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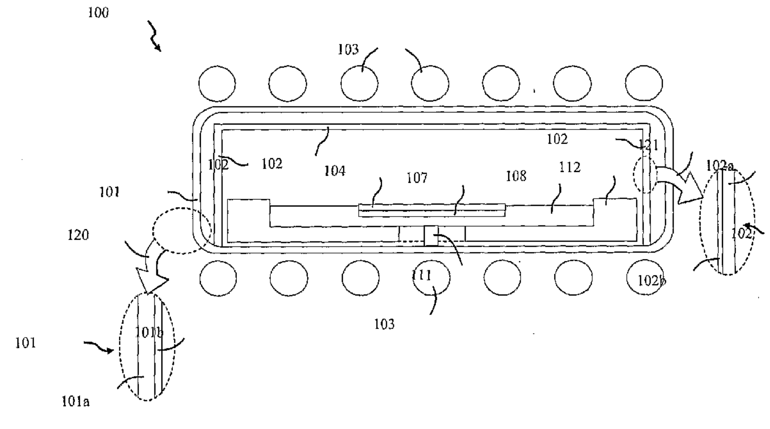
(54) Title: SEMICONDUCTOR GROWTH SYSTEM WHICH INCLUDES A BORON CARBIDE REACTOR COMPONENT

FIG. 1



(57) Abstract: The present invention employs a semiconductor growth system which includes a reaction chamber and a reactor component which is a single piece of boron carbide. The reaction chamber is typically a III-nitride reaction chamber and the reactor component is positioned within it. The reactor component can be of many different types, such as a susceptor control ring, susceptor and wafer holder.

SEMICONDUCTOR GROWTH SYSTEM WHICH INCLUDES A BORON CARBIDE REACTOR COMPONENT

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to semiconductor growth systems.

Description of the Related Art

[0002] Semiconductor growth systems are used to grow a number of different semiconductor materials, such as nitride-based semiconductors. Examples of nitride-based semiconductors include gallium nitride and its alloys. Nitride-based semiconductors can be grown using many different types of semiconductor growth systems, such as those associated with metalorganic chemical vapor deposition (MOCVD) and hydride (or halide) vapor phase epitaxy (HVPE). More information regarding MOCVD and HVPE growth systems can be found in U.S. Patent Application Nos. 20060076559 and 20060118513, as well as in M.A. Mastro *et al.*, "Influence of polarity on GaN thermal Stability", Journal of Crystal Growth, Vol. 274, Pages 38-46 (2005) and M.A. Mastro *et al.*, "Thermal stability of MOCVD and HVPE GaN layers in H_2, HCl, NH_3 and N_2", Physica Status Solidi (a), Vol. 188, No. 1, Pages 467-471 (2001).

[0003] The semiconductor growth system typically includes a reaction chamber in which the nitride-based semiconductor is grown. The nitride-based semiconductor is grown on a substrate, which is positioned within the reaction chamber and carried by one or more reactor components. The reactor components can be of many different types, such as a susceptor, wafer holder and susceptor control ring, among others. In some situations, the reactor component is a heating plate which flows heat towards the substrate. More information regarding reactor components can be found in U.S. Patent Nos. 5,514,439, 5,858,486, 6,120,640, 6,410,172, 6,506,254 and 6,808,747.

[0004] However, there are a limited number of materials suitable for use in reactor components because the material needs to be able to withstand high temperature caustic environments for prolonged periods of time without experiencing significant degradation. Examples of materials typically included in reactor components are quartz, sapphire, graphite, pyrolytic graphite, silicon carbide (SiC), aluminum nitride (AlN), boron nitride (BN) and pyrolytic boron nitride (PBN). One problem with these materials, however, is that they can behave as a source of impurities, which can be undesirably incorporated into the nitride-based semiconductor. Further, reactor components made from these materials make it more difficult to control the density of impurities incorporated into the nitride-based semiconductor. More information regarding impurities in nitride-based semiconductors can be found in Armitage *et al.* Applied Physics Letters **82** 3457 (2003).

[0005] The reactor components can be coated with the above materials to restrict the flow of impurities to the nitride-based semiconductor. Examples of coated reactor components can be found in U.S. Patent Nos. 3,925,577, 4,264,803, 5,514,439, 6,410,172, and 7,118,781, as well as in U.S. Patent Application No. 20060225643. However, reactor components coated with the above materials are more complicated to manufacture and often experience many different problems, such as cracking.

BRIEF SUMMARY OF THE INVENTION

[0006] The present invention employs a semiconductor growth system which includes a reaction chamber and a first reactor component which is a single piece of boron carbide. The reaction chamber is typically a III-nitride reaction chamber and the first reactor component is positioned within it. In one embodiment, the single piece of boron carbide consists of boron carbide and, in another embodiment, the single piece of boron carbide consists essentially of boron carbide. The first reactor component can be of many different types, such as a susceptor control ring, susceptor and wafer holder. In some embodiments, the semiconductor growth system includes a second reactor component, such as a heating plate, which is a single piece of boron carbide. The heating plate is positioned to direct heat at the other reactor component. In some embodiments, the semiconductor growth system includes a third reactor component which includes a boron carbide coating layer. It should be noted that the boron carbide coating layer can extend over the reactor component, or a portion thereof.

[0007] The present invention provides a method of fabricating a semiconductor layer which includes providing a reaction chamber and positioning a first reactor component, which consists essentially of boron carbide, within the reaction chamber. In one embodiment, the first reactor component is a single piece of boron carbide. In some embodiments, the method of fabricating the semiconductor layer includes providing the semiconductor growth system with a second reactor component which is a single piece of boron carbide. In some embodiments, the method of fabricating the semiconductor layer includes providing the semiconductor growth system with a third reactor component which includes a boron carbide coating layer.

[0008] The present invention provides a method of manufacturing a semiconductor growth system, wherein the method includes providing a reaction chamber and providing a first reactor component, which consists essentially of boron carbide. In one embodiment, the first reactor component is a single piece of boron carbide. The first reactor component is typically formed using sintering or hot pressing. In some embodiments, the method of manufacturing the semiconductor growth system includes providing the semiconductor growth system with a second reactor component which is a single piece of boron carbide. In some embodiments, method of manufacturing a semiconductor growth system includes providing the semiconductor growth system with a third reactor component which includes a boron carbide coating layer.

[0009] Further features and advantages of the invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a side view of a reaction chamber, which includes a boron carbide reactor component, in accordance with the invention.

[0011] FIGS. 2a and 2b are perspective views of a reactor component of the reaction chamber of FIG. 1, which is embodied as a susceptor control ring.

[0012] FIG. 3 is a perspective view of a reactor component of the reaction chamber of FIG. 1, which is embodied as a susceptor.

[0013] FIG. 4 is a perspective view of a reactor component of the reaction chamber of FIG. 1, which is embodied as a wafer holder.

[0014] FIG. 5 is a perspective view of a wafer, which is fabricated using the reaction chamber of FIG. 1.

[0015] FIGS. 6a, 6b and 6c are flow diagrams of a method, in accordance with the invention, of fabricating a III-nitride semiconductor layer.

[0016] FIGS. 7a, 7b and 7c are flow diagrams of a method, in accordance with the invention, of manufacturing a semiconductor growth system.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The invention involves a semiconductor growth system which includes a reaction chamber and one or more reactor components which are a single piece of boron carbide. In some embodiments, the semiconductor growth system includes a another reactor component which includes a boron carbide coating layer. Boron carbide is generally denoted as B_4C and more information regarding it can be found in U.S. Patent Nos. 4,824,624 and 5,252,267. As discussed in more detail below, the reactor component can be of many different types, such as a heating plate, susceptor control ring, susceptor and wafer holder.

[0018] Previous reactor components are not single pieces of boron carbide because they include a reactor component body coated with a material that does not include boron carbide, wherein the reactor component body also does not include boron carbide. Hence, previous coated reactor components are two pieces of different materials and are not a single piece of boron carbide. It should be noted, however, that the reactor component, in accordance with the invention, can include one or more pieces of boron carbide coupled together to form a single integral piece of boron carbide. For example, in some embodiments, a piece of boron carbide is coated with a boron carbide coating so that a single piece of boron carbide is formed.

[0019] In some embodiments, the reactor component consists of boron carbide and, in other embodiments, the reactor component consists essentially of boron carbide, wherein it includes impurities, such as carbon, typically associated with the manufacturing process used to fabricate it. The reactor component can be fabricated as a single piece of boron carbide in many different ways, such as by using sintering and hot pressing. More information regarding forming boron carbide using sintering and hot pressing can be found in U.S. Patent Nos. 4,017,587, 4,081,284, 4,195,066, 4,215,088, 4,320,204, 4,824,624, 5,252,267, 5,418,196, 6,120,640 and 6,808,747. Other methods of fabricating boron carbide include spray, chemical vapor deposition (CVD) and surface conversion.

[0020] Solid plates of boron carbide produced by the hot pressing process are available commercially from Ceradyne, and are generally known by the trade name of CERALLOY®. Further, Saint-Gobain Ceramics & Plastics, Inc. produces solid plates of boron carbide using hot pressing, which are know by the trade name NORBIDE®. In some embodiments, these solid pieces of boron carbide can be processed to form the reactor component. The solid piece of boron carbide can be processed in many different ways, such as by wet and dry etching, as well as machining.

[0021] There are many different reasons for using boron carbide to form one of the reactor components. One reason for using boron carbide is that it is relatively inexpensive compared to other materials, such as quartz and silicon carbide, typically used to form reactor components. Another reason is that boron carbide is a material that is capable of being exposed to a high temperature caustic environment for a prolonged period of time without degrading significantly. The caustic environment generally includes caustic chemicals, such as chlorine gas, at elevated temperatures which enhances their ability to etch materials typically included in reactor components. For example, it is known that quartz is etched significantly when exposed at high temperatures to chlorine gas. More information about materials used in reactor components, as well as their behavior in caustic environments, can be found in U.S. Patent Nos. 3,549,847, 5,444,217 and 5,858,486.

[0022] As discussed in some of the references above, high temperature and caustic environments are often necessary to form a wafer which includes semiconductor materials, such as nitride-based semiconductors. Hence, a reactor component made of boron carbide will have a longer lifetime and will need to be replaced less often. This decreases the operation and maintenance costs of the semiconductor growth system. Further, since the boron carbide reactor component needs to be replaced less often, the semiconductor growth system experiences less down time so that more wafers can be fabricated in a given amount of time. This is useful in high volume manufacturing (HVM), wherein it is desired to increase the number of wafers processed in a given amount of time to reduce the cost per wafer.

[0023] Boron carbide can be exposed to a high temperature without degrading significantly because it has a high melting point. Some references disclose the melting point of boron carbide to be between about 2300 degrees Celsius (°C) and about 2500 °C. When fabricating nitride-based semiconductors, it is often necessary to heat the wafer to temperatures in a range of about 900 °C to 1300 °C.

[0024] Boron carbide can be exposed to a high temperature caustic environment for a prolonged period of time because it is a hard material. Some references disclose that boron carbide is the hardest known material after diamond, cubic boron nitride and boron oxide. However, these materials that are harder than boron carbide can be extremely expensive (i.e. diamond), and some of them are less resistant to etching (i.e. cubic boron nitride and boron oxide) than boron carbide. Boron carbide is more resistant to etching because it, along with silicon carbide, are covalent carbides, and possess excellent thermal and chemical stability because they are covalent materials. In a covalent material, the bonding between the atoms included therein is more covalent than it is ionic. It is known that a covalent bond is stronger than an ionic bond.

[0025] Another reason for using boron carbide to form one of the reactor components is that boron carbide has a desired emissivity which allows it to behave as a black body radiator. The emissivity of a material, generally denoted by the symbol ε, is the ability of its surface to emit radiant energy compared to that of a black body at the same temperature and with the same area. Hence, the emissivity of a material is the ratio of the radiation emitted by its surface compared to the radiation emitted by a blackbody at the same temperature. The emissivity of a material is generally determined indirectly by assuming that $\varepsilon=1-R$, wherein R is the reflectivity of the material. For example, a mirrored surface may have a 98% reflectivity (i.e. $R=0.98$), which means that it reflects 98% of the incident heat energy and absorbs 2% ($\varepsilon=1-R=1-0.98=0.02$). A good blackbody surface will reverse the ratio, for example absorbing 98% of the incident heat energy and reflecting only 2% ($\varepsilon=1-R=1-0.02=0.98$).

[0026] U.S. Patent No. 6,140,624 provides an emissivity for PBN of 0.55 at a wavelength 1.55 µm, while the more commonly used SiC has a value of 0.92 at the same wavelength. This same reference estimates the emissivity of boron carbide to be in a range of about 0.80 to 0.85, although it is indicated that the emissivity of boron carbide can approach that of SiC. For example, the work of Fuentes *et al.* (Fusion Engineering and Design **56-57** 315 (2001)) relates to the use of boron carbide protective plates in a fusion environment, which is one of the most caustic environments available. Fuentes *et al.* obtained an emissivity value of 0.92 for boron carbide, which indicates that it is an effective substitute for silicon carbide, as well as other materials, as a black body radiator.

[0027] **FIG. 1** is a side view of a reaction chamber 100, which includes a boron carbide reactor component, in accordance with the invention. It should be noted that reaction chamber 100 is typically included in a semiconductor growth system which is used to grow III-nitride semiconductor materials, such as gallium nitride and its alloys. The semiconductor growth system can be of many different types, such as those associated with MOCVD and HVPE. Hence, in some embodiments, reaction chamber 100 is a MOCVD reaction chamber and, in other embodiments, reaction chamber 100 is a HVPE reaction chamber. More information regarding MOCVD and HVPE reaction chambers can be found in the references cited above. In some embodiments, reaction chamber 100 is a cold-wall MOCVD reaction chamber and, in other embodiments, reaction chamber 100 is a cold-wall HVPE reaction chamber. More information regarding cold-wall reaction chambers can be found in U.S. Patent Nos. 6,218,280, 6,350,666 and 6,733,591. It should be noted that the boron carbide reactor component can be used in many other semiconductor growth and processing systems, such as those associated with vapor phase epitaxy, plasma processing, thermal diffusion furnaces and rapid thermal processors, among others.

[0028] In this embodiment, reaction chamber 100 includes a housing 101, which houses the reactor components. Housing 101 can be made of many different materials, but it is often made of quartz. In some embodiments, however, housing 101 can include boron carbide. For example, as indicated by a substitution arrow 120, housing 101 can include a housing body 101a which carries a boron carbide coating layer 101b, wherein coating layer 101b is positioned so it faces the interior of housing 101. In these embodiments, housing body 101a can include a material other than boron carbide, such as those mentioned above (i.e. quartz, sapphire, graphite, pyrolytic graphite, silicon carbide (SiC), aluminum nitride (AlN), boron nitride (BN) and/or pyrolytic boron nitride (PBN)). It should be noted that boron carbide coating layer 101b can extend over housing 101 or a portion thereof. For example, portions of housing 101 are not covered by carbide coating layer 101b so that a window is formed and light can flow therethrough.

[0029] In this embodiment, reaction chamber 100 includes heat sources 103 positioned proximate to housing 101. Heat sources 103 are used to flow heat to the reactor components housed by housing 101. Heat sources 103 can be of many different types, such as infrared (IR) lamps, resistive heaters and inductive heaters. An IR lamp emits infrared energy, a resistive heater operates by flowing a current through a wire so that heat is emitted in response and an inductive heater provides heat through magnetic energy.

[0030] In this embodiment, reaction chamber 100 includes a reactor component embodied as a heating plate 102. In one particular embodiment, heating plate 102 is a black body heating plate so it operates as a black body radiator which flows heat in a desired direction. In this embodiment, reaction chamber 100 includes three heating plates coupled together. However, in other embodiments, the heating plates can be a single integral piece.

[0031] In some embodiments, heating plate 102 is a single piece of boron carbide. Further, in some embodiments, heating plate 102 consists of boron carbide and, in other embodiments, heating plate 102 consists essentially of boron carbide. Heating plate 102 can include impurities, such as carbon, typically incorporated into it during its manufacture. In these embodiments, heating plate 102 generally does not include a coating layer of boron carbide. However, in some embodiments, heating plate 102 includes a piece of boron carbide with a boron carbide coating layer formed thereon.

[0032] Further, in these embodiments, heating plate 102 does not include a coating layer of any other coating material. Examples of coating materials not included are aluminum nitride, silicon carbide and boron nitride, among others. Also, in these embodiments, heating plate 102 does not include quartz, graphite, pyrolytic graphite, silicon carbide, aluminum, aluminum nitride, boron nitride, and/or pyrolytic boron nitride in any significant amount.

[0033] In other embodiments, heating plate 102 does include a boron carbide coating layer. For example, as indicated by a substitution arrow 121, heating plate 102 can include a heating plate body 102a which carries a boron carbide coating layer 102b. In these embodiments, heating plate body 102a can include a material other than boron carbide, such as those mentioned above.

[0034] It should be noted that quartz is generally used in the manufacture of cold-wall reactor housings because of its ability to allow IR energy to flow therethrough. Hence, quartz allows IR energy from heat source 103 to heat desired portions of the reactor components positioned within housing 101, while maintaining the outer reactor walls at a lower temperature. The lower temperature of the outer reactor walls restricts the ability of material to be undesirably deposited thereon.

[0035] It should also be noted that it is sometimes desirable to heat some portions of the reactor components and not others. Hence, heating plates 102 are made to operate as black body radiators which absorb heat from heat source 103 and reradiate the heat in a desired direction, such as towards a portion of the reactor component.

[0036] It can be advantageous in a cold-wall reactor with a quartz housing to be able to position heating plates at desired locations to control the flow of heat or to protect delicate quartz areas of the reaction chamber. For example, quartz is useful when IR heating is used for reactor heating. However, the transparency of the quartz may keep its temperature well below that of the central core of the reaction chamber. In some cases, depending on the deposition process, the quartz housing may require some heating, such as to restrict condensation of precursor gases thereon. This can be achieved by the controlled positioning of one or more black body ceramic plates, which include boron carbide. The boron carbide ceramic plates reradiate energy from the IR lamps at a broader spectrum, wherein the spectrum includes wavelengths more readily absorbed by the quartz housing. Hence, the temperature of housing 101 can be controlled by using cooling fans to prevent over heating of the reaction chamber and boron carbide ceramic plates to flow heat in desired directions.

[0037] In this embodiment, reaction chamber 100 includes a reactor component embodied as a susceptor control ring 112, wherein susceptor control ring 112 is shown in a perspective view in **FIG. 2a**. It should be noted that susceptor control rings are often referred to as Saturn rings, slip rings and susceptor rings, among other names. In this embodiment, susceptor control ring 112 includes a susceptor control ring body 113 with a susceptor recess 115 extending therethrough. Susceptor recess 115 is sized and shaped to receive a susceptor 108, which will be discussed in more detail below. Susceptor recess 115 can be formed in many different ways, such as by wet and/or dry etching susceptor control ring body 113 or it can be formed during the hot press formation of susceptor control ring body 113. Susceptor control ring body 113 can also be machined to form susceptor recess 115. In other embodiments, the susceptor control ring can include a susceptor control ring body 112a having an annular torus, as shown in **FIG. 2b**. Susceptor control ring 112 includes a rotation arm opening 114 for receiving a rotation arm 111 (**FIG. 1**). Rotation arm opening 114 extends through susceptor control ring body 113 and susceptor recess 115. Rotation arm 111 is for rotating susceptor 108, which is useful for rotating a wafer 104. Rotating wafer 104 is useful so that the semiconductor layers included with it have a more uniform thickness.

[0038] In some embodiments, susceptor control ring 112 is a single piece of boron carbide. Further, in some embodiments, susceptor control ring 112 consists of boron carbide and, in other embodiments, susceptor control ring 112 consists essentially of boron carbide. Susceptor control ring 112 can include impurities, such as carbon, typically incorporated into it during its manufacture. In these embodiments, susceptor control ring 112 generally does not include a coating layer of boron carbide. However, in some embodiments, susceptor control ring 112 includes a piece of boron carbide with a boron carbide coating layer formed thereon.

[0039] Further, in these embodiments, susceptor control ring 112 does not include a coating layer of any other coating material. Examples of coating materials not included are aluminum nitride, silicon carbide and boron nitride, among others. Also, in these embodiments, susceptor control ring 112 does not include quartz, graphite, pyrolytic graphite, silicon carbide, aluminum, aluminum nitride, boron nitride, and/or pyrolytic boron nitride in any significant amount.

[0040] It is useful when susceptor control ring 112 is a single piece of boron carbide because it can absorb heat from heating plate 102 and/or heat source 103. The heat absorbed by susceptor control ring 112 can heat growth gases before the growth gases flow to wafer 104. In this way, the growth gases are preheated by susceptor control ring 112. The growth gases are preheated so that the semiconductor layers included with wafer 104 are of higher quality and more uniform. Susceptor control ring 112 also reduces the temperature gradient across wafer 104 so that the semiconductor layers included with it are more uniform.

[0041] In other embodiments, susceptor control ring 112 does include a boron carbide coating layer. For example, as indicated by a substitution arrow 122, susceptor control ring 112 can include a boron carbide coating layer 113a positioned on susceptor control ring body 113. In these embodiments, susceptor control ring body 113 can include a material other than boron carbide, such as those mentioned above. It should be noted that boron carbide coating layer 113a can extend over susceptor control ring 112 or a portion of it.

[0042] In this embodiment, reaction chamber 100 includes a reactor component embodied as a susceptor 108, wherein susceptor 108 is shown in a perspective view in **FIG. 3**. In this embodiment, susceptor 108 includes a susceptor body 109 with a wafer holder recess 110 extending therethrough. Wafer holder recess 110 is sized and shaped to receive a wafer holder 107, which will be discussed in more detail below. Wafer holder recess 110 can be formed in many different ways, such as by wet and/or dry etching susceptor body 109. Susceptor body 109 can also be machined to form wafer holder recess 110.

[0043] In some embodiments, susceptor 108 is a single piece of boron carbide. Further, in some embodiments, susceptor 108 consists of boron carbide and, in other embodiments, susceptor 108 consists essentially of boron carbide. Susceptor 108 can include impurities, such as carbon, typically incorporated into it during its manufacture. In these embodiments, susceptor 108 generally does not include a coating layer of boron carbide. However, in some embodiments, susceptor 108 includes a piece of boron carbide with a boron carbide coating layer formed thereon. It is useful when susceptor 108 is a single piece of boron carbide because a larger percentage of the heat from heating plate 102 and/or heat source 103 is directed towards wafer 104 and wafer holder 107.

[0044] Further, in these embodiments, susceptor 108 does not include a coating layer of any other coating material. Examples of coating materials not included are aluminum nitride, silicon carbide and boron nitride, among others. Also, in these embodiments, susceptor 108 does not include quartz, graphite, silicon carbide, aluminum, aluminum nitride, boron nitride, and/or pyrolytic boron nitride in any significant amount.

[0045] In other embodiments, susceptor 108 does include a boron carbide coating layer. For example, as indicated by a substitution arrow 123, susceptor 108 can include a boron carbide coating layer 109a positioned on susceptor body 109. In these embodiments, susceptor body 109 can include a material other than boron carbide, such as those mentioned above.

[0046] In this embodiment, reaction chamber 100 includes a reactor component embodied as a wafer holder 107, which is used to hold one or more wafers 104. Wafer holder 107 is shown in a perspective view in **FIG. 4**. In some embodiments, wafer holder 107 is a single piece of boron carbide. Further, in some embodiments, wafer holder 107 consists of boron carbide and, in other embodiments, wafer holder 107 consists essentially of boron carbide. Wafer holder 107 can include impurities, such as carbon, typically incorporated into it during its manufacture. In these embodiments, wafer holder 107 generally does not include a coating layer of boron carbide. However, in some embodiments, wafer holder 107 includes a piece of boron carbide with a boron carbide coating layer formed thereon.

[0047] Further, in these embodiments, wafer holder 107 does not include a coating layer of any other coating material. Examples of coating materials not included are aluminum nitride, silicon carbide and boron nitride, among others. Also, in these embodiments, wafer holder 107 does not include quartz, graphite, pyrolytic graphite, silicon carbide, aluminum, aluminum nitride, boron nitride, and/or pyrolytic boron nitride in any significant amount.

[0048] In other embodiments, wafer holder 107 does include a boron carbide coating layer. For example, as indicated by a substitution arrow 124, wafer holder 107 can include a wafer holder body 107a which carries a boron carbide coating layer 107b. In these embodiments, wafer holder body 107a can include a material other than boron carbide, such as those mentioned above.

[0049] It should be noted that reaction chamber 100 generally includes one or more reactor components that are a single piece of boron carbide. For example, in one particular embodiment, wafer holder 107 is a single piece of boron carbide and each of heating plates 102 is a single piece of boron carbide. In another embodiment, susceptor 108 is a single piece of boron carbide, wafer holder 107 is a single piece of boron carbide, and susceptor control ring 112 includes a different material, such as quartz.

[0050] In other embodiments, reaction chamber 100 includes one or more reactor components that are a single piece of boron carbide, and another reactor component that has a boron carbide coating layer. For example, in one particular embodiment, susceptor control ring 112 is a single piece of boron carbide and susceptor 108 includes susceptor body 109 which carries boron carbide coating layer 109a. In another embodiment, susceptor 108 is a single piece of boron carbide, wafer holder 107 is a single piece of boron carbide; and susceptor control ring 112 includes susceptor control ring body 113 which carries boron carbide coating layer 113a.

[0051] It should also be noted that many other components of the semiconductor growth system can include boron carbide. For example, it is known that MOCVD and HVPE growth systems include various types of tubing, delivery lines, liquid and gas containers, inlet and outlet valves, fittings, seals, wafer boats, liners, shields, tubes, crucibles, etc. More information regarding these components can be found in U.S. Patent Nos. 3,549,847, 5,444,217 and 5,858,486. Further, it is known that these components can be positioned within reaction chamber 100, wherein they are exposed to high temperature and caustic environments for prolonged periods of time. Hence, in accordance with the invention, a single piece of boron carbide is manufactured to protect one or more of these components from heat and caustic chemicals associated with growing semiconductor layers. Further, any area of the reactor system, external to the reaction chamber which requires protection from a high temperature/corrosive environment will benefit from being produced from boron carbide or coated with a boron carbide coating layer. For example one or more of the tubing, delivery lines, liquid/gas containers, inlet and outlet valves, fittings, seals etc., can be coated with a boron carbide coating layer. The resistance of the boron carbide coating layer to the high temperature and corrosive chemical environment of reaction chamber 100 assists in maintaining its operation, which increases its productivity. The resistance of the boron carbide coating layer to the high temperature and corrosive chemical environment of reaction chamber 100 decreases maintenance.

[0052] **FIG. 5** is a perspective view of wafer 104. Wafer 104 can have many different configurations, but, in this embodiment, wafer 104 includes a substrate 105 which carries a semiconductor layer 106. Substrate 105 can include many different types of materials, such as sapphire and silicon carbide. Further, semiconductor layer 106 can include many different types of materials, such as a nitride-based semiconductor. It should be noted that semiconductor layer 106 is shown as being a single layer of material for illustrative purposes. However, one or more semiconductor layers are typically grown on substrate 105 and a solid-state device is formed therewith. The solid-state devices can be of many different types, such as optical and non-optical devices. Optical devices generally include lasers, light emitting diodes and photodetectors, and non-optical devices generally include diodes and transistors, among others. Further, it should be noted that substrate 105 can be of many different sizes. However, substrate 105 typically has a diameter between about 50 millimeters to 100 millimeters when semiconductor layer 106 includes a nitride-based semiconductor.

[0053] In operation, susceptor control ring 112 is positioned within housing 101 so that rotation arm 111 extends through it. Susceptor 108 is positioned within housing 101 so that it is coupled to rotation arm 111. In this way, susceptor 108 rotates in response to the rotation of rotation arm 111. Susceptor 108 extends through susceptor recess 115 when it is coupled to rotation arm 111. Wafer holder 107 is positioned within housing 101 so it is carried by susceptor 108. Wafer holder 107 is carried by susceptor 108 by positioning it so it extends through wafer holder recess 110.

[0054] Wafer 104 is positioned within housing 101 so it is carried by wafer holder 107. It should be noted that, in some embodiments, wafer holder 107 is removed from housing 101 so that wafer 104 can be positioned so it is carried by susceptor 108. When wafer 104 is carried by susceptor 108, it is generally positioned so it extends through wafer holder recess 110.

[0055] Heat source 103 provides heat which flows to heating plate 102. When heating plate 102 includes a heat transparent material, such as quartz, the heat flows therethrough and is incident to susceptor control ring 112, susceptor 108, wafer holder 107 and/or wafer 104. When heating plate 102 operates as a black body radiator, heat is absorbed by it and reradiated towards susceptor control ring 112, susceptor 108, wafer holder 107 and/or wafer 104. As mentioned above, heating plate 102 operates as a black body radiator when it includes boron carbide.

[0056] It is useful when wafer holder 107 includes a single piece of boron carbide and semiconductor layer 106 includes a III-nitride semiconductor material because these materials have similar coefficients of thermal expansion (CTE). Some references report that the CTE of boron carbide is about 5.6 x 10^{-6} $°C^{-1}$, which is about the same as most III-nitride semiconductor materials, such as gallium nitride. The amount of wafer slip between wafer holder 107 and semiconductor layer 106 is reduced when their CTE's are driven to match each other. Strain in semiconductor layer 106 occurs in response to wafer slip. Hence, in some situations, it is desirable to decrease the amount of slip to decrease the amount of strain in semiconductor layer 106. This is especially true as the thickness of semiconductor layer 106 increases because a thicker semiconductor layer generally has more strain than a thinner semiconductor layer of the same material. It should be noted that the strain in a semiconductor layer can be tensile or compressive.

[0057] **FIG. 6a** is a flow diagram of a method 200, in accordance with the invention, of fabricating a semiconductor layer. In this embodiment, method 200 includes a step 201 of providing a reaction chamber. The reaction chamber can be of many different types, such as those discussed in more detail above. The reaction chamber is generally one that is capable of forming nitride-based semiconductors.

[0058] In this embodiment, method 200 includes a step 202 of positioning a first reactor component, which consists essentially of boron carbide, within the reaction chamber. In some embodiments, the first reactor component is a single piece of boron carbide. In some embodiments, the first reactor component is a single piece of boron carbide with a boron carbide coating layer formed thereon.

[0059] It should be noted that method 200 can include many other steps. For example, in some embodiments, method 200 includes a step of fabricating the semiconductor layer with the reaction chamber and first reactor component. For example, when the first reactor component is a susceptor or wafer holder, a substrate is typically carried by it, and the semiconductor layer is formed on the substrate.

[0060] In some embodiments, method 200 includes a step of positioning a second reactor component within the reaction chamber, wherein the second reactor component consisting essentially of boron carbide. In some embodiments, method 200 includes a step of positioning a third reactor component within the reaction chamber, wherein the third reactor component includes a boron carbide coating layer.

[0061] The first, second and third reactor components can be of many different types, such as those discussed in more detail above. In some embodiments, method 200 includes a step of positioning a support substrate on the first reactor component and growing a semiconductor layer thereon. The coefficient of thermal expansion of the semiconductor layer can be chosen to match the coefficient of thermal expansion of the first reactor component.

[0062] In some embodiments, method 200 includes a step of coating one or more of the reactor components of the reaction chamber with a boron carbide layer. The reactor component(s) include tubing, delivery lines, liquid and gas containers, inlet and outlet valves, fittings, seals, wafer boats, liners, shields, tubes, crucibles, etc.

[0063] **FIG. 6b** is a flow diagram of a method 210, in accordance with the invention, of fabricating a III-nitride semiconductor layer. In this embodiment, method 210 includes a step 211 of providing a reaction chamber and a step 212 of positioning a first reactor component, which is a single piece of boron carbide, within the reaction chamber. In accordance with the invention, the first reactor component consists essentially of boron nitride. It should be noted that the first reactor component does not include quartz, aluminum and/or aluminum nitride. Further, the first reactor component does not include a coating layer, such as a layer of silicon carbide and aluminum nitride. In some embodiments, method 220 includes a step of positioning a second reactor component within the reaction chamber, wherein the second reactor component includes a boron carbide coating layer.

[0064] In some embodiments, method 210 includes a step of fabricating the III-nitride semiconductor layer with the reaction chamber and first reactor component. For example, when the first reactor component is a heating plate, a substrate is typically positioned so that the heating plate directs heat at it, and the semiconductor layer is formed on the substrate.

[0065] **FIG. 6c** is a flow diagram of a method 215, in accordance with the invention, of fabricating a semiconductor layer. In this embodiment, method 215 includes a step 216 of providing a reaction chamber and a step 217 of positioning a reactor component, which includes boron carbide, within the reaction chamber. In some embodiments, the reactor component is a single piece of boron carbide. In other embodiments, the reactor component includes a boron carbide coating layer. For example, the reactor component can include a boron carbide coating layer formed on a reactor component body, wherein the reactor component body includes a material, such as quartz, sapphire, graphite, etc., that is not boron carbide.

[0066] In some embodiments, method 215 includes a step of fabricating the semiconductor layer with the reaction chamber and reactor component. For example, when the first reactor component is a susceptor control ring, a substrate is typically positioned so that it is carried by the susceptor control ring, and the semiconductor layer is formed on the substrate.

[0067] **FIG. 7a** is a flow diagram of a method 220, in accordance with the invention, of manufacturing a semiconductor growth system. In this embodiment, method 220 includes a step 221 of providing a reaction chamber. The reaction chamber can be of many different types, such as those discussed in more detail above.

[0068] In this embodiment, method 220 includes a step 222 of providing a first reactor component, which consists essentially of boron carbide. The first reactor component is positioned within the reaction chamber. In some embodiments, the first reactor component is a single piece of boron carbide. The first reactor component can be provided in many different ways. In some situations, it is provided to the user already manufactured and, in other situations, it is manufactured by the user. The first reactor component can be manufactured in many different ways, such as those discussed in more detail above.

[0069] It should be noted that method 220 can include many other steps. For example, in some embodiments, method 220 includes a step of providing a second reactor component. The second reactor component consists essentially of boron carbide and typically is a single piece of material. The first and second reactor components can be of many different types, such as those discussed in more detail above.

[0070] In some embodiments, method 220 includes a step of positioning a third reactor component within the reaction chamber, wherein the third reactor component includes a boron carbide coating layer. In some embodiments, method 220 includes a step of coating one or more of the reactor components of the semiconductor growth system with a boron carbide layer. The reactor component(s) include tubing, delivery lines, liquid and gas containers, inlet and outlet valves, fittings, seals, wafer boats, liners, shields, tubes, crucibles, etc.

[0071] **FIG. 7b** is a flow diagram of a method 230, in accordance with the invention, of manufacturing a semiconductor growth system. In this embodiment, method 230 includes a step 231 of providing a reaction chamber and a step 232 of providing a reactor component, which is a single piece of boron carbide, and positioning it within the reaction chamber. In accordance with the invention, the reactor component consists essentially of boron nitride. It should be noted that the reactor component does not include quartz, aluminum and/or aluminum nitride. Further, the reactor component does not include a coating layer, such as a layer of silicon carbide and aluminum nitride.

[0072] It should be noted that method 200 can include many other steps, several of which are discussed in more detail with method 210. Further, method 220 can include many other steps, several of which are discussed in more detail with method 230. Also, it should be noted that the steps in methods 200, 210, 220 and 230 can be performed in many different orders.

[0073] **FIG. 7c** is a flow diagram of a method 235, in accordance with the invention, of manufacturing a semiconductor growth system. In this embodiment, method 235 includes a step 236 of providing a reaction chamber and a step 237 of providing a reactor component, which includes boron carbide. The reactor component is positioned within the reaction chamber. In some embodiments, the reactor component is a single piece of boron carbide. In other embodiments, the reactor component includes a boron carbide coating layer. For example, the reactor component can include a boron carbide coating layer formed on a reactor component body, wherein the reactor component body includes a material, such as quartz, that is not boron carbide.

[0074] While particular embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

CLAIMS

1. A semiconductor growth system, comprising:
a reaction chamber; and
a reactor component which is a single piece of boron carbide.

2. The system of claim 1, wherein the reactor component consists essentially of boron carbide.

3. The system of claim 1, wherein the reaction chamber is a metalorganic chemical vapor deposition reaction chamber or hydride vapor phase epitaxy reaction chamber.

4. The system of claim 1, wherein the reaction chamber is a cold-wall hydride vapor phase epitaxy reaction chamber.

5. The system of claim 1, wherein the reactor component is fabricated using hot pressing.

6. The system of claim 1, wherein the reactor component is fabricated using sintering.

7. The system of claim 1, wherein the reactor component is one of a susceptor, susceptor control ring and wafer holder.

8. A semiconductor growth system, comprising:

a reaction chamber; and

a first reactor component which includes boron carbide, wherein the first reactor component is positioned within the reaction chamber.

9. The system of claim 8, wherein the first reactor component is a single piece of boron carbide.

10. The system of claim 8, wherein the first reactor component is one of a susceptor, susceptor control ring and wafer holder.

11. The system of claim 8, wherein the first reactor component includes a boron carbide coating layer.

12. The system of claim 8, wherein the first reactor component does not include quartz, sapphire, graphite and silicon carbide.

13. The system of claim 8, further including a second reactor component which includes boron carbide.

14. The system of claim 13, wherein the second reactor component is a black body heating plate.

15. The system of claim 14, wherein the black body heating plate is positioned to radiate heat towards the first reactor component.

16. A method, comprising:

providing a reaction chamber; and

positioning a reactor component, which consists essentially of boron carbide, within the reaction chamber.

17. The method of claim 16, wherein the reactor component is a single piece of boron carbide.

18. The method of claim 16, further including positioning a support substrate on the reactor component and growing a semiconductor layer thereon.

19. The method of claim 16, wherein the coefficient of thermal expansion of the semiconductor layer is chosen to match the coefficient of thermal expansion of the reactor component.

20. The method of claim 16, further including positioning a boron carbide heating plate within the reaction chamber, wherein the boron carbide heating plate radiates heat towards the reactor component.

FIG. 1

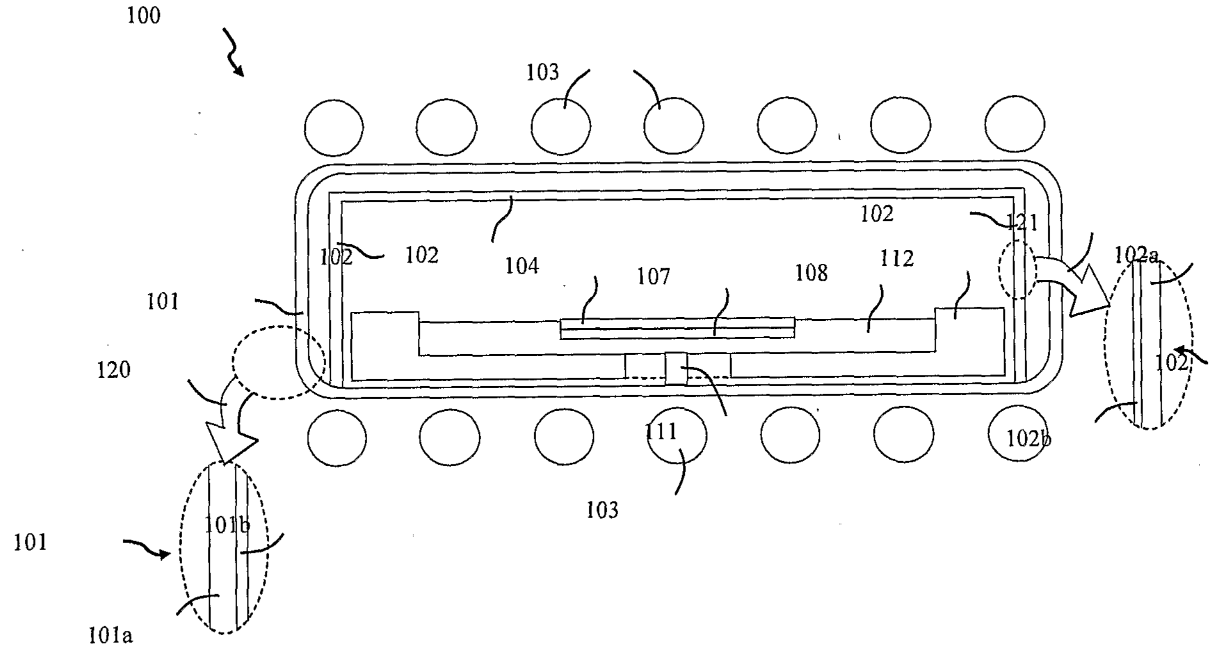

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FIG. 2a

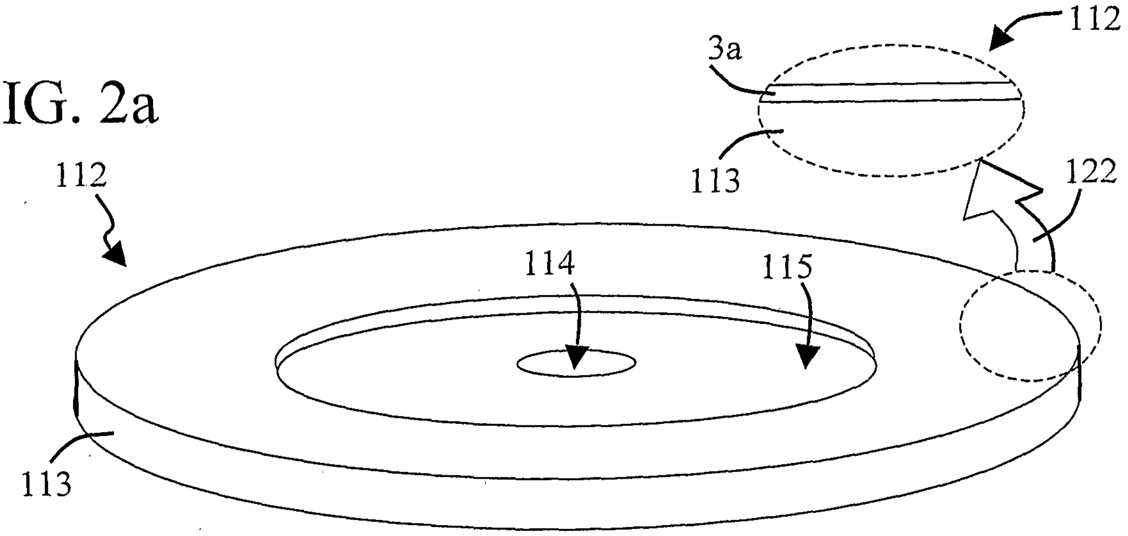


FIG. 2b

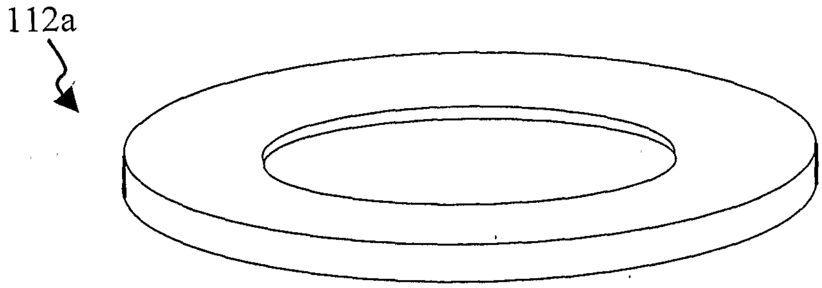


FIG. 3

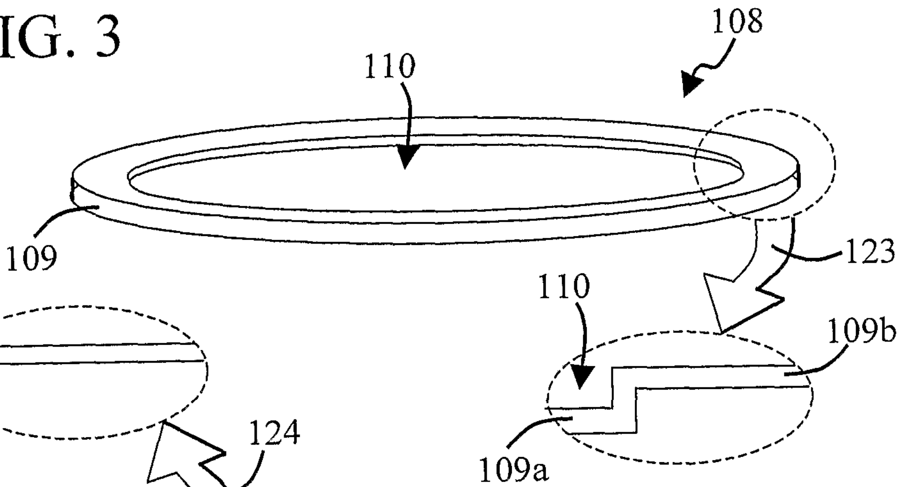


FIG. 4

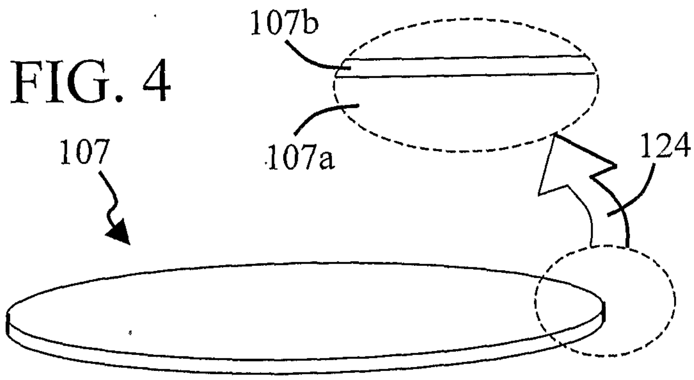


FIG. 5

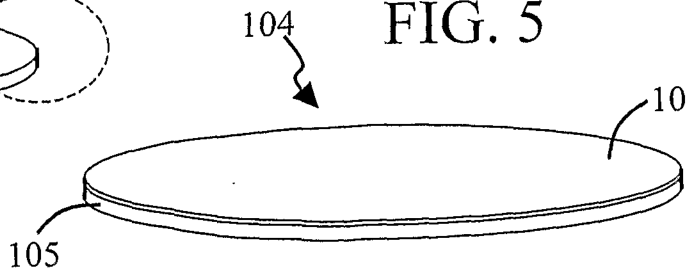


FIG. 6a

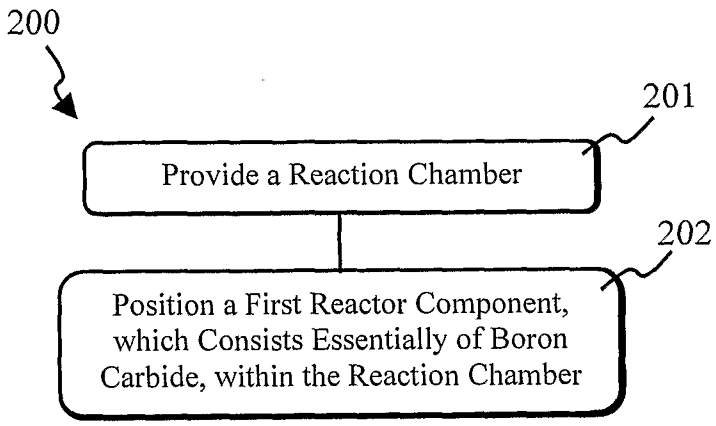


FIG. 6b

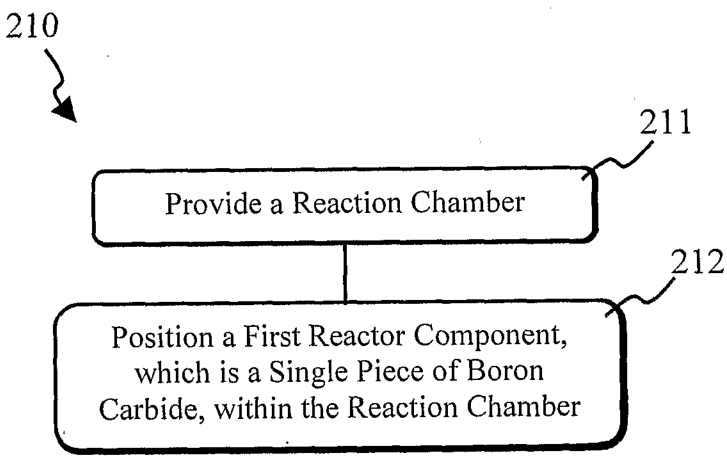


FIG. 6c

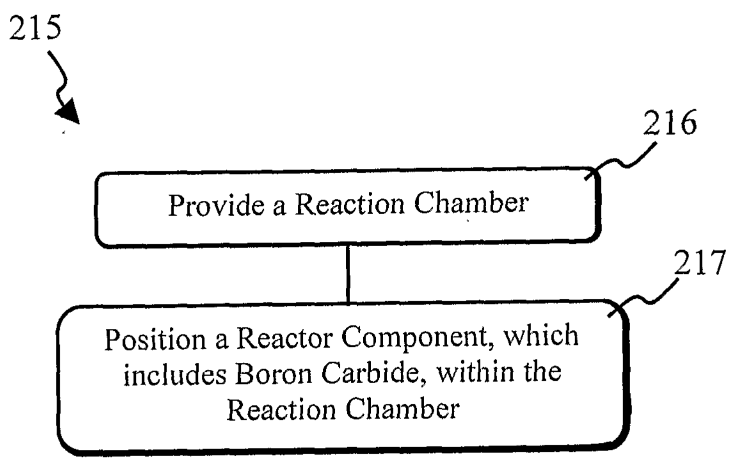


FIG. 7a

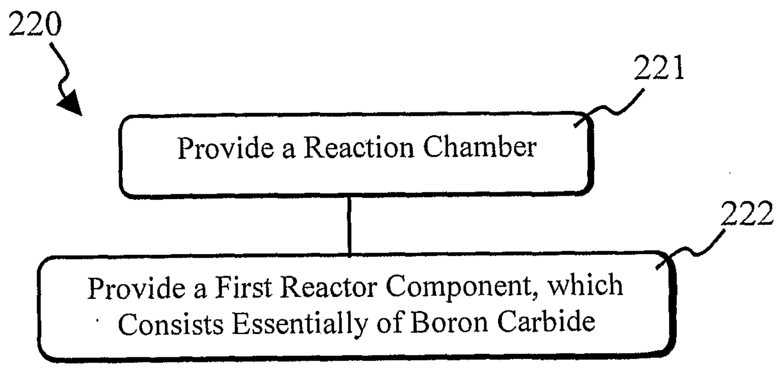


FIG. 7b

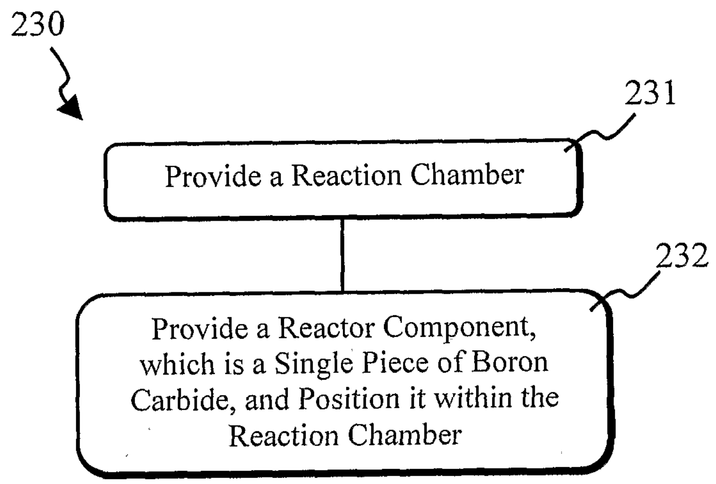
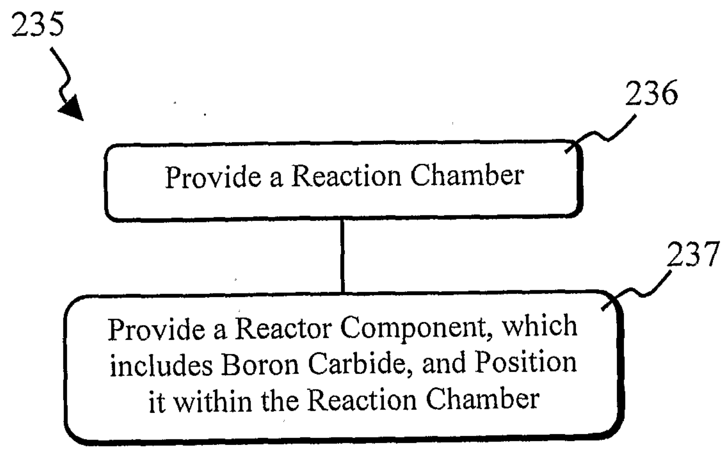


FIG. 7c



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/000226

A. CLASSIFICATION OF SUBJECT MATTER
INV. C23C16/44 C30B25/12 H01J37/32

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 C30B H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 506 254 B1 (BOSCH WILLIAM FREDERICK [US] ET AL) 14 January 2003 (2003-01-14)	1-3, 5-10,13, 16,17
Y	column 2, line 66 - column 3, line 26; claim 2; figure 6 column 5, lines 10-20 column 9, lines 8-24 -----	4,11,12, 14,15, 18,20
Y	EP 1 065 913 A (ADVANCED CERAMICS CORP [US]) 3 January 2001 (2001-01-03) paragraphs [0003] - [0005], [0009]; claims 1,2; figures 2a,2b,2c -----	4,11,12, 14,15, 18,20
A	US 6 108 190 A (NAGASAKI KOICHI [JP]) 22 August 2000 (2000-08-22) column 4, lines 34-40; figures 1A,1B -----	19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"E" earlier document 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	Date of mailing of the international search report
5 May 2009	13/05/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Fax: (+31–70) 340–3016	Hoyer, Wolfgang

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2009/000226

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			KR	20010014985	A	26-02-2001
			US	6140624	A	31-10-2000
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