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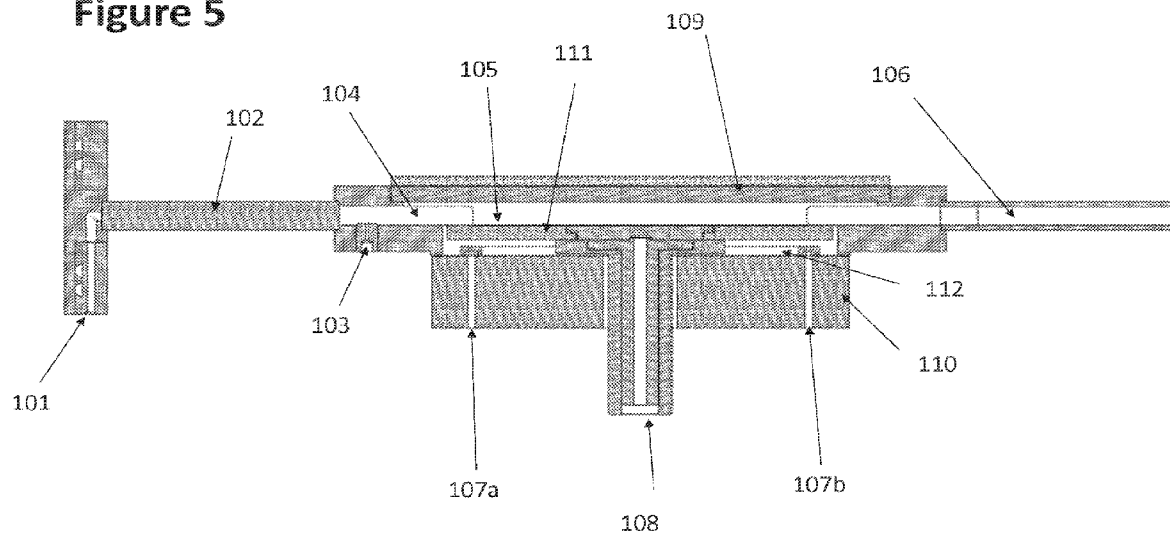
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(54) Title: UNIFORM SILICON CARBIDE EPITAXIAL LAYER DEPOSITION SYSTEM UTILIZING FLUID PREHEATING

Figure 5



(57) Abstract: A system for chemical vapor deposition, the system includes a process chamber having a top plate; a rotating chuck within the process chamber configured to support a growth substrate; a carrier gas inlet configured to direct a carrier gas flow to a preheat zone, the preheat zone configured to heat the carrier gas to a desired process temperature; a precursor gas inlet configured to direct precursor gas into contact with heated carrier gas to provide a heated mixture of carrier gas and precursor gas, the heated mixture of carrier gas and precursor gas being directed by the carrier gas flow across a top of the rotating chuck; and a purge port under the rotating chuck to purge gasses from the process chamber. Methods for depositing a coating on a rotating substrate include pre-heating a carrier gas; mixing an unheated precursor gas with the pre-heated carrier gas to provide a reactive gas mixture; directing the reactive gas mixture across the rotating substrate positioned on a rotating chuck; and purging gasses through a purge port positioned under the rotating chuck.

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- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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UNIFORM SILICON CARBIDE EPITAXIAL LAYER DEPOSITION SYSTEM UTILIZING FLUID PREHEATING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of, and priority to, U.S. Provisional Patent Application No. 63/590,504 filed on October 16, 2023, the entire contents of which is hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure generally relates to chemical vapor deposition (CVD) systems. More specifically, the present disclosure relates to epitaxial deposition of silicon carbide (SiC).

BACKGROUND

[0003] Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted as being prior art by inclusion in this section.

[0004] Chemical vapor deposition systems are used to deposit a coating upon a substrate (e.g., a wafer). The substrate may be supported by a rotating wafer chuck. In high temperature CVD, e.g., when the deposition temperature is above 1400°C, a hot wall reactor configuration is frequently used. In a hot wall reactor, precursor reactants are typically preheated via thermal exchange with hot surfaces. This frequently leads to unwanted parasitic deposition, particulate generation due to nucleation in a gas phase, precursor depletion, and the potential for clogging of the preheat zone. It also usually leads to a higher maintenance burden on the preheat zone, where parasitic deposits periodically need to be removed from preheat zone surfaces, lining the preheat zone with a deposition shield that is removed periodically, or simply accepting that the preheat zone baffles are consumable parts that periodically require replacement. Precursor depletion onto hot solid surfaces is undesirable, not only for increased maintenance burden and consumables cost, but also because this leads to higher cost of operation due to the increased amount of wasted precursor reactant gases and vapors.

[0005] Previous precursor preheating methods primarily focus on heating precursor reactant gases and vapors that are premixed with their carrier gases, for example as disclosed in U.S. Patent No. 7,976,634. In other prior systems, (see, e.g., U.S. Patent Application Publication No.

2002/0188376), preheating of precursor gases/vapors occurs in a separate ancillary system where the precursors and carrier gas are again already premixed. Vertical reactor systems that utilize a multi zone showerhead to provide gas injection profiles intended to improve process uniformity in chemical vapor deposition systems are disclosed in U.S. Patent No. 8,551,248.

[0006] Despite these attempts by the prior art, there remains room for improvement in the design of chemical vapor deposition (CVD) systems, such as systems for epitaxial deposition of SiC.

SUMMARY

[0007] This disclosure relates to a design for the separate injection of a preheated carrier gas (e.g., hydrogen) and unheated precursor reactant gases into a CVD reactor (e.g., a silicon carbide epitaxial reactor), as well as the uniform deposition of coatings (e.g., epitaxial silicon carbide layers) on a rotating substrate (e.g., a wafer). The precursor reactant gases are mixed with the hot carrier gas stream in order to heat the precursor reactant gases via the fluid mixing without the need for hot surfaces to preheat those reactant gases. By preheating in the gas stream, the precursor reactant gases and vapors can form desirable intermediate species, (e.g., Si_2C and SiC_2 in silicon carbide deposition systems) with reduced nucleation in the gas phase and depletion on hot surfaces. The wafer substrate and preheated hydrogen can be heated to process temperature (typically in the range of 1600°C to 1800°C) to generate a true hot wall environment that promotes uniform low defect density and low polytype inclusion crystal layer growth. Moreover, by preheating only the carrier gas in the preheat zone of the reactor, the preheat zone remains substantially free of parasitic deposition and reduces the need for maintenance of the preheat zone as well as zero particulate generation from the preheat zone. By avoiding or substantially reducing parasitic deposition in the preheat zone, the precursor efficiency is increased and therefore the cost of operation of the system is reduced. This disclosure also presents precursor injection strategies that improve deposition uniformity while maintaining high gas velocities in the injectors. High velocities are desirable to maintain a low temperature in the injection holes and avoid clogging of the injectors.

[0008] According to one aspect of the present disclosure, a system for chemical vapor deposition is described. The system includes a process chamber having a top plate and a rotating chuck within the process chamber configured to support a growth substrate. A carrier gas inlet is configured to direct a carrier gas flow to a preheat zone, where the preheat zone is configured to

heat the carrier gas to a desired process temperature. A precursor gas inlet is configured to direct precursor gas into contact with heated carrier gas to provide a heated mixture of carrier gas and precursor gas. The heated mixture of carrier gas and precursor gas is directed by the carrier gas flow across a top of the rotating chuck. The system also includes a purge port under the rotating chuck to purge gasses from the process chamber.

[0009] In aspects, the carrier gas inlet includes a plurality of inlet ports directing carrier gas to a heat exchanger in the preheat zone. In aspects each inlet port of the plurality of inlet ports directs carrier gas to a serpentine path in the heat exchanger.

[0010] In aspects, the precursor gas inlet includes an injector manifold including a plurality of precursor gas inlet holes. In aspects, a first pair of gas inlet holes of the plurality of precursor gas inlet holes are positioned a first distance apart and a second pair of gas inlet holes of the plurality of precursor gas inlet holes are positioned a second distance apart, the first distance being greater than the second distance. In yet other aspects, the first distance is twice the second distance. In aspects, the precursor gases are injected into the injector manifold from a location below the preheat zone. In aspects, the carrier gas inlet directs a carrier gas flow including hydrogen to the preheat zone. In aspects, the precursor gas inlet directs a precursor gas composition suitable for epitaxial deposition of silicon carbide on the growth substrate into contact with heated carrier gas.

[0011] In aspects, the growth substrate is a wafer. In other aspects, the rotating check is a composite chuck including an inner part configured to support the growth substrate and an outer part including a recess dimensioned and configured to receive the inner part. In aspects, the system further includes a heating coil located above a reactor ceiling of the process chamber to inductively heat the growth substrate positioned upon the rotating chuck. In aspects, the heating coil includes a two piece susceptor. In aspects, the process chamber includes reactor walls heated by resistive heaters or inductive coupling positioned externally of the process chamber.

[0012] According to another aspect of the present disclosure, a method of depositing a coating on a rotating substrate is described. The method includes pre-heating a carrier gas and mixing an unheated precursor gas with the pre-heated carrier gas to provide a reactive gas mixture. The method further includes directing the reactive gas mixture across the rotating substrate positioned on a rotating chuck and purging gasses through a purge port positioned under the rotating chuck.

[0013] In aspects, pre-heating the carrier gas includes introducing carrier gas through a plurality of inlet ports into a heat exchanger. In aspects, introducing carrier gas into the heat exchanger includes introducing carrier gas from each inlet port of the plurality of inlet ports into a serpentine path in the heat exchanger. In aspects, mixing the unheated precursor gas with the pre-heated carrier gas includes introducing precursor gas through an injector manifold including a plurality of precursor gas inlet holes. In aspects, the precursor gases are injected into the injector manifold from a location below the heat exchanger. In aspects, mixing the unheated precursor gas with the pre-heated carrier gas includes mixing hydrogen as the carrier gas and a composition suitable for epitaxial deposition of silicon carbide on the substrate as the precursor gas, and directing the reactive gas mixture across the rotating substrate includes directing the reactive gas mixture across a wafer.

BRIEF DESCRIPTION OF THE FIGURES

[0014] Features of the present disclosure will become more fully apparent from the following description, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings, in which:

[0015] Fig. 1 shows an illustrative system for chemical vapor deposition that may incorporate various aspects of the presently disclosed features;

[0016] Fig. 2 shows the process chamber of the system of Fig. 1 with the cover removed to show internal structures thereof;

[0017] Fig. 3 schematically illustrates a side cross sectional view of a composite rotating wafer chuck having a wafer loaded thereon for exposure to a CVD process in accordance with aspects of the present disclosure;

[0018] Fig. 4 schematically illustrates a side cross sectional view of a CVD reactor with a single wafer heating coil located above the process chamber top plate and incorporating a composite rotating wafer chuck having a wafer loaded thereon for exposure to a CVD process in accordance with aspects of the present disclosure;

[0019] Fig. 5 shows a cross section of a reactor that utilizes separate injection of a preheated carrier gas and unheated precursor reactant gases in accordance with aspects of the present disclosure;

[0020] Fig. 6 shows a top down section view of a reactor in accordance with aspects of the present disclosure;

[0021] Fig. 7 shows numerical simulation thermal modelling results from a top down section view of the reactor of Fig. 4;

[0022] Fig. 8A shows numerical simulation flow modelling of the precursor mass fraction in the reactor of Fig. 4; and

[0023] Fig. 8B shows a radial plot of the precursor mole fraction from center to edge of the substrate.

DETAILED DESCRIPTION

[0024] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well as the singular forms, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof.

[0025] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one having ordinary skill in the art to which this disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0026] In describing the present disclosure, it will be understood that a number of systems, methodologies, techniques, and steps are disclosed. Each of these has individual benefit and each

can also be used in conjunction with one or more, or in some cases all, of the other disclosed techniques. Accordingly, for the sake of clarity, this description will refrain from repeating every possible combination of the individual steps in an unnecessary fashion.

[0027] Nevertheless, the specification should be read with the understanding that such combinations are entirely within the scope of the disclosure.

[0028] Turning now to Fig. 1, an illustrative system 100 for chemical vapor deposition includes a wafer transport unit 10, a cassette housing 20, a process chamber 30 and a process module 60. Wafer transport unit 10 includes a robotic arm (not shown) and suitable motors (not shown) and controls (not shown) for movement of the robotic arm to allow wafer transport unit 10 to retrieve a wafer 50 from cassette 22 in cassette housing 20, and deliver wafer 50 to process chamber 30. Process module 60 includes heating and cooling systems, gases for CVD deposition processes, one or more plasma generators, a vacuum system, exhaust structures, etc. typically found in CVD systems. The one or more plasma generators may generate one or more of: DC plasma, pulsed DC plasma, RF plasma, pulsed RF plasma, intermediate frequency (IF) plasma, pulsed IF plasma, mixed DC and RF plasma, mixed DC and IF plasma, mixed IF and RF plasma, mixed DC and RF and IF plasma, microwave plasma, or microwave plasma mixed with one or more of DC, RF, or IF plasma. In embodiments, a “pulsed DC” source may be employed to create plasma with constant electric field orientation with optional on/off cycling (unlike RF plasma, where polarity is switching during one oscillation period). Process module 60 also includes controller(s) to control the various functions of the CVD system.

[0029] As seen in Fig. 2, process chamber 30 includes a flange 32 including an opening 33 through which wafer 50 is introduced by wafer transport unit 10 into process chamber 30. A valve (not shown) seals process chamber 30 after introduction of wafer 50 as is known to those skilled in the art. A showerhead 300 is mounted to process chamber 30. Sensors 35a, 35b and 35c are mounted through showerhead 300 to detect the temperature of the wafer 50. In embodiments, sensors 35a-c are optical pyrometers that can sense a temperature of wafer 50 as it rotates, without requiring direct contact with wafer 50. A gas inlet port 37 is also provided to permit introduction of process gas (e.g., premixed gases required for CVD deposition of a film onto a substrate) into process chamber 30. Process chamber 30 also includes a view port 39 and a port (not shown) to remove exhaust gases from process chamber 30.

[0030] Fig. 3 shows a cross section drawing of a composite wafer chuck 40 including outer support part 41, inner support part 42 and rotation shafts 43 and 44. Rotation shaft 43 is connected to the outer support part 41 to enable wafer rotation, and rotation shaft 44 is connected to the inner support part 42 to enable lifting the inner support part in the unload position. Rotation shaft 43 is also coupled to a bottom plate 45 of a CVD reactor by a flexible bellows 46 or other vacuum connection to allow for vertical motion. Systems including a composite wafer chuck are suitable for supporting a wafer 50 for exposure to a CVD process in accordance with aspects of the present disclosure.

[0031] Fig. 4 shows a CVD reactor a cross section view of a prior art horizontal cross-flow epitaxial reactor geometry where a wafer is resting on a chuck, or susceptor, that is inductively heated from below by a flat “pancake” induction coil 21. A chuck with a wafer can be rotated during the deposition process for improved uniformity. A hot wall reactor enclosure can be made of graphite walls 221 and 223 and ceiling 222. For thermal insulation, the reactor enclosure may be surrounded by thermally insulating material 231, 232 and 233 made, for example, from graphite foam or, for example, graphite felt. A gas inlet port 24 provides delivery of the precursor species for reaction, port 103 provides delivery of unheated precursor reactant gases, and an exhaust port 25 provides exhaust of any unreacted precursor and byproduct gases. Multiple zone heaters such as those previously disclosed in International Patent Application Publication PCT/US22/50351 are also contemplated.

[0032] Fig. 5 shows a cross section of a reactor in accordance with aspects of the present disclosure. Carrier gas introduced via carrier gas inlet 101 is heated in preheat zone 102 to the desired process temperature by any suitable heating method such as, for example, resistive heating, infrared lamp heating, RF induction heating, or the like. Precursor gases and vapors are introduced into the unheated injectors 103 and are heated by the hot fluid carrier gas in zone 104 up to the desired process temperature prior to impinging on the growth substrate, e.g., wafer 105. Gases exit through exhaust 106. The wafer sits on a heated susceptor 111 which is a two-piece construction coupled to a coaxial rotation shaft 108 (as described above in connection with Fig. 3, although other configurations of composite wafer chucks are also contemplated). The volume beneath the susceptor is purged through ports 107a,b penetrating through reactor bottom insulation 110 and plenum 112 to avoid parasitic deposition in this volume. Susceptor 111 can be

inductively heated by a single or multiple induction coils located above composite reactor ceiling 109 that does not inductively couple to such coils.

[0033] Fig. 6 shows shows a top down section view of a reactor in accordance with aspects of the present disclosure. Separate inject ports 201a-e are provided for the carrier gas, allowing for adjustment of the flow from the center to the edge of the reactor. The carrier gas enters 201a-e from underneath in this illustrative reactor. Carrier gas then enters heat exchanger 202 which is heated to a temperature that promotes heating of the carrier gas to the desired process temperature prior to exiting preheat heat exchanger 202. Briefly, the carrier gas enters multiple serpentine paths to increase contact with hot surfaces in the heat exchanger and promote efficient heating of the carrier gas. It should be understood that Fig. 6 shows an example of heat exchanger 202 geometry and that the design of the heat exchanger may be optimized for a specific carrier gas, a desired range of gas flow rates, and a desired temperature of the carrier gas at the output of heat exchanger. Precursor gases and vapors are injected into an injector manifold 203 from below, and enter the reactor via a number of holes of predetermined cross sectional area in order to define the gas velocity in the injectors. As shown, there are seven (7) injectors labelled 203a-g, although fewer or more injectors may be employed. The distance from a to c is twice the distance from a to b, with the remaining injectors evenly spaced. This forms, under wafer rotation, an effectively close-packed pattern that is shown through numerical simulation to achieve a high degree of uniformity in precursor mole fraction and hence deposition rate across the rotating wafer. As the precursor gases and vapors are injected into the reactor, they mix with the preheated carrier gas and are drawn into the carrier gas flow, and towards the wafer 206. The precursors are shown by numerical simulation to reach process temperature over a short distance 204 between injectors 203a-g and wafer 206. Where the heated susceptor 205 is exposed around the edge of the wafer, a deposition liner may be used to shield the susceptor surface from buildup of parasitic deposits. The wafer 206 is heated by a two piece susceptor as well as by heated reactor walls 207a,b which, in turn, are heated externally by resistive heaters or inductive coupling from dedicated coils (such as the heating coils described above in connection Figure 4, although other configurations of heating coils are also contemplated). Gases exit through the exhaust 208.

[0034] Fig. 7 shows numerical simulation thermal modelling results from a top down section view of the reactor. Nearly uniform hydrogen carrier gas at a temperature of 1650°C enters the volume from the left 301. As the preheated hydrogen mixes with the cool precursor gases and

vapors, the gas mixture drops in temperature in zone 302 as expected, and quickly rises again in zone 303 to the desired process temperature before reaching the leading edge of the wafer.

[0035] Fig. 8A shows numerical simulation flow modelling of the precursor mass fraction, in this case trichlorosilane (TCS). The precursor mole fraction map 401 over the wafer surface under rotation is shown. In Fig. 8B, 402 is a radial plot of the precursor mole fraction from center to edge of the substrate, in this case a 200 mm wafer. It should be understood that further optimization may be achieved by adjusting the flow rates and injector hole patterns in accordance with aspects of the present disclosure.

[0036] While epitaxial deposition of silicon carbide (SiC) has been disclosed, it is contemplated that systems in accordance with the present disclosure may be utilized in many different applications where CVD is used to apply material (e.g., coating layers) on a rotating substrate. The system may be especially suitable to “flat” rotating surfaces found in cluster tool (and non-cluster) process chambers for metal organic chemical vapor deposition (MOCVD), atomic layer deposition (ALD), low pressure chemical vapor deposition (LPCVD), physical vapor deposition (PVD), annealing, heat treating, plasma etching and other similar processes. The described techniques may also be applicable to larger, non-planar processed parts, when rotary motion is involved.

[0037] It is further contemplated that while epitaxial deposition of silicon carbide (SiC) has been disclosed, other material systems may benefit from reactor geometries in accordance with the present disclosure, for example aluminum nitride (AlN), aluminum gallium nitride (AlGaN), aluminum scandium nitride (AlScN), boron nitride (BN), boron-doped aluminum nitride (BAIN) and other material systems requiring high ($>1400^{\circ}\text{C}$) deposition temperatures. Similarly, the use of chlorine or HCl based precursors to form chloride adatoms at the growth surface may benefit from higher material quality of AlN, AlGaN, AlScN, BN, BAIN and other materials by suppressing gas phase nucleation and pre-reactions and, thus, enabling use of higher deposition temperature.

[0038] Also, while described in terms of depositing a coating on a wafer, it should be understood that the present systems may be used to provide deposition of material on any suitable substrate.

[0039] The systems described herein may utilize one or more controllers to receive various information and transform the received information to generate an output. The controller may include any type of computing device, computational circuit, or any type of processor or

processing circuit capable of executing a series of instructions that are stored in a memory. The controller may include multiple processors and/or multicore central processing units (CPUs) and may include any type of processor, such as a microprocessor, digital signal processor, microcontroller, programmable logic controller (PLC), field programmable gate array (FPGA), or the like. The controller may also include a memory to store data and/or instructions that, when executed by the one or more processors, causes the one or more processors to perform one or more methods and/or algorithms.

[0040] Any of the herein described methods, programs, algorithms or codes may be converted to, or expressed in, a programming language or computer program. The terms “programming language” and “computer program,” as used herein, each include any language used to specify instructions to a computer, and include (but is not limited to) the following languages and their derivatives: Assembler, Basic, Batch files, BCPL, C, C+, C++, Ladder Logic, Delphi, Fortran, Java, JavaScript, machine code, operating system command languages, Pascal, Perl, PL1, scripting languages, Visual Basic, metalanguages which themselves specify programs, and all first, second, third, fourth, fifth, or further generation computer languages. Also included are database and other data schemas, and any other meta-languages. No distinction is made between languages which are interpreted, compiled, or use both compiled and interpreted approaches. No distinction is made between compiled and source versions of a program. Thus, reference to a program, where the programming language could exist in more than one state (such as source, compiled, object, or linked) is a reference to any and all such states. Reference to a program may encompass the actual instructions and/or the intent of those instructions.

[0041] The storage and/or memory device may be one or more physical apparatus used to store data or programs on a temporary or permanent basis. In some embodiments, the controller may include volatile memory and requires power to maintain stored information. In some embodiments, the controller includes non-volatile memory and retains stored information when it is not powered. In some embodiments, the non-volatile memory includes flash memory. In some embodiments, the non-volatile memory includes dynamic random-access memory (DRAM). In some embodiments, the non-volatile memory includes ferroelectric random access memory (FRAM). In some embodiments, the nonvolatile memory includes phase-change random access memory (PRAM). In some embodiments, the controller is a storage device including, by way of non-limiting examples, CD-ROMs, DVDs, flash memory devices, magnetic disk drives, magnetic tapes

drives, optical disk drives, and cloud computing based storage. In some embodiments, the storage and/or memory device is a combination of devices such as those disclosed herein. Code or instructions contained thereon can be represented by carrier wave signals, infrared signals, digital signals, and by other like signals.

[0042] It should be understood that the foregoing description is only illustrative of the present disclosure. Various alternatives and modifications can be devised by those skilled in the art without departing from the disclosure. Accordingly, the present disclosure is intended to embrace all such alternatives, modifications, and variances. The embodiments described with reference to the attached drawing figures are presented only to demonstrate certain examples of the disclosure. Other elements, steps, methods, and techniques that are insubstantially different from those described above are also intended to be within the scope of the disclosure.

WHAT IS CLAIMED IS:

1. A system for chemical vapor deposition, the system comprising:
a process chamber having a top plate;
a rotating chuck within the process chamber configured to support a growth substrate;
a carrier gas inlet configured to direct a carrier gas flow to a preheat zone, the preheat zone configured to heat the carrier gas to a desired process temperature;
a precursor gas inlet configured to direct precursor gas into contact with heated carrier gas to provide a heated mixture of carrier gas and precursor gas, the heated mixture of carrier gas and precursor gas being directed by the carrier gas flow across a top of the rotating chuck; and
a purge port under the rotating chuck to purge gasses from the process chamber.
2. The system of claim 1, wherein the carrier gas inlet includes a plurality of inlet ports directing carrier gas to a heat exchanger in the preheat zone.
3. The system of claim 2, wherein each inlet port of the plurality of inlet ports directs carrier gas to a serpentine path in the heat exchanger.
4. The system of claim 1, wherein the precursor gas inlet includes an injector manifold including a plurality of precursor gas inlet holes.
5. The system of claim 4, wherein a first pair of gas inlet holes of the plurality of precursor gas inlet holes are positioned a first distance apart and a second pair of gas inlet holes of the plurality of precursor gas inlet holes are positioned a second distance apart, the first distance being greater than the second distance.
6. The system of claim 4, wherein the first distance is twice the second distance.
7. The system of claim 1, wherein the precursor gases are injected into the injector manifold from a location below the preheat zone.

8. The system of claim 1, wherein the carrier gas inlet directs a carrier gas flow including hydrogen to the preheat zone.

9. The system of claim 1, wherein the precursor gas inlet directs a precursor gas composition suitable for epitaxial deposition of silicon carbide on the growth substrate into contact with heated carrier gas.

10. The system of claim 1, wherein the growth substrate is a wafer.

11. The system of claim 1, wherein the rotating chuck is a composite chuck including an inner part configured to support the growth substrate and an outer part including a recess dimensioned and configured to receive the inner part.

12. The system of claim 1, further comprising a heating coil located above a reactor ceiling of the process chamber to inductively heat the growth substrate positioned upon the rotating chuck.

13. The system of claim 12, wherein the heating coil includes a two piece susceptor.

14. The system of claim 1, the process chamber includes reactor walls heated by resistive heaters or inductive coupling positioned externally of the process chamber.

15. A method of depositing a coating on a rotating substrate, the method comprising:
pre-heating a carrier gas;
mixing an unheated precursor gas with the pre-heated carrier gas to provide a reactive gas mixture;
directing the reactive gas mixture across the rotating substrate positioned on a rotating chuck; and
purging gasses through a purge port positioned under the rotating chuck.

16. The method of claim 15 wherein pre-heating the carrier gas includes introducing carrier gas through a plurality of inlet ports into a heat exchanger.

17. The method of claim 16 wherein introducing carrier gas into the heat exchanger includes introducing carrier gas from each inlet port of the plurality of inlet ports into a serpentine path in the heat exchanger.

18. The method of claim 16 wherein mixing the unheated precursor gas with the pre-heated carrier gas includes introducing precursor gas through an injector manifold including a plurality of precursor gas inlet holes.

19. The method of claim 16 wherein the precursor gases are injected into the injector manifold from a location below the heat exchanger.

20. The method of claim 16 wherein:
mixing the unheated precursor gas with the pre-heated carrier gas includes mixing hydrogen as the carrier gas and a composition suitable for epitaxial deposition of silicon carbide on the substrate as the precursor gas;
and directing the reactive gas mixture across the rotating substrate includes directing the reactive gas mixture across a wafer.

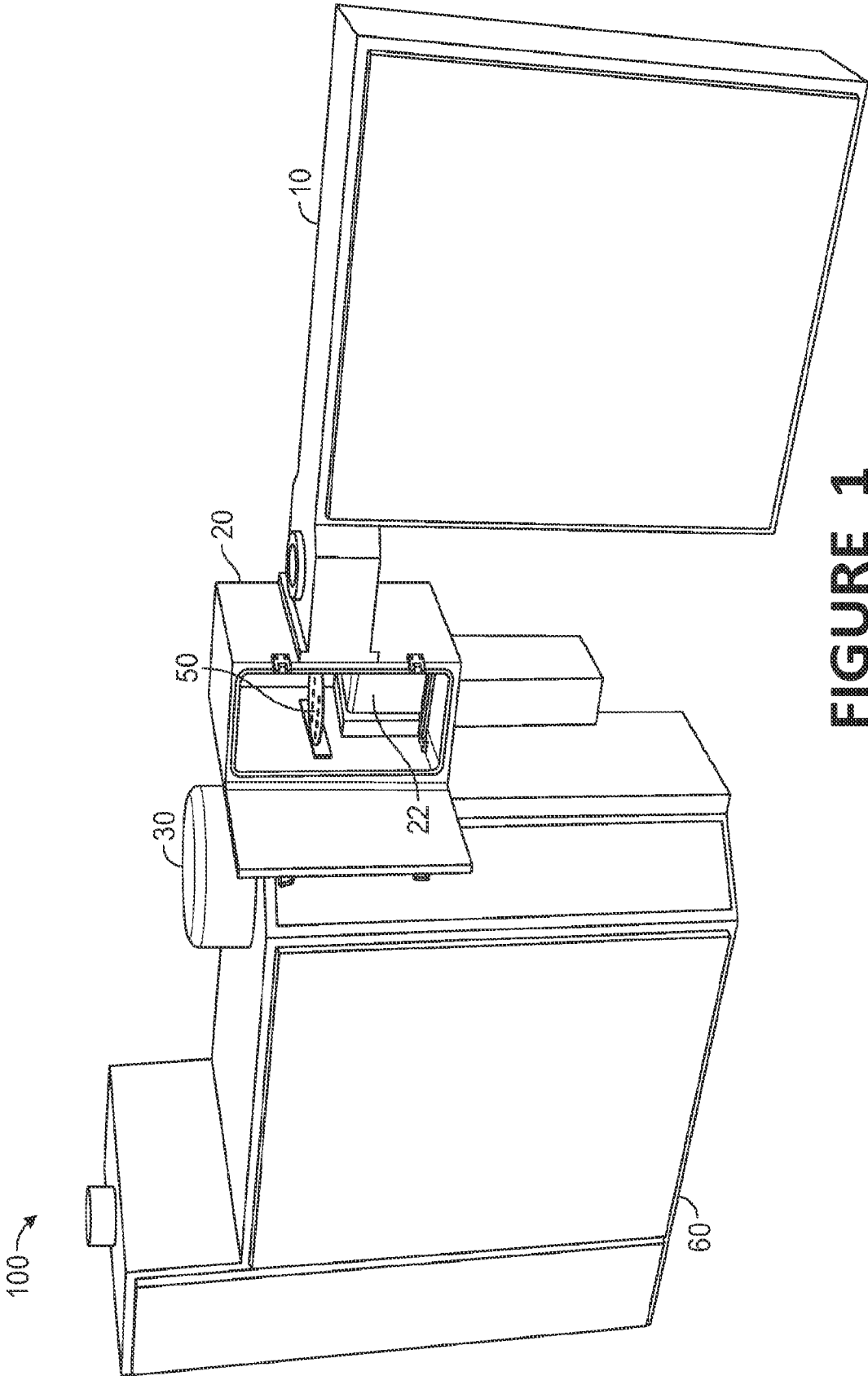
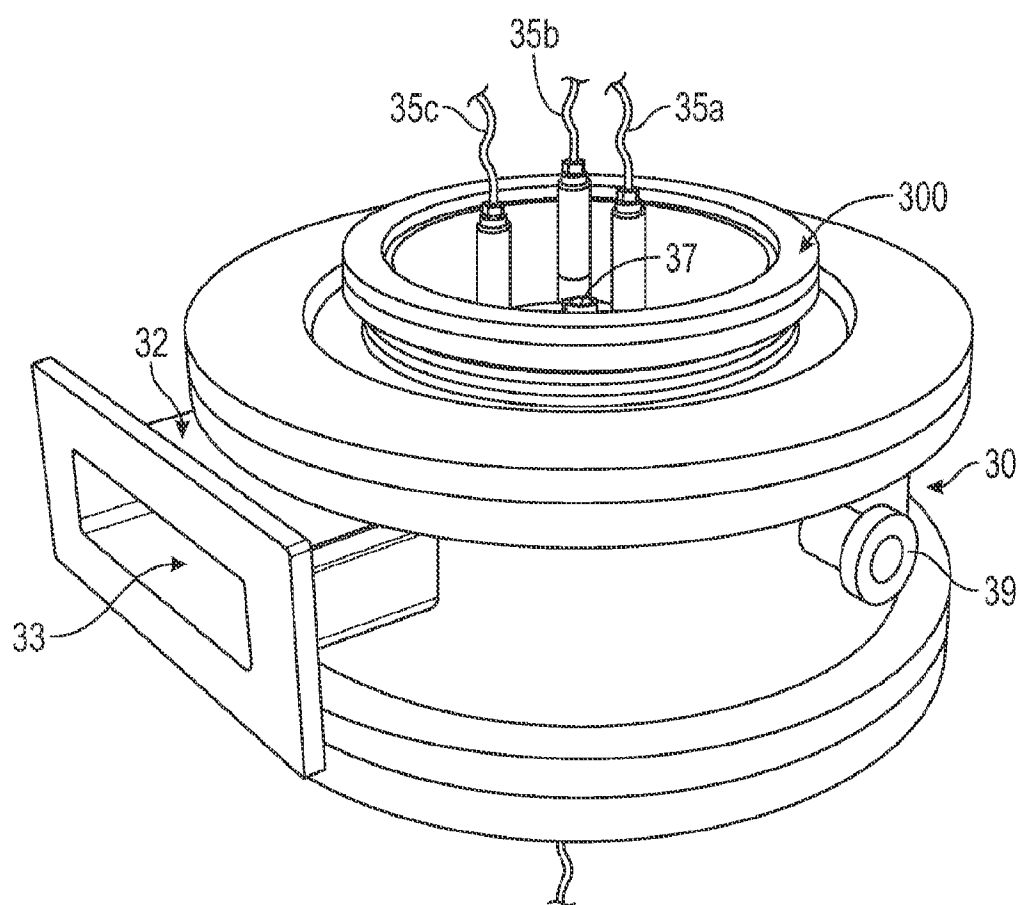
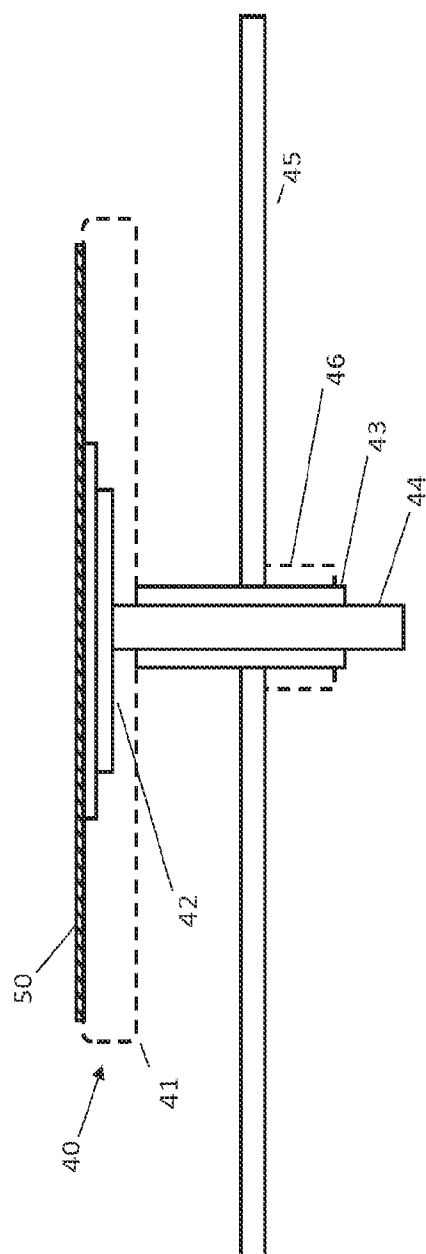
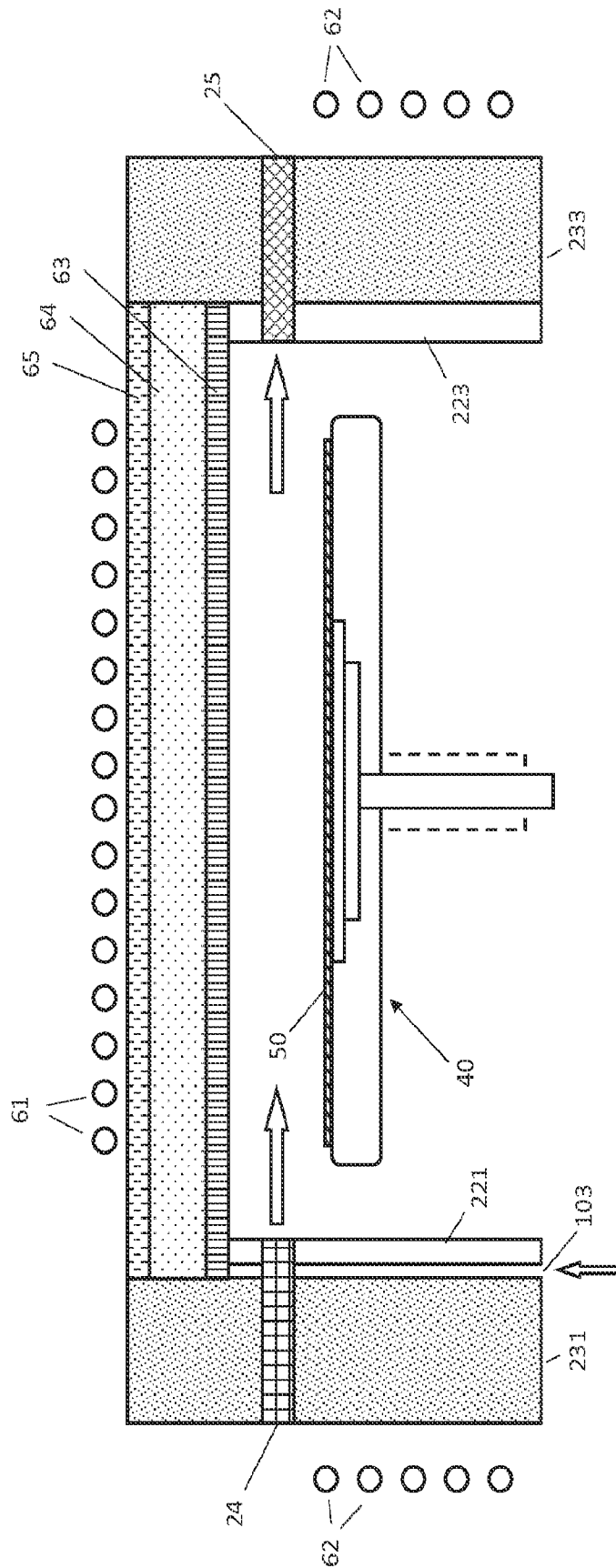


FIGURE 1

**FIGURE 2**

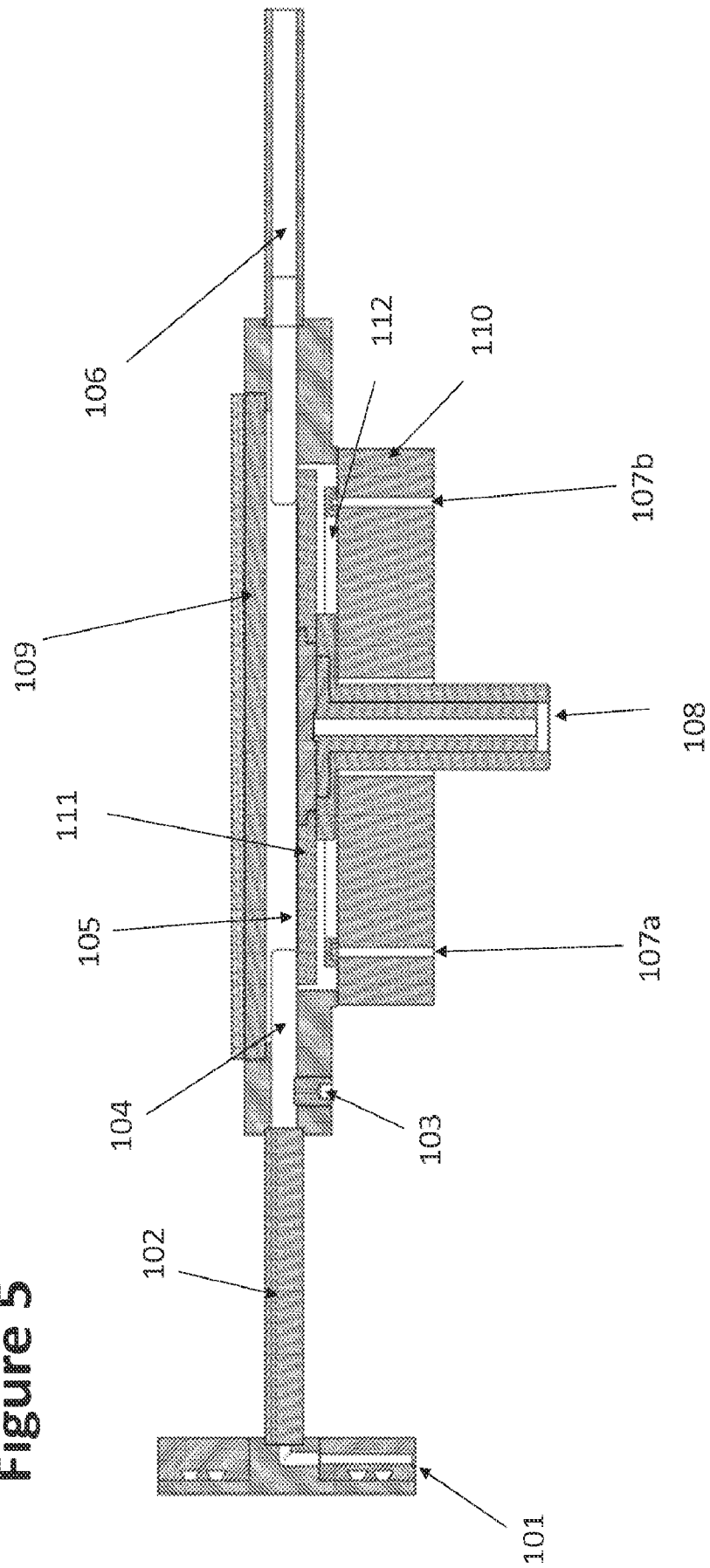


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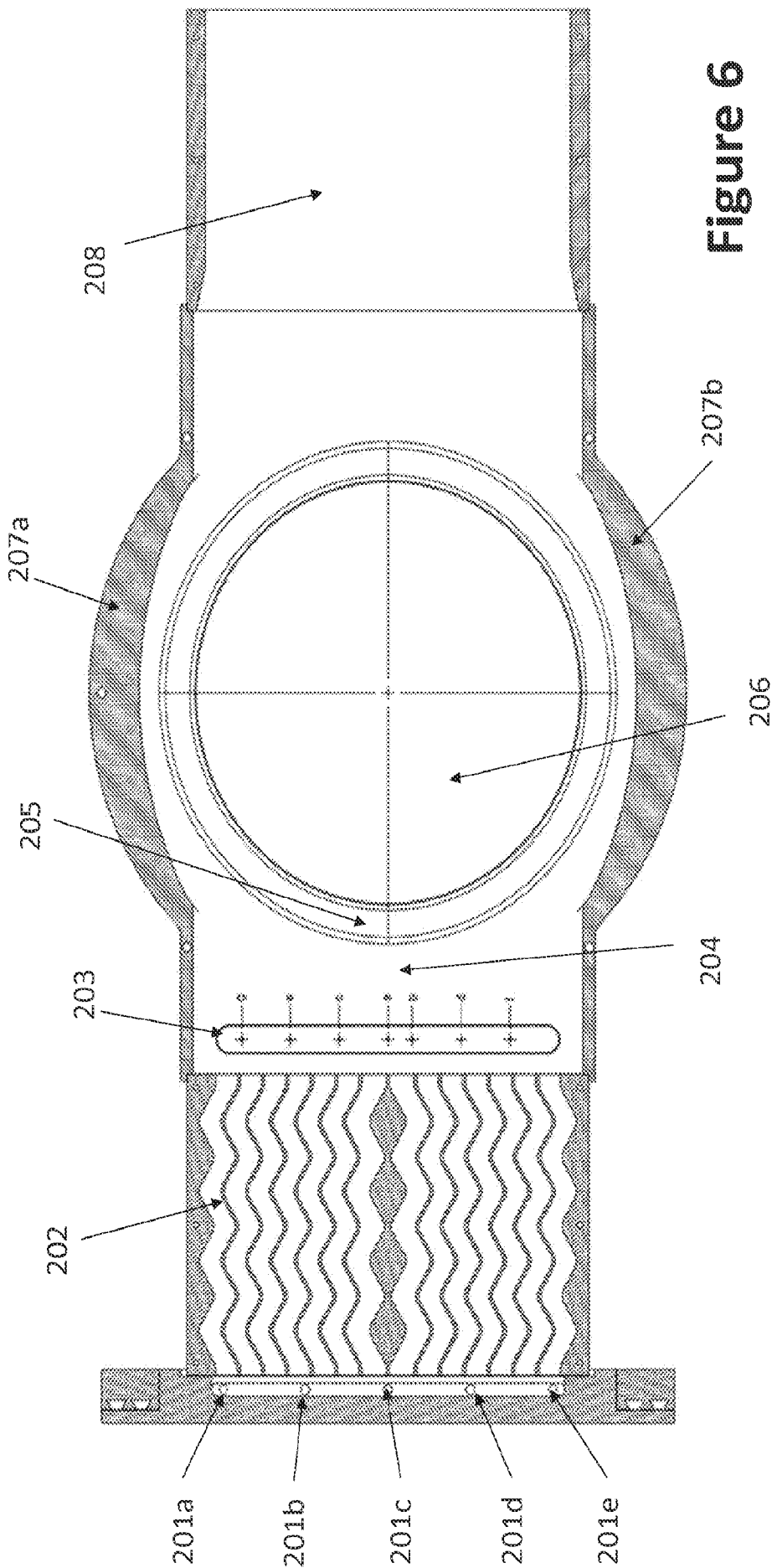


Figure 6

Temperature Distribution Contours on Horizontal Slice 1mm Above Wafer

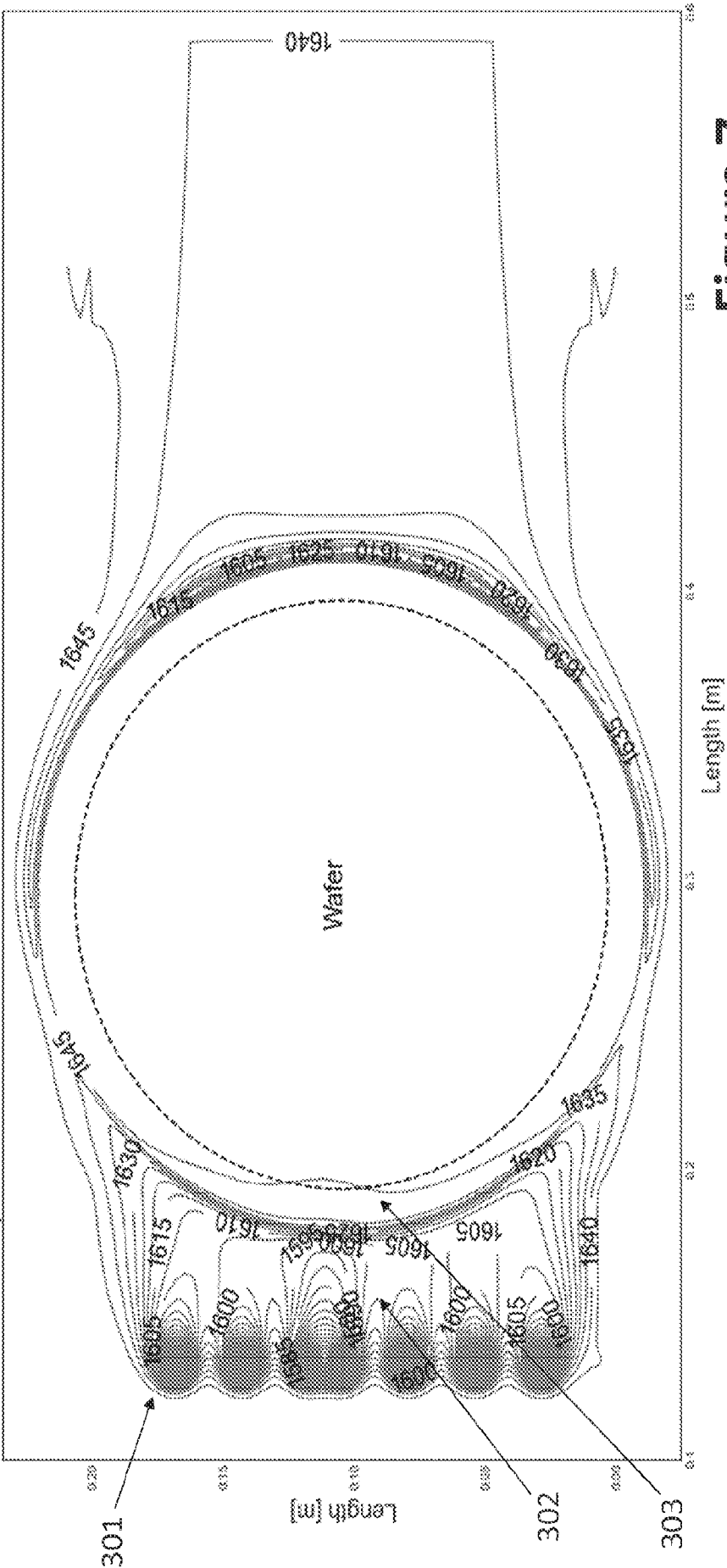


Figure 7

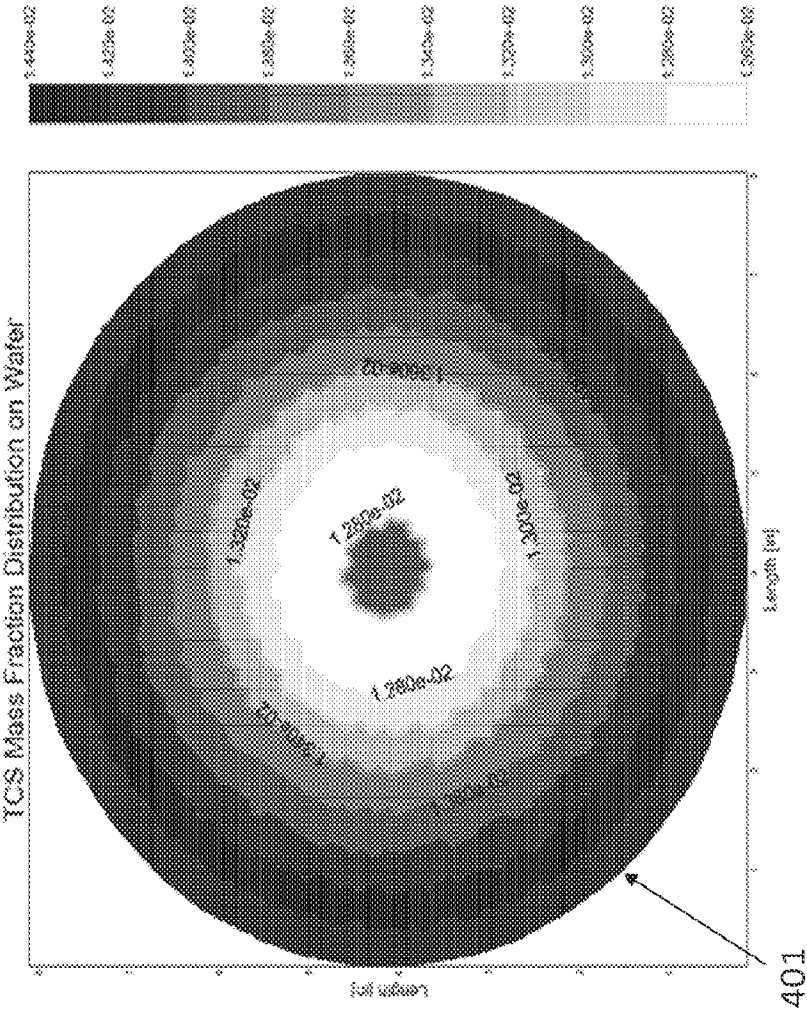


Figure 8A

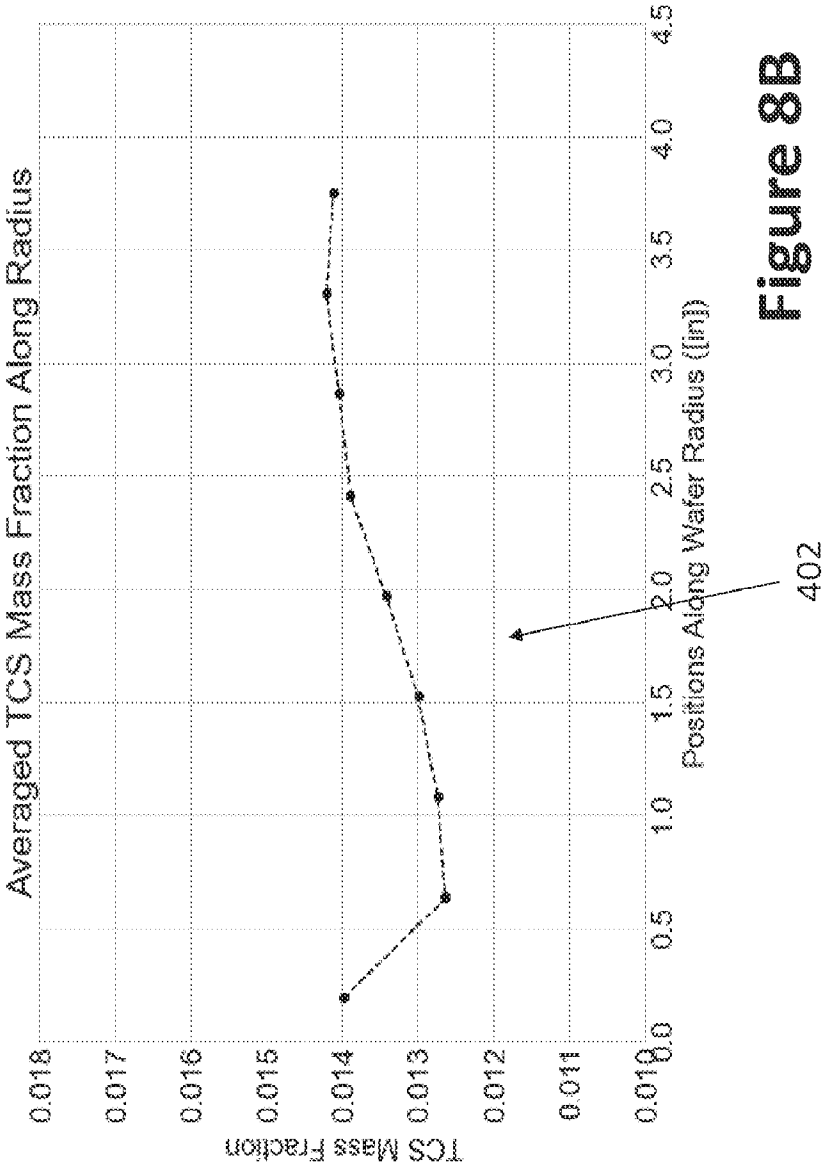


Figure 8B