



(51) International Patent Classification:
C23C 16/455 (2006.01)

(21) International Application Number:
PCT/US2024/060938

(22) International Filing Date:
19 December 2024 (19.12.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/617,042 02 January 2024 (02.01.2024) US
63/623,139 19 January 2024 (19.01.2024) US

(71) Applicant: **LAM RESEARCH CORPORATION**
[US/US]; 4650 Cushing Pkwy., Fremont, California 94538
(US).

(72) Inventors: **DANTE, Edward**; 4650 Cushing Pkwy., Fremont, California 94538 (US). **HAYNES, Katherine Elizabeth**; 4650 Cushing Pkwy., Fremont, California 94538 (US). **DAS, Saurish**; 4650 Cushing Pkwy., Fremont, California 94538 (US). **SHRIVASTAVA, Anmol Vijay**; 4650 Cushing Pkwy., Fremont, California 94538 (US).

(74) Agent: **OTIS, Ryan J.** et al.; WEAVER AUSTIN VILLENEUVE & SAMPSON LLP, P.O. Box 70250, Oakland, California 94612-0250 (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,

(54) Title: SHOWERHEAD FOR A SEMICONDUCTOR PROCESSING SYSTEM

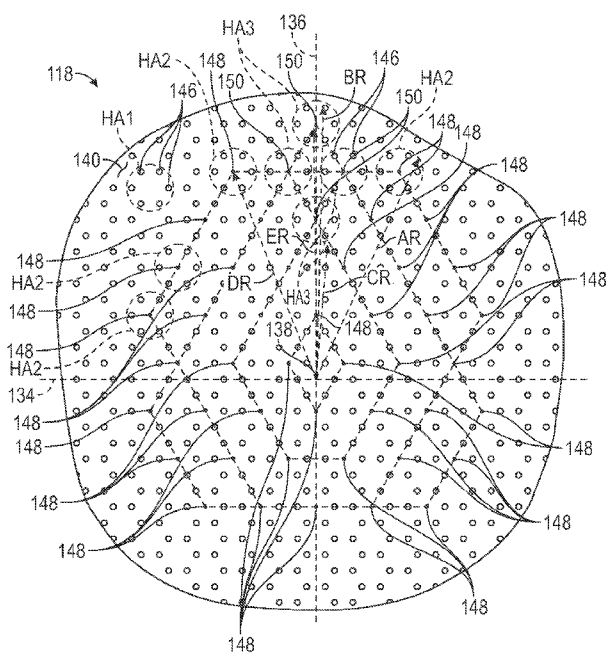


FIG. 6

(57) Abstract: A showerhead includes a faceplate having multiple faceplate through-holes that extend from a first side to a second side of the faceplate. The showerhead further includes a backplate opposite the faceplate, with a plenum volume defined between the backplate and the faceplate. The faceplate through-holes include a first subset of the faceplate through-holes each having a first diameter when measured from the second side of the faceplate, a second subset of the faceplate through-holes each having a second diameter when measured from the second side of the faceplate, and a third subset of the faceplate through-holes each having a third diameter when measured from the second side of the faceplate. The second diameter is less than the first diameter, and the third diameter is less than the second diameter.

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, 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).

Published:

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

SHOWERHEAD FOR A SEMICONDUCTOR PROCESSING SYSTEM

INCORPORATION BY REFERENCE

[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 their entireties and for all purposes.

FIELD

[0002] The present disclosure relates to showerheads for semiconductor processing systems, and more specifically to a showerhead having a faceplate with multiple subsets of faceplate through-holes configured to deposit a substantially uniform layer on a substrate.

BACKGROUND

[0003] The background description provided herein 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] Chemical deposition systems may be used to deposit films on substrates (e.g., semiconductor wafers, etc.). Examples of chemical deposition systems may include plasma-enhanced chemical vapor deposition (PECVD) systems, and chemical vapor deposition (CVD) systems. Such systems may include one or more showerheads that are positioned within a processing chamber to define substrate processing regions. The substrate processing region may be defined between a bottom side of the showerhead and a wafer support (i.e., a pedestal, a substrate support, etc.) that may be positioned beneath each showerhead and configured to support a substrate within the substrate region. The bottom side of the showerhead may include ports facing the wafer support and configured to supply one or more precursor gases to facilitate deposition of layers of material onto the substrates. The chemical deposition systems may further include a foreline fluidically connected with the processing chamber to evacuate precursor gases from the processing chamber.

SUMMARY

[0005] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims.

[0006] The present disclosure relates to a faceplate of a showerhead, with the faceplate including three or more subsets of the faceplate through-holes. Each subset of the faceplate through-holes may have characteristic parameters (e.g., a diameter of each faceplate through-hole in the corresponding subset of faceplate through-holes, a quantity of faceplate through-holes in the corresponding subset of faceplate through-holes, a location of faceplate through-holes for each subset of faceplate through-holes, etc.) configured independently and/or relative to one another to cause one or more process gases to flow through the corresponding faceplate through-holes and cause a material from the one or more process gases to be deposited on a substrate in a layer that is within a range of a predetermined thickness uniformity from the center of the substrate to the outer edge of the substrate. In one implementation, such uniformity may include each AtOx layer (Atmospheric Thermal Oxide layer) having a thickness at an outer edge region of the substrate that is less than 0.5% higher than the thickness at a center region of the substrate, and each silicon nickel (SiN) layer having a thickness at the outer edge region of the substrate being less than 0.3% higher than the thickness at the center region of the substrate.

[0007] The showerhead may be provided for use in a semiconductor processing apparatus. The showerhead may include a faceplate having a plurality of faceplate through-holes that extend from a first side to a second side of the faceplate. The showerhead may further include a backplate opposite the faceplate, and a plenum volume may be defined between the backplate and the faceplate. The first side of the faceplate may define a first internal surface of the plenum volume. The showerhead may further include one or more gas inlets in fluid communication with the plenum volume. The faceplate through-holes may include a first subset of the plurality of the faceplate through-holes each having a first diameter when measured from the second side of the faceplate. The faceplate through-holes may further include a second subset of the plurality of faceplate through-holes each having a second diameter when measured from the second side of the faceplate, and the second diameter may be less than the first diameter. The faceplate through-holes may further include a third subset of the plurality of faceplate through-holes each having a third diameter when measured from the second side of the faceplate, and the third diameter may be less than the second diameter.

[0008] In other implementations, the first diameter may be about 0.030 to 0.050 inches.

[0009] In other implementations, the first diameter may be about 0.035 to 0.045 inches.

[0010] In other implementations, the first subset of through-holes may be about 3,400 to 4,100 of the faceplate through-holes.

[0011] In other implementations, the first subset of through-holes may be about 97.50% to 99.50% of the faceplate through-holes.

[0012] In other implementations, the first subset of through-holes may have 80 to 100 times more through-holes than the second subset of through-holes.

[0013] In other implementations, the first subset of through-holes may have 950 to 1,050 times more through-holes than the third subset of through-holes.

[0014] In other implementations, the second diameter may be about 0.020 to 0.030 inches.

[0015] In other implementations, the second subset of through-holes may be 35 to 55 of the plurality of faceplate through-holes.

[0016] In other implementations, the second subset of through-holes may be about 0.08% to 2.18% of the plurality of faceplate through-holes.

[0017] In other implementations, the second subset of through-holes may have 5 to 15 times more through-holes than the third subset of through-holes.

[0018] In other implementations, the third diameter may be about 0.022 to 0.028 inches.

[0019] In other implementations, the third subset of through-holes may have 2 to 8 of the plurality of faceplate through-holes.

[0020] In other implementations, the third subset of through-holes may be about 0.05% to 0.15% of the plurality of faceplate through-holes.

[0021] In other implementations, the faceplate may have an X-axis and a Y-axis that may be perpendicular to the X-axis. Both the X and Y axes may define a diameter of the faceplate, and the X and Y axes may also define four quadrants of the faceplate.

[0022] In other implementations, the faceplate through-holes may include a plurality of first hexagonal areas each enclosed only by through-holes of the first subset of through-holes.

[0023] In other implementations, the faceplate through-holes may include one or more second hexagonal areas each enclosed by through-holes of the first subset of through-holes with one or more of the through-holes of the second subset of through-holes in the second hexagonal area.

[0024] In other implementations, all the second hexagonal areas may be within a radius AR of the faceplate, and the radius AR may be about 1.90 to 2.40 inches from a center of the faceplate.

[0025] In other implementations, two of the second hexagonal areas may be arranged adjacent to one another such that two through-holes of the first subset of through-holes may be between the two through-holes of the second subset of through-holes.

[0026] In other implementations, the second hexagonal areas may be arranged on the faceplate such that the second hexagonal areas form a mirror image along a Y-axis of the faceplate but not along an X-axis that is perpendicular to the Y-axis.

[0027] In other implementations, the faceplate through-holes may include one or more third hexagonal areas each enclosed by through-holes the first subset of through-holes with one or more of the through-holes of the third subset of through-holes in the third hexagonal area.

[0028] In other implementations, all the third hexagonal areas may be within a radius BR of the faceplate, and the radius BR may be about 2.15 to 2.65 inches from a center of the faceplate.

[0029] In other implementations, all the third hexagonal areas may be between a radius CR and the radius BR of the faceplate, and the radius CR may be about 1.06 to 1.56 from the center of the faceplate.

[0030] In other implementations, at least two of the third hexagonal areas may be along a Y-axis of the faceplate.

[0031] In other implementations, none of the third hexagonal areas may be on an X-axis of the faceplate.

[0032] In other implementations, there may be no through-holes of the second subset of through-holes outside of a radius DR of the faceplate, and the radius DR may be about 1.72 to 2.22 inches from a center of the faceplate.

[0033] In other implementations, there may be no through-holes of the third subset of through-holes outside of an radius ER of the faceplate, and the radius ER may be about 2.30 to 2.50 inches from a center of the faceplate.

[0034] In other implementations, at least four of through-holes of the third subset of through-holes form a diamond pattern, and at least two through-holes of the first subset of through-holes may be within the diamond pattern.

[0035] Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that 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

[0036] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0037] FIG. 1 depicts a schematic diagram of an example semiconductor processing system having a processing chamber with an interior and a showerhead configured to be caused to flow one or more process gases into the interior of the processing chamber.

[0038] FIG. 2 depicts an isometric view of the showerhead of FIG. 1, with a portion of the showerhead partially cutaway to show the showerhead having a backplate, a faceplate, a plenum volume defined between the backplate and the faceplate, and a non-porous baffle located within the plenum volume.

[0039] FIG. 3 depicts an isometric section view of another implementation of a showerhead with a porous baffle.

[0040] FIG. 4 depicts an enlarged isometric section view of the porous baffle in the low volume showerhead of FIG. 3.

[0041] FIG. 5 depicts a bottom plan view of the showerhead of FIG. 2, illustrating the faceplate with three subsets of faceplate through-holes each having characteristic parameters configured independently and/or relative to one another to cause one or more process gases to flow through the corresponding faceplate through-holes and cause a material from the one or more process gases to be deposited on the substrate in a substantially uniform layer from the center of the substrate to the outer edge of the substrate.

[0042] FIG. 6 depicts an enlarged cutaway view of Region A of the faceplate of FIG. 5 showing an implementation of the faceplate in which the faceplate includes a first subset of the plurality of faceplate through-holes and a second subset of the plurality of faceplate through-holes, and a third subset of the plurality of faceplate through-holes.

[0043] FIG. 7 depicts an enlarged cutaway view of Region B of the faceplate of FIG. 5 showing a center region of the faceplate with a portion of the first subset of the plurality of faceplate through-holes and a portion of the second subset of the plurality of faceplate through-holes.

[0044] FIG. 8 depicts an enlarged cutaway view of Region C of the faceplate of FIG. 5 showing a peripheral region of the faceplate offset from the center region of the faceplate and including the third subset of the plurality of faceplate through-holes and another portion of the first subset of the plurality of faceplate through-holes.

[0045] FIG. 9 depicts an enlarged view of a center portion of a test faceplate structure having two subsets of faceplate through-holes.

[0046] FIG. 10A depicts a first heat map result associated with the test faceplate structure of FIG. 9 and FIG. 10B depicts a second heat map result associated with a showerhead with the faceplate of FIG. 5. Each heat map reflects an average layer thickness at a plurality of locations from a center of the corresponding substrate to an outer edge of that substrate.

[0047] FIG. 11 depicts a heat map having shading representative of deposition layer thickness across a substrate and a schematic diagram of a substrate with 49 locations where the deposition layer thickness is measured for a corresponding one of the test structure of FIG. 9 and the faceplate of FIG. 5.

[0048] FIG. 12 depicts an enlarged cutaway view of some of Region B of the faceplate of FIG. 5 showing a peripheral region of the faceplate offset from the center region of the faceplate and including the third subset of the plurality of faceplate through-holes and another portion of the first subset of the plurality of faceplate through-holes.

DETAILED DESCRIPTION

[0049] A faceplate 126 of a showerhead 112 includes three or more subsets of the faceplate through-holes 127, each having various characteristic parameters, such as a diameter of each faceplate through-hole in each subset of faceplate through-holes, a quantity of faceplate through-holes in each subset of faceplate through-holes, a location of the faceplate through-holes for each subset of faceplate through-holes, or the like. These parameters may be configured independently and/or relative to one another to cause the one or more process gases to flow through the corresponding faceplate through-holes 127 and cause a material from the one or more process gases to be deposited on the substrate 110. The material may be deposited in a layer that is within a range of a predetermined thickness uniformity from the center of the substrate to the outer edge of the substrate. For example, each Atmospheric Thermal Oxide layer (AtOx) or oxide layer may have a thickness at an outer edge region of the substrate less than 0.5% higher than the thickness at a center region of the substrate. In another example, each silicon nickel (SiN) layer may have a thickness at the outer edge region of the substrate less than 0.3% higher than the thickness at the center region of the substrate, etc.

[0050] In certain embodiments, the faceplate through-holes comprise or consist essentially of three subsets, each subset having a different diameter and each subset distributed in a different region of the faceplate. In some embodiments, the through-holes of the first subset have the largest diameter, the through-holes of the second subset have the second largest diameter, and the through-holes of the third subset have the smallest diameter. In some such embodiments, all through-holes of any of the three subsets have the substantially same diameter. In certain

embodiments, in comparison to the through-holes in the other subsets, the through-holes of the first subset are the most numerous and are the most widely distributed over the faceplate (they collectively occupy the most area). In some embodiments, the through-holes of the first subset are arranged in a repeating geometric unit such as a repeating hexagon. In some embodiments, some of the repeating geometric units surround some through-holes of the second subset and/or the third subset. In certain embodiments, the through-holes of the second subset are the second most numerous and second most widely distributed over the faceplate.

[0051] In some embodiments, the through-holes of the first subset are relatively evenly distributed over the faceplate surface from both a radial and an azimuthal perspective. In contrast, the through-holes of the second and third subsets may occupy regions that are limited to a particular radial region, a particular azimuthal region, or both. In some embodiments, the positions of the through-holes of the second and/or third subsets are influenced by the position of a baffle that is in a position offset from the center of the faceplate and at a defined azimuthal position. In some embodiments, the second and/or third subsets of through-holes group in an azimuthal position that aligns with or is opposite that of the baffle's azimuthal position.

[0052] In the following example figures and discussion, some characteristic parameter values of the three subsets of through-hole are presented. Any one or more of the parameters may independently characterize the faceplate hole pattern. In other words, while the figures and associated discussion present a combination of faceplate features, the disclosure embodies many other combinations, some of which do not include one or more of the disclosed features.

[0053] Referring to FIG. 1, a semiconductor processing system 100 (e.g., a chemical deposition system, a heat treatment system, etc.) has a processing chamber 102 with an interior volume 104 and one or more exhaust ports 106. The semiconductor processing system 100 further includes one or more wafer supports 108 positioned within the interior volume 104 and configured to support a corresponding one or more substrates 110 during one or more semiconductor processing operations (e.g., a deposition process, a preparation process, a heat treatment process, etc.) conducted in the interior volume 104. In this implementation, the semiconductor processing system 100 further includes one or more showerheads 112 positioned above a corresponding one of the wafer supports 108; and the showerheads 112 may be used to flow one or more process gases onto the substrate 110 during processing operations.

[0054] In general, there are two main types of showerheads 112: a chandelier-type showerhead and a flush-mount showerhead. The chandelier-type showerhead has a stem attached to the top of the chamber on one end and a faceplate or a backplate on the other end. A part of the stem may protrude from the chamber top for connecting gas lines and RF power. A flush-mount

showerhead is integrated into the top of the processing chamber 102 and may not have a stem. While FIGS. 2-4 generally depict chandelier-type showerheads, the present disclosure may apply to flush-mount type showerheads, as well.

[0055] FIG. 2 depicts an implementation of the showerhead 112 of FIG. 1. The showerhead 112 includes a stem 114 defining a passage 115 configured to fluidically connect with a gas supply or supplies (e.g., a gas distribution system) the semiconductor processing system 100 and receive a flow of one or more process gases, such as reactant gas or purge gas, from the gas supply or supplies. In this implementation, the stem 114 may include a narrow tube 116 fluidically connected with the gas distribution system and an expanded tube 118 fluidically connected with the narrow tube 116. The expanded tube 118 may have a diameter greater than a diameter of the narrow tube 116 to provide a more spatially distributed flow into a plenum volume 120 as discussed below.

[0056] The showerhead 112 further includes a backplate 122 having one or more gas inlets 124 in fluid communication with the plenum volume 120 (i.e., the one or more gas inlets 124 may be fluidically interposed between the passage 115 in the expanded tube 118 of the stem 114 and the plenum volume 120). The one or more gas inlets 124 may be fluidically connected with the gas supply or supplies (e.g., the gas distribution system) via the stem 114 for receiving the flow of one or more process gases.

[0057] The showerhead 112 further includes a faceplate 126 positioned opposite to the backplate 122. The faceplate 126 includes a plurality of faceplate through-holes 127 extending from a first side 128 to a second side 130 to facilitate delivery of gas to the substrate 108. The faceplate 126 and the backplate 122 may be separate mechanical components or integrated into a single body. The plenum volume 120 is defined between the faceplate 126 and the backplate 122, with the first side 128 of the faceplate 126 defining a first internal surface of the plenum volume 120 and a first side 129 of the backplate 122 defining a second internal surface of the plenum volume 120. The total volume of the showerhead 112 may be greater than 500 milliliters (e.g., 743 milliliters). In some implementations, the faceplate 126 and/or the backplate 122 may have one or more circumferential surfaces 132 facing radially inward toward the plenum volume 120 and at least partially defining the plenum volume 120. Generally, the first internal surface of the plenum volume 120 may have a diameter that is similar or substantially similar to a diameter of the substrate 108 for which the showerhead 112 is configured for use. In some implementations, as illustrated in FIG. 2, the second internal surface of the plenum volume 120 may define a substantially conical portion of the plenum volume 120.

[0058] The plenum volume 120 may be supplied with the one or more process gases via the one or more gas inlets 124. The showerhead 112 may further include one or more baffles 133 (e.g., one or more porous or non-porous baffle plates, support structures, sensors, such as one or more thermocouples, etc.) in the plenum volume 120 that may restrain a flow of the one or more process gases along a direction from the one or more gas inlets 124 toward one or more of the faceplate through-holes 127.

[0059] In this implementation, the showerhead 112 may include a non-porous baffle 133 recessed in the plenum volume 120. The baffle 133 may be a solid or non-porous structure mounted in the plenum volume 120 to direct the gas outwardly throughout the plenum volume 120 and towards the edge of the faceplate 126. The baffle 133 may be proximate the gas inlet 124. The baffle 133 may be mounted at a certain distance from the gas inlet 124 to permit distribution of the gas within the plenum volume 120. The baffle 133 may be centered underneath the stem 114 to avoid or otherwise minimize the effects of jetting through the center of the faceplate 126. For example, the large, non-porous baffle 133 may have a diameter of 2.10 inches. The diameter of the non-porous baffle 133 may be greater than a diameter of the expanded tube 118 in the showerhead 112. However, a volume of the plenum volume 120 may be increased to accommodate the large, non-porous baffle 133 underneath the stem 114 for sufficient flow uniformity. The increased volume may be provided by a conical portion of the plenum volume 120 so that the flow of gas may be distributed outwardly. The backplate 122 may be sloped back to provide the conical portion of the plenum volume 120. Put another way, the plenum volume 120 at the second surface may be conical to provide more space between the gas inlet 124 and the baffle 133. In some implementations, the baffle 133 may be circular and have a diameter greater than a diameter of the expanded tube 118. By directing the flow of gas outwardly throughout the plenum volume 120, greater flow uniformity may be obtained. Moreover, the baffle 133 may be substantially centered on the gas inlet 124 to avoid or otherwise reduce the flow of gas from jetting through the center of the faceplate 126.

[0060] Referring to FIG. 3, another implementation of a showerhead 212 (i.e., a low-volume showerhead) is somewhat analogous to the showerhead 112 of FIG. 2. To avoid undue repetition, elements in the implementation of FIG. 2 that are analogous to elements shown in FIG. 3 are called out with numbers that share the same last two digits as those analogous elements in FIG. 3. Thus, the discussion provided above with respect to the elements of the implementation of FIG. 2 will be understood to be equally applicable to the analogous elements in FIG. 3 unless indicated otherwise. In the interest of conciseness, discussion of these elements that would be redundant of earlier discussion herein of similar elements is not provided, with

the understanding that the earlier discussion of such elements is applicable to these similar elements in FIG. 3.

[0061] While the showerhead 112 of FIG. 2 may include the second internal surface of the plenum volume 120 (i.e., the first surface 129 of the backplate 122) with a conical shape configured to define a substantially conical portion of the plenum volume 120, the low volume showerhead 212 of FIG. 3 may include the second internal surface of the plenum volume 220 (i.e., the first surface 229 of the backplate 222) with a planar shape configured to define in part the plenum volume 220 having a cylindrical or substantially cylindrical shape. This may reduce the overall internal volume of the showerhead 212 because the plenum volume 220 has a reduced volume compared to the plenum volume 120 in FIG. 2.

[0062] While the showerhead 112 of FIG. 2 may include the non-porous baffle 133, the low volume showerhead 212 of FIG. 3 may include a porous baffle 233 (e.g., a porous baffle plate). In some implementations, the porous baffle 233 may be recessed in the region 235, where the porous baffle 233 may be mounted at a certain distance from the gas inlet 224 and above the plenum volume 220. While the porous baffle 233 may be positioned within the region 235, it is understood that the porous baffle 233 may be positioned within the plenum volume 220 in some other implementations. Thus, the porous baffle 233 may be mounted at a distance from the gas inlet 224 that extends through the region 235. The region 235 may be a recessed volume of the backplate 222. The region 235 provides a transition area for the flow of gas between the gas inlet 224 and the plenum volume 220. In some implementations, the region 235 may be recessed into the first side 229 of the backplate 222, where the first side 229 of the backplate 222 defines the second surface of the plenum volume 220. While it is understood that the porous baffle 233 may be characterized as positioned in the region 235 between the plenum volume 220 and the gas inlet 224, it should be understood by a person of ordinary skill in the art that the region 235 may be considered as part of the gas inlet 224, and that the porous baffle 233 may be positioned within the gas inlet 224. However, rather than blocking the flow of gas while being positioned in the gas inlet 224, the porous baffle 233 may have a porosity that permits gas to flow through.

[0063] In some implementations, each of the stem 214, the region 235, and the plenum volume 220 define a cylindrical volume, where a diameter of the plenum volume 220 is greater than a diameter of the region 235, and the diameter of the region 235 is greater than a diameter of the stem 214. The small, porous baffle 233 of FIG. 3 may be substantially smaller than the large, non-porous baffle 133 FIG. 2. In some implementations, the small, porous baffle 233 may have a diameter between about 0.1 inches and about 2.0 inches (e.g., a diameter of 0.79 inches).

[0064] The baffle 233 may be selectively porous, where the porosity of the baffle 233 may be between about 5% and about 25%. In some implementations, the baffle 233 may include or otherwise made of a porous material. Examples of porous material may include porous aluminum, porous alumina, porous quartz, and stainless steel. The material may be compatible with remote cleans and may be material that passivates or does not readily react with ammonia/fluorine radicals.

[0065] FIG. 4 depicts an enlarged isometric section view of the porous baffle in the low volume showerhead of FIG. 3. As seen in FIG. 4, in some implementations, the baffle 233 may include a plurality of through-holes 233a extending through the baffle 233. The through-holes 233a may be provided through a material of the baffle 233 to effectively simulate and mimic porosity. In some implementations, the baffle 233 may be circular and have a diameter greater than a diameter of the stem 214. However, in some implementations, the baffle 233 is substantially smaller than the faceplate 226. For example, a diameter of the faceplate 226 is at least four times greater than a diameter of the baffle plate 233, or at least ten times greater than a diameter of the baffle plate 233. Also, the baffle 233 may have a diameter smaller than the diameter of the region 235. Accordingly, gas flow may be directed not only through the through-holes 233a, but also outwardly throughout the plenum volume 220 towards the edges of the faceplate 226. By directing the flow of gas through the through-holes 233a and outwardly throughout the plenum volume 220, a more spatially uniform flow of gas may be obtained despite lowering the overall internal volume of the showerhead 212 compared to the showerhead 112 in FIG. 2. Furthermore, the baffle 233 may be substantially centered on the gas inlet 224 so that the position of the baffle 233 and the porosity of the baffle 233 may reduce the effects of gas jetting through the center of the faceplate 226. In some implementations, the baffle 233 may be substantially parallel to the first internal surface and the second internal surface of the plenum volume 220.

[0066] Furthermore, while the showerhead 112 of FIG. 2 may have a total volume above 500 milliliters (e.g., 742.7 milliliters), the low volume showerhead 212 of FIG. 3 may have a total volume about equal to or less than 500 milliliters (e.g., a volume between about 50 milliliters and about 500 milliliters, a volume between about 100 milliliters and about 300 milliliters, etc.). In some implementations, the plenum volume 220 may have a volume between about 50 milliliters and about 500 milliliters (e.g., 256.4 milliliters). The reduction in the internal volume from the showerhead 112 to the low volume showerhead 212 produces a “volume penalty” where the reduced internal volume adversely affects flow uniformity by reducing flow uniformity across the faceplate 226. To avoid this volume penalty in a low volume showerhead

212, the small, porous baffle 233 may be positioned in the region 235 for improved flow uniformity, where the diameter of the small, porous baffle 233 as well as the size, number, and arrangement of through-holes 233a in the small, porous baffle 233 may direct the flow of gas into the plenum volume 220, thereby influencing flow uniformity across the faceplate 226.

[0067] The volume of the stem 214 may be between about 1 milliliter and about 50 milliliters in some implementations. Providing the narrow tube 216 as the entirety of the stem 214 may also reduce the overall internal volume of the showerhead because the narrow tube 216 in FIG. 3 has a smaller diameter than the expanded tube 118 in FIG. 2.

[0068] Referring to FIGS. 5-8, the implementation of the faceplate 126 in FIG. 2 and discussed in detail below is analogous to the faceplate 226 in FIG. 3. Thus, the discussion of the elements of the faceplate 126 provided below with reference to FIGS. 5-8 will be understood to be equally applicable to the analogous elements of the faceplate 226 in FIG. 3 unless indicated otherwise. In the interest of conciseness, discussion of these elements of the faceplate 126 with reference to FIGS. 5-8 that would be redundant of discussion herein of similar elements of the faceplate 226 is not provided, with the understanding that the discussion of such elements is applicable to these similar elements. It is contemplated that the faceplate 126 may be a separate component or an integral portion of any suitable showerhead.

[0069] Referring to FIG. 5, the faceplate 126 has an X-axis 134 and a Y-axis 136 that are perpendicular to one another and intersect one another at a center 138 of the faceplate 126, with both the X and Y axes 134, 136 defining a diameter of the faceplate 126. The faceplate 126 has a center region 140 (i.e., Region A depicted in FIG. 5) including the center 138, an outer edge region 142 (e.g., without faceplate through-holes in this implementation), and a peripheral region 144 concentrically interposed radially between the center region 140 and the outer edge region 142. The X and Y axes 134, 136 define four quadrants Q1, Q2, Q3, Q4 of the faceplate 126.

[0070] As shown in FIG. 6, the faceplate through-holes 127 include a first subset 146 of faceplate through-holes, a second subset 148 of faceplate through-holes, and a third subset 150 of faceplate through-holes arranged in multiple areas and having one or more characteristic parameters values, such as relative to the X and Y axes 134, 136, relative to the quadrants Q1, Q2, Q3, Q4, relative to each other, relative to the one or more baffles 162 in the plenum volume 120, independent of characteristic parameters values of the showerhead, or a combination thereof. The arrangement of the three subsets of faceplate through-holes 146, 148, and 150 may allow the one or more process gases to flow to the substrate 110 in a manner that causes material from the one or more process gases to be deposited onto the substrate 110 in a layer with

desirable uniformity. For example, the layer may be within a range of a predetermined thickness uniformity from the center of the substrate to the outer edge of the substrate. In some instances, each AtOx or oxide layer has a thickness at an outer edge region of the substrate less than 0.5% higher than the thickness at a center region of the substrate, and/or each SiN layer has a thickness at the outer edge region of the substrate being less than 0.3% higher than the thickness at the center region of the substrate.

[0071] Referring to FIG. 6, the faceplate through-holes 127 include a plurality of first hexagonal areas HA1 defined by only the through-holes in the first subset 146 of through-holes. For example, each first hexagonal area HA1 has six vertices and each vertex coincides with a center of a respective through-hole of the first subset of through-holes. For illustration purposes in the Figures, each first hexagonal area HA1 is encircled by a dashed circle. Referring to FIG. 8, one first hexagonal area HA1 is shown and encircled by the dashed circle. Within this circle are six through-holes 146 of the first subset 146 of through-holes that define the first hexagonal area HA1. The first hexagonal area HA1 has a dotted boundary and six vertices, two of which are labeled V1, and each vertex coincides with one respective first subset 146 of through-holes. For example, one vertex V1 coincides with through-hole 146A. For all of these first hexagonal areas HA1, no other through-holes are positioned within the first hexagonal areas HA1. For instance, no through-holes from the second subset 148 of through-holes or the third subset 150 of through-holes are within the first hexagonal areas HA1.

[0072] The plurality of first hexagonal areas HA1 are substantially uniformly distributed across a first area in a repeating pattern. In some implementations, the first area may include the peripheral region 144 (FIG. 5) and a portion of the center region 140 (i.e., Region A) radially interposed between the peripheral region 144 and one or more second hexagonal areas HA2 and one or more third hexagonal areas HA3 as discussed in detail below with reference to FIG. 8. In other implementations, the faceplate through-holes 127 may omit or not be arranged in first hexagonal areas HA1 and instead have a repeated pattern of areas with other suitable polygon shapes having three or more sides (e.g., triangular, quadrilateral, pentagonal, heptagonal, octagonal, nonagonal, decagonal, etc.). These areas with other suitable polygon shapes may again be defined by the first subset 146 of through-holes. In these instances, the vertices of these polygon shapes coincide with the center of the through-holes of the first subset 146 of through-holes. In these implementations, no other through-holes of the second or third subsets of through-holes 148 and 150 are positioned therein.

[0073] Each of the faceplate through-holes in the first subset 146 of faceplate through-holes has a first diameter when measured from the second side 130 of the faceplate 126. In one

implementation, the first diameter is about 0.030 to about 0.050 inches, about 0.035 to about 0.045 inches, and may be a first diameter of about 0.040 inches. The first subset 146 of through-holes may be about 3,400 to 4,100 of the total plurality of faceplate through-holes 120 in the faceplate 126 (e.g., about 3,931 of the total plurality of 3,978 faceplate through-holes 127). The first subset 146 of through-holes may provide about 97.50% to 99.50% of the total plurality of faceplate through-holes in the faceplate 126 (e.g., about 98.82% of the total plurality of faceplate through-holes 127). The first subset 146 of through-holes may have 80 to 100 times more through-holes than the second subset 148 of through-holes (e.g., about 91.42 times more through-holes than the second subset 148 of through-holes), and the first subset 146 of through-holes may have 950 to 1,050 times more through-holes than the third subset 150 of through-holes (e.g., about 982.75 times more through-holes than the third subset 150 of through-holes).

[0074] As provided above, the faceplate through-holes 127 include one or more second hexagonal areas HA2 that are defined by the through-holes in the first subset 146 of through-holes, and that have one or more of the through-holes of the second subset 148 of through-holes positioned within that second hexagonal area HA2. For example, as with the first hexagonal area HA1, each second hexagonal area HA2 has six vertices and each vertex coincides with a center of a respective through-hole of the first subset 146 of through-holes. In FIG. 6, each second hexagonal area HA2 is encircled by a dashed circle. Referring to FIG. 12, one second hexagonal area HA2 is shown and encircled by the dashed circle. Within this circle are six through-holes of the first subset 146 of through-holes that define the second hexagonal area HA2. The second hexagonal area HA2 has a dotted boundary and six vertices, two of which are labeled V2, and each vertex coincides with one respective first subset 146 of through-holes. For example, one vertex V2 coincides with through-hole 146B. Positioned within this second hexagonal area HA2 is one through-hole from the second subset 148 of through-holes. In some instances, more than one through-hole from the second subset 148 of through-holes may be positioned within the second hexagonal area HA2. In this implementation of FIG. 12, the single through-hole of the second subset 148 of through-holes is positioned at the center of that second hexagonal area HA2 and equidistant from the six through-holes of the first subset 146 of through-holes.

[0075] All of the second hexagonal areas HA2 may be substantially uniformly distributed across a second area in a repeating pattern, with the second area being located within a radius AR of the faceplate 126 (as depicted in FIG. 6) and separate from the first area and a third area as discussed below, and the radius AR being about 1.90 to 2.40 inches from the center 138 of the faceplate. Two of the second hexagonal areas HA2 are arranged relative to one another

(e.g., adjacent to one another) such that two through-holes of the first subset 146 of through-holes are between the two through-holes of the second subset 148 of through-holes (i.e., along a reference line extending between the two through-holes of the second subset 148 of through-holes). The second hexagonal areas HA2 are arranged on the faceplate 126 such that the second hexagonal areas HA2 form a mirror image along the Y-axis 136 of the faceplate 126 but not along an X-axis 134. There are no through-holes of the second subset 148 of through-holes located outside of a radius DR of the faceplate 126 (as depicted in FIG. 6), with the radius DR being about 1.72 to 2.20 inches from the center of the faceplate. In other implementations, the plurality of faceplate through-holes 127 may omit the second hexagonal areas HA2 and instead have a repeated pattern of areas with other suitable polygon shapes having three or more sides (e.g., triangular, quadrilateral, pentagonal, heptagonal, octagonal, nonagonal, decagonal, etc.) defined by the through-holes of the first subset 146 of through-holes and one or more through-holes of the second subset 148 of through-holes.

[0076] Each of the faceplate through-holes in the second subset 148 of faceplate through-holes has a second diameter when measured from the second side 130 of the faceplate 126, with the second diameter being less than the first diameter of each of the faceplate through-holes in the first subset 146 of faceplate through-holes. In one implementation, the second diameter is about 0.020 to about 0.030 inches, and the second subset 148 of through-holes provide about 35 to 55 of the total plurality of faceplate through-holes 120 in the faceplate 126 (e.g., about 43 of the total plurality of 3,978 faceplate through-holes 127). The second subset 148 of through-holes may provide about 0.08% to 2.18% of the total plurality of faceplate through-holes in the faceplate 126 (e.g., 1.08% of the total plurality of faceplate through-holes 127, etc.). The first subset 146 of through-holes has 80 to 100 times more through-holes than the second subset 148 of through-holes (e.g., 91.42 times more through-holes than the second subset 148 of through-holes). The second subset 148 of through-holes has 5 to 15 times more through-holes than the third subset 150 of through-holes (e.g., 10.75 times more through-holes than the third subset 150 of through-holes).

[0077] As provided above, the faceplate through-holes 127 include one or more third hexagonal areas HA3 that are defined by the through-holes in the first subset 146 of through-holes, and that have one or more of the through-holes of the third subset 150 of through-holes positioned within that third hexagonal area HA3. For example, as with the first hexagonal area HA1, each third hexagonal area HA3 has six vertices and each vertex coincides with a center of a respective through-hole of the first subset of through-holes. In FIG. 6, each third hexagonal area HA3 is encircled by a dashed circle. Referring to FIG. 8, four third hexagonal areas HA3

are shown and encircled by the dashed circles. Within each of these circles are six through-holes 146 of the first subset 146 of through-holes that define the third hexagonal area HA3. One of the third hexagonal areas HA3 illustrates a dotted boundary and six vertices, two of which are labeled V3, and each vertex coincides with one respective first subset 146 of through-holes. For example, one vertex V3 coincides with through-hole 146C. Positioned within each third hexagonal area HA3 is one through-hole from the third subset 150 of through-holes. In some instances, more than one through-hole from the third subset 150 of through-holes may be positioned within the third hexagonal area HA3. In this implementation of FIG. 8, the single through-hole of the third subset 150 of through-holes is positioned at the center of that third hexagonal area HA3 and equidistant from the six through-holes of the first subset 146 of through-holes.

[0078] All of the third hexagonal areas HA3 may be substantially uniformly distributed across a third area in a repeated pattern, with the third area being located within a radius BR of the faceplate 126 (as depicted in FIG. 6) and separate from the first area and the second area. The third area may be offset from the center 138 of the faceplate to a position of the baffle 133 in the plenum volume 120 (e.g., a thermocouple, etc.). The radius BR may about 2.15 to 2.65 inches from the center 138 of the faceplate 126. In this implementation, all the third hexagonal areas are between a radius CR (as depicted in FIG. 6) and the radius BR of the faceplate 126, with the radius CR being about 1.06 to 1.56 inches from the center 138 of the faceplate 126. As depicted in FIGS. 6 and 7, at least two of the third hexagonal areas HA3 are along the Y-axis 136 of the faceplate 126, and none of the third hexagonal areas HA3 are on positioned the X-axis 134 of the faceplate 126. Furthermore, in this implementation, none of the through-holes of the third subset 150 of through-holes are positioned outside of a radius ER of the faceplate 126 (as depicted in FIG. 6), with the radius ER being about 2.30 to 2.50 inches from the center 138 of the faceplate 126. As best shown in FIG. 8, at least four of through-holes of the third subset 150 of through-holes may form a diamond pattern including an acute angle up to 20 degrees, and at least two through-holes of the first subset 146 of through-holes are within the diamond pattern. In other implementations, the plurality of faceplate through-holes 127 may omit the third hexagonal areas HA3 and instead have a repeated pattern of areas with other suitable polygon shapes having three or more sides (e.g., triangular, quadrilateral, pentagonal, heptagonal, octagonal, nonagonal, decagonal, etc.) defined by the through-holes of the first subset 146 of through-holes and one or more through-holes of the third subset 150 of through-holes.

[0079] Each of the faceplate through-holes of the third subset 150 of faceplate through-holes has a third diameter when measured from the second side 130 of the faceplate 126, with the third diameter being less than the second diameter. In one implementation, the third diameter may be about 0.022 to about 0.028 inches, and the third subset 150 of through-holes may provide about 2 to 8 of the total plurality of faceplate through-holes 127 in the faceplate 126 (e.g., about 4 of the total plurality of faceplate through-holes 127). The third subset 150 of through-holes may provide about 0.05% to 0.15% of the total plurality of faceplate through-holes in the faceplate 126 (e.g., about 0.10% of the total plurality of faceplate through-holes 127). The first subset 146 of through-holes has 950 to 1,050 times more through-holes than the third subset 150 of through-holes (e.g., 982.75 times more through-holes than the third subset 150 of through-holes, etc.). The second subset 148 of through-holes may have 5 to 15 times more through-holes than the third subset 150 of through-holes (e.g., about 10.75 times more through-holes than the third subset 150 of through-holes, etc.).

[0080] The characteristic parameters of the first subset 146 of faceplate through-holes, the second subset 148 of faceplate through-holes, and the third subset 150 of faceplate through-holes, as exemplified above, are configured independently and/or relative to one another to cause the one or more process gases to flow through the corresponding faceplate through-holes 127 and cause a material from the one or more process gases to be deposited on the substrate 110 in a layer that is within a range of a predetermined thickness uniformity from the center of the substrate to the outer edge of the substrate. In one non-limiting implementation, the third subset 150 of faceplate through-holes may be located in the third area of the faceplate 126 (e.g., Region C depicted in FIG. 5 and located between the radius BR of the faceplate 126 and the radius CR depicted in FIG. 6), with the radius BR being about 2.15 to 2.65 inches from the center 138 of the faceplate 126 and the radius CR being about 1.06 to 1.56 inches from the center 138 of the faceplate 126. Such location may allow the one or more process gases to reach certain regions of the plenum volume 120 more rapidly despite local structural constraints (e.g., baffles, standoff support members, sensors, other impeding structures in the plenum etc.) such that the deposition rate may be adjusted around the region immediately underneath the third subset 150 to counteract the shadowing effect from local structural constraints (e.g., the deposition rate may increase as compared to a faceplate not having any holes in such location).

[0081] In some examples, deposition layer thickness on a portion of the substrate facing the third area may become more leveled with other substrate regions that are not directly facing areas of the plenum with structure constraints. In some instances, the uniformity can be within 0.5 % of the average deposition layer thickness across the entire substrate. In another non-

limiting implementation, the third subset 150 of faceplate through-holes may be arranged in a diamond pattern within that third area so as to direct flow of the one or more process gases relative to the structural constraints arranged in a corresponding pattern that may, in the absence of the diamond pattern of the third subset 150 of holes, overly increase the flow of the one or more process gases to the portion of the substrate facing the third area of the faceplate and cause deposition layer thickness on the portion of the substrate facing the third area of the faceplate to be more than 0.5% above the average deposition layer thickness across the entire substrate. Strategic placement/pattern of the third subset of holes can change the flow rate of the gas reaching that region. In some embodiments, arranging the third subset of the through-holes in a diamond shape relative to the surrounding first and second sets of through-holes, provides the more uniform depositing result.

[0082] In yet another non-limiting implementation, the diameter of each faceplate through-hole in the third subset 150 of faceplate through-holes may be about 0.022 to 0.028 inches because a diameter above this range may also increase flow of the one or more process gases to the portion of the substrate facing the third area of the faceplate and cause deposition layer thickness on the portion of the substrate facing the third area of the faceplate to be more than 0.5% above the average deposition layer thickness across the entire substrate. Responsive to these and other characteristic parameters of the faceplate, individually and/or collectively, each AtOx layer, i.e., the oxide layer, may have a thickness at an outer edge region of the substrate less than 0.5% higher than the thickness at a center region of the substrate, and each SiN layer may have a thickness at the outer edge region of the substrate less than 0.3% higher than the thickness at the center region of the substrate.

[0083] FIG. 9 depicts a center portion of a test faceplate structure (“test structure”) of a showerhead with faceplate through-holes configured to allow a center region of the substrate layers to be deposited more uniformly. While the faceplate 126 of FIGS. 5-8 and 12 includes three subsets of faceplate through-holes (i.e., the first subset 146 of faceplate through-holes, the second subset 148 of faceplate through-holes, and the third subset 150 of faceplate through-holes) and three hexagonal areas (i.e., the first hexagonal areas HA1, the second hexagonal areas HA2, and the third hexagonal areas HA3), the test structure of FIG. 9 consists of only two subsets of faceplate through-holes (i.e., a first subset 346 of faceplate through-holes and a second subset 348 of faceplate through-holes) and only two types of hexagonal areas (i.e., a plurality of first hexagonal areas HA1’ and a plurality of second hexagonal areas HA2’). The location of the second hexagonal areas HA21 within the center region of the faceplate increases

gas channels underneath a baffle 333 within the plenum volume to reduce non-uniformity caused by the baffle in the plenum.

[0084] FIG. 10A depicts a simulation test result (heat map) of a test structure having a faceplate pattern similar to that shown in FIG. 9. FIG. 10B depicts a simulation result (heat map) from a faceplate having a through-hole pattern shown in FIGS. 5-8 and 12. The plenums of the showerheads used to generate the results in FIGS. 10A and 10B have the same structural constraints, e.g., locations of the baffles, standoff supports, and inner supporting pillars, etc., are the same), except for the through-hole patterns/distributions of the showerheads. Each heat map has sections of darker shading representative of a lack of uniformity in deposition layer thickness likely caused by the structures within the plenum volume. Stated another way, the two heat maps indicate relative average deposition thickness at different locations on a substrate and produced by a corresponding one of two deposition processes (e.g., an AtOx deposition process and a SiN deposition process) using a flow of a corresponding one of two process gases that may be impeded by structural constraints within the plenum volume of a corresponding one of the test structure and the showerhead.

[0085] In FIG. 10A, a first heat map 402 corresponds with average deposition thickness on a first simulated substrate result produced by one of two deposition processes (e.g., an AtOx deposition process and a SiN deposition process). Although the placement of the second hexagonal areas HA2 appeared to enable the substrate area underneath the baffle (Section D) to have a more uniform deposition, uneven deposition was observed proximal to or within an edge portion of the first section D. In FIG. 10B, a second heat map 404 illustrates less dark shading as compared to that shown in the first heat map 402, thus representing that the faceplate 126 is configured to allow for even better uniformity in the first section D and surrounding sections of the substrate. The improved uniformity is accomplished (at least partially) by the combination of features of the showerhead of Figures 5–8 and 12. For example, the improved uniformity was accomplished by arranging the second hexagonal regions HA2 in a spaced-apart pattern within the second area (i.e., located within the radius AR of the center 138 of the faceplate 126 as depicted in FIG. 6, with the radius AR being about 1.90 to 2.40 inches from the center 138 of the faceplate 126) and adding the one or more third hexagonal regions HA3 in the third area (i.e., offset from the center 138 of the faceplate 126 and located within the radius BR of the faceplate 126 as depicted in FIG. 6, with the radius BR being about 2.15 to 2.65 inches from the center 138 of the faceplate 126) to further reduce the shadowing effect that leads to non-uniformity.

[0086] As can be seen, the first heat map 402 includes the first section D (i.e., the first section D facing the center portion of the test structure with faceplate through-holes proximal to the baffle 333). The first heat map 402 further includes a second section E surrounded by and excluding the first section D (i.e., the second section E facing a portion of the test structure with faceplate through-holes located between the baffle plate 333 and one or more structural constraints). The darker shading of section E relative to section D represents that the deposition layer thickness within section E is not uniform with (e.g., not the same as) that of section D (e.g., the deposition layer thickness within section E is less than that of section D). The first heat map 402 further includes a third section F surrounding and excluding the first section D and the second section E (i.e., the third section F facing a portion of the test structure with faceplate through-holes located radially outward from one or more structural constraints in the plenum volume). The darker shading of section F relative to section D represents that the deposition layer thickness within section F is not uniform with (e.g., not the same as) that of section D (e.g., the deposition layer thickness within section F is less than that of section D). While the second hexagonal areas HA2 in the center portion of the faceplate of the test structure provide improved uniformity within the first section D, the baffle 333 and one or more structural constraints within the plenum volume may cause uneven deposition surrounding the edge of the baffle 333 in some processes (i.e., proximal to or within the outer edge portion of the first section D, such as the second section E and the third section F). As can be further seen, the second heat map 404 includes a first section G (i.e., the first section G facing the center portion of the faceplate 126 having faceplate through-holes proximal to the baffle 133), a second section H surrounded by and excluding the first section G (i.e., the second section H facing a portion of the faceplate 126 having faceplate through-holes located between the baffle plate 133 and one or more structural constraints), and a third section I surrounding and excluding the first section G and the second section H (i.e., the third section I facing a portion of the faceplate 126 having faceplate through-holes located radially outward from one or more structural constraints in the plenum volume 120). The overall shading in the first section G, the second section H, and the third section I for the second heat map 404 associated with the faceplate 126 is lighter than that of the first section D, the second section E, and the third section F for the first heat map 402. Therefore, improved uniformity is achieved by the showerhead with the characteristics of faceplate 126. Notably, the arrangement of the second hexagonal areas HA2 and the third hexagonal areas HA3 in the faceplate 126 improved deposition layer uniformity across the entire substrate (including the first section G, the second section H, and the third section I).

[0087] FIG. 11 depicts schematic diagram of a 49 measurement points where deposition layer thickness is measured on corresponding substrates produced by the test structure depicted in FIG. 9 and the disclosed faceplate 126 shown in FIGS. 5-8. As can be seen, the 49 points include point 1 at the center of the corresponding test substrate, points 2 through 9 offset a first common radius from the center and uniformly spaced from one another at corresponding rotational phases, points 10 through 25 offset a second common radius from the center and uniformly spaced from one another at corresponding rotational phases, and points 26 through 49 offset a third common radius from the center and uniformly spaced from one another at corresponding rotational phases. In one test, the average deposition thickness of a SiN layer by the test structure was out of specification requirements because the average deposition thickness for the SiN layer at locations near the center region of the substrate (e.g., at points 1 through 9) was above the predetermined maximum thickness (i.e., as was set forth in the specification requirements). Furthermore, the average deposition thickness of a SiN layer by the test structure was out of specification requirements because the average deposition thickness for the SiN layer at locations proximal to the outer edge region of the substrate (e.g., at points 41 through 49) was above the predetermined maximum thickness (i.e., as was set forth in the specification requirements). In contrast to the test structure, the average deposition thickness of the SiN layer by the faceplate 126 of FIGS. 5-8 was within specification requirements because the average deposition thickness for the SiN layer at all locations from the center region of the substrate to the outer edge region of the substrate (i.e., points 1 through 49) was below the predetermined maximum thickness and above the predetermined minimum thickness (i.e., as was set forth in the specification requirements).

[0088] The term “between,” as used herein and when used with a range of values, is to be understood, unless otherwise indicated, as being inclusive of the start and end values of that range. For example, between 1 and 5 is to be understood to be inclusive of the numbers 1, 2, 3, 4, and 5, not just the numbers 2, 3, and 4.

[0089] 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 may 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. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A, B, or C), using a non-exclusive logical OR. 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.

CLAIMS

What is claimed is:

1. A showerhead for use in a semiconductor processing apparatus, the showerhead comprising:

a faceplate comprising a plurality of faceplate through-holes that extend from a first side to a second side of the faceplate;

a backplate opposite the faceplate, wherein a plenum volume is defined between the backplate and the faceplate, wherein the first side of the faceplate defines a first internal surface of the plenum volume; and

one or more gas inlets in fluid communication with the plenum volume;

wherein the plurality of faceplate through-holes comprises:

a first subset of the plurality of the faceplate through-holes each having a first diameter when measured from the second side of the faceplate,

a second subset of the plurality of faceplate through-holes each having a second diameter when measured from the second side of the faceplate, wherein the second diameter is less than the first diameter, and

a third subset of the plurality of faceplate through-holes each having a third diameter when measured from the second side of the faceplate, wherein the third diameter is less than the second diameter.

2. The showerhead of claim 1, wherein the first diameter is about 0.030 to 0.050 inches.

3. The showerhead of claim 1, wherein the first diameter is about 0.035 to 0.045 inches.

4. The showerhead of claim 1, wherein the first subset of through-holes comprises about 3,400 to 4,100 of the plurality of faceplate through-holes.

5. The showerhead of claim 1, wherein the first subset of through-holes comprise about 97.50% to 99.50% of the plurality of faceplate through-holes.

6. The showerhead of claim 1, wherein the first subset of through-holes has 80 to 100 times more through-holes than the second subset of through-holes.

7. The showerhead of claim 1, wherein the first subset of through-holes has 950 to 1,050 times more through-holes than the third subset of through-holes.

8. The showerhead of claim 1, wherein the second diameter is about 0.020 to 0.030 inches.

9. The showerhead of claim 1, wherein the second subset of through-holes has 35 to 55 of the plurality of faceplate through-holes.

10. The showerhead of claim 1, wherein the second subset of through-holes comprises about 0.08% to 2.18% of the plurality of faceplate through-holes.

11. The showerhead of claim 1, wherein the second subset of through-holes has 5 to 15 times more through-holes than the third subset of through-holes.

12. The showerhead of claim 1, wherein the third diameter is about 0.022 to 0.028 inches.

13. The showerhead of claim 1, wherein the third subset of through-holes has 2 to 8 of the plurality of faceplate through-holes.

14. The showerhead of claim 1, wherein the third subset of through-holes comprises about 0.05% to 0.15% of the plurality of faceplate through-holes.

15. The showerhead of claim 1, wherein the faceplate has an X-axis and a Y-axis that is perpendicular to the X-axis, both the X and Y axes defining a diameter of the faceplate, and wherein the X and Y axes also define four quadrants of the faceplate.

16. The showerhead of claim 1, wherein the plurality of faceplate through-holes comprises a plurality of first hexagonal areas, each first hexagonal area is defined by through-holes of the first subset of through-holes, each vertex of the first hexagonal area coincides with a respective through-hole of the first subset of through-holes, and no through-holes of the second subset of through-holes or through-holes of the third subset of through-holes are positioned inside the first hexagonal areas.

17. The showerhead of claim 1, wherein the plurality of faceplate through-holes comprises one or more second hexagonal areas, each second hexagonal area is defined by through-holes of the first subset of through-holes, each vertex of the first hexagonal area coincides with a respective through-hole of the first subset of through-holes, and one or more of the through-holes of the second subset of through-holes is in each of the one or more second hexagonal areas.

18. The showerhead of claim 17, wherein all the second hexagonal areas are within a radius AR of the faceplate, wherein the radius AR is about 1.90 to 2.40 inches from a center of the faceplate.

19. The showerhead of claim 17, wherein two of the second hexagonal areas are arranged adjacent to one another such that two through-holes of the first subset of through-holes are between the two through-holes of the second subset of through-holes.

20. The showerhead of claim 17, wherein the second hexagonal areas are arranged on the faceplate such that the second hexagonal areas form a mirror image along a Y-axis of the faceplate but not along an X-axis that is perpendicular to the Y-axis.

21. The showerhead of claim 1, wherein the plurality of faceplate through-holes comprises one or more third hexagonal areas, each third hexagonal area is defined by through-holes of the first subset of through-holes, each vertex of the first hexagonal area coincides with a respective through-hole of the first subset of through-holes, and one or more of the through-holes of the third subset of through-holes is in each the third hexagonal area.

22. The showerhead of claim 21, wherein all the third hexagonal areas are within a radius BR of the faceplate, wherein the radius BR is about 2.15 to 2.65 inches from a center of the faceplate.

23. The showerhead of claim 22, wherein all the third hexagonal areas are between a radius CR and the radius BR of the faceplate, wherein the radius CR is about 1.06 to 1.56 inches from the center of the faceplate.

24. The showerhead of claim 21, wherein at least two of the third hexagonal areas are along a Y-axis of the faceplate.

25. The showerhead of claim 21, wherein none of the third hexagonal areas are on an X-axis of the faceplate.

26. The showerhead of claim 1, wherein there are no through-holes of the second subset of through-holes outside of a radius DR of the faceplate, wherein the radius DR is about 1.72 to 2.22 inches from a center of the faceplate.

27. The showerhead of claim 1, wherein there are no through-holes of the third subset of through-holes outside of a radius ER of the faceplate, wherein the radius ER is about 2.30 to 2.50 inches from a center of the faceplate.

28. The showerhead of claim 1, wherein at least four of through-holes of the third subset of through-holes form a diamond pattern and wherein at least two through-holes of the first subset of through-holes are within the diamond pattern.

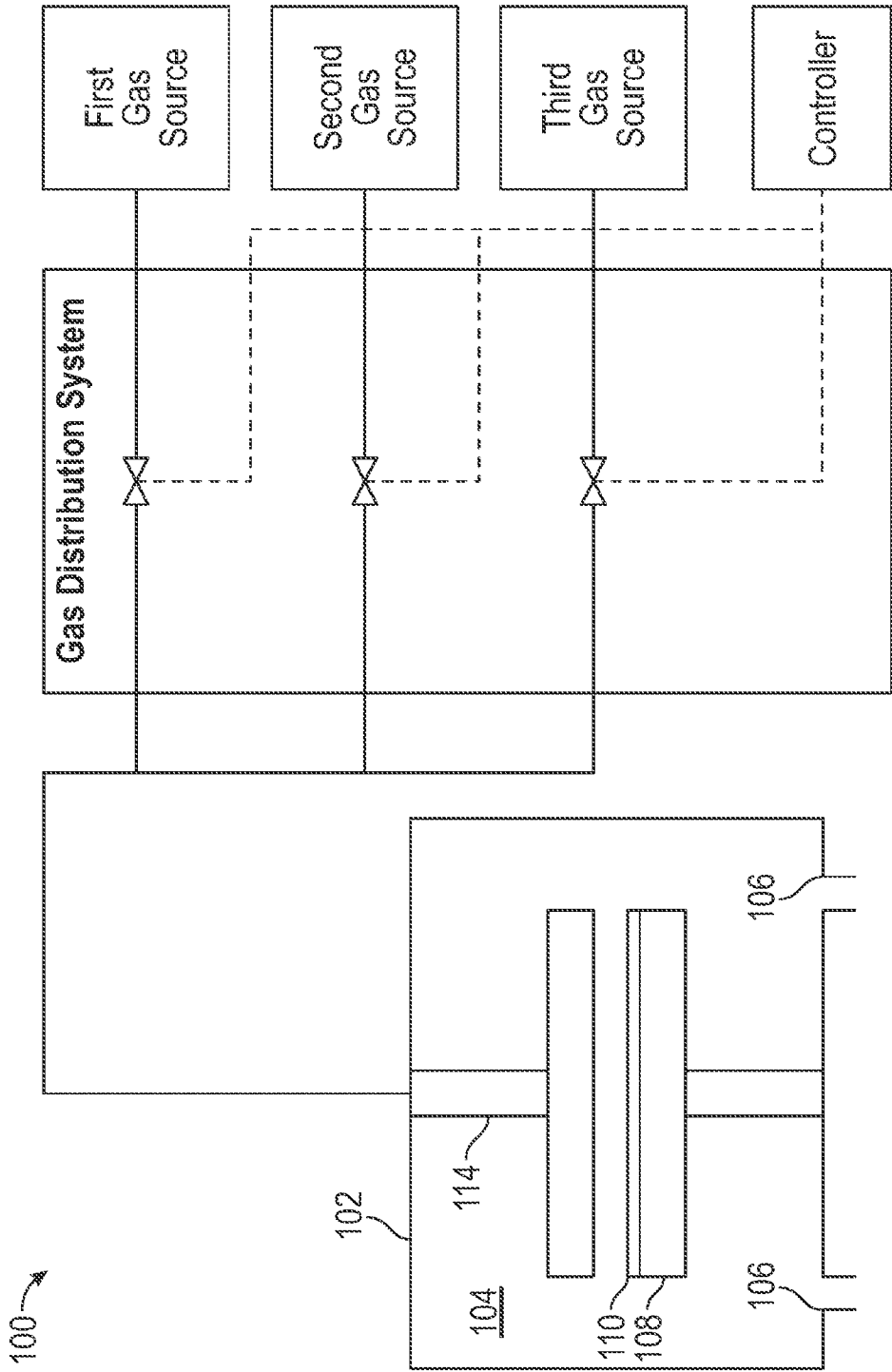


FIG. 1

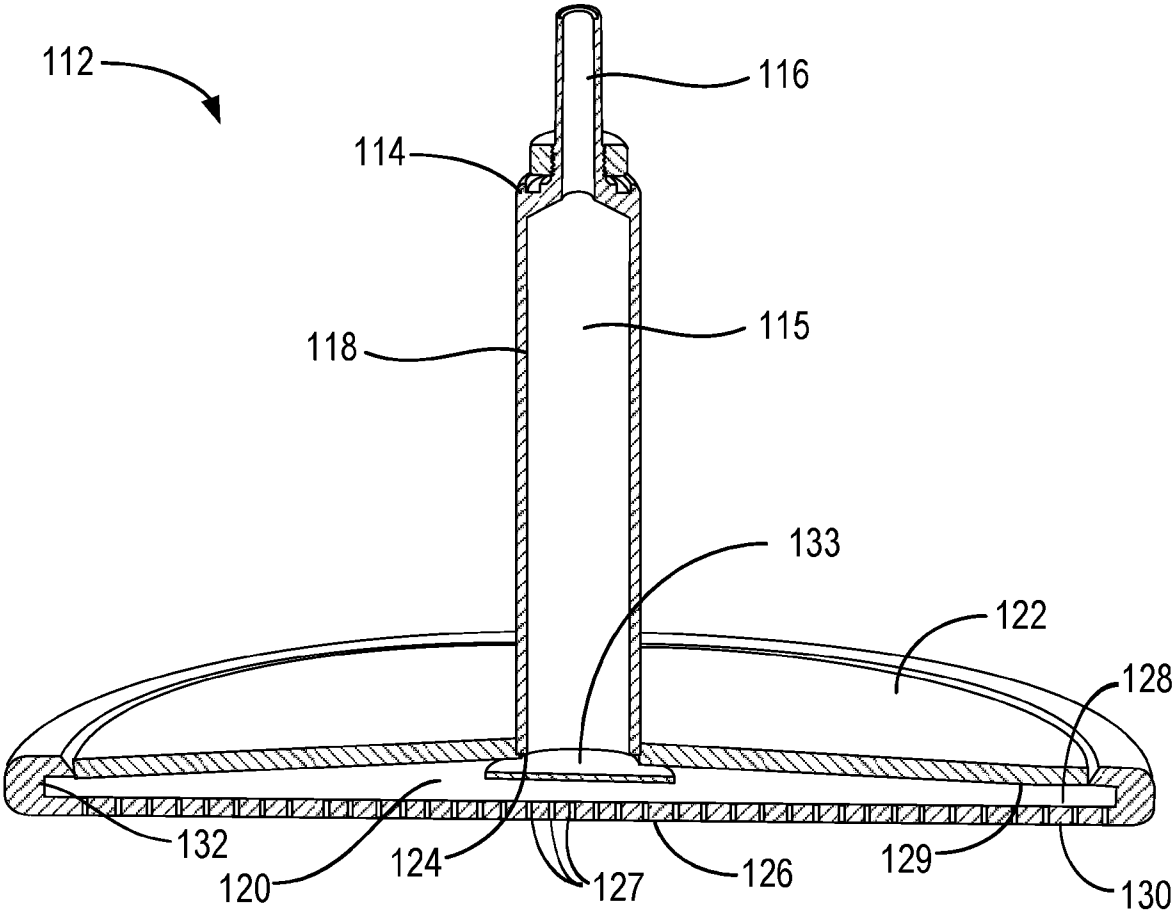


FIG. 2

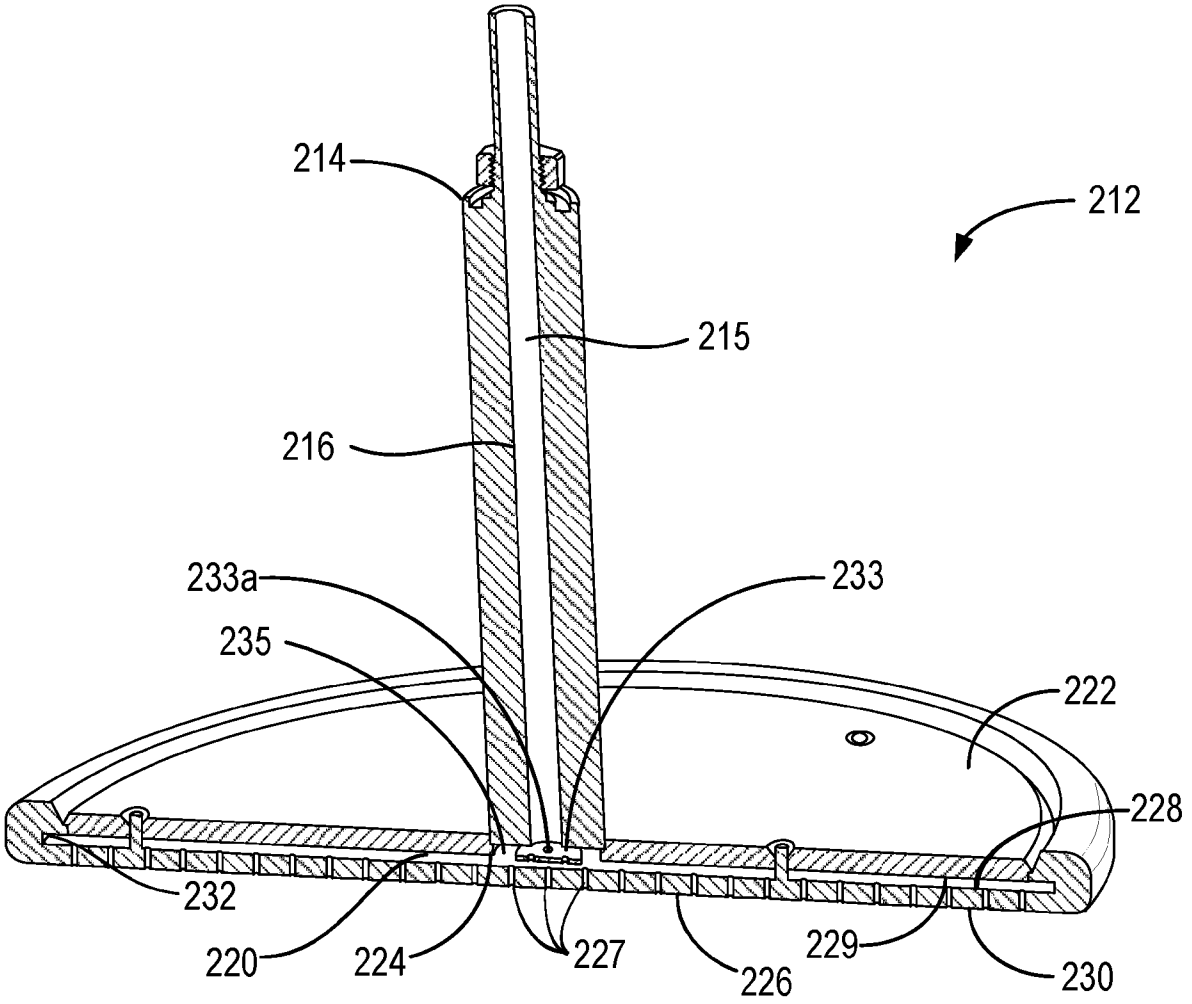


FIG. 3

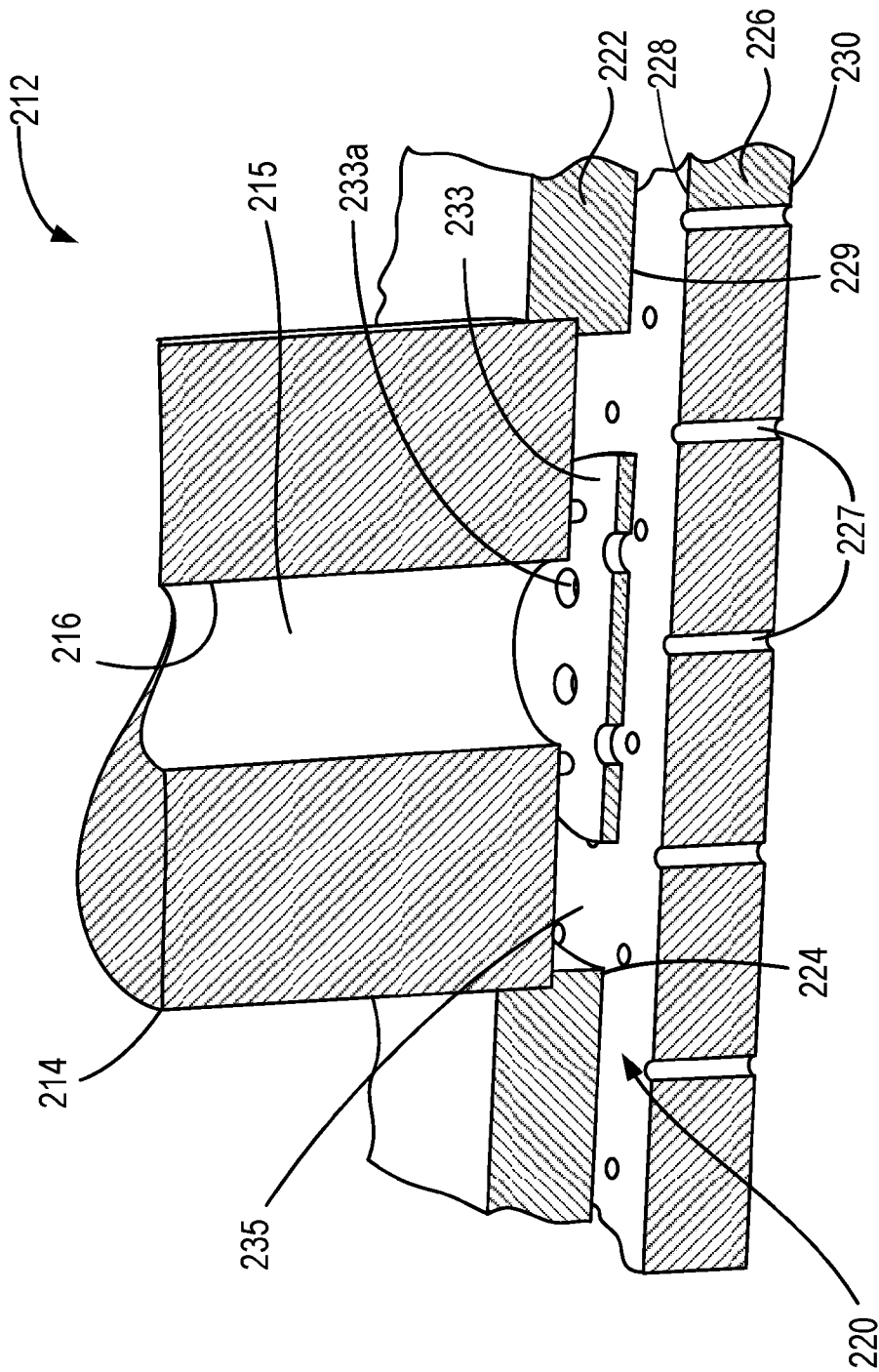


FIG. 4

5/11

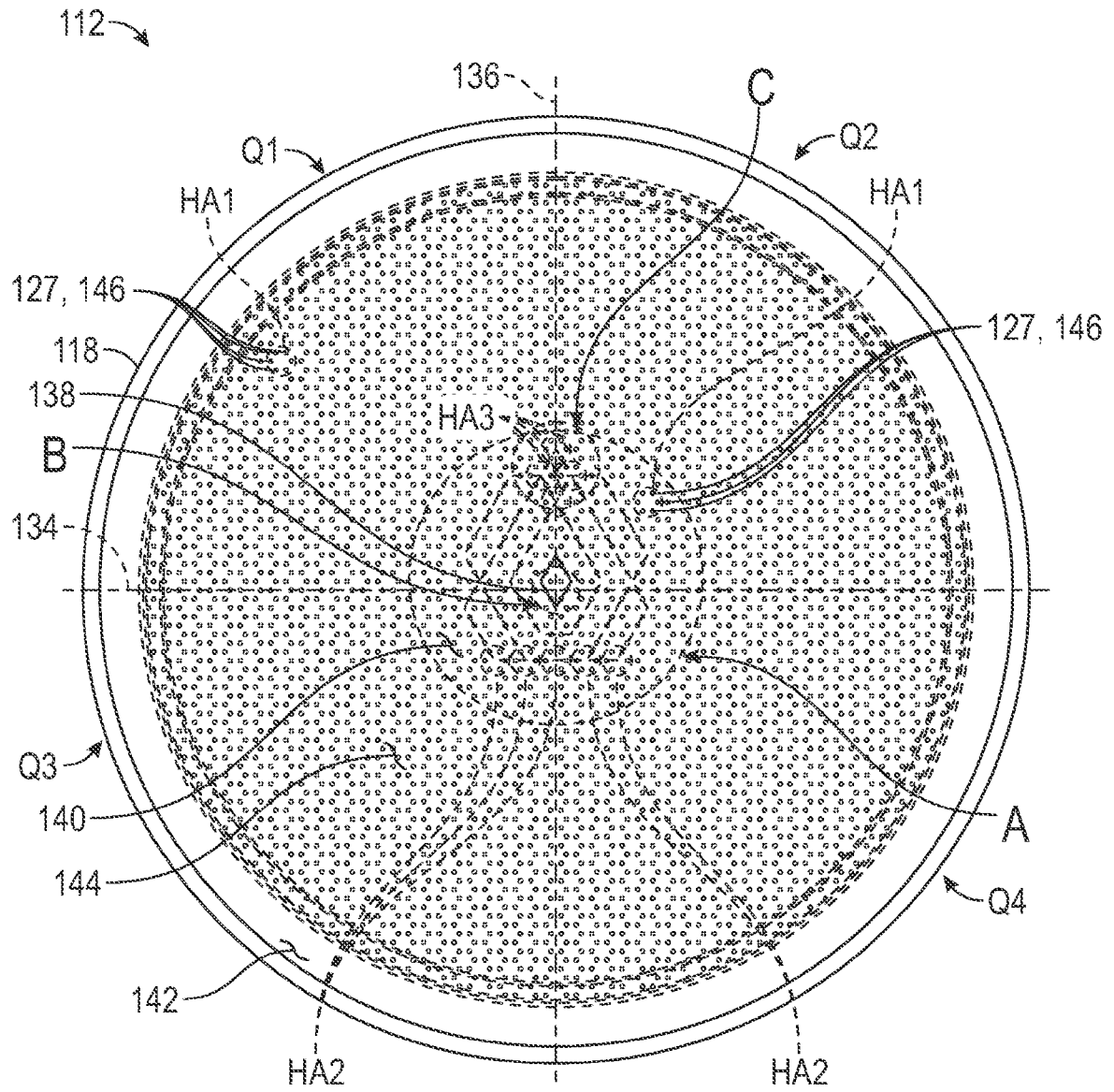


FIG. 5

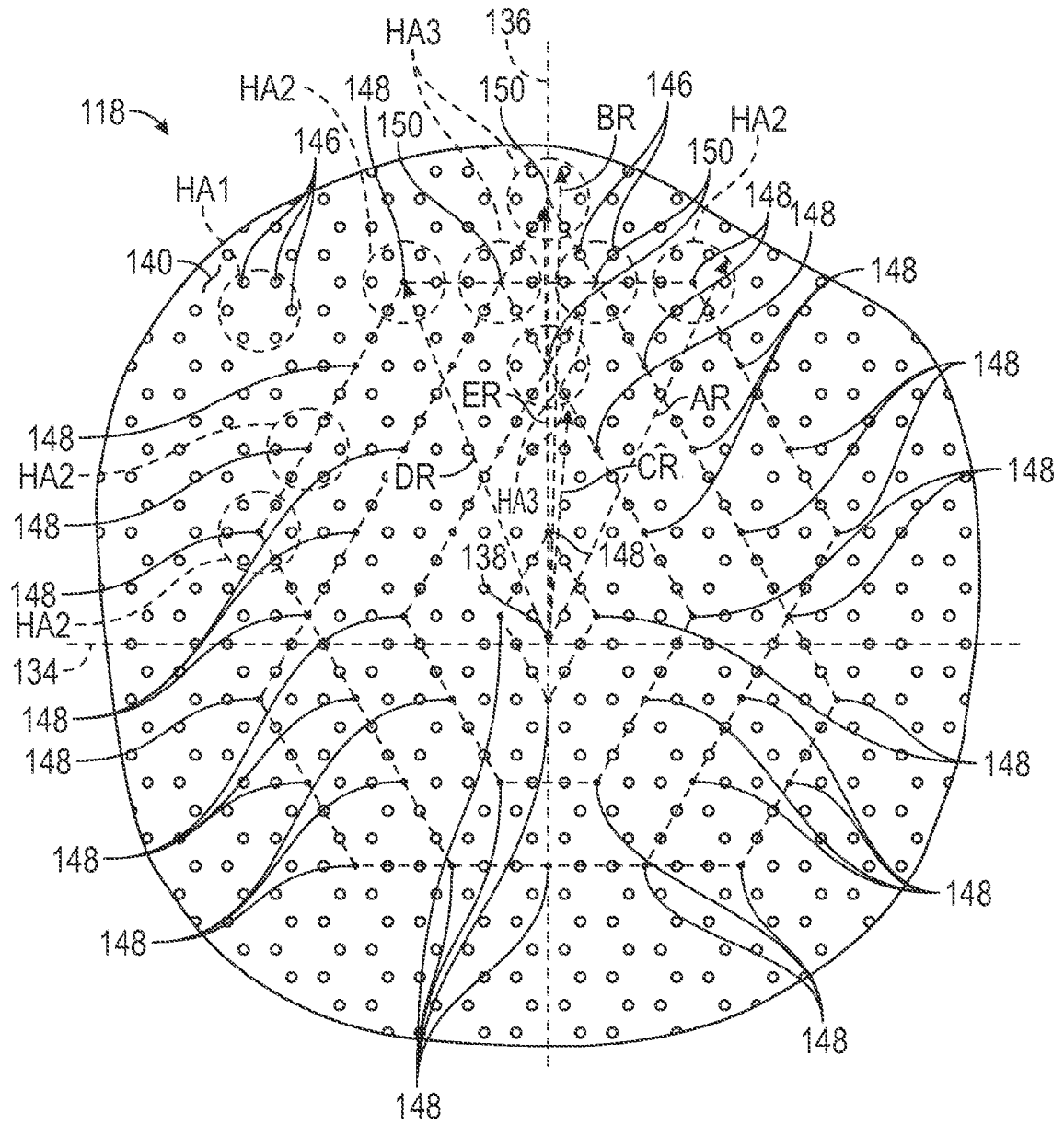


FIG. 6

7/11

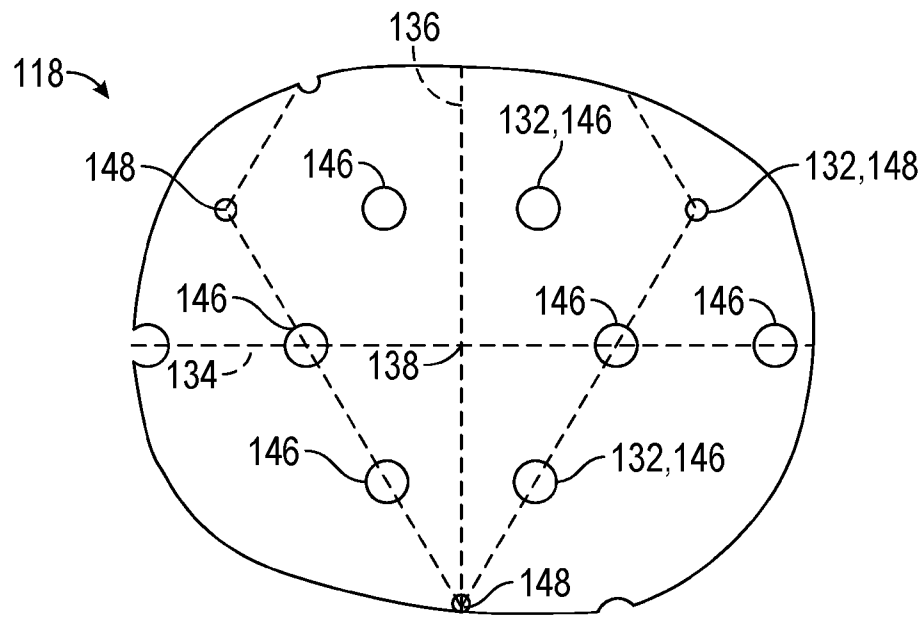


FIG. 7

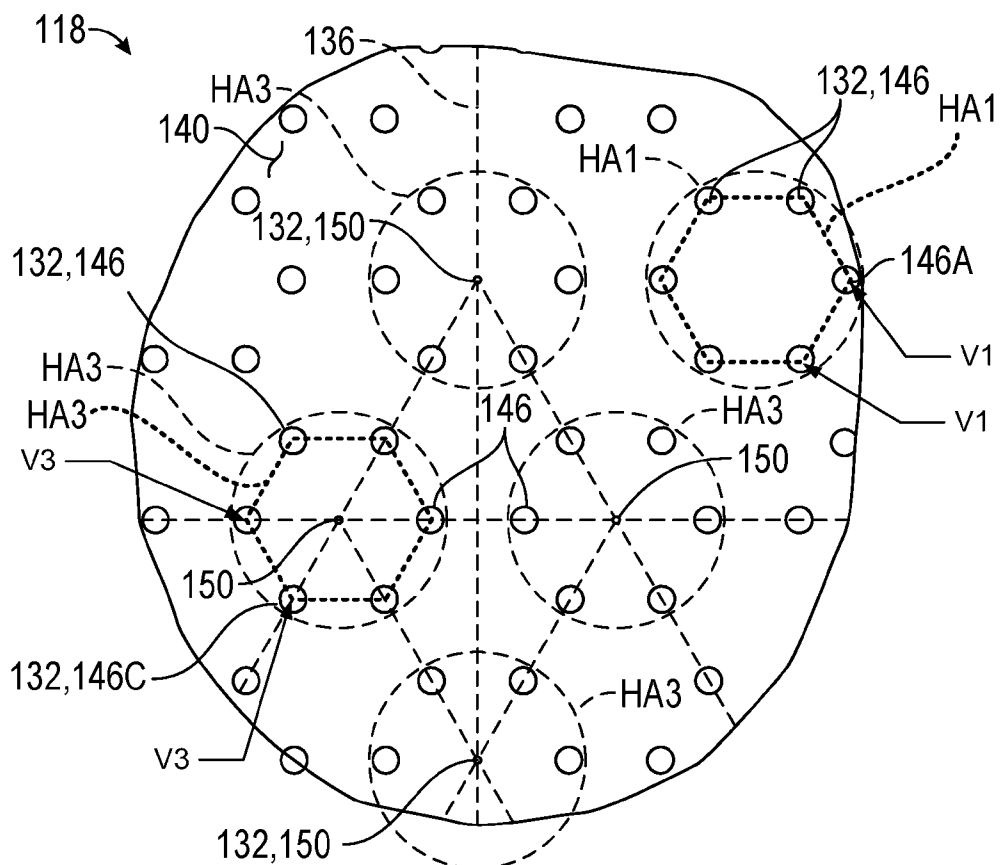


FIG. 8

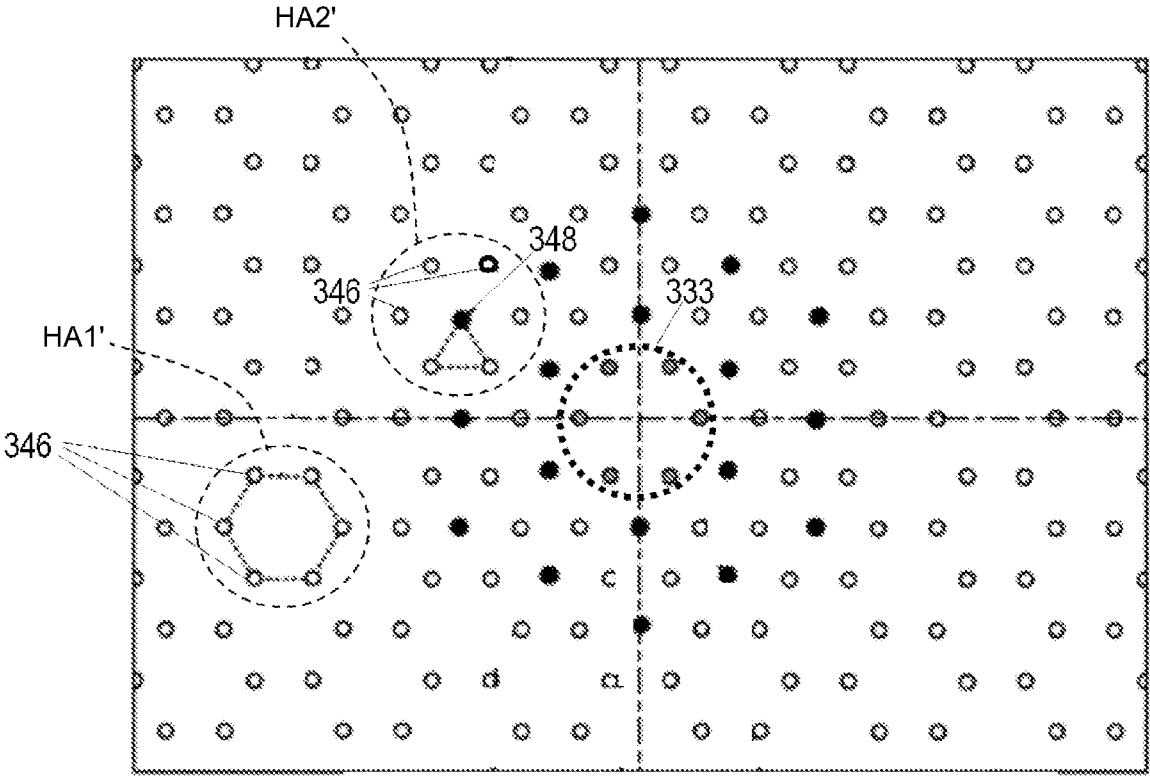
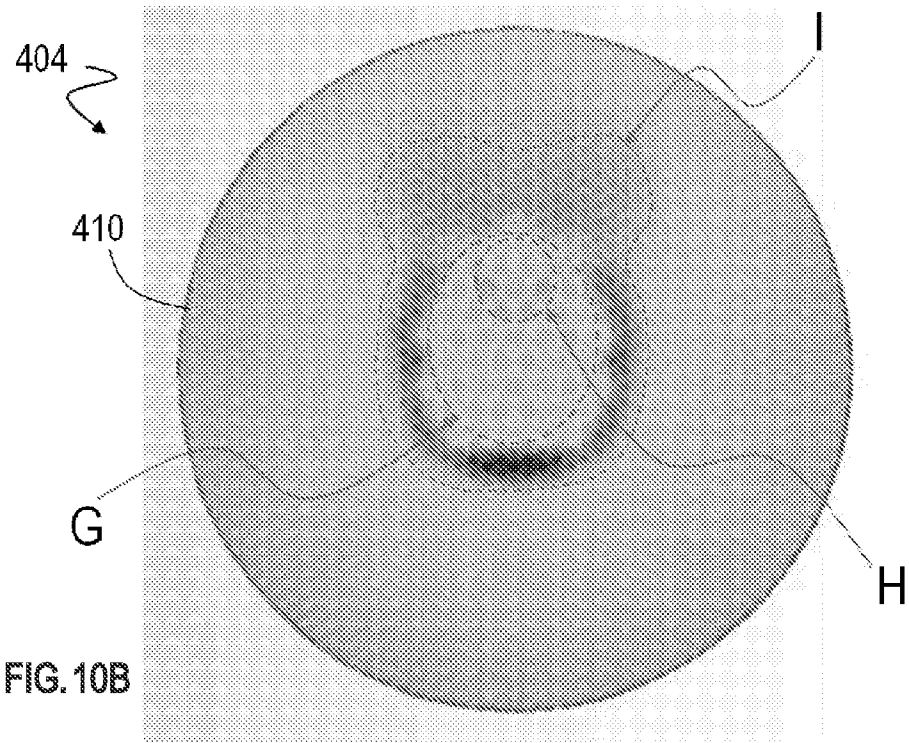
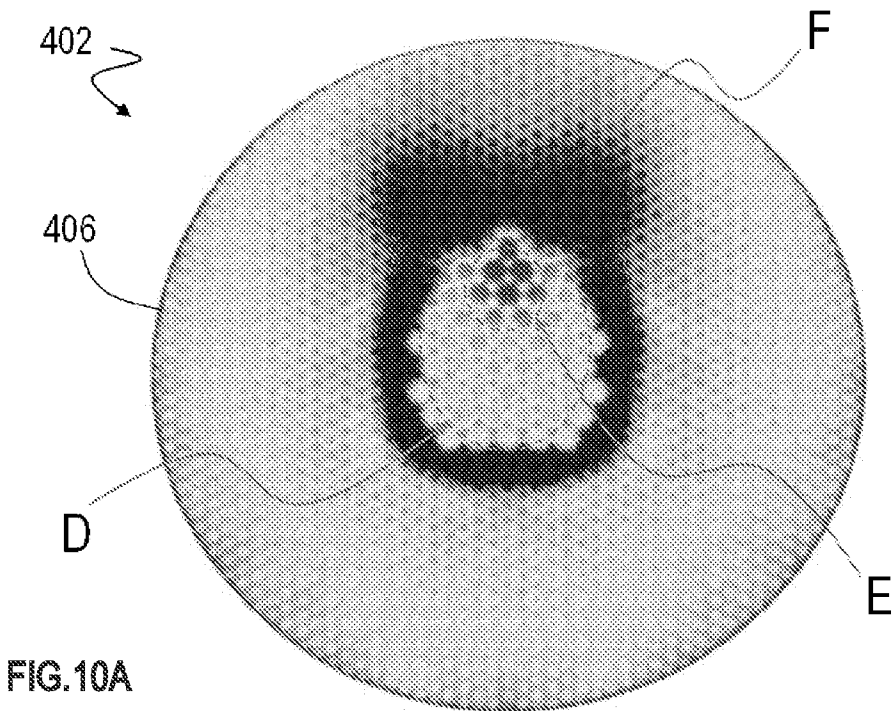
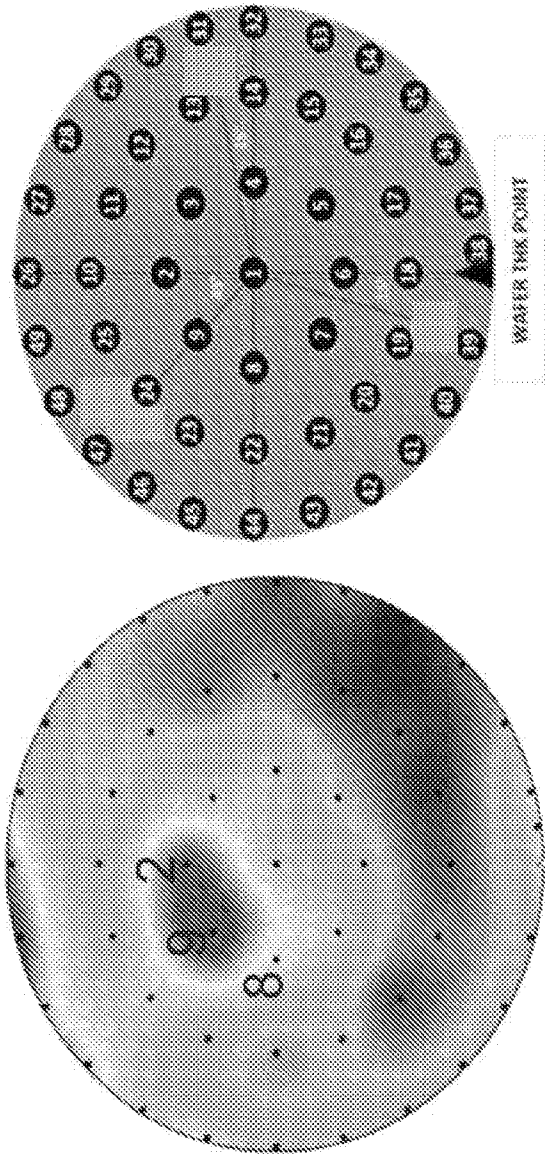


FIG.9





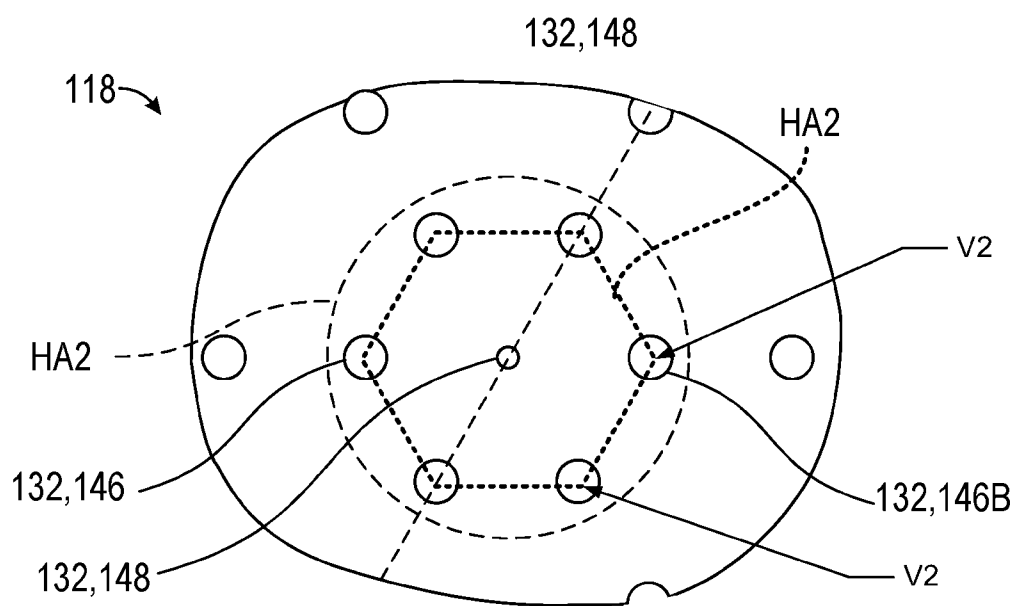


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/060938

A. CLASSIFICATION OF SUBJECT MATTER C23C 16/455(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) C23C 16/455(2006.01); B05B 1/00(2006.01); B05B 1/18(2006.01); C23C 16/52(2006.01); H01J 37/32(2006.01); H01L 21/205(2006.01); H01L 21/306(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: semiconductor, showerhead, faceplate, backplate, through hole, subset, diameter, hexagonal area, pattern		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012-0108066 A1 (NEW et al.) 03 May 2012 (2012-05-03) paragraphs [0017], [0025], [0027], claim 3, and figures 1A, 5-6	1-15,26-27
Y		16-25,28
Y	US 2019-0177846 A1 (LAM RESEARCH CORPORATION) 13 June 2019 (2019-06-13) paragraphs [0033], [0039] and figure 4	16-25,28
A	US 2021-0054506 A1 (TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY LTD.) 25 February 2021 (2021-02-25) paragraphs [0033]-[0037] and figures 2A-2B	1-28
A	WO 2013-070438 A1 (APPLIED MATERIALS, INC.) 16 May 2013 (2013-05-16) page 9, line 17 - page 11, line 10 and figures 3C-3I	1-28
☒ 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 21 April 2025		Date of mailing of the international search report 21 April 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 PARK, Tae Wook Telephone No. +82-42-481-3405

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/060938

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2019-240954 A1 (LAM RESEARCH CORPORATION) 19 December 2019 (2019-12-19) claim 1 and figure 4A	1-28

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2024/060938

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)		Publication date (day/month/year)
US	2012-0108066	A1	03 May 2012	US	8470614 B2	25 June 2013
US	2019-0177846	A1	13 June 2019	CN	111433902 A	17 July 2020
				JP	2021-505766 A	18 February 2021
				JP	2024-160403 A	13 November 2024
				JP	7546483 B2	06 September 2024
				KR	10-2020-0087267 A	20 July 2020
				US	11015247 B2	25 May 2021
				US	12116669 B2	15 October 2024
				US	2021-0269918 A1	02 September 2021
				US	2025-0003074 A1	02 January 2025
				WO	2019-113478 A1	13 June 2019
US	2021-0054506	A1	25 February 2021	CN	112410759 A	26 February 2021
				TW	202109704 A	01 March 2021
				US	11859284 B2	02 January 2024
				US	12215422 B2	04 February 2025
				US	2024-0084450 A1	14 March 2024
WO	2013-070438	A1	16 May 2013	KR	10-2014-0092892 A	24 July 2014
				TW	201324663 A	16 June 2013
				US	2013-0306758 A1	21 November 2013
WO	2019-240954	A1	19 December 2019	CN	112262229 A	22 January 2021
				KR	10-2021-0008562 A	22 January 2021
				TW	202012690 A	01 April 2020
				TW	I850231 B	01 August 2024
				US	2019-0376184 A1	12 December 2019