



(43) International Publication Date
25 September 2014 (25.09.2014)

- (51) International Patent Classification:
H01L 21/66 (2006.01)
- (21) International Application Number:
PCT/US2014/027189
- (22) International Filing Date:
14 March 2014 (14.03.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/787,075 15 March 2013 (15.03.2013) US
- (71) Applicant (for all designated States except US): **APPLIED MATERIALS, INC.** [US/US]; 3050 Bowers Avenue, Santa Clara, California 95054 (US).
- (72) Inventors; and
- (71) Applicants (for US only): **GRIFFIN, Kevin** [US/US]; 2422 Robinson Cir., Livermore, California 94550 (US).
YUDOVSKY, Joseph [US/US]; 594 Smokey Court, Campbell, California 95008 (US).
- (74) Agent: **BLANKMAN, Jeffrey I.**; Servilla Whitney LLC, 33 Wood Avenue South, Second Floor, Suite 210, Iselin, New Jersey 08830 (US).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

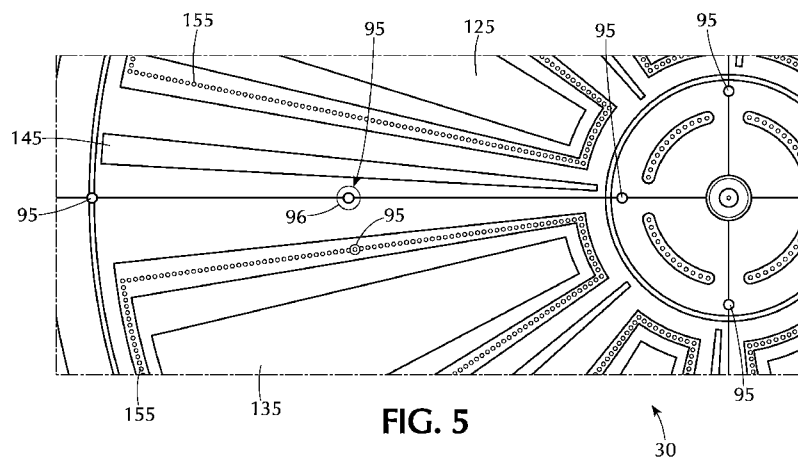
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, 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, 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))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: CAROUSEL GAS DISTRIBUTION ASSEMBLY WITH OPTICAL MEASUREMENTS



(57) Abstract: Described are apparatus and methods for processing a semiconductor wafer in which an optical sensor positioned in the gas distribution assembly measures temperature and/or a film parameter during deposition.

CAROUSEL GAS DISTRIBUTION ASSEMBLY WITH OPTICAL MEASUREMENTS

FIELD

[0001] Embodiments of the invention generally relate to apparatus and methods of processing a substrate. In particular, embodiments of the invention are directed to apparatus and methods measuring temperature and other parameters of substrates during processing.

BACKGROUND

[0002] The process of forming semiconductor devices is commonly conducted in substrate processing platforms containing multiple chambers. In some instances, the purpose of a multi-chamber processing platform or cluster tool is to perform two or more processes on a substrate sequentially in a controlled environment. In other instances, however, a multiple chamber processing platform may only perform a single processing step on substrates; the additional chambers are intended to maximize the rate at which substrates are processed by the platform. In the latter case, the process performed on substrates is typically a batch process, wherein a relatively large number of substrates, e.g. 25 or 50, are processed in a given chamber simultaneously. Batch processing is especially beneficial for processes that are too time-consuming to be performed on individual substrates in an economically viable manner, such as for ALD processes and some chemical vapor deposition (CVD) processes.

[0003] The effectiveness of a substrate processing platform, or system, is often quantified by cost of ownership (COO). The COO, while influenced by many factors, is largely affected by the system footprint, i.e., the total floor space required to operate the system in a fabrication plant, and system throughput, i.e., the number of substrates processed per hour. Footprint typically includes access areas adjacent the system that are required for maintenance. Hence, although a substrate processing platform may be relatively small, if it requires access from all sides for operation and maintenance, the system's effective footprint may still be prohibitively large.

[0004] The semiconductor industry's tolerance for process variability continues to decrease as the size of semiconductor devices shrink. To meet these tighter process requirements, the industry has developed a host of new processes which meet the tighter process window requirements, but these processes often take a longer time to complete. For example, for forming a copper diffusion barrier layer conformally onto the surface of a high aspect ratio, 65 nm or smaller interconnect feature, it may be necessary to use an ALD process. ALD is a variant of CVD that demonstrates superior step coverage compared to CVD. ALD is based upon atomic layer epitaxy (ALE) that was originally employed to fabricate electroluminescent displays. ALD employs chemisorption to deposit a saturated monolayer of reactive precursor molecules on a substrate surface. This is achieved by cyclically alternating the pulsing of appropriate reactive precursors into a deposition chamber. Each injection of a reactive precursor is typically separated by an inert gas purge to provide a new atomic layer to previous deposited layers to form an uniform material layer on the surface of a substrate. Cycles of reactive precursor and inert purge gases are repeated to form the material layer to a desired thickness. The biggest drawback with ALD techniques is that the deposition rate is much lower than typical CVD techniques by at least an order of magnitude. For example, some ALD processes can require a chamber processing time from about 10 to about 200 minutes to deposit a high quality layer on the surface of the substrate. In choosing such ALD and epitaxy processes for better device performance, the cost to fabricate devices in a conventional single substrate processing chamber would increase due to very low substrate processing throughput. Hence, when implementing such processes, a continuous substrate processing approach is needed to be economically feasible.

[0005] Evaluating a deposition process dynamically provides a rapid and accurate means to determining the quality of deposited films and process completion. However, optical measurements of a wafer (e.g., temperature, film characteristics) in a carousel-type processing chamber cannot be performed while processing. Positioning the necessary optical devices in the processing chamber during deposition (e.g., pyrometers) is problematic because the optical instruments become fouled by the deposition reaction, rendering them unsuitable for use.

[0006] Therefore, there is a need in the art for methods and apparatus capable of measuring wafer and process parameters during a spatial atomic layer deposition.

SUMMARY

[0007] Embodiments of the invention are directed to processing chambers comprising a susceptor assembly and a gas distribution assembly. The susceptor assembly includes a top surface to support and rotate a plurality of substrates around a central axis. The top surface has an inner peripheral edge and an outer peripheral edge. The gas distribution assembly is above the susceptor assembly and comprises a plurality of elongate gas ports to direct flows of gases toward the susceptor assembly and at least one optical sensor directed toward the susceptor assembly.

[0008] In some embodiments, the at least one optical sensor is positioned within one of the gas ports.

[0009] In one or more embodiments, the plurality of elongate gas ports include a first reactive gas port, a second reactive gas port, a purge gas port and at least one vacuum port. In some embodiments, the at least one optical sensor is positioned within a purge gas port.

[0010] In some embodiments, the gas distribution assembly further comprises at least one hole located in a region of the gas distribution assembly not exposed to a reactive gas and the at least one optical sensor is positioned within the hole.

[0011] In one or more embodiments, the at least one optical sensor is selected from the group consisting of pyrometers, interferometers and combinations thereof.

[0012] In some embodiments, the at least one optical sensor comprises a pyrometer and is positioned to measure the temperature of the susceptor assembly during processing. In one or more embodiments, there are at least two optical sensors to measure temperature, at least one optical sensor positioned to measure temperature near the inner peripheral edge of the susceptor assembly and at least one optical sensor positioned to measure temperature near the outer peripheral edge of the susceptor assembly.

[0013] In some embodiments, the at least one optical sensor comprises an interferometer and is positioned to record an interferogram from a surface of a substrate.

5 [0014] In one or more embodiments, the top surface of the susceptor assembly comprises at least one recess to support an edge of a wafer. In some embodiments, the at least one recess in the top surface of the susceptor assembly is sized so that a wafer supported in the recess has a top surface substantially coplanar with the top surface of the susceptor assembly.

10 [0015] Some embodiments further comprise a controller in communication with the at least one optical sensor to analyze data from the optical sensor.

15 [0016] Additional embodiments of the invention are directed to methods of processing at least one substrate in a processing chamber. The at least one substrate is positioned in a recess in a top surface of a susceptor assembly, the substrate having a top surface. The substrate and susceptor assembly are passed under a gas distribution assembly comprising a plurality of substantially parallel gas channels directing flows of gases toward the top surface of the substrate to deposit a film on the top surface of the substrate. An optical measurement is taken from an optical sensor positioned at an inert region of the gas distribution assembly.

20 [0017] In some embodiments, the optical sensor comprises a pyrometer and the optical measurement is a temperature measurement. In one or more embodiments, the temperature measurement is taken at one or more of an outer peripheral edge of the susceptor assembly or an inner peripheral edge of the susceptor assembly.

25 [0018] In some embodiments, the optical sensor comprises an interferometer and the optical measurement measures a property of the film. One or more embodiments further comprise evaluating the optical measurement to determine the quality of the film during processing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] So that the manner in which the above recited features of the invention are attained and can be understood in detail, a more particular description of the

invention, briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to
5 other equally effective embodiments.

[0020] FIG. 1 is a partial cross-sectional side view of a spatial atomic layer deposition chamber in accordance with one or more embodiment of the invention;

[0021] FIG. 2 shows a perspective view of a susceptor in accordance with one or more embodiments of the invention;

10 **[0022]** FIG. 3 shows a schematic of a pie-shaped gas distribution assembly in accordance with one or more embodiments of the invention;

[0023] FIG. 4 is a schematic plan view of a substrate processing system configured with four gas distribution assemblies and four inductively coupled pie-shaped plasma sources with a loading station in accordance with one or more embodiments of the
15 invention; and

[0024] FIG. 5 is a front view of a gas distribution plate with optical sensors in accordance with one or more embodiment of the invention;

[0025] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is
20 contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0026] Embodiments of the invention are directed to apparatus and methods for taking optical measurements of a wafer during processing. As used in this
25 specification and the appended claims, the terms “substrate” and “wafer” are used interchangeably, both referring to a surface, or portion of a surface, upon which a process acts. It will also be understood by those skilled in the art that reference to a substrate can also refer to only a portion of the substrate, unless the context clearly indicates otherwise. For example, in spatially separated ALD, described with respect

to FIG. 1, each precursor is delivered to the substrate, but any individual precursor stream, at any given time, is only delivered to a portion of the substrate. Additionally, reference to depositing on a substrate can mean both a bare substrate and a substrate with one or more films or features deposited or formed thereon.

- 5 **[0027]** As used in this specification and the appended claims, the terms “reactive gas”, “precursor”, “reactant”, and the like, are used interchangeably to mean a gas that includes a species which is reactive in an atomic layer deposition process. For example, a first “reactive gas” may simply adsorb onto the surface of a substrate and be available for further chemical reaction with a second reactive gas.
- 10 **[0028]** Embodiments of the invention provide apparatus and methods to take optical measurements during carousel processing. The spatial ALD showerhead has segregated sections within the injector design which are substantially free of reactive gas flows. Therefore, no film can be deposited on an optical instrument positioned in these locations. Due to the segregated sections within the injector design,
- 15 pyrometers, interferometers and related devices can be installed to gain active temperature and film characterization data of the actual process environment. The data can be acquired before, during and/or after the process. The placement of the optical instruments allow for the monitoring of the susceptor or wafer at the inner diameter, middle or outer diameter regions from the top side of the wafer.
- 20 **[0029]** FIG. 1 is a schematic cross-sectional view of a portion of a processing chamber 20 in accordance with one or more embodiments of the invention. The processing chamber 20 is generally a sealable enclosure, which is operated under vacuum, or at least low pressure conditions. The system 100 includes a gas distribution assembly 30 capable of distributing one or more gases across the top
- 25 surface 61 of a substrate 60. The gas distribution assembly 30 can be any suitable assembly known to those skilled in the art, and specific gas distribution assemblies described should not be taken as limiting the scope of the invention. The output face of the gas distribution assembly 30 faces the first surface 61 of the substrate 60.
- 30 **[0030]** Substrates for use with the embodiments of the invention can be any suitable substrate. In some embodiments, the substrate is a rigid, discrete, generally planar substrate. As used in this specification and the appended claims, the term

“discrete” when referring to a substrate means that the substrate has a fixed dimension. The substrate of one or more embodiments is a semiconductor substrate, such as a 200 mm or 300 mm diameter silicon substrate. In some embodiments, the substrate is one or more of silicon, silicon germanium, gallium arsenide, gallium nitride, germanium, gallium phosphide, indium phosphide, sapphire and silicon carbide.

[0031] The gas distribution assembly 30 comprises a plurality of gas ports to transmit one or more gas streams to the substrate 60 and a plurality of vacuum ports disposed between each gas port to transmit the gas streams out of the processing chamber 20. In the embodiment of FIG. 1, the gas distribution assembly 30 comprises a first precursor injector 120, a second precursor injector 130 and a purge gas injector 140. The injectors 120, 130, 140 may be controlled by a system computer (not shown), such as a mainframe, or by a chamber-specific controller, such as a programmable logic controller. The precursor injector 120 injects a continuous (or pulse) stream of a reactive precursor of compound A into the processing chamber 20 through a plurality of gas ports 125. The precursor injector 130 injects a continuous (or pulse) stream of a reactive precursor of compound B into the processing chamber 20 through a plurality of gas ports 135. The purge gas injector 140 injects a continuous (or pulse) stream of a non-reactive or purge gas into the processing chamber 20 through a plurality of gas ports 145. The purge gas removes reactive material and reactive by-products from the processing chamber 20. The purge gas is typically an inert gas, such as, nitrogen, argon and helium. Gas ports 145 are disposed in between gas ports 125 and gas ports 135 so as to separate the precursor of compound A from the precursor of compound B, thereby avoiding cross-contamination between the precursors.

[0032] In another aspect, a remote plasma source (not shown) may be connected to the precursor injector 120 and the precursor injector 130 prior to injecting the precursors into the processing chamber 20. The plasma of reactive species may be generated by applying an electric field to a compound within the remote plasma source. Any power source that is capable of activating the intended compounds may be used. For example, power sources using DC, radio frequency (RF), and microwave (MW) based discharge techniques may be used. If an RF power source is used, it can

be either capacitively or inductively coupled. The activation may also be generated by a thermally based technique, a gas breakdown technique, a high energy light source (e.g., UV energy), or exposure to an x-ray source. Exemplary remote plasma sources are available from vendors such as MKS Instruments, Inc. and Advanced Energy Industries, Inc.

[0033] The system 100 further includes a pumping system 150 connected to the processing chamber 20. The pumping system 150 is generally configured to evacuate the gas streams out of the processing chamber 20 through one or more vacuum ports 155. The vacuum ports 155 are disposed between each gas port so as to evacuate the gas streams out of the processing chamber 20 after the gas streams react with the substrate surface and to further limit cross-contamination between the precursors.

[0034] The system 100 includes a plurality of partitions 160 disposed on the processing chamber 20 between each port. A lower portion of each partition extends close to the first surface 61 of substrate 60, for example, about 0.5 mm or greater from the first surface 61. In this manner, the lower portions of the partitions 160 are separated from the substrate surface by a distance sufficient to allow the gas streams to flow around the lower portions toward the vacuum ports 155 after the gas streams react with the substrate surface. Arrows 198 indicate the direction of the gas streams. Since the partitions 160 operate as a physical barrier to the gas streams, they also limit cross-contamination between the precursors. The arrangement shown is merely illustrative and should not be taken as limiting the scope of the invention. It will be understood by those skilled in the art that the gas distribution system shown is merely one possible distribution system and the other types of showerheads and gas distribution assemblies may be employed.

[0035] Atomic layer deposition systems of this sort (i.e., where multiple gases are separately flowed toward the substrate at the same time) are referred to as spatial ALD. In operation, a substrate 60 is delivered (e.g., by a robot) to the processing chamber 20 and can be placed on a shuttle 65 before or after entry into the processing chamber. The shuttle 65 is moved along the track 70, or some other suitable movement mechanism, through the processing chamber 20, passing beneath (or above) the gas distribution assembly 30. In the embodiment shown in FIG. 1, the

shuttle 65 is moved in a linear path through the chamber. FIG. 3, as explained further below, shows an embodiment in which wafers are moved in a circular path through a carousel processing system.

[0036] Referring back to FIG. 1, as the substrate 60 moves through the processing chamber 20, the first surface 61 of substrate 60 is repeatedly exposed to the reactive gas A coming from gas ports 125 and reactive gas B coming from gas ports 135, with the purge gas coming from gas ports 145 in between. Injection of the purge gas is designed to remove unreacted material from the previous precursor prior to exposing the substrate surface 110 to the next precursor. After each exposure to the various gas streams (e.g., the reactive gases or the purge gas), the gas streams are evacuated through the vacuum ports 155 by the pumping system 150. Since a vacuum port may be disposed on both sides of each gas port, the gas streams are evacuated through the vacuum ports 155 on both sides. Thus, the gas streams flow from the respective gas ports vertically downward toward the first surface 61 of the substrate 60, across the substrate surface 110 and around the lower portions of the partitions 160, and finally upward toward the vacuum ports 155. In this manner, each gas may be uniformly distributed across the substrate surface 110. Arrows 198 indicate the direction of the gas flow. Substrate 60 may also be rotated while being exposed to the various gas streams. Rotation of the substrate may be useful in preventing the formation of strips in the formed layers. Rotation of the substrate can be continuous or in discrete steps and can occur while the substrate is passing beneath the gas distribution assembly 30 or when the substrate is in a region before and/or after the gas distribution assembly 30.

[0037] Sufficient space is generally provided after the gas distribution assembly 30 to ensure complete exposure to the last gas port. Once the substrate 60 has completely passed beneath the gas distribution assembly 30, the first surface 61 has completely been exposed to every gas port in the processing chamber 20. The substrate can then be transported back in the opposite direction or forward. If the substrate 60 moves in the opposite direction, the substrate surface may be exposed again to the reactive gas A, the purge gas, and reactive gas B, in reverse order from the first exposure.

[0038] The extent to which the substrate surface 110 is exposed to each gas may be determined by, for example, the flow rates of each gas coming out of the gas port and the rate of movement of the substrate 60. In one embodiment, the flow rates of each gas are controlled so as not to remove adsorbed precursors from the substrate surface 61. The width between each partition, the number of gas ports disposed on the processing chamber 20, and the number of times the substrate is passed across the gas distribution assembly may also determine the extent to which the substrate surface 61 is exposed to the various gases. Consequently, the quantity and quality of a deposited film may be optimized by varying the above-referenced factors.

[0039] Although description of the process has been made with the gas distribution assembly 30 directing a flow of gas downward toward a substrate positioned below the gas distribution assembly, it will be understood that this orientation can be different. In some embodiments, the gas distribution assembly 30 directs a flow of gas upward toward a substrate surface. As used in this specification and the appended claims, the term "passed across" means that the substrate has been moved from one side of the gas distribution assembly to the other side so that the entire surface of the substrate is exposed to each gas stream from the gas distribution plate. Absent additional description, the term "passed across" does not imply any particular orientation of gas distribution assemblies, gas flows or substrate positions.

[0040] In some embodiments, the shuttle 65 is a susceptor 66 for carrying the substrate 60. Generally, the susceptor 66 is a carrier which helps to form a uniform temperature across the substrate. The susceptor 66 is movable in both directions (left-to-right and right-to-left, relative to the arrangement of FIG. 1) or in a circular direction (relative to FIG. 3). The susceptor 66 has a top surface 67 for carrying the substrate 60. The susceptor 66 may be a heated susceptor so that the substrate 60 may be heated for processing. As an example, the susceptor 66 may be heated by radiant heat lamps 90, a heating plate, resistive coils, or other heating devices, disposed underneath the susceptor 66.

[0041] In still another embodiment, the top surface 67 of the susceptor 66 includes a recess 68 to accept the substrate 60, as shown in FIG. 2. The susceptor 66 is generally thicker than the thickness of the substrate so that there is susceptor material

beneath the substrate. In some embodiments, the recess 68 is sized such that when the substrate 60 is disposed inside the recess 68, the first surface 61 of substrate 60 is level with, or substantially coplanar with, the top surface 67 of the susceptor 66. Stated differently, the recess 68 of some embodiments is sized such that when a substrate 60 is disposed therein, the first surface 61 of the substrate 60 does not protrude above the top surface 67 of the susceptor 66. As used in this specification and the appended claims, the term "substantially coplanar" means that the top surface of the wafer and the top surface of the susceptor assembly are coplanar within ± 0.2 mm. In some embodiments, the top surfaces are coplanar within ± 0.15 mm, ± 0.10 mm or ± 0.05 mm.

[0042] FIG. 1 shows a cross-sectional view of a processing chamber in which the individual gas ports are shown. This embodiment can be either a linear processing system in which the width of the individual gas ports is substantially the same across the entire width of the gas distribution plate, or a pie-shaped segment in which the individual gas ports change width to conform to the pie shape. FIG. 3 shows a portion of a pie-shaped gas distribution assembly 30. A substrate would be passed across this gas distribution assembly 30 in an arc shaped path 32. Each of the individual gas ports 125, 135, 145 and vacuum ports 155 have a narrower width near the inner peripheral edge 33 of the gas distribution assembly 30 and a larger width near the outer peripheral edge 34 of the gas distribution assembly 30. The shape or aspect ratio of the individual ports can be proportional to, or different from, the shape or aspect ratio of the gas distribution assembly 30 segment. In some embodiments, the individual ports are shaped so that each point of a wafer passing across the gas distribution assembly 30 following path 32 would have about the same residence time under each gas port. The path of the substrates can be perpendicular to the gas ports. In some embodiments, each of the gas distribution assemblies comprises a plurality of elongate gas ports which extend in a direction substantially perpendicular to the path traversed by a substrate. As used in this specification and the appended claims, the term "substantially perpendicular" means that the general direction of movement is approximately perpendicular to the axis of the gas ports. For a pie-shaped gas port, the axis of the gas port can be considered to be a line defined as the mid-point of the width of the port extending along the length of the port.

[0043] Processing chambers having multiple gas injectors can be used to process multiple wafers simultaneously so that the wafers experience the same process flow. For example, as shown in FIG. 4, the processing chamber 100 has four gas distribution assemblies 30 (also referred to as injector assemblies) and four wafers 60. At the outset of processing, the wafers 60 can be positioned between the distribution assemblies 30. Rotating the susceptor 66 of the carousel by 45° will result in each wafer 60 being moved to an distribution assembly 30 for film deposition. An additional 45° rotation would move the wafers 60 away from the distribution assemblies 30. With spatial ALD injectors, a film is deposited on the wafer during movement of the wafer relative to the injector assembly. In some embodiments, the susceptor 66 is rotated so that the wafers 60 do not stop beneath the distribution assemblies 30. The number of wafers 60 and gas distribution assemblies 30 can be the same or different. In some embodiments, there are the same number of wafers being processed as there are gas distribution assemblies. In one or more embodiments, the number of wafers being processed are an integer multiple of the number of gas distribution assemblies. For example, if there are four gas distribution assemblies, there are 4X wafers being processed, where X is an integer value greater than or equal to one.

[0044] The processing chamber 100 shown in FIG. 4 is merely representative of one possible configuration and should not be taken as limiting the scope of the invention. Here, the processing chamber 100 includes a plurality of gas distribution assemblies 30. In the embodiment shown, there are four gas distribution assemblies 30 evenly spaced about the processing chamber 100. The processing chamber 100 shown is octagonal, however, it will be understood by those skilled in the art that this is one possible shape and should not be taken as limiting the scope of the invention. The gas distribution assemblies 30 shown are trapezoidal, but it will be understood by those skilled in the art that the gas distribution assemblies can be pie-shaped segments, like that shown in FIG. 3. As used in this specification and the appended claims, the terms “pie-shaped” and “wedge-shaped” are used interchangeably to describe a body that is a generally circular sector. For example, a wedge-shaped segment may be a fraction or portion of a circle or disc-shaped object. In some embodiments, the fraction or portion defines an arc less than 180 degrees, more specifically, less than 135 degrees and most specifically less than 90 degrees. In

particular embodiments, the pie-shaped or wedge-shaped sectors define an arc of 90, 85, 80, 75, 70, 65, 60, 55, 50, 45, 40, 35, 30, 25, 20, or 15 degrees. The inner edge of the pie-shaped segment can terminate at a point or can be truncated to a flat edge or rounded. Similarly, the outer edge of the pie-shaped segment can be straight or curved.

[0045] The processing chamber 100 includes a substrate support apparatus, shown as a round susceptor 66 or susceptor assembly. The substrate support apparatus, or susceptor 66, is capable of moving a plurality of substrates 60 beneath each of the gas distribution assemblies 30. A load lock 82 might be connected to a side of the processing chamber 100 to allow the substrates 60 to be loaded/unloaded from the chamber 100.

[0046] In some embodiments, the processing chamber comprises a plurality of gas curtains (not shown) positioned between the gas distribution plates 30 and the plasma stations 80. Each gas curtain can create a barrier to prevent, or minimize, the movement of processing gases from the gas distribution assemblies 30 from migrating from the gas distribution assembly regions and gases from the plasma sources 80 from migrating from the plasma regions. The gas curtain can include any suitable combination of gas and vacuum streams which can isolate the individual processing sections from the adjacent sections. In some embodiments, the gas curtain is a purge (or inert) gas stream. In one or more embodiments, the gas curtain is a vacuum stream that removes gases from the processing chamber. In some embodiments, the gas curtain is a combination of purge gas and vacuum streams so that there are, in order, a purge gas stream, a vacuum stream and a purge gas stream. In one or more embodiments, the gas curtain is a combination of vacuum streams and purge gas streams so that there are, in order, a vacuum stream, a purge gas stream and a vacuum stream.

[0047] During processing, it may be desirable to monitor the temperature of the susceptor assembly and/or wafers or monitor a specific property of the film being deposited. For example, measuring the emissivity of the film during formation. Embodiments of the invention have an optical sensor on or in the gas distribution

assembly which can directly measure these, and a number of other, parameters during processing.

[0048] Accordingly, one or more embodiment of the invention is directed to a processing chamber comprising a susceptor assembly 66 and a gas distribution assembly 30. The susceptor assembly 66 includes a top surface 67 to support and rotate a plurality of substrates 60 around 17 a central axis 18. The top surface 67 of the susceptor assembly 66 has an inner peripheral edge 90 and an outer peripheral edge 91. The gas distribution assembly 30 is positioned above the susceptor assembly 66. As shown in FIG. 5, the gas distribution assembly 30 comprises a plurality of elongate gas ports 125, 135, 145 to direct flows of gases toward the susceptor assembly 66 and vacuum ports 155 to direct flows of gases out of the processing chamber. The gas distribution assembly 30 also includes at least one optical sensor 95 directed toward the susceptor assembly 66.

[0049] The optical sensors 95 shown in FIG. 5 are located between a vacuum port 155 and a purge port 145. In this region, in theory, only purge gases might come into contact with the optical sensor 95. In some embodiments, the optical sensor 95 is located within a purge gas port 145. In this position, in theory, only purge gases can flow past the sensor 95 and may keep a steady flow of inert gas around the sensor 95. The optical sensors 95 are positioned to measure points near the inner peripheral edge and the outer peripheral edge of the susceptor assembly as well as a middle region which could be susceptor assembly or wafer, depending on when the measurement is taken.

[0050] The optical sensor 95 can be positioned directly on the surface of the gas distribution plate 30 or in a recess or hole 96 in the gas distribution plate. The hole 96 can be any suitable size depending on the size of the optical sensor 95. In some embodiments, the hole 96 is up to about 10 mm in diameter.

[0051] The optical sensor can be any suitable sensor for measuring an optical property of the substrate, film or susceptor assembly. Non-limiting examples of optical sensors include pyrometers and interferometers. The system can use a combination of more than one type of optical sensor to allow measurement of multiple parameters simultaneously.

[0052] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It will be apparent to those skilled in the art that various modifications and variations can be made to the method and apparatus of the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention include modifications and variations that are within the scope of the appended claims and their equivalents.

What is claimed is:

1. A processing chamber comprising:

5 a susceptor assembly including a top surface to support and rotate a plurality of substrates around a central axis, the top surface having an inner peripheral edge and an outer peripheral edge; and

a gas distribution assembly above the susceptor assembly, the gas distribution assembly comprising a plurality of elongate gas ports to direct flows of gases toward the susceptor assembly and at least one optical sensor directed toward the susceptor assembly.

- 10 2. The processing chamber of claim 1, wherein the at least one optical sensor is positioned within one of the gas ports.

- 15 3. The processing chamber of claim 1, wherein the plurality of elongate gas ports include a first reactive gas port, a second reactive gas port, a purge gas port and at least one vacuum port.

- 20 4. The processing chamber of claim 3, wherein the at least one optical sensor is positioned within a purge gas port.

- 25 5. The processing chamber of any of claims 1 to 4, wherein the gas distribution assembly further comprises at least one hole located in a region of the gas distribution assembly not exposed to a reactive gas and the at least one optical sensor is positioned within the hole.

6. The processing chamber of any of claims 1 to 4, wherein the at least one optical sensor is selected from the group consisting of pyrometers, interferometers and combinations thereof.

7. The processing chamber of any of claims 1 to 4, wherein the at least one optical sensor comprises a pyrometer and is positioned to measure the temperature of the susceptor assembly during processing.
- 5 8. The processing chamber of claim 7, wherein there are at least two optical sensors to measure temperature, at least one optical sensor positioned to measure temperature near the inner peripheral edge of the susceptor assembly and at least one optical sensor positioned to measure temperature near the outer peripheral edge of the susceptor assembly.
- 10 9. The processing chamber of any of claims 1 to 4, wherein the at least one optical sensor comprises an interferometer and is positioned to record an interferogram from a surface of a substrate.
- 15 10. The processing chamber of any of claims 1 to 4, further comprising a controller in communication with the at least one optical sensor to analyze data from the optical sensor.
- 20 11. A method of processing at least one substrate in a processing chamber, the method comprising:
positioning the at least one substrate in a recess in a top surface of a susceptor assembly, the substrate having a top surface;
passing the substrate and susceptor assembly under a gas distribution assembly comprising a plurality of substantially parallel gas channels directing
25 flows of gases toward the top surface of the substrate to deposit a film on the top surface of the substrate; and
taking an optical measurement from an optical sensor positioned at an inert region of the gas distribution assembly.
- 30 12. The method of claim 11, wherein the optical sensor comprises a pyrometer and the optical measurement is a temperature measurement.

13. The method of claim 12, wherein the temperature measurement is taken at one or more of an outer peripheral edge of the susceptor assembly or an inner peripheral edge of the susceptor assembly.

5

14. The method of claim 11, wherein the optical sensor comprises an interferometer and the optical measurement measures a property of the film.

15. The method of claim 14, further comprising evaluating the optical measurement to determine the quality of the film during processing.

10

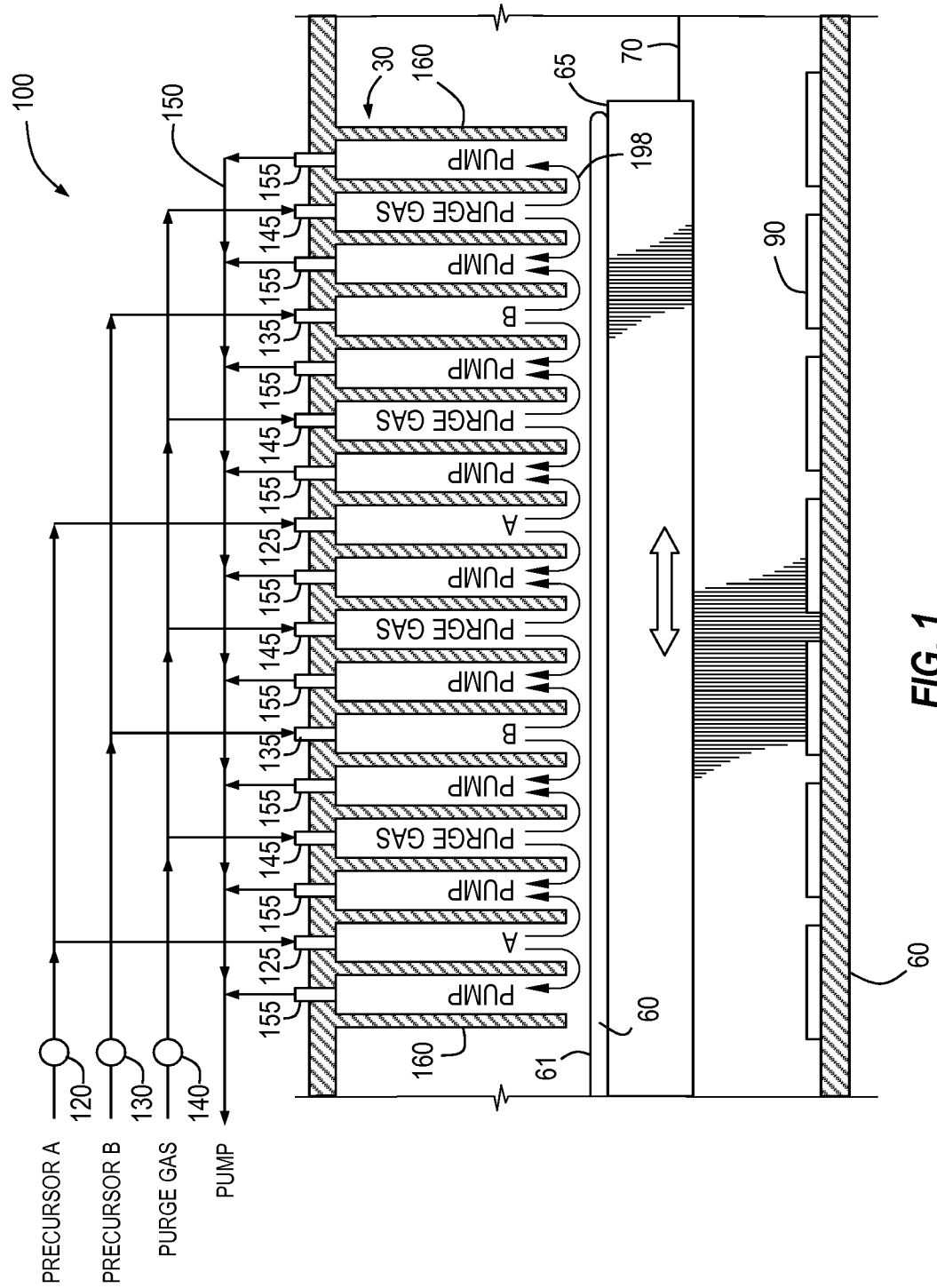


FIG. 1

2/4

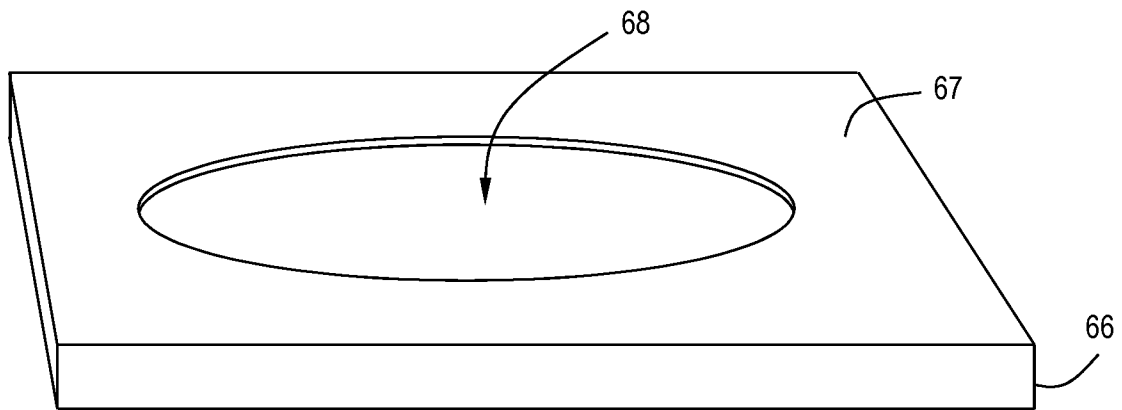


FIG. 2

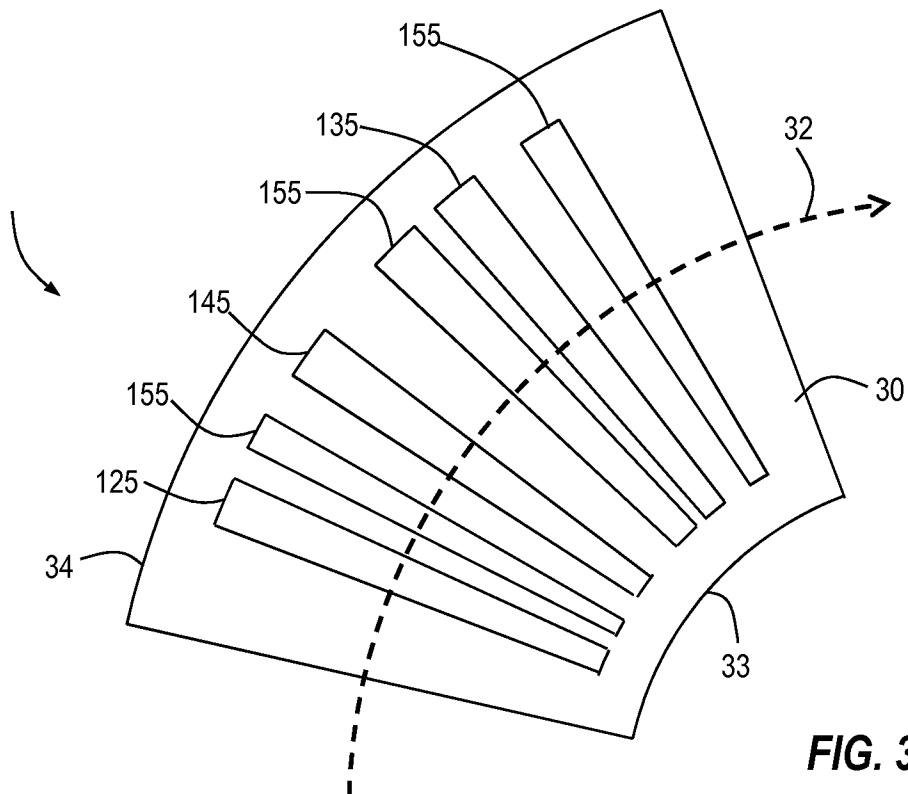
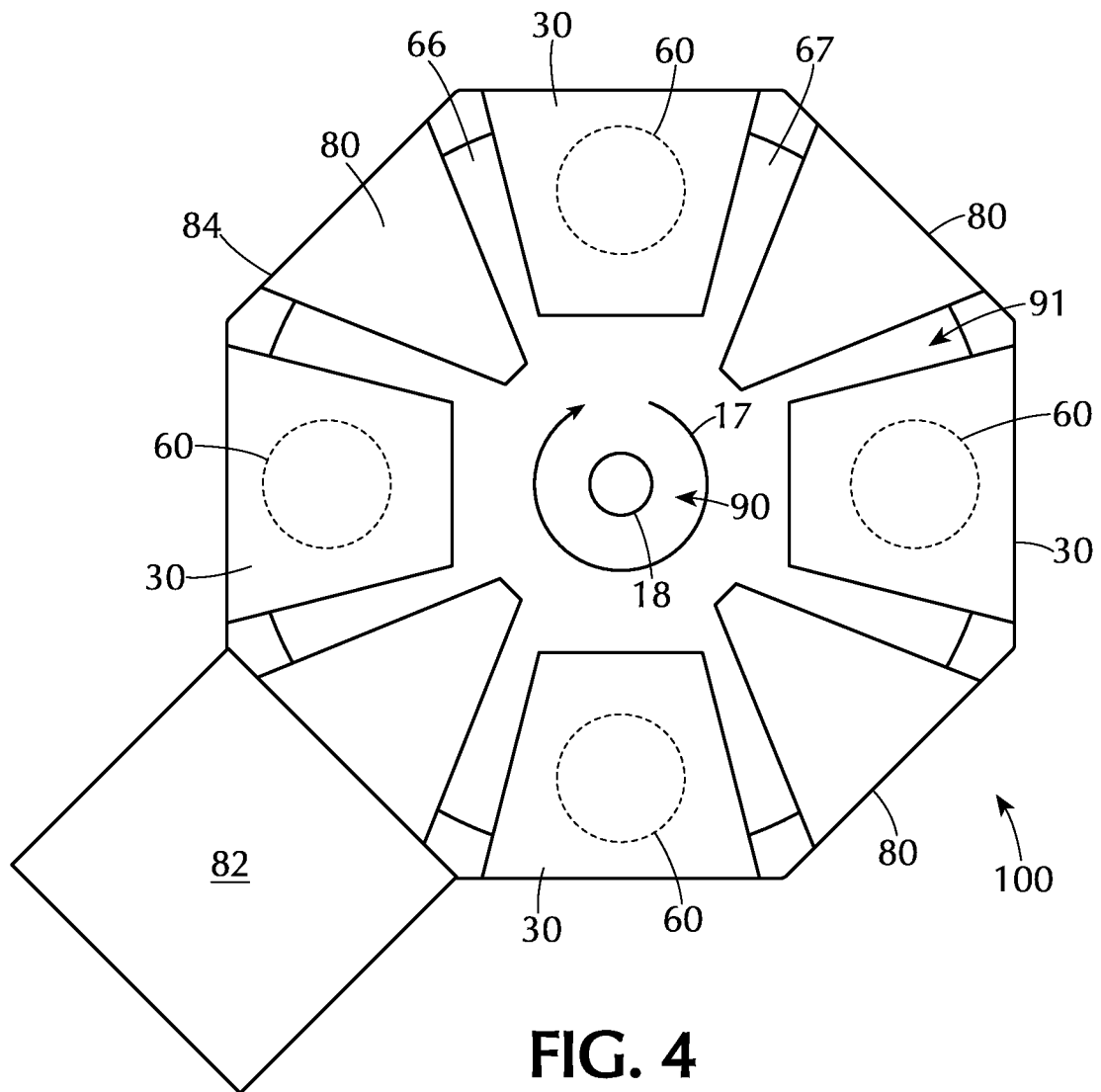
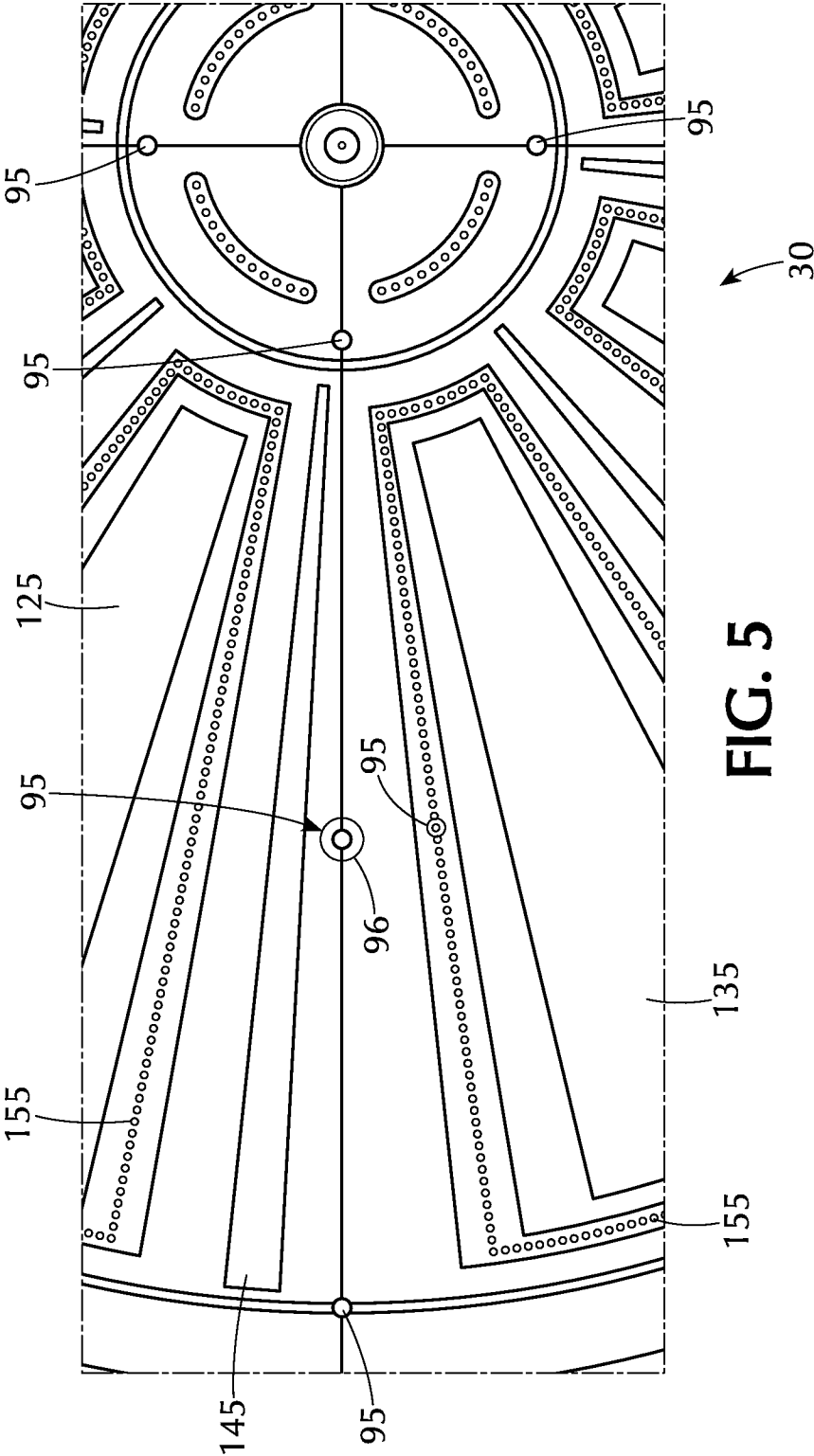


FIG. 3





A. CLASSIFICATION OF SUBJECT MATTER**H01L 21/66(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)

H01L 21/66; B05D 5/12; C23C 16/52; H01L 21/311; C23C 16/54; F27D 19/00; H01L 21/02; C23C 16/455; H01L 21/683; C23C 16/00

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: ALD, optical sensor, pyrometer, susceptor, gas distribution, interferometer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2012-0225191 A1 (JOSEPH YUDOVSKY et al.) 06 September 2012	1,3,6-15
A	See paragraphs [0033]-[0052], claims 1, 4, 17 and figures 1-4A.	2,4-5
Y	US 2012-0216747 A1 (SUNG JAE HONG) 30 August 2012	1,3,6-15
A	See abstract, paragraphs [0010], [0014], [0040]-[0044], claim 1 and figure 1.	2,4-5
A	EP 2360293 A1 (NEDERLANDSE ORGANISATIE VOOR TOEGEPAST-NATUURWETENSCHAPPELIJK ONDERZOEK TNO) 24 August 2011	1-15
	See paragraphs [0072]-[0083], claim 1 and figures 2A-4.	
A	US 2009-0081885 A1 (DAVID H. LEVY et al.) 26 March 2009	1-15
	See abstract, paragraphs [0170]-[0173] and figures 15-18.	
A	KR 10-2006-0106736 A (TOKYO ELECTRON LTD.) 12 October 2006	1-15
	See abstract, pages 7-11 and figure 1.	



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

"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

28 July 2014 (28.07.2014)

Date of mailing of the international search report

29 July 2014 (29.07.2014)

Name and mailing address of the ISA/KR

International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

CHOI, Sang Won

Telephone No. +82-42-481-8291



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/027189

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2012-0225191 A1	06/09/2012	CN 103415912 A JP 2014-508224 A KR 10-2014-0009415 A TW 201239133 A US 2012-0225192 A1 WO 2012-118946 A2 WO 2012-118946 A3	27/11/2013 03/04/2014 22/01/2014 01/10/2012 06/09/2012 07/09/2012 29/11/2012
US 2012-0216747 A1	30/08/2012	CN 102640260 A EP 2498277 A1 EP 2498277 A4 KR 10-1383283 B1 KR 10-2012-0062921 A KR 10-2013-0140920 A WO 2011-052832 A1	15/08/2012 12/09/2012 20/03/2013 08/04/2014 14/06/2012 24/12/2013 05/05/2011
EP 2360293 A1	24/08/2011	CN 102822384 A EP 2534278 A1 KR 10-2012-0120399 A TW 201137164 A US 2013-0064977 A1 WO 2011-099858 A1	12/12/2012 19/12/2012 01/11/2012 01/11/2011 14/03/2013 18/08/2011
US 2009-0081885 A1	26/03/2009	CN 101809193 A EP 2191037 A1 JP 2010-541236 A TW 200934886 A US 8398770 B2 WO 2009-042044 A1	18/08/2010 02/06/2010 24/12/2010 16/08/2009 19/03/2013 02/04/2009
KR 10-2006-0106736 A	12/10/2006	JP 2006-286733 A JP 4551256 B2 TW 200703489 A US 2006-0219360 A1 US 2010-0224355 A1 US 7789962 B2 US 8182869 B2	19/10/2006 22/09/2010 16/01/2007 05/10/2006 09/09/2010 07/09/2010 22/05/2012