator is configured to power the pedestal while the showerhead is grounded to ionize the one or more second gases, thereby forming radicals, ions, and other reactive species of the one or more second gases. The substrate is directly exposed to the radicals, ions, and other reactive species of the one or more second gases.

[0111] The pedestal height may be adjusted to confine the capacitively-coupled plasma in the micro-volume or space between the pedestal and the showerhead. Additionally, the showerhead may include a planar base portion and a downwardly protruding portion located around a periphery of the planar base portion, where an inner wall of the downwardly protruding portion and the planar base portion define a bore of the showerhead. The pedestal height may be adjusted so that narrow gap is formed between the inner wall of the downwardly protruding portion and the edge of the pedestal. The narrow gap and the pedestal height ensure that the capacitively-coupled plasma is confined within the micro-volume or space between the pedestal and the showerhead.

[0112] In some embodiments, the capacitively-coupled plasma may be used to etch the first layer of the substrate. The etch may be depth-controlled and directional to obtain a desired etch profile and etch depth. In some implementations, a non-conformal or tapered etch is performed on the first layer of the substrate. For instance, the capacitively-coupled plasma removes more of the first layer at the top of a feature than at the bottom of the feature. In some cases, the capacitively-coupled plasma non-conformally etches the first layer of the substrate using ions and radicals of fluorine-containing species such as nitrogen trifluoride.

[0113] In some embodiments, the capacitively-coupled plasma may be used to treat the first

layer of the substrate. The treatment may tune the properties of the first layer. Ions and radicals in the capacitively-coupled plasma may be used to tune a stress, composition, doping, dielectric constant, chemical resistance, thermal resistance, density, or in-feature profile of the first layer. In some cases, the capacitively-coupled plasma densifies the first layer of the substrate using ion bombardment.

[0114] In some embodiments, the capacitively-coupled plasma may be used to deposit a second layer on the first layer of the substrate. The second layer may have different properties than the first layer. In some cases, the first layer deposited using inductively-coupled plasma may have tensile stress and the second layer deposited using capacitively-coupled plasma may have compressive stress.

[0115] Generation of the capacitively-coupled plasma and the inductively-coupled plasma for processing the substrate may occur without transferring the substrate to another station, module, or tool. Though the process 700 processes the substrate using the inductively-coupled plasma prior to the capacitively-coupled plasma, it will be understood that the process 700 may process the substrate using the capacitively-coupled plasma prior to the inductively-coupled plasma.

Multi-Station Apparatus

[0116] Figure 8 shows a schematic diagram of an example process tool including multiple stations, where one or more stations are each configured to generate an inductively-coupled plasma and a capacitively-coupled plasma according to some implementations.

[0117] Figure 8 shows a schematic view of an implementation of a multi-station processing apparatus 800 with an inbound load lock 802 and an outbound load lock 804, either or both of which may include a remote plasma source. A robot 806 at atmospheric pressure is configured to move wafers from a cassette loaded through a pod 808 into inbound load lock 802 via an atmospheric port 810. A wafer is placed by the robot 806 on a pedestal 812 in the inbound load lock 802, the atmospheric port 810 is closed, and the load lock is pumped down. Where the inbound load lock 802 includes a remote plasma source, the wafer may be exposed to a remote plasma to treat the substrate surface in the load lock prior to being introduced into a processing chamber 814. Further, the wafer also may be heated in the inbound load lock 802 as well, for example, to remove moisture and adsorbed gases. Next, a chamber transport port 816 to processing chamber 814 is opened, and another robot (not shown) places the wafer into the reactor on a pedestal of a first station shown in the reactor for processing. While the implementation depicted in Figure 8 includes load locks, it will be appreciated that, in some implementations, direct entry of a wafer into a process station may be provided.

[0118] The depicted processing chamber 814 includes four process stations, numbered from 1 to 4 in the implementation shown in Figure 8. Each station has a heated pedestal (shown at 818 for station 1), and gas line inlets. It will be appreciated that in some implementations, each process station may have different or multiple purposes. For example, in some implementations, a process station may be configured to perform deposition and etch process operations. In some implementations, a process station may be configured to perform deposition and treatment process operations. In some implementations, a process station may be configured for etch and treatment operations. In some implementations, a process station may be configured for deposition operations only. While the depicted processing chamber 814 includes four stations, it will be understood that a processing chamber 814 according to the present disclosure may have any suitable number of stations. For example, in some implementations, a processing chamber 814 may have five or more stations, while in other implementations a processing chamber 814 may have three or fewer stations.

[0119] The multi-station processing apparatus 800 comprises a plurality of processing stations. At least one of the stations may be configured generate a capacitively-coupled plasma in a CCP generating chamber and an inductively-coupled plasma in an ICP generating chamber, where a showerhead separates the CCP generating chamber from the ICP generating chamber. The wafer may be supported on a pedestal in the CCP generating chamber for processing. The ICP generating chamber may be a remote plasma source in fluid communication with the CCP generating chamber. In some implementations, the ICP generating chamber may be configured to generate an inductively-coupled plasma comprising radicals and ions of one or more first gases, and the CCP generating chamber may be configured to generate radicals and ions of one or more second gases. The showerhead filters out ions of the inductively-coupled plasma.

[0120] Figure 8 depicts an implementation of a wafer handling system 890 for transferring wafers within processing chamber 814. In some implementations, wafer handling system 890 may transfer wafers between various process stations and/or between a process station and a load lock. It will be appreciated that any suitable wafer handling system may be employed. Non-limiting examples include wafer carousels and wafer handling robots. Figure 8 also depicts an implementation of a system controller 850 employed to control process conditions and hardware states of the multi-station processing apparatus 800. System controller 850 may include one or more memory devices 856, one or more mass storage devices 854, and one or more processors 852. Processor 852 may include a CPU or computer, analog, and/or digital input/output connections, stepper motor controller boards, etc.

[0121] In some implementations, system controller 850 controls all of the activities of the multi-station processing apparatus 800. System controller 850 executes system control software 858 stored in mass storage device 854, loaded into memory device 856, and executed on processor 852. Alternatively, the control logic may be hard coded in the system controller 850. Applications
5 Specific Integrated Circuits, Programmable Logic Devices (e.g., field-programmable gate arrays, or FPGAs) and the like may be used for these purposes. In the following discussion, wherever “software” or “code” is used, functionally comparable hard coded logic may be used in its place. System control software 858 may include instructions for controlling the timing, mixture of gases, gas flow rates, chamber and/or station pressure, chamber and/or station temperature, wafer
10 temperature, target power levels, RF power levels, substrate pedestal, chuck and/or susceptor position, and other parameters of a particular process performed by the multi-station processing apparatus 800. System control software 858 may be configured in any suitable way. For example, various process tool component subroutines or control objects may be written to control operation of the process tool components used to carry out various process tool processes. System control
15 software 858 may be coded in any suitable computer readable programming language.

[0122] In some embodiments, the system controller 850 may be configured with instructions to perform the following operations: generate the inductively-coupled plasma in the ICP generating chamber for depositing a first layer on the wafer, and generate the capacitively-coupled plasma in the CCP generating chamber for etching or treating the first layer, or depositing a second layer on
20 the first layer of the wafer. Multiple stations in the processing chamber 814 may be equipped to process a wafer in the station using either a capacitively-coupled plasma or inductively-coupled plasma. If a wafer is initially processed using a capacitively-coupled plasma or inductively-coupled plasma, the wafer need not be transferred to downstream tools or applications for processing via the other type of plasma technique.

[0123] In some implementations, system control software 858 may include input/output control (IOC) sequencing instructions for controlling the various parameters described above. Other computer software and/or programs stored on mass storage device 854 and/or memory device 856 associated with system controller 850 may be employed in some implementations. Examples of
25 programs or sections of programs for this purpose include a substrate positioning program, a process gas control program, a pressure control program, a heater control program, and a plasma control program.
30

[0124] As noted above, depending on the process step or steps to be performed by the tool, the system controller 850 might communicate with one or more of other tool circuits or modules, other

tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

5

CONCLUSION

[0125] It is understood that the examples and implementations described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art. Although various details have been omitted for clarity's sake, various design alternatives may be implemented. Therefore, the present examples are to be considered as illustrative and not restrictive, and the disclosure is not to be limited to the details given herein, but may be modified within the scope of the disclosure.

10

CLAIMS

1. A plasma processing apparatus comprising:
an inductively-coupled plasma (ICP) generating chamber;
a capacitively-coupled plasma (CCP) generating chamber separate from the ICP
5 generating chamber;
a showerhead between the CCP generating chamber and the ICP generating chamber,
wherein the CCP generating chamber and the ICP generating chamber are in fluid
communication with one another via the showerhead; and
a pedestal configured to support a substrate in the CCP generating chamber.
- 10 2. The plasma processing apparatus of claim 1, wherein the ICP generating chamber is
configured to generate inductively-coupled plasma comprising radicals and ions of one or more
first gases and wherein the CCP generating chamber is configured to generate capacitively-
coupled plasma comprising radicals and ions of one or more second gases, wherein the
showerhead is configured to filter out ions of the inductively-coupled plasma.
- 15 3. The plasma processing apparatus of claim 2, wherein the capacitively-coupled plasma
modifies the substrate in a first step and the inductively-coupled plasma modifies the substrate in
a second step.
4. The plasma processing apparatus of claim 2, wherein the inductively-coupled plasma
modifies the substrate in a first step and the capacitively-coupled plasma modifies the substrate
20 in a second step.
5. The plasma processing apparatus of claim 2, wherein the pedestal is powered by an RF
generator and the showerhead is grounded for generation of the capacitively-coupled plasma in
the CCP generating chamber.
6. The plasma processing apparatus of claim 1, wherein the showerhead comprises:
25 a planar base portion; and
a downwardly protruding portion having an inner wall and an outer wall and positioned
along a periphery of the planar base portion, wherein the inner wall of the downwardly
protruding portion and the planar base portion define a bore of the showerhead.
7. The plasma processing apparatus of claim 6, wherein the showerhead further comprises
30 a plurality of through-holes configured to filter out ions from the inductively-coupled plasma
generated in the ICP generating chamber.

8. The plasma processing apparatus of claim 7, wherein the showerhead comprises grooves configured to circulate coolant through the showerhead.
9. The plasma processing apparatus of claim 8, wherein the CCP generating chamber is configured to generate and confine the capacitively-coupled plasma in the bore of the showerhead.
10. The plasma processing apparatus of claim 6, wherein the pedestal is configured to tilt so that a major surface of the pedestal is parallel with a major surface of the planar base portion of the showerhead.
11. The plasma processing apparatus of claim 1, further comprising:
a first RF generator coupled to the ICP generating chamber; and
a second RF generator coupled to the CCP generating chamber, wherein the first RF generator is configured to deliver higher RF power and higher frequency than the second RF generator.
12. The plasma processing apparatus of claim 1, further comprising:
an RF generator; and
a power splitter coupled to the RF generator, wherein the power splitter is configured to deliver RF power via the RF generator to either the ICP generating chamber or the CCP generating chamber.
13. The plasma processing apparatus of claim 1, further comprising:
a gas injector in fluid communication with the ICP generating chamber for delivering one or more first gases to the ICP generating chamber; and
one or more gas ports in fluid communication with the showerhead but not in fluid communication with the ICP generating chamber for delivering one or more second gases to the CCP generating chamber.
14. The plasma processing apparatus of claim 1, further comprising a controller configured with instructions for performing the following operations:
generate an inductively-coupled plasma in the ICP generating chamber to assist in deposition of a dielectric layer on the substrate; and
generate a capacitively-coupled plasma in the CCP generating chamber to assist in etch or partial etch of the dielectric layer on the substrate.
15. The plasma processing apparatus of claim 14, wherein the controller is further configured with instructions to perform the following operations:

flow one or more precursor gases towards the substrate, wherein radicals of one or more first gases are provided from the inductively-coupled plasma from the ICP generating chamber, wherein the one or more precursor gases reacts with the radicals of the one or more first gases to deposit the dielectric layer on the substrate.

- 5 16. The plasma processing apparatus of claim 14, wherein the controller is further configured with instructions to perform the following operations:

flow one or more second gases towards the substrate, wherein the capacitively-coupled plasma comprises ions of the one or more second gases to etch or partially etch the dielectric layer on the substrate.

- 10 17. The plasma processing apparatus of claim 1, further comprising a controller configured with instructions for performing the following operations:

generate an inductively-coupled plasma in the ICP generating chamber to assist in deposition of a tensile film on the substrate; and

- 15 generate a capacitively-coupled plasma in the CCP generating chamber to assist in deposition of a compressive film on the substrate.

18. The plasma processing apparatus of claim 1, further comprising a controller configured with instructions for performing the following operations:

generate an inductively-coupled plasma in the ICP generating chamber to assist in deposition of a film on the substrate; and

- 20 generate a capacitively-coupled plasma in the CCP generating chamber to assist in treatment of the film on the substrate.

19. A multi-station processing apparatus comprising:

a plurality of processing stations each comprising:

an inductively-coupled plasma (ICP) generating chamber;

- 25 a capacitively-coupled plasma (CCP) generating chamber separate from the ICP generating chamber;

a showerhead between the CCP generating chamber and the ICP generating chamber, wherein the CCP generating chamber and the ICP generating chamber are in fluid communication with one another via the showerhead; and

- 30 a pedestal configured to support a substrate in the CCP generating chamber.

20. The multi-station processing apparatus of claim 19, wherein the ICP generating chamber is configured to generate inductively-coupled plasma comprising radicals and ions of one or more first gases and wherein the CCP generating chamber is configured to generate

capacitively-coupled plasma comprising radicals and ions of one or more second gases, wherein the showerhead is configured to filter out ions of the inductively-coupled plasma.

21. The multi-station processing apparatus of claim 19, further comprising a controller configured with instructions for performing the following operations:

5 generate an inductively-coupled plasma in the ICP generating chamber for depositing a first layer on the substrate; and

generate a capacitively-coupled plasma in the CCP generating chamber for etching the first layer or treating the first layer, or depositing a second layer on the first layer of the substrate.

10 22. A method of processing a substrate, the method comprising:

generating an inductively-coupled plasma in a remote plasma chamber to assist in deposition of a first layer on the substrate in a processing chamber; and

generating a capacitively-coupled plasma in the processing chamber to assist in etch or treatment of the first layer, or in deposition of a second layer on the substrate.

15 23. The method of claim 22, wherein the remote plasma chamber and the processing chamber are in fluid communication with one another via a showerhead, wherein the showerhead is positioned between the remote plasma chamber and the processing chamber.

24. The method of claim 22, further comprising:

20 flowing a precursor gas into the processing chamber, wherein the precursor gas reacts with radicals of the inductively-coupled plasma to deposit the first layer on the substrate.