



- (51) **International Patent Classification:**
H01J 37/32 (2006.01) *C09D 1/00* (2006.01)
- (21) **International Application Number:**
PCT/US2024/051192
- (22) **International Filing Date:**
14 October 2024 (14.10.2024)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
63/597,191 08 November 2023 (08.11.2023) US
- (71) **Applicant: LAM RESEARCH CORPORATION**
[US/US]; 4650 Cushing Parkway, Fremont, California 94538 (US).
- (72) **Inventors: DREWERY, John;** 4650 Cushing Parkway, Fremont, California 94538 (US). **ALBERTI, Andrea;** 4650 Cushing Parkway, Fremont, California 94538 (US). **PATERSON, Alexander Miller;** 4650 Cushing Parkway, Fremont, California 94538 (US). **SRIRAMAN, Sar-**

avanapriyan; 4650 Cushing Parkway, Fremont, California 94538 (US). **MARSH, Richard A.;** 4650 Cushing Parkway, Fremont, California 94538 (US).

(74) **Agent: WIGGINS, Michael D.** et al.; Harness, Dickey & Pierce, P.L.C., 5445 Corporate Drive, Suite 200, Troy, Michigan 48098 (US).

(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV,

(54) **Title:** COMPOSITE WINDOW WITH LIQUID COOLING FOR INDUCTIVELY COUPLED PLASMA PROCESSING SYSTEM

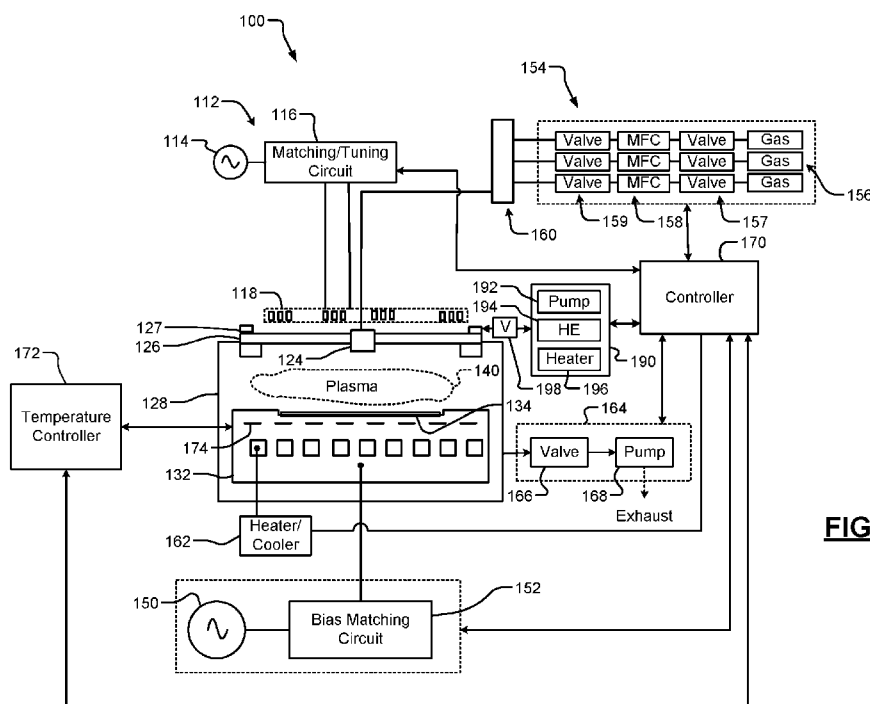


FIG. 1

(57) **Abstract:** A liquid cooled window includes a composite window including a cylindrical body made of ceramic, a layer made of ceramic attached to a plasma-facing side of the cylindrical body, and an annular cooling ring arranged on a backside surface of the cylindrical body and including an inlet port, an outlet port, and a channel extending from the inlet port to the outlet port. The backside surface of the cylindrical body encloses one side of the channel and the backside surface is in fluid communication with coolant flowing through the channel.

GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST,
SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ,
RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ,
DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT,
LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,
SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

COMPOSITE WINDOW WITH LIQUID COOLING FOR INDUCTIVELY COUPLED PLASMA PROCESSING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/597,191, filed on November 8, 2023. The entire disclosure of the application referenced above is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to substrate processing systems, and more particularly to composite windows with liquid cooling for substrate processing systems.

BACKGROUND

[0003] The background description provided here is for the purpose of generally presenting the context of the disclosure. 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 disclosure.

[0004] During manufacturing of substrates such as semiconductor wafers, treatments such as deposition, etching and/or cleaning are performed on the substrate. The substrate is typically delivered by a robot onto a substrate support such as an electrostatic chuck (ESC) or a pedestal in a processing chamber. Process gases are introduced into the processing chamber via a gas distribution device and plasma may be struck in the processing chamber to enhance chemical reactions.

[0005] In inductively coupled plasma (ICP) processes, one or more inductive coils are arranged outside of the processing chamber adjacent to a composite window enclosing one side of the processing chamber. RF power is supplied to the inductive coils while the process gases are being supplied inside of the processing chamber. The inductive coils generate magnetic fields inside of the processing chamber to ignite plasma. The plasma heats the composite window during plasma processing. In some substrate processing systems, cooling fans or air amplifiers including plenums are used to supply cooling gas to cool the composite window during plasma processing. The cooling fans and/or air amplifiers create noise and consume a significant amount of clean dry air

(CDA). Further, the cooling fans or air amplifiers do not provide sufficient cooling for higher power processes.

SUMMARY

5 [0006] A liquid cooled window includes a composite window including a cylindrical body made of ceramic, a layer made of ceramic attached to a plasma-facing side of the cylindrical body, and an annular cooling ring arranged on a backside surface of the cylindrical body and including an inlet port, an outlet port, and a channel extending from the inlet port to the outlet port. The backside surface of the cylindrical body encloses one side of the channel and the backside surface is in fluid communication with coolant
10 flowing through the channel.

[0007] In other features, the composite window further comprises a center port arranged at a center of the cylindrical body. The channel comprises a single loop. The channel comprises a bifilar cooling loop. The cylindrical body is made of aluminum nitride. The layer comprises a material selected from a group consisting of aluminum
15 oxide, alumina, zirconium oxide, yttrium oxide, lanthanum oxide, and combinations thereof. A coating layer is arranged on the layer. The coating layer is made of a material selected from a group consisting of yttrium oxide, lanthanum oxide, and combinations thereof.

[0008] In other features, a gasket is arranged between the annular cooling ring and
20 the backside surface of the cylindrical body. A plurality of fasteners connect the annular cooling ring to the cylindrical body. The layer is diffusion bonded to the annular cooling ring. The layer is glass bonded by a glass layer to the annular cooling ring. The layer is coated on the cylindrical body.

[0009] A plasma processing system comprises the liquid cooled window, a processing
25 chamber including at least one side enclosed by the liquid cooled window, and a first inductive coil arranged adjacent to the backside surface of the cylindrical body.

[0010] In other features, the annular cooling ring of the liquid cooled window is arranged radially outside of the first inductive coil. An air cooled plenum arranged on the backside surface of the cylindrical body and radially inside of the annular cooling
30 ring.

[0011] In other features, a second inductive coil arranged radially inside of the first inductive coil. The air cooled plenum is arranged on the cylindrical body between the

first inductive coil and the second inductive coil. A second inductive coil is arranged radially inside of the first inductive coil. The air cooled plenum is arranged on the cylindrical body extends along the backside surface and between at least one of the first inductive coil and the second inductive coil and the cylindrical body.

5 **[0012]** A liquid cooled window includes a composite window including a cylindrical body made of ceramic and including a channel arranged on a backside surface of the cylindrical body adjacent to a radially outer surface of the cylindrical body, and a layer arranged on a plasma-facing side of the cylindrical body. An annular cooling ring is arranged on the backside surface of the cylindrical body and includes an inlet port and
10 an outlet port. The channel is in fluid communication with the inlet port and the outlet port of the annular cooling ring.

[0013] In other features, the composite window further comprises a center port arranged at a center of the cylindrical body. The channel comprises a single loop. The channel comprises a bifilar cooling loop. The cylindrical body is made of aluminum
15 nitride. The layer comprises a material selected from a group consisting of aluminum oxide, alumina, zirconium oxide, yttrium oxide, lanthanum oxide, and combinations thereof.

[0014] In other features, a coating layer is arranged on a plasma-facing surface of the layer. The coating layer is made of a material selected from a group consisting of
20 yttrium oxide, lanthanum oxide, and combinations thereof.

[0015] In other features, a gasket is arranged between the annular cooling ring and the backside surface of the cylindrical body. A plurality of fasteners connect the annular cooling ring to the cylindrical body. The layer is diffusion bonded to the annular cooling ring. The layer is glass bonded by a glass layer to the annular cooling ring. The layer is
25 coated on the cylindrical body.

[0016] A plasma processing system includes the liquid cooled window, a processing chamber including at least one side enclosed by the liquid cooled window, and a first inductive coil arranged adjacent to the backside surface of the cylindrical body.

[0017] In other features, the annular cooling ring of the liquid cooled window is
30 arranged radially outside of the first inductive coil. An air cooled plenum is arranged on the backside surface of the cylindrical body and radially inside of the annular cooling ring.

[0018] In other features, a second inductive coil is arranged radially inside of the first inductive coil. The air cooled plenum is arranged on the cylindrical body between the first inductive coil and the second inductive coil.

[0019] In other features, a second inductive coil arranged radially inside of the first inductive coil. The air cooled plenum extends between at least one of the first inductive coil and the second inductive coil and the cylindrical body.

[0020] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims, and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0022] FIG. 1 is a functional block diagram of an example of a substrate processing system including a liquid cooled composite window of a processing chamber according to the present disclosure;

[0023] FIG. 2 is an example of an inductive coil including a set of inner coils and a set of outer coils;

[0024] FIG. 3A is a perspective view of an example of a composite window including an annular cooling ring according to the present disclosure;

[0025] FIG. 3B is a plan view of an example of the composite window of FIG. 3A;

[0026] FIG. 3C is a side view of an example portion of the composite window of FIG. 3A;

[0027] FIG. 4A is a perspective view of an example of a composite window including a bifilar annular cooling ring according to the present disclosure;

[0028] FIG. 4B is a plan view of an example of the composite window of FIG. 4A;

[0029] FIG. 5 is a perspective view of an example of a composite window including a cooling channel on a backside surface thereof and an annular cooling ring covering the cooling channel according to the present disclosure;

[0030] FIG. 6 is a perspective view of an example of a composite window including a bifilar cooling channel on a backside surface thereof and an annular cooling ring covering the cooling channel according to the present disclosure;

[0031] FIG. 7 is a plan view illustrating an example arrangement of inductive coils, the annular cooling ring, and the composite window according to the present disclosure;

[0032] FIG. 8 is a plan view illustrating an example arrangement of inductive coils, the annular cooling ring, a gas plenum, and the composite window according to the present disclosure; and

[0033] FIGS. 9 and 10 are side cross sectional views of example arrangements of the composite window, the annular cooling ring, the air plenum, and the inductive coils.

[0034] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0035] A composite window of an inductively coupled plasma (ICP) processing system supports several functions. The composite window forms a wall of the processing chamber and passage of alternating magnetic fields with minimal or at least uniform power losses. The composite window should not be a source of particles, outgassing, or other contributors to substrate defects or inconsistent processing. The composite window also allows removal of heat that is transferred to the composite window as a side effect of the substrate treatment.

[0036] The requirements to form a wall of the processing chamber and pass the alternating magnetic fields restrict the materials of the composite window to high-strength ceramic materials with extremely high electrical resistance. Removing heat from the composite window has become increasingly difficult with increasing process/plasma power. Some ICP processing systems use a fan to cool the composite window. Other ICP processing systems use forced air that is entrained over a surface of the composite window using a gas plenum to increase flow velocity and the effectiveness of heat transfer from the composite window to the air. As power continues to increase, it is increasingly difficult to remove sufficient heat using these approaches. In addition, the high volume of air required is a serious cost to the tool user.

[0037] A lack of sufficient cooling poses several problems. The composite window temperature will not be constant but will increase over time. In some situations, the

composite window temperature increases to a level that may cause damage to the composite window and/or surrounding components. The composite window may not be heated evenly by the process and/or the air cooling system may not cool evenly. Variations in temperature across the composite window can cause the composite window to break due to thermal stress.

[0038] Use of high thermal conductivity ceramics such as aluminum nitride can reduce temperature variations across the composite window and reduce the risk of thermal stress. An air-cooled aluminum nitride window heats up and cools down uniformly. The result is that heat transfer to air is improved as a larger hot area is available to transfer heat to the air. However, air cooling systems of the size needed to remove a few kW of heat are costly for the process tool owner. Air has to be supplied, often from the fab environment. In other words, the air needs to be conditioned to a predetermined temperature and humidity at considerable cost. The heated air exiting the system is also problematic since it must be ducted away from the module. The heater air may cause the exhaust handling system to overheat and/or the exhaust air stream to be hotter than facility limits. Compressors that are needed to supply the air are costly and consume a lot of energy. Aluminum nitride is not compatible with surface coatings that are used to control particle levels in the processing system. This problem rules out the use of a solid aluminum nitride windows in most cases.

[0039] To resolve these issues, a composite window made of high purity alumina with internal cooling channels may be used. These composite windows include a cooling loop with a closed channel that traces a generally serpentine path across the composite window. A cooling fluid flows through these channels. This approach is able to remove a large amount of heat from the composite window and alumina will accept the coatings needed for good particle performance. However, since the cooling channels are arranged between the inductive coils and the processing chamber, special cooling fluid such as perfluorinated fluids needs to be used. Regulatory and customer requirements surrounding perfluorinated fluids are changing and these fluids may not be available in the future.

[0040] Even if the cooling fluids are available, emissions of these fluids into the fab environment is problematic and requires time consuming precautions (e.g., when the cooling loop must be opened for service). Alternate cooling fluids present issues of

flammability, toxicity, low dielectric strength, high dielectric constant, high dielectric loss, and/or a combination of these problems.

[0041] A composite window according to the present disclosure combines the thermal conductivity of aluminum nitride with a bonded face layer (e.g., alumina) to allow coating. Heat passes from the area of high RF field to the edge of the composite window by conduction, and is then extracted by liquid cooling. This greatly increases the selection of coolants (e.g., benign coolant such as water can be used).

[0042] Referring now to FIGs. 1 and 2, an example of a substrate processing system 100 including a liquid cooled composite window is shown. The substrate processing system 100 includes a coil driving circuit 112. As shown, the coil driving circuit 112 includes an RF source 114 and a matching/tuning circuit 116. The matching/tuning circuit 116 may be directly connected to one or more inductive coils 118. The matching/tuning circuit 116 tunes an output of the RF source 114 to a desired frequency and/or a desired phase, matches an impedance of the inductive coils 118 and optionally splits power between two or more sets of the inductive coils 118 (if used).

[0043] An annular cooling ring 127 is arranged on the composite window 126 to cool the composite window 126. In some examples, the annular cooling ring 127 is arranged on a peripheral edge of the composite window or radially inwardly from the peripheral edge. In some examples, the annular cooling ring 127 has a radial width that is less than 30% of a radial width of the composite window 126. In other examples, the composite window 126 includes cooling channels that are enclosed by the annular cooling ring 127.

[0044] The substrate processing system 100 includes a gas injector 124 arranged in a central port of a composite window 126. The gas injector 124 injects gas into a processing chamber 128. The substrate support 132 may include an electrostatic chuck (ESC), or a mechanical chuck or other types of chuck. In operation, a process gas is supplied to the processing chamber 128 via the gas injector 124 and plasma 140 is generated inside of the processing chamber 128. For example, a magnetic field generated by the inductive coils passes through the composite window 126 into the interior of the processing chamber 128. The magnetic field excites gas molecules within the processing chamber 128 to generate the plasma 140. The plasma 140 etches an

exposed surface of a substrate 134. An RF source 150 and a bias matching circuit 152 may be used to bias the substrate support 132 during operation to control ion energy.

[0045] A gas delivery system 154 may be used to supply a process gas mixture to the processing chamber 128. The gas delivery system 154 may include process and inert gas sources 156 (e.g., including deposition gases, etch gases, carrier gases, inert gases, etc.), valves 157, mass flow controllers 158, valves 159 and a manifold 160. A heater/cooler 162 may be used to heat/cool the substrate support 132 to a predetermined temperature. An exhaust system 164 includes a valve 166 and pump 168 to remove reactants from the processing chamber 128 by purging or evacuation and/or to control pressure in the processing chamber.

[0046] A controller 170 may be used to control the process. The controller 170 monitors system parameters and controls delivery of the gas mixture, striking, maintaining, and extinguishing the plasma, removal of reactants, and so on. Additionally, the controller 170 may control various aspects of the coil driving circuit 112, the RF source 150, etc. A temperature controller 172 may be used to control a temperature of the substrate 134 using resistive heaters 174 arranged in a top ceramic plate of the substrate support 132.

[0047] A coolant supply system 190 includes a pump 192 to circulate the coolant through channels that are part of and/or in thermal communication with the composite window 126. The coolant supply system 190 may further include a heat exchanger 194 and/or a heater 196 to cool and/or heat the coolant, respectively. A pressure relief valve 198 may be arranged in coolant supply lines to cutoff flow in the event that pressure in coolant lines exceeds a predetermined pressure threshold.

[0048] In FIG. 2, an example of the inductive coil 118 including a set of inner coils 210 and a set of outer coils 212 is shown. While two sets of coils are shown, a single coil, a single set of coils, or additional sets coils can be used.

[0049] Referring now to FIGS. 3A to 3C, a composite window 300 includes a body 310 including a center port 314. In some examples, the body has a cylindrical shape. In some examples, a gas injector is arranged in the center port to supply process gas. In other examples, the center port 314 is omitted and process gas is injected from the side or another location. In some examples, the body 310 further includes a layer 320 arranged on a plasma-facing surface of the body 310. An annular cooling ring 330 is attached to a backside surface of the body 310 adjacent to a peripheral or radially outer

edge thereof. The annular cooling ring 330 includes inlet and an outlet ports 334 and 336 in fluid communication with a channel 340 defined along a body-facing surface of the annular cooling ring 330. In some examples, the channel 340 extends around the cylindrical body near a peripheral edge thereof except for at location 337 between the inlet and outlet ports.

[0050] In some examples, the body 310 of the annular cooling ring 330 is made of aluminum nitride or boron nitride. However, boron nitride has lower thermal conductivity than aluminum nitride. In some examples, the layer 320 comprises a material selected from a group consisting of aluminum oxide, alumina, zirconium oxide, yttrium oxide, lanthanum oxide, and combinations thereof. The layer 320 has a thickness in an axial direction that is less than the thickness of the body 310 to minimize thermal stress effects. In some examples, the layer 320 is bonded to the body 310 using a high pressure and temperature process to form a diffusion bond. In some examples, a glass layer (e.g., borosilicate) is arranged between the body 310 and the layer 320 before firing the layers to form a glass bond. In other examples, co-sintering of ceramic green sheet layers may be performed. In other examples, the layer 320 may be coated onto the body 310 using a coating process such as plasma spraying.

[0051] After grinding to the required profile and surface treatment, a coating layer 321 may be applied to the body 310 and/or the layer 320 to improve particle performance. In some examples, the coating layer 321 is selected from a group consisting of yttrium oxide, lanthanum oxide, or other suitable materials. The coating layer 321 may be applied using plasma spraying or other processes. In some examples, a post-treatment step is used to further improve the performance of the coating. Examples of post-treatment include polishing, ice blasting, annealing, chemical conversion and/or another treatment.

[0052] The annular cooling ring 330 is attached at or adjacent to a peripheral edge the backside surface of the body 310. In some examples, the annular cooling ring 330 is bonded using adhesive (or diffusion or glass bonded) to the body 310. In other examples, the annular cooling ring 330 is mechanically attached to the backside surface of the body 310 using fasteners such as screws 343 and a gasket 345 arranged between the annular cooling ring 330 and the body 310, as shown in FIG. 3C.

[0053] Referring now to FIGS. 4A and 4B, a composite window 400 includes the body 310 with the center port 314, the layer 320, the coating layer 321, and an annular

cooling ring 350. The annular cooling ring 350 includes inlet and outlet ports 354 and 356 and a channel 360, 362 that is bifilar. The channels 360 and 362 include two parallel channels extending in parallel direction around the circumference of the annular cooling ring 350 between the inlet and the outlet ports 354 and 356. In some examples, the channels 360 and 362 extend around the cylindrical body near a peripheral edge thereof except for at location 357 between the inlet and outlet ports.

[0054] Referring now to FIGS. 5 and 6, a backside surface of the body 310 may define the cooling channels instead of the annular cooling ring. In FIG. 5, the body 310 further includes a channel 420 located on the backside surface thereof adjacent to a peripheral edge of the cylindrical body. In some examples, the channel 420 extends almost fully around the backside surface of the body 310 adjacent to a peripheral or radially outer edge of the body 310. An annular cooling ring 410 is arranged on the body 310 and includes inlet and outlet ports 414 and 416 that fluidly communicate with opposite ends of the channel 420. While forming the channel in the body 310 of FIG. 5 is more complicated, locating the channel 420 in the body 310 increases heat transfer by increasing the contact surface area between the body 310 and the fluid in the channel 420.

[0055] The channel in FIG. 5 includes a single coolant loop while channels 430 and 432 in FIG. 6 define a bifilar loop fluidly communicates with the inlet and outlet ports 414 and 416 of the annular cooling ring 410. In some examples, the channels are rectangular-shaped. In other examples, the channels are keystone-shaped (or isosceles trapezoid-shaped) to improve heat transfer to the coolant. In other examples, the channels include stair-stepped surfaces (e.g., when ceramic green sheets are used).

[0056] Referring now to FIG. 7, the annular cooling ring 330 is shown on the body 310 of FIG. 3A. The annular cooling ring 330 is located radially outside of the coils 210 and 212. Heat transfer by conduction through the thickness of the body 310 to the cooling fluid will typically be sufficient to maintain the composite window within temperature operating limits. In some examples, the composite window temperature is controlled by circulating a cooling fluid. In some examples, the cooling fluid is selected from a group consisting of water, a perfluorinated fluid (e.g., 3M Novek, 3M Fluorinert, or Solvay Galden fluids), a glycol (e.g., ethylene glycol, polyalphaolefin (PAO), or another liquid that remain in a liquid state over the required temperature range.

[0057] In some examples, the liquid is circulated in the annular cooling ring 330 by the coolant supply system 190 of FIG. 1 (e.g., including the pump 192, the heat exchanger 194, and the heater 196) via the inlet and an outlet ports 334 and 336. The heater 196 can be used to ensure that the coolant has a predetermined minimum temperature. In some examples, heat is rejected by the heat exchanger 194 to facility cooling water. In some examples, the temperature of the composite window is controlled in a range from 40°C to 180°C. In some examples, the temperature of the composite window is controlled in a range from 80°C to 120°C. The temperature of the composite window depends on process requirements and the cooling fluid that is selected. In some cases, a pressure relief device (e.g., the pressure relief valve 198) is used to prevent overpressure in the case that coolant flow unexpectedly stops during high power processing.

[0058] Referring now to FIG. 8, air cooling may be used in combination with liquid cooling in some applications. A gas plenum 510 may be arranged on the backside surface of the body 310. The gas plenum 510 includes an inlet 514 and an outlet 516. Air cooling may be useful to respond to time-varying heat loads on the composite window. Air cooling may be used to reduce variation of the temperature distribution across the composite window surface and/or transient temperature variations.

[0059] Referring now to FIGS. 9 and 10, the gas plenum 510 may provide different areas of contact between cooling air and the body 310 depending upon cooling needs of a particular application. In FIG. 9, the gas plenum 510 is arranged between the coils 210 and 212. In FIG. 10, the gas plenum 510 is arranged under one or both of the coils 210 and 212 to increase cooling. Gas conduits 524 and 526 connect to the inlet 514 and the outlet 516 to a gas source such as CDA or another cooling gas.

[0060] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features

described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

[0061] Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

[0062] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform, or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0063] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control 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, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0064] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, 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.

5 **[0065]** Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or
10 module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0066] As noted above, depending on the process step or steps to be performed by
15 the tool, the controller 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.

CLAIMS

What is claimed is:

1. A liquid cooled window comprising:
a composite window including:
 - 5 a cylindrical body made of ceramic; and
 - a layer made of ceramic attached to a plasma-facing side of the cylindrical body; and
 - an annular cooling ring arranged on a backside surface of the cylindrical body and including an inlet port, an outlet port, and a channel extending from the inlet port to
 - 10 the outlet port,
 - wherein the backside surface of the cylindrical body encloses one side of the channel and the backside surface is in fluid communication with coolant flowing through the channel.
2. The liquid cooled window of claim 1, wherein the composite window further
- 15 comprises a center port arranged at a center of the cylindrical body.
3. The liquid cooled window of claim 1, wherein the channel comprises a single loop.
4. The liquid cooled window of claim 1, wherein the channel comprises a bifilar cooling loop.
- 20 5. The liquid cooled window of claim 1, wherein the cylindrical body is made of aluminum nitride.
6. The liquid cooled window of claim 1, wherein the layer comprises a material selected from a group consisting of aluminum oxide, alumina, zirconium oxide, yttrium oxide, lanthanum oxide, and combinations thereof.
- 25 7. The liquid cooled window of claim 1, further comprising a coating layer arranged on the layer.

8. The liquid cooled window of claim 7, wherein the coating layer is made of a material selected from a group consisting of yttrium oxide, lanthanum oxide, and combinations thereof.
9. The liquid cooled window of claim 1, further comprising:
5 a gasket arranged between the annular cooling ring and the backside surface of the cylindrical body; and
a plurality of fasteners connecting the annular cooling ring to the cylindrical body.
10. The liquid cooled window of claim 1, wherein the layer is diffusion bonded to the annular cooling ring.
- 10 11. The liquid cooled window of claim 1, wherein the layer is glass bonded by a glass layer to the annular cooling ring.
12. The liquid cooled window of claim 1, wherein the layer is coated on the cylindrical body.
13. A plasma processing system comprising:
15 the liquid cooled window of claim 1;
a processing chamber including at least one side enclosed by the liquid cooled window; and
a first inductive coil arranged adjacent to the backside surface of the cylindrical body.
- 20 14. The plasma processing system of claim 13, wherein the annular cooling ring of the liquid cooled window is arranged radially outside of the first inductive coil.
15. The plasma processing system of claim 14, further comprising an air cooled plenum arranged on the backside surface of the cylindrical body and radially inside of the annular cooling ring.

16. The plasma processing system of claim 15, further comprising:
a second inductive coil arranged radially inside of the first inductive coil,
wherein the air cooled plenum is arranged on the cylindrical body between the
first inductive coil and the second inductive coil.
- 5 17. The plasma processing system of claim 15, further comprising:
a second inductive coil arranged radially inside of the first inductive coil,
wherein the air cooled plenum extends along the backside surface and between
at least one of the first inductive coil and the second inductive coil and the cylindrical
body.
- 10 18. A liquid cooled window comprising:
a composite window including:
a cylindrical body made of ceramic and including a channel arranged on a
backside surface of the cylindrical body adjacent to a radially outer surface of the
cylindrical body; and
15 a layer arranged on a plasma-facing side of the cylindrical body; and
an annular cooling ring arranged on the backside surface of the cylindrical body
and including an inlet port and an outlet port,
wherein the channel is in fluid communication with the inlet port and the outlet
port of the annular cooling ring.
- 20 19. The liquid cooled window of claim 18, wherein the composite window further
comprises a center port arranged at a center of the cylindrical body.
20. The liquid cooled window of claim 18, wherein the channel comprises a single
loop.
21. The liquid cooled window of claim 18, wherein the channel comprises a bifilar
25 cooling loop.
22. The liquid cooled window of claim 18, wherein the cylindrical body is made of
aluminum nitride.

23. The liquid cooled window of claim 18, wherein the layer comprises a material selected from a group consisting of aluminum oxide, alumina, zirconium oxide, yttrium oxide, lanthanum oxide, and combinations thereof.
24. The liquid cooled window of claim 18, further comprising a coating layer
5 arranged on a plasma-facing surface of the layer.
25. The liquid cooled window of claim 24, wherein the coating layer is made of a material selected from a group consisting of yttrium oxide, lanthanum oxide, and combinations thereof.
26. The liquid cooled window of claim 18, further comprising:
10 a gasket arranged between the annular cooling ring and the backside surface of the cylindrical body; and
a plurality of fasteners connecting the annular cooling ring to the cylindrical body.
27. The liquid cooled window of claim 18, wherein the layer is diffusion bonded to the annular cooling ring.
- 15 28. The liquid cooled window of claim 18, wherein the layer is glass bonded by a glass layer to the annular cooling ring.
29. The liquid cooled window of claim 18, wherein the layer is coated on the cylindrical body.
30. A plasma processing system comprising:
20 the liquid cooled window of claim 18;
a processing chamber including at least one side enclosed by the liquid cooled window; and
a first inductive coil arranged adjacent to the backside surface of the cylindrical body.
- 25 31. The plasma processing system of claim 30, wherein the annular cooling ring of the liquid cooled window is arranged radially outside of the first inductive coil.

32. The plasma processing system of claim 31, further comprising an air cooled plenum arranged on the backside surface of the cylindrical body and radially inside of the annular cooling ring.

33. The plasma processing system of claim 32, further comprising:

5 a second inductive coil arranged radially inside of the first inductive coil, wherein the air cooled plenum is arranged on the cylindrical body between the first inductive coil and the second inductive coil.

34. The plasma processing system of claim 32, further comprising:

10 a second inductive coil arranged radially inside of the first inductive coil, wherein the air cooled plenum extends between at least one of the first inductive coil and the second inductive coil and the cylindrical body.

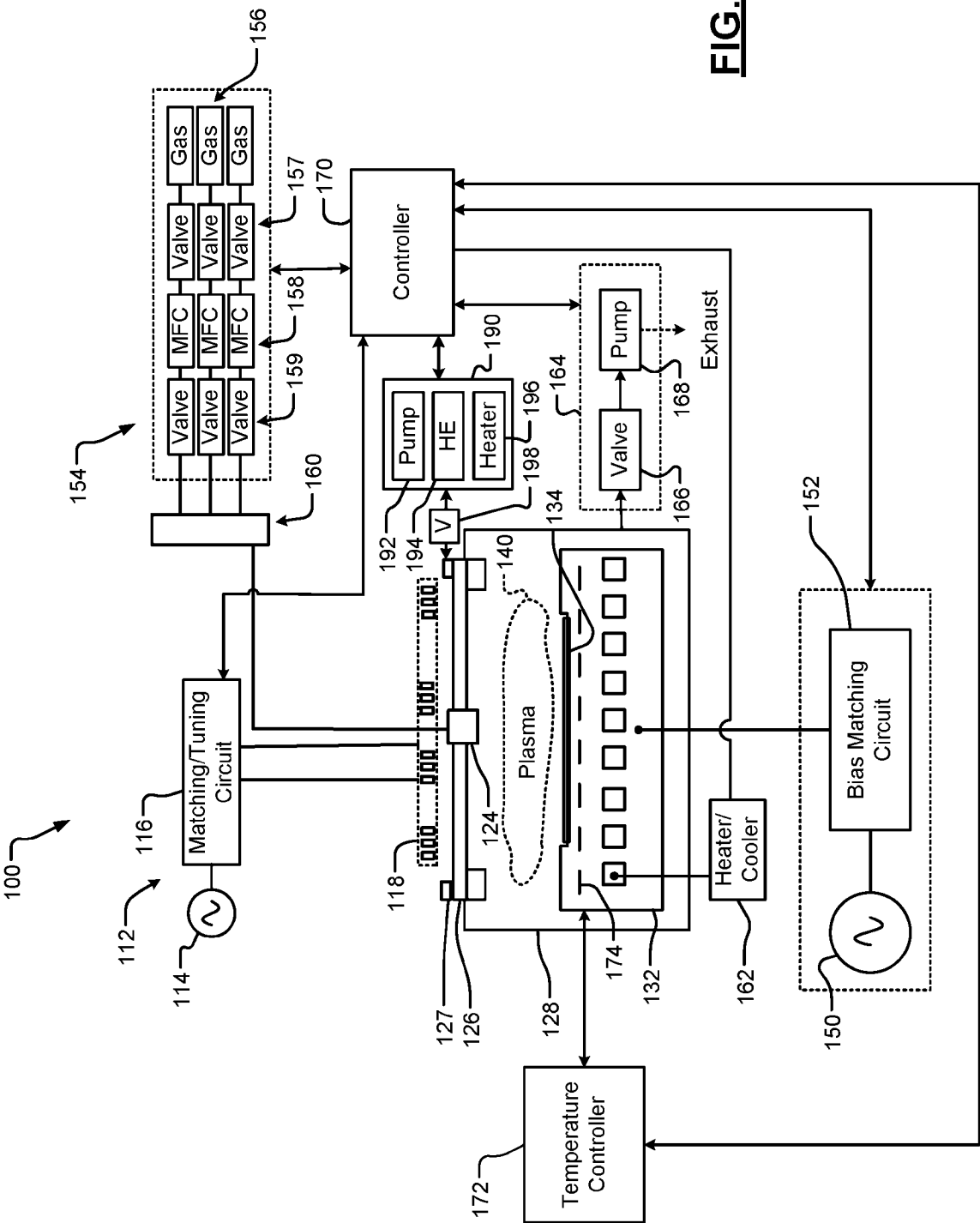


FIG. 1

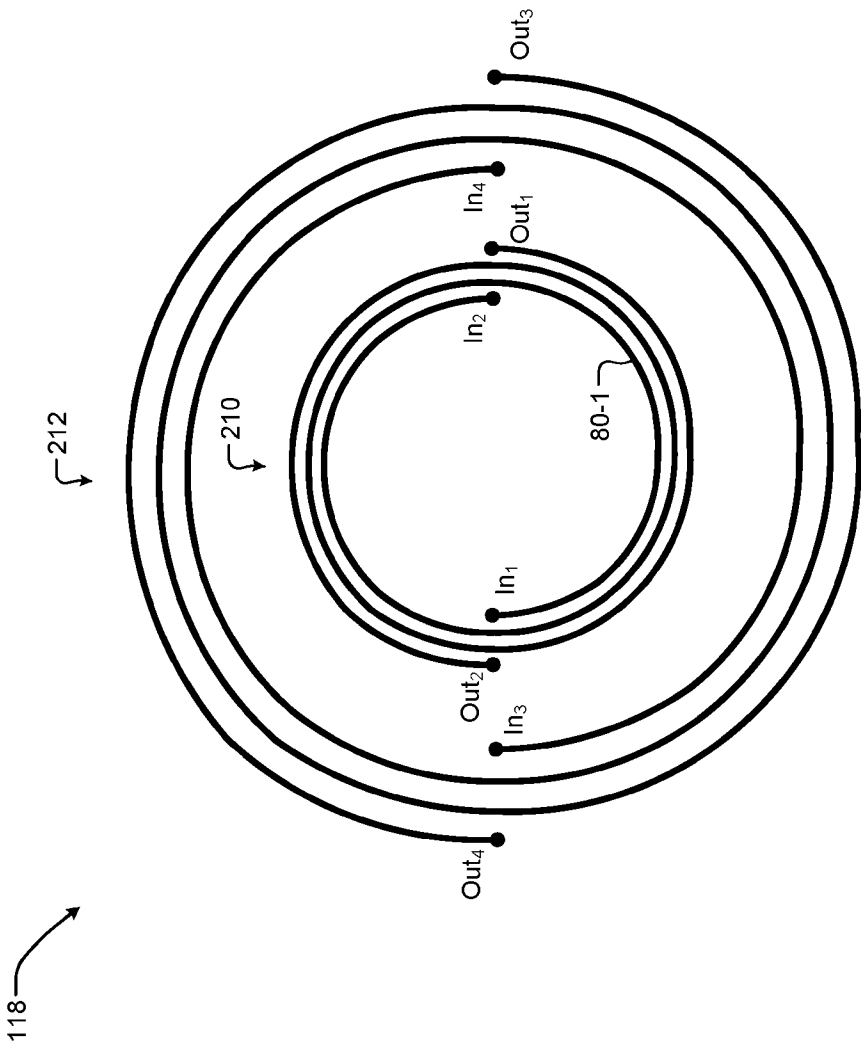


FIG. 2

3/8

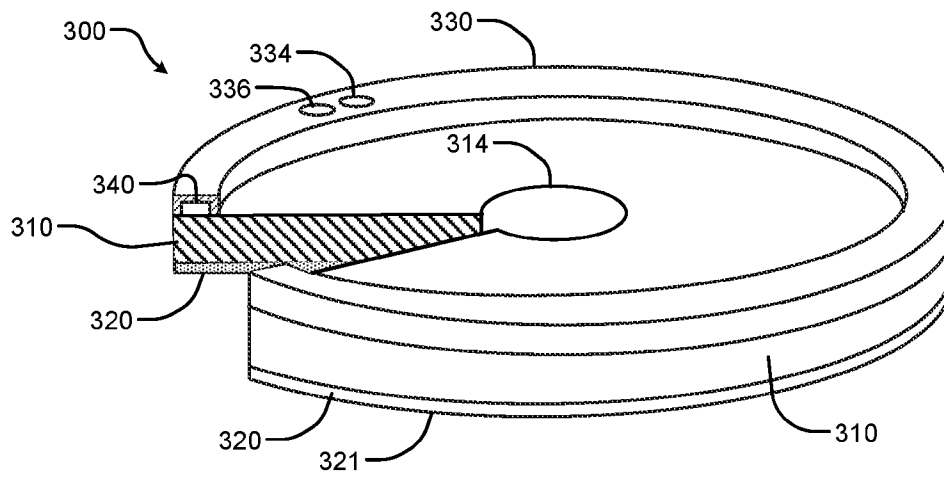


FIG. 3A

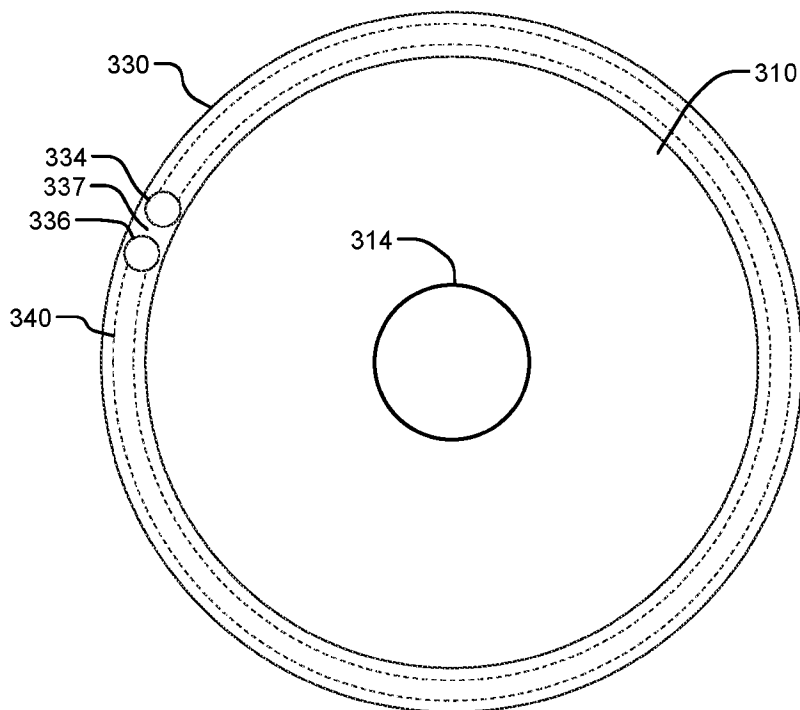


FIG. 3B

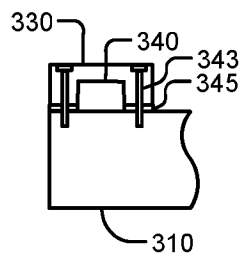


FIG. 3C

4/8

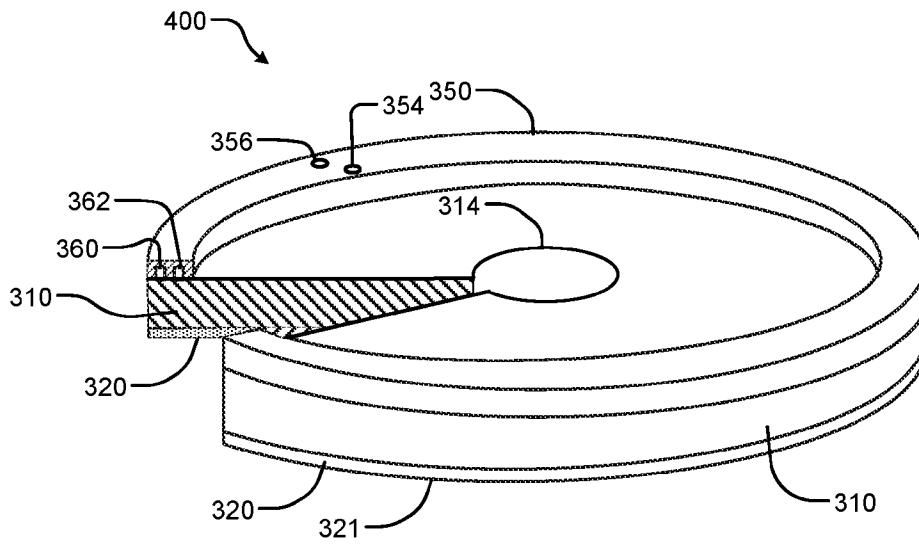


FIG. 4A

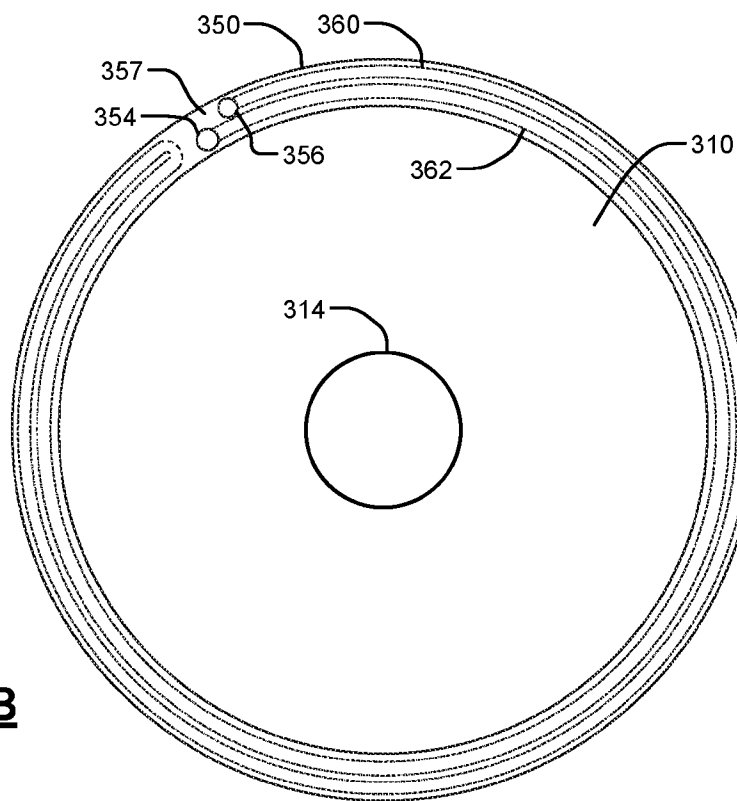


FIG. 4B

5/8

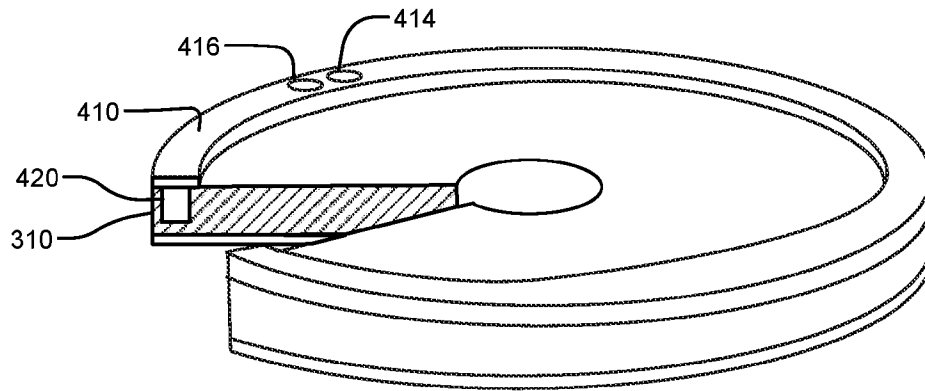


FIG. 5

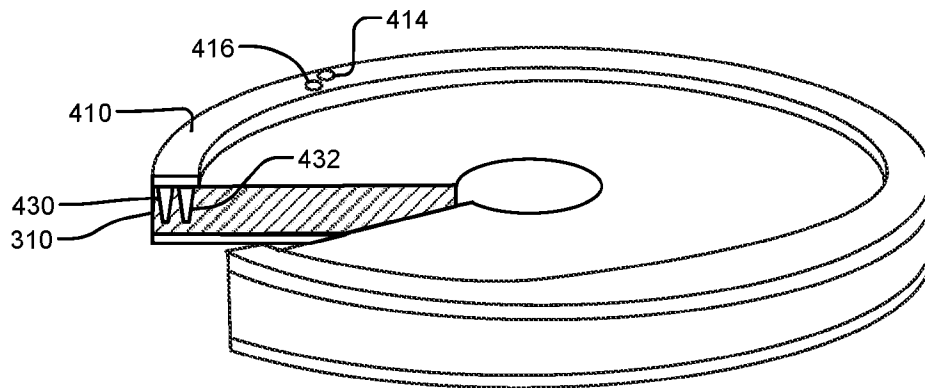
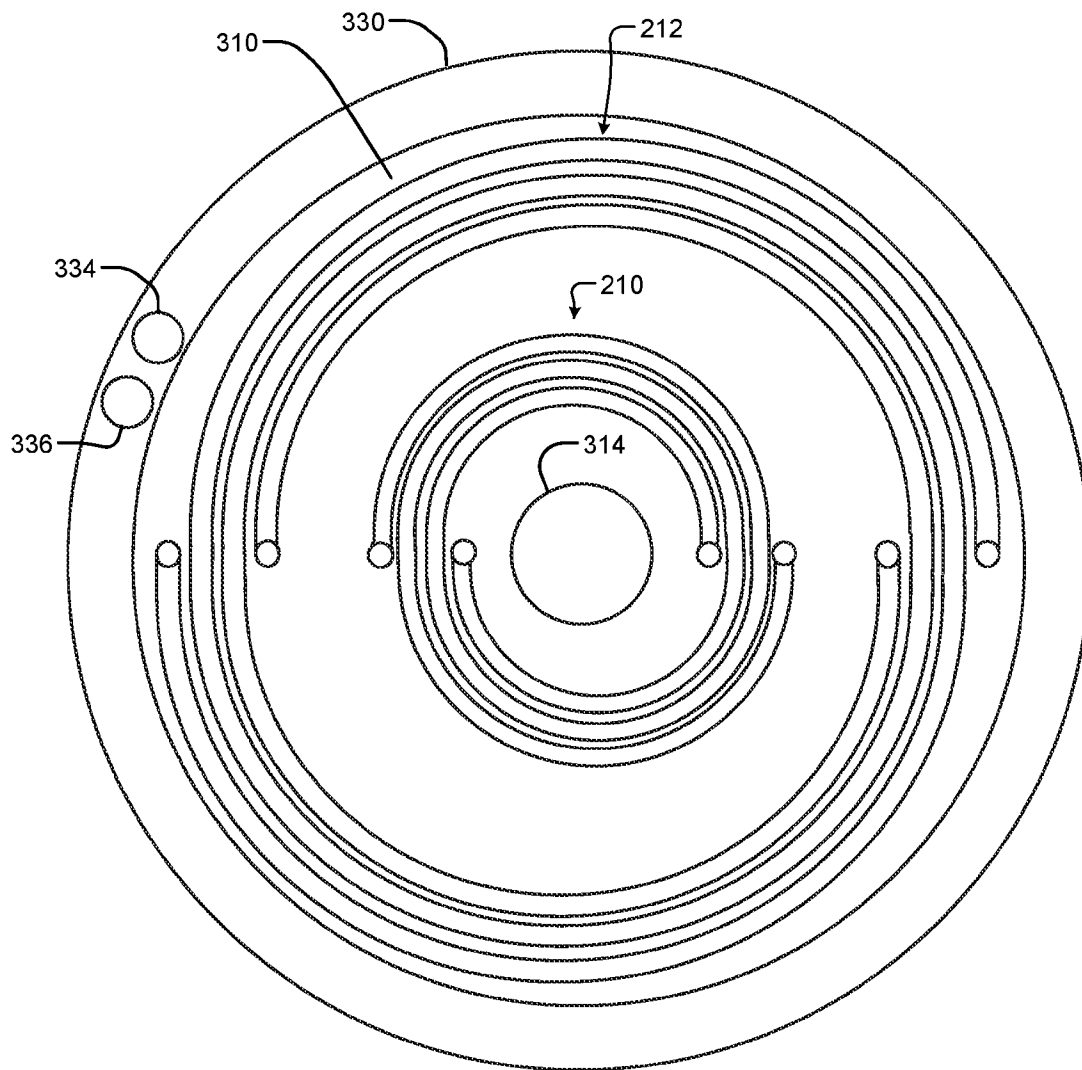


FIG. 6

6/8

**FIG. 7**

7/8

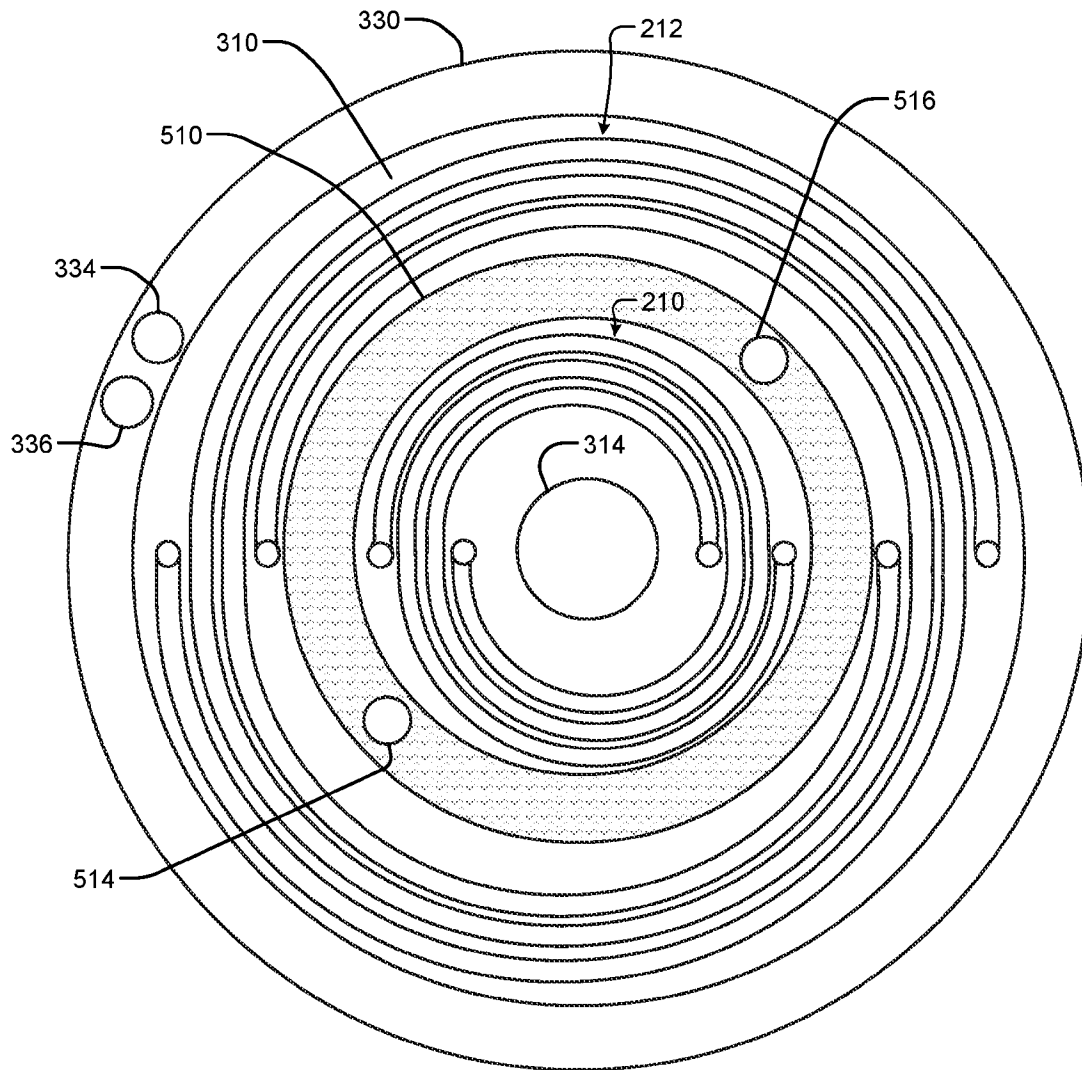


FIG. 8

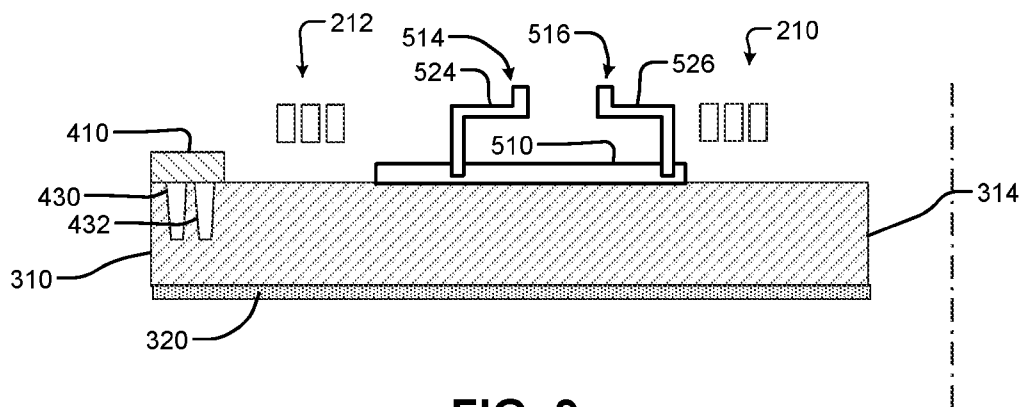


FIG. 9

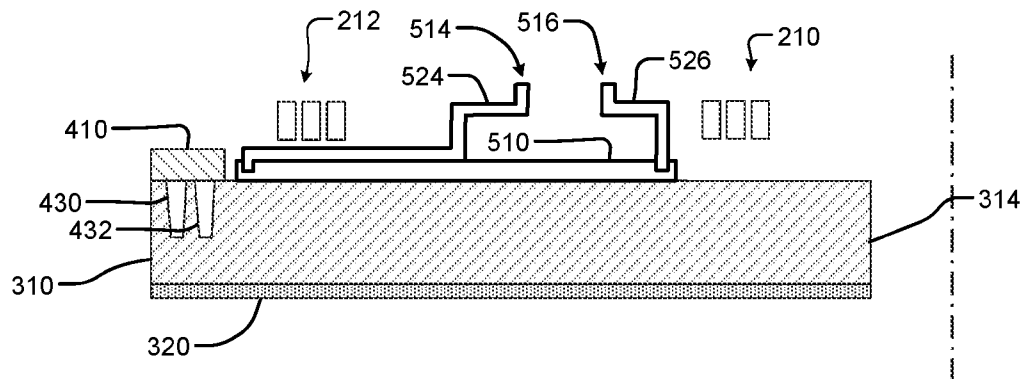


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/051192

A. CLASSIFICATION OF SUBJECT MATTER H01J 37/32(2006.01)i; C09D 1/00(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01J 37/32(2006.01); C23C 16/46(2006.01); F24F 13/00(2006.01); F28F 1/12(2006.01); H01L 21/3065(2006.01); H01L 21/67(2006.01); H05H 1/46(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: window, cool, layer, ring, channel, inlet, outlet, coil, chamber		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2020-0318852 A1 (LAM RESEARCH CORPORATION) 08 October 2020 (2020-10-08) See paragraphs [0008], [0035]-[0074]; and figures 1-4B.	1-34
Y	US 2023-0245854 A1 (LAM RESEARCH CORPORATION) 03 August 2023 (2023-08-03) See paragraphs [0028]-[0047]; and figures 1-3D.	1-17
Y	US 2023-0250532 A1 (ASM IP HOLDING B.V.) 10 August 2023 (2023-08-10) See paragraphs [0035]-[0053]; and figures 1A-2, 7A-7C.	18-34
A	KR 10-2093559 B1 (INNOVATION FOR CREATIVE DEVICES CO., LTD.) 25 March 2020 (2020-03-25) See paragraphs [0027]-[0065]; and figures 1-4.	1-34
A	JP 2018-116836 A (TOKYO ELECTRON LTD.) 26 July 2018 (2018-07-26) See paragraphs [0021]-[0064]; and figures 1-3.	1-34
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “E” earlier application or patent but published on or after the international filing date “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family		
Date of the actual completion of the international search 16 January 2025		Date of mailing of the international search report 16 January 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer LEE, Kang Ha Telephone No. +82-42-481-5687

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2024/051192

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2020-0318852	A1	08 October 2020	CN	104302084	A	21 January 2015
				CN	104302084	B	12 April 2017
				KR	10-2015-0009941	A	27 January 2015
				KR	10-2306397	B1	29 September 2021
				SG	10201404158	RA	27 February 2015
				TW	201516350	A	01 May 2015
				TW	I640728	B	11 November 2018
				US	10690374	B2	23 June 2020
				US	11692732	B2	04 July 2023
				US	2015-0020969	A1	22 January 2015
				US	2018-0156489	A1	07 June 2018
				US	9885493	B2	06 February 2018
US	2023-0245854	A1	03 August 2023	JP	2024-506289	A	13 February 2024
				KR	10-2023-0142334	A	11 October 2023
				WO	2022-173695	A1	18 August 2022
US	2023-0250532	A1	10 August 2023	CN	116581055	A	11 August 2023
				KR	10-2023-0120101	A	16 August 2023
				TW	202342812	A	01 November 2023
KR	10-2093559	B1	25 March 2020	KR	10-2019-0002345	A	08 January 2019
JP	2018-116836	A	26 July 2018	KR	10-2019-0103367	A	04 September 2019
				KR	10-2491984	B1	27 January 2023
				TW	201832619	A	01 September 2018
				US	10832892	B2	10 November 2020
				US	2020-0058468	A1	20 February 2020
				WO	2018-135307	A1	26 July 2018