WAFER CARRIER WITH HUB

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of United States Application No. 12/001,761, filed on December 12, 2007, entitled WAFER CARRIER WITH HUB, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to chemical vapor deposition apparatus.

[0003] Certain materials such as compound semiconductors are formed by exposing a surface of a workpiece, most commonly a disc-like wafer, to gases at elevated temperatures so that the gases react and deposit the desired material on the surface of the workpiece. For example, numerous layers of III-V semiconductors such as gallium nitride, indium nitride, gallium arsenide, indium phosphide and gallium antimonide and the like can be deposited onto a substrate to form electronic devices such as diodes and transistors and optoelectronic devices such as light-emitting diodes and semiconductor lasers. II-VI semiconductors can be deposited by similar processes. The properties of the finished device are profoundly influenced by minor variations in properties of the various layers deposited during the process. Therefore, considerable effort has been devoted in the art to development of reactors and processing methods which can achieve uniform deposition over a large wafer surface or over the surfaces of numerous smaller wafers held in the reactor.

[0004] One form of reactor which has been widely used in the industry is the rotating disc reactor. Such a reactor typically includes a disc-like wafer carrier. The wafer carrier has pockets or other features arranged to hold one or more wafers to be treated. The carrier, with the wafers thereon, is placed into a reaction chamber and held with the wafer-bearing surface of the carrier facing in an upstream direction. The carrier is rotated, typically at rotational velocities of several hundred revolutions per minute, about an axis extending in the upstream to downstream direction.

Reactive gases are directed in the downstream direction towards the wafers on the carrier from an injector head positioned at the upstream end of the reactor. The wafer carrier is maintained at a desired elevated temperature, most commonly about 350°C to about 1600°C during this process. The rotation of the wafer carrier helps to assure that all areas of the exposed wafers are exposed to substantially uniform conditions and that helps to assure uniform deposition of the desired semiconductor material. After the wafers on a particular wafer carrier have been treated, the wafer carrier is removed from the reaction chamber and replaced by a new wafer carrier bearing new wafers and the process is repeated with the new wafer carrier.

[0005] Many rotating disc reactor designs incorporate a spindle with a disc-like metallic element, referred to as a "susceptor" permanently mounted on the spindle. The wafer carrier to be treated is disposed on the susceptor and held by the susceptor during the treatment process. Heating elements such as electrical resistance elements disposed downstream of the susceptor heat the susceptor and the wafer carrier during the process. More recently, as disclosed in United States Patent No. 6,685,774, the disclosure of which is incorporated by reference herein, "susceptorless" reactors have been developed. In a susceptorless reactor, the wafer carrier is mounted directly onto the spindle of the reactor when the wafer carrier is placed into the reactor chamber for treatment. The surface of the wafer carrier facing downstream is directly exposed to the heating elements. The susceptorless reactor design provides significantly improved heat transfer from the heating elements of the reactor to the wafer carrier and significantly improved uniformity of heat transfer to all areas of the wafer carrier.

[0006] A wafer carrier for a susceptorless reactor must incorporate features which allow the wafer carrier to mechanically engage the spindle when the wafer carrier is placed into the reaction chamber. Such engagement must be provided without damaging the spindle or the wafer carrier.

Moreover, the wafer carrier must be formed from materials which retain substantial strength and rigidity at the elevated temperatures employed and which do not react with the gases employed in the process. Although satisfactory wafer carriers for susceptorless reactors can be formed from materials such as silicon carbide-coated ceramic materials, still further improvement would be desirable.

SUMMARY OF THE INVENTION

[0007] One aspect of the invention provides a wafer carrier for a CVD reactor. The wafer carrier desirably includes a plate of a non-metallic refractory material, preferably a ceramic material such as silicon carbide. The plate has oppositely-facing upstream and downstream surfaces, and has a central region and a peripheral region. The plate has wafer-holding features adapted to hold a plurality of wafers exposed at the upstream surface of the plate in the peripheral region. The wafer carrier according to this aspect of the invention desirably also includes a hub attached to the plate in the central region, the hub having a spindle connection adapted to engage a spindle of a CVD reactor so as to mechanically connect the plate with the spindle. The spindle connection of the hub is preferably adapted to removably engage the spindle. The hub may be formed at least in part from one or more materials other than the material of the plate. For example, the hub may include metallic elements. The hub may also include an insert formed from a relatively soft material such as graphite defining the spindle connection. In another example, the plate may include an opening in the central region, and the insert may be received within the opening. In one example, the insert may be press fit into the opening. A cap, preferably formed from silicon carbide, may also be provided partially overlying a portion of the upstream surface of the plate in the central region. In another example, the cap may be secured to the insert. For example, the cap and the insert may each include threads configured to engage one another. In operation, the hub mechanically connects the plate to the spindle without

imposing potentially damaging concentrated loads on the plate. Desirably, the hub is removably attached to the plate.

[0008] A further aspect of the invention provides a chemical vapor deposition reactor incorporating a wafer carrier as discussed above, together with additional elements such as a reaction chamber, a spindle mounted within the reaction chamber for rotation about an axis extending generally in the upstream to downstream direction, an injector head for introducing one or more reaction gases into the reaction chamber, and one or more heating elements surrounding the spindle. The spindle connection of the wafer carrier is adapted to mount the wafer carrier on the spindle with the upstream surface of the plate facing toward the injector head and with the downstream surface of the plate facing toward the one or more heating elements. Preferably, when the wafer carrier is mounted on the spindle, the downstream surface of the plate in the peripheral region of the plate directly confronts the heating elements. Stated another way, the hub preferably does not extend between the peripheral region of the plate downstream surface and the heating elements. Thus, the hub does not interfere with radiant heat transfer between the heating elements and the plate.

[0009] Yet another aspect of the invention provides methods of treating wafers. A method according to this aspect of the invention desirably includes the steps of processing a plurality of wafer carriers, each including a hub and a plate removably attached to the hub, by engaging the hub of each wafer carrier with a spindle of a processing apparatus and rotating the spindle and wafer carrier while treating wafers carried on the plate, and removing wafers from each wafer carrier after that wafer carrier has been processed. The treatment preferably includes a chemical vapor deposition process. These steps desirably are repeated using new wafers. The method according to this aspect of the invention most desirably includes the further step of renewing each wafer carrier by removing the hub from the plate, then cleaning the plate, and then reassembling the plate with the same or a

different hub. The step of cleaning the plate may include etching the plate. Because the hub is removed from the plate before cleaning, the steps used to clean the plate may include treatments which would attack the hub.

[0010] Another aspect of the invention provides a wafer carrier for a CVD reactor. The wafer carrier desirably includes a plate having oppositely-facing upstream and downstream surfaces, and has a central region and a peripheral region. The plate has wafer-holding features adapted to hold a plurality of wafers exposed at the upstream surface of the plate in the peripheral region. The wafer carrier according to this aspect of the invention desirably also includes a gas flow facilitating element projecting from the upstream surface of the plate in the central region. The plate may have a central axis, and the gas flow facilitating element desirably has a perimeter surface in the form of a surface of revolution about the central axis.

[0011] A further aspect of the invention provides a chemical vapor deposition reactor incorporating a wafer carrier as discussed above, together with additional elements such as a reaction chamber, a spindle mounted within the reaction chamber for rotation about an axis extending generally in the upstream to downstream direction, and an injector head for introducing one or more reaction gases into the reaction chamber. The spindle connection of the wafer carrier is adapted to mount the wafer carrier on the spindle with the upstream surface of the plate facing toward the injector head and with the gas flow facilitating element lying along the axis. The reactor is configured to direct one or more reaction gasses in the downstream direction toward the wafer carrier and the gas flow facilitating element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a diagrammatic view of a reactor and associated wafer carrier in accordance with one embodiment of the invention.

[0013] FIG. 2 is a view similar to FIG. 1 depicting the system in a different operating state.

[0014] FIG. 3 is diagrammatic top plan view depicting the wafer carrier used in the system of FIGS. 1 and 2.

[0015] FIG. 4 is a fragmentary sectional view taken along line 4-4 in FIG. 3.

[0016] FIG. 5 is a fragmentary partially sectional view depicting portions of a wafer carrier in accordance with a further embodiment of the invention.

[0017] FIG. 6 is a view similar to FIG. 4 but depicting portions of a wafer carrier in accordance with yet another embodiment of the invention.

[0018] FIGS. 7 and 8 are fragmentary diagrammatic sectional views depicting wafer carriers, in accordance with further embodiments of the invention.

[0019] FIG. 9 is a perspective sectional view of a wafer carrier in accordance with another embodiment of the invention.

[0020] FIG. 10 is a fragmentary sectional view depicting portions of the wafer carrier of FIG. 9.

[0021] FIG. 11 is a diagrammatic exploded perspective view of components used in yet another embodiment of the invention.

[0022] FIG. 12 is a sectional view of the components of FIG. 11.

[0023] FIG. 13 is a fragmentary sectional view depicting portions of a wafer carrier in accordance with a further embodiment of the invention.

DETAILED DESCRIPTION

[0024] A susceptorless reactor system according to one embodiment of the invention incorporates a reaction chamber 10. Chamber 10 has a gas injector head 12 at its upstream end and an exhaust connection 14 open to the interior of the chamber adjacent its downstream end. Reaction chamber 10 is equipped with a spindle 16 having its axis 18 extending generally in the upstream to downstream direction of the chamber. Spindle 16 is connected to a motor drive 20 for rotating the spindle about axis 18. The spindle is equipped with a suitable vacuum seal (not shown). A heating device 22 is mounted within chamber 10 in a fixed position so that the heating device surrounds

spindle 16 adjacent its upstream end. By way of example, heating device 22 may include one or more electrical resistance heaters, one or more elements suitable for receiving RF energy and converting the same to heat or essentially any other device capable of evolving heat without contaminating the interior of chamber 10.

[0025] The interior of chamber 10 is connected to the interior of a preload chamber 24 by a loading lock 26. Lock 26 is equipped with a gas-tight shutter which can be selectively opened to permit communication between chambers 10 and 24 and closed to block such communication. The preload chamber 24 is provided with an appropriate loading door (not shown) so that wafer carriers can be placed into the preload chamber and removed therefrom. Also, the preload chamber 24 is connected to an atmospheric control system (not shown) so that an atmosphere corresponding to the atmosphere within chamber 10 can be provided within chamber 24. Chambers 10 and 24 are provided with an appropriate robotic handling device (not shown) for moving wafer carriers between the chambers and for placing wafer carriers onto spindle 16 and removing the wafer carriers from the spindle.

[0026] The system further includes one or more wafer carriers 30. As discussed in greater detail below, each wafer carrier includes unitary plate or body 32 defining an upstream surface 34 and an oppositely facing downstream surface 36. The upstream surface 34 is provided with features such as pockets 38 arranged to hold wafers so that the surfaces of the wafers face generally upstream. Each wafer carrier also includes a hub 40 exposed adjacent the center of body 32, the hub 40 being adapted to mate with the upstream end of spindle 16. In the loading position depicted in FIG. 1, a wafer carrier 34 with wafers in pockets 38 is disposed within chamber 24. In the operative, deposition position depicted in FIG. 2, the same wafer carrier 30 is disposed within reaction chamber 10 and is engaged on spindle 16. While the wafer carrier is in the active or deposition position depicted in FIG. 2, the body 32 of the wafer carrier overlies heating

elements 22. In this condition, the heating elements are operated to heat the wafer carrier to the desired elevated temperature. Spindle 16 is rotated so as to thereby rotate the wafer carrier and the wafers thereon about axis 18. Reactive gases pass downstream from injector head 12 and pass over the upstream facing surface of the wafer carrier and over the surfaces of the wafers disposed in the pockets of the wafer carrier. The gases react at the surfaces of the wafers, thereby forming the desired material on the surfaces of the wafers. Merely by way of example, in a deposition process for forming a III-V semiconductor, the reactive gases may include first and second gases. The first gas may include one or more organometallic compounds, most typically metal alkyls selected from the group consisting of gallium, indium and aluminum alkyls, in admixture with a carrier gas such as nitrogen or hydrogen. The second gas may include one or more hydrides of a group V element, such as ammonia or arsine, and may also include one or more carrier gases. Following deposition, the wafer carrier with the finished wafers is returned to preload chamber 24 and a different wafer carrier with new wafers is placed onto the spindle 16. The features of the deposition apparatus apart from the wafer carrier and the related mating features of the spindle may be generally similar to those disclosed in the aforementioned United States Patent No. 6,685,774, the disclosure of which is hereby incorporated by reference herein.

[0027] As best seen in FIGS. 3 and 4, wafer carrier 30 has a central axis 42 which is coincident with the axis 18 of the spindle when the wafer carrier is mounted on the spindle. Plate 32 is a plate of one or more refractory materials, preferably one or more non-metallic refractory materials. As used in this disclosure, the term "non-metallic" material includes compounds of metals with non-metals, such as oxides, nitrides and carbides of metals, and also includes carbon and other non-metallic elements and compounds thereof. Also, as used in this disclosure, a plate "of" one or more materials should be understood as referring to a plate in which the one

or more materials constitute at least the majority of the thickness of the plate over at least the majority of the area of the plate, and in which the one or more materials contribute at least a substantial portion of structural strength of the plate. Thus, unless otherwise specified, a plate of one or more non-metallic materials may include minor layers or other minor features formed from other materials. The material of the plate desirably is resistant to the temperatures and chemical environment encountered in the wafer processing operation and in operations used to clean the wafer carrier. Although the material of the plate should have substantial structural strength, it may be a brittle material with high sensitivity to localized stresses. As explained below, the structure of the wafer carrier desirably protects the plate from high localized stresses imposed by the spindle in use. Non-metallic refractory materials selected from the group consisting of silicon carbide, boron nitride, boron carbide, aluminum nitride, alumina, sapphire, quartz, graphite, and combinations thereof are preferred. Most desirably, the plate is a unitary slab of a single non-metallic refractory material. Unitary plates formed from silicon carbide are particularly preferred. In some cases, the plate may include a coating. The coating material desirably is resistant to the temperatures and chemicals encountered in use and cleaning of the wafer carrier as, for example, a coating of a metal carbide, oxide or nitride such as titanium carbide or tantalum carbide. Such a coating is particularly desirable where plate is formed from graphite.

[0028] Although the upstream and downstream surfaces 34 and 36 are depicted as completely planar surfaces apart from the pockets 38 in upstream surface 34, this is not essential. The thickness of plate 32 can vary over a wide range. However, in one example, plate 32 has an outside diameter of about 300 mm and is about 8 mm thick.

[0029] Plate 32 has a central region 44 encompassing central axis 42 and a peripheral region surrounding the central region 44. Although the border of central region 44 is

depicted in broken lines in FIG. 3 for illustrative purposes, there may not be a visible boundary between the central region and the peripheral region. The wafer engaging features or pockets 38 are disposed in the peripheral region of the plate 32. Plate 32 has a central bore 46 extending through the plate from upstream surface 34 to downstream surface 36 in the central region so that the central bore encompasses the axis 42.

[0030] Hub 40 most preferably is removably attached to the central region of plate 32. Hub 40 includes an upstream hub element 48 having a generally cylindrical portion received in central bore 46 of plate 32 and also having a flange 50 overlying a portion of the upstream surface 34 of the plate immediately surrounding the central bore. Hub 40 further includes a downstream hub element 52 having a generally cylindrical portion extending into central bore 46 and having a flange 54 which overlies a portion of the downstream surface 36 of plate 32 within the central region of the plate. Hub elements 48 and 52 have a slight clearance fit within central bore 46. For example, the outside diameters of the hub elements (apart from the flanges) may be about 25 microns (.001 inches) or so smaller than the inside diameter of central bore 46. Hub elements 48 and 52 are held together and urged toward one another by fasteners such as screws 56, of which only one is visible in FIG. 4, spaced around central axis 42. Thus, flanges 50 and 54 are forcibly engaged with the upstream and downstream surfaces 34 and 36 of plate 32. The hub elements may be formed from materials other than the materials of the plate. Hub elements 50 and 52 desirably are formed from metals which can survive the temperatures to be encountered in service and which will not corrode or contaminate the interior of the reaction chamber during use. For example, the hub elements may be formed from metals selected from the group consisting of molybdenum, tungsten, and rhenium, combinations of these metals and alloys of these metals. In other embodiments, the hub elements may be formed from the same materials as the plate.

[0031] Hub 40 further includes an insert 58 defining a tapered hole with an open end facing in the downstream direction (toward the bottom of the drawing in FIG. 4), the hole having an interior diameter which decreases progressively in the upstream direction. Insert 58 desirably is formed from a material which can withstand the temperatures attained during service, but which is somewhat softer than the materials used to form the hub elements 48 and 52. For example, insert 58 may be formed from graphite. Insert 58 is retained within hub elements 48 and 52 by an insert retainer plate 62 which in turn is fastened to the downstream hub element 52 by one or more screws.

[0032] In the operative, deposition position depicted in FIGS. 2 and 4, the wafer carrier 30 is mounted on spindle 16. Spindle 16 has a tapered end 66, and this tapered end is received within the tapered hole 60 of the insert. In the particular embodiment illustrated, the included angle of tapered end 66 is slightly less than the included angle of tapered hole 60 in the insert, so that the spindle engages insert 58 only at the extreme upstream end of the spindle and there is a slight clearance fit around tapered end 66 near the downstream or opened end of hole 60. In the operative position, the downstream surface 36 of plate 32 confronts the heating elements 22 of the reaction chamber. Because the hub 40, and particularly the downstream hub element 54 is disposed only within the central region of the plate 32, the downstream surface 36 of plate 32 within the peripheral region is not covered by the hub. Thus, as seen in FIG. 4, the downstream surface 36 plate in the peripheral region directly confronts the heating elements 22, with no solid structures intervening between the downstream surface 36 of the plate peripheral region and the heating elements 22. Thus, there is a direct path for radiant heat transfer from the heating elements to the peripheral region of the plate. This promotes efficient heat transfer between heating elements 22 and plate 32. Stated another way, the hub 40 does not extend between the heating elements and the downstream surface of the

plate in the peripheral regions and does not interfere with heat transfer from the heating elements to the plate. Use of a hub tends to retard heat transfer from the plate to spindle 16. Thus, as best seen in FIG. 4, there are physical interfaces between the plate 32 and the hub elements 48 and 52, an additional interface between the hub elements and insert 58, and yet a further interface between the insert 58 and spindle 16. All of these interfaces have the desirable effect of reducing heat transfer from the plate to the spindle.

[0033] The use of a solid plate such as a solid plate of a non-metallic refractory material such as silicon carbide or other materials having high thermal conductivity provides significant advantages. The solid plate tends to promote temperature uniformity. A solid silicon carbide plate can be fabricated with a well-controlled surface morphology. Also, a solid silicon carbide plate is durable and can be subjected to cleaning processes such as wet etching to remove materials deposited on the plate during wafer processing. The hub may be detached from the plate prior to any such cleaning processes. Typically, the apparatus includes numerous wafer carriers, so that some wafer carriers are available for treating wafers while others are being cleaned. Depending on process conditions, the cleaning process can be performed after each use of the wafer carrier to treat a batch of wafers, or can be performed less frequently. Also, after cleaning, the plate may be reassembled with the same hub or with another similar hub to provide a renewed wafer carrier.

[0034] The hub provides a secure mounting for the plate on the spindle of the reaction chamber. Because the spindle does not directly engage the plate, the spindle does not tend to crack the plate during use. This can be significant when using a plate formed from a brittle material, such as solid silicon carbide. Heretofore it was not feasible to construct rotating wafer carrier plates from solid silicon carbide because the spindle would tend to cause the plate to crack during use. This tendency to crack would be exacerbated by a tapered spindle, which increases significantly the localized stresses

imposed on the wafer carrier. However, the use of a hub, such as disclosed in the present application, allows for wafer carrier plates formed from solid silicon carbide to be used in rotating disk reactors with less risk of damage to the plates.

[0035] The relatively soft material of insert 58 assures that the spindle of the reaction chamber will not be damaged when the wafer carrier is engaged with the spindle. Although insert 58 may become worn with repeated use of the wafer carrier, the insert 58 can be readily removed and replaced.

[0036] Numerous variations and combinations of the features discussed above may be employed. For example, as seen in FIG. 5, a hub element 152 which extends within the central bore 146 of the plate may be provided with a polygonal exterior surface 153 so as to provide relatively large clearances 155 between the hub element and the surface of central bore 146 except at the corners of the polygonal element. This arrangement further reduces conductive heat transfer from plate 132 to the hub element 152. Other shapes such as fluted or splined shapes may be used to provide a similar reduction in conductive heat transfer. Likewise, the surfaces of flanges 50 and 54 (FIG. 4) which are in contact with the surfaces of the plate may be ridged or fluted so as to reduce conductive heat transfer between the plate and the hub and thus reduce conductive heat transfer to the spindle.

[0037] It is not essential to provide a central bore in the plate. Thus, as shown in FIG. 6, a plate 232 is provided with a set of small bores 233 extending between its upstream and downstream surfaces in the central region. An upstream hub element 248 and downstream hub element 252 are provided on the upstream and downstream surfaces of plate 232 and connected to one another by bolts 256 extending through holes 233. In this arrangement as well, the hub is removably attached to the plate. As used in this disclosure with reference to a plate and hub, the term "removably attached" means that the hub can be removed from the plate without damaging the plate and without damaging the major structural elements of the hub. Removable attachments other than bolted attachments can be

used. For example, the removable attachment may include pins, wedges, clips or other mechanical fastening arrangements. Also, the connection between the hub and the spindle may not incorporate a tapered fitting as discussed above with reference to FIG. 4. Thus, in the embodiment of FIG. 6, the hub has an insert 258 with a set of recesses that engage mating pins 266 on the end of the spindle 106. Any other type of mechanical connection between the hub and the spindle can be employed.

[0038] In the embodiment discussed above with reference to FIGS. 1-4, the upstream hub element has a low, flat profile. However, as seen in FIG. 6, the upstream hub element 248 may have a domed shape so as to facilitate gas flow in the vicinity of the central axis 242. Other shapes to facilitate gas flow may be used. For example, as shown in FIG. 7, upstream element 348 may include a concave shaped perimeter surface 368 which approaches a sharp tip 370 at its upstream end. Perimeter surface 368 desirably is a surface of revolution about axis 342. Such a design may help the flow of reactive gases from the incident direction D be redirected along the upstream surface 334 of the wafer carrier 330 and away from the flow discontinuity created at the center of the rotating wafer carrier 330. In another example, the upstream element 448 may include a convex shaped perimeter surface 468, such as the generally parabolic shape of the perimeter surface 468 illustrated in FIG. 8. Surface 468 desirably is also in the form of a surface of revolution about the central axis.

[0039] As the wafer carrier is rotating rapidly, the upstream surface of the wafer carrier is moving rapidly. The rapid motion of the wafer carrier entrains the gases into rotational motion around central axis 342, and radial flow away from axis 342, and causes the gases to flow outwardly across the upstream surface of the wafer carrier within a boundary layer. Of course, in actual practice, there is a gradual transition between the generally downstream flow regime denoted by the arrow D and the flow in the boundary layer. However, the boundary layer can be regarded as the region in which the gases flow substantially parallel to the upstream surface of

the wafer carrier. Under typical operating conditions, the thickness of the boundary layer is about 1 cm or so. In some embodiments of the present invention, the height H of the upstream element may be shorter than the boundary layer. In other embodiments, the height H of the upstream element may be taller than the boundary layer.

[0040] In an alternative embodiment, one or both of the hub elements may directly engage the spindle without an intervening insert. In yet another embodiment, an insert may serve as the hub element. For example, referring to FIG. 9, plate 532 has a central bore 546 extending through the plate 532 from upstream surface 534 to downstream surface 536. Insert 572 is received within the bore 546. As shown in FIG. 10, the insert 572 has a generally cylindrical portion received in central bore 546 of plate 532. Insert 572 also has a flange 554 engaging the downstream surface 536 of the plate 532 immediately surrounding the central bore 546. The insert 572 is preferably press fit into the bore 546 in order to create a secure connection between the insert 572 and the plate 532. For example, the outside diameter of the insert 572 (apart from the flange) may be slightly larger than the inside diameter of central bore 546, such as, for example, on the order of a thousandth of a centimeter larger. In one example, the insert 572 may be inserted into the bore 546 by heating the plate 532, for example to 300°C, to expand the plate 532, including the bore 546. The insert 572 may be formed from materials other than the materials of the plate 532. Desirably, the insert 572 is formed from materials which can survive the temperatures to be encountered in service and which will not corrode or contaminate the interior of the reaction chamber during use. It is preferred that the insert 572 has a thermal expansion coefficient which is equal to or greater than that of the plate 532, so that the insert 572 may continue to remain secured within the bore 546, even at elevated temperatures. The insert 572 is also preferably relatively soft so that the spindle of the reaction chamber will not be damaged when the wafer carrier is engaged with the spindle. In

a preferred embodiment, the insert 572 may be formed from graphite. Although the insert 572 may become worn with repeated use of the wafer carrier, the insert 572 can be readily removed and replaced.

[0041] A cap 574 may be included having a solid planar top portion 576 with a flange 577 partially overlying the upstream surface 534 of the plate 532 in the region immediately surrounding the central bore 546. The cap 574 includes a portion 578 protruding downwardly from the top portion 576. Portion 578 is received within central bore 546. Like the insert 572, the protruding portion 578 of the cap 574 is also preferably press fit into the bore 546. The cap 574 desirably protects the insert material from contact with the corrosive gases injected into the reaction chamber. The cap 574 also preferably evens out some of the disruption to the gas flows caused by the bore 546 through the upstream surface 534. For example, the cap 574 may have an upstream surface as discussed above with reference to FIGS. 6-8. Desirably, the cap 574 is formed from materials which can survive the temperatures to be encountered in service and which will not corrode or contaminate the interior of the reaction chamber during use. In a preferred embodiment, the cap 574 may be formed from silicon carbide.

[0042] In another alternative embodiment, the cap and the insert may be secured to one another. For example, referring to FIGS. 11 and 12, the generally cylindrical portion of insert 672 may have a threaded portion 680 thereon which is configured to threadedly engage a threaded portion 682 on the protruding portion 678 of cap 674. The protruding portion 678 of cap 674 has an open interior portion 684, which is configured to receive a portion of insert 672 therein. The insert 672 may thus be secured to the wafer carrier plate by inserting the insert 672 into the central bore from the downstream side and inserting the cap 674 into the bore from the upstream side, whereupon the insert 672 and cap 674 are threadedly engaged with one another. By progressively threading the cap 674 onto the insert 672, the insert 672 will be further received within

the open interior portion of the cap 674, which, in turn, will cause the flange 654 of the insert 672 to approach the flange 677 of the cap 674. Continued threading of the cap 674 onto the insert 672 will cause the flanges 654 and 677 to become forcibly engaged with the upstream and downstream surfaces of the wafer carrier plate, thus securing the insert 672 and cap 674 to the wafer carrier plate. Therefore, in this embodiment, the insert and cap need not be press fit into the central bore of the wafer carrier plate. Furthermore, the cap and the insert need not be threadedly secured to one another. Other forms of securing the cap to the insert may be employed. For example, the cap and insert may be bolted to one another in a manner similar to that illustrated in FIG. 6. In such an embodiment, small bores may be provided in either the insert or the cap or both, and bolts may extend through the bores to connect the insert and cap together. For example, the bores in either the insert or the cap may include threads which are configured to engage threads provided on the bolts. In another alternative, the bolts may extend through both components, and nuts may be provided which are tightened onto threaded ends of the bolts.

[0043] In yet a further embodiment, the central bore in the plate need not extend all the way through the wafer carrier plate from the upstream surface to the downstream surface. For example, as shown in FIG. 13, central bore 746 extends into plate 732 from downstream surface 736 towards upstream surface 734, leaving a central portion 786 of the plate 732 overlying the bore 746 along the upstream surface 734. As described above with respect to the embodiment illustrated in FIGS. 9 and 10, the insert 772 of this embodiment may be press fit into the bore 746. No cap is needed in this embodiment, as the central portion 786 overlying the bore 746 preferably protects the insert material from contact with the corrosive gases injected into the reaction chamber. The central portion 786 also provides a continuous upstream surface 734 of the plate 732, which preferably minimizes disruption to the gas flows over the surface 734.

[0044] As shown FIGS. 9-13, the insert may define a tapered hole with an open end facing in the downstream direction, similar to the embodiment illustrated in FIG. 4. In conjunction with such a tapered insert, a spindle with a tapered end may be used. In one example, the included angle of the tapered end of the spindle may be slightly less than the included angle of the hole in the insert, so that the spindle engages the insert only at the extreme upstream end of the spindle and so that there is a slight clearance fit around the tapered end of the spindle near the downstream or opened end of the hole. Furthermore, any of the embodiments disclosed above may also include an upstream element, as described above, having one of a variety of shapes to facilitate gas flow. For example, an upstream element having a specific profile may be attached to or integrally formed on the upstream surface of the hub, cap, or wafer carrier plate along the central axis of rotation. As these and other variations and combinations of the features discussed above can be utilized without departing from the present invention, the foregoing description of the preferred embodiment should be taken by way of illustration rather than by way of limitation of the invention as defined by the claims.

[0045] 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 is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

CLAIMS

1. A wafer carrier for a CVD reactor comprising:

(a) a plate of a non-metallic refractory material having oppositely-facing upstream and downstream surfaces, the plate having a central region and a peripheral region, the plate having wafer-holding features adapted to hold a plurality of wafers exposed at the upstream surface of the plate in the peripheral region; and

(b) a hub formed separately from the plate, the hub being attached to the plate in the central region, the hub having a spindle connection adapted to engage a spindle of a CVD reactor so as to mechanically connect the plate with the spindle.

2. A wafer carrier as claimed in claim 1 wherein the non-metallic refractory material is selected from the group consisting of silicon carbide, boron nitride, boron carbide, aluminum nitride, alumina, sapphire, quartz, graphite, and combinations thereof.

3. A wafer carrier as claimed in claim 1 wherein the non-metallic refractory material consists essentially of silicon carbide.

4. A wafer carrier as claimed in claim 1 wherein the plate is a unitary slab formed entirely from the non-metallic refractory material.

5. A wafer carrier as claimed in claim 4 wherein the non-metallic refractory material is silicon carbide.

6. A wafer carrier as claimed in claim 1 wherein the plate includes a coating covering the non-metallic refractory material at least on the upstream surface of the plate.

7. A wafer carrier as claimed in claim 6 wherein the coating is formed from a material selected from the group consisting of titanium carbide and tantalum carbide.

8. A wafer carrier as claimed in claim 1 wherein the hub is formed at least in part from one or more materials other than the non-metallic refractory material of the plate.

9. Chemical vapor deposition apparatus comprising a reaction chamber, a spindle mounted within the reaction chamber for rotation about an axis extending generally in an upstream to downstream direction, an injector head for introducing one or more reaction gases into the reaction chamber, and one or more heating elements surrounding the spindle, the apparatus further comprising a wafer carrier as claimed in claim 1, the connection of the wafer carrier being adapted to mount the wafer carrier on the spindle with the upstream surface of the plate facing toward the injector head and with the downstream surface of the plate facing toward the one or more heating elements.

10. Apparatus as claimed in claim 9 wherein, when the wafer carrier is mounted on the spindle, the downstream surface of the plate in the peripheral region of the plate directly confronts the heating elements.

11. A method of processing wafers comprising the steps of:

(a) processing a plurality of wafer carriers, each including a hub and a plate removably attached to the hub, by engaging the hub of each wafer carrier with a spindle of a processing apparatus and rotating the spindle and wafer carrier while treating wafers carried on the plate;

(b) removing wafers from each wafer carrier after that wafer carrier has been processed;

(c) repeating steps (a) and (b) with each wafer carrier using new wafers; and

(d) renewing each wafer carrier by removing the hub from the plate, then cleaning the plate, and then reassembling the plate with the same or a different hub.

12. A method as claimed in claim 11 in which the step of cleaning the plate includes etching the plate.

13. A method as claimed in claim 11 wherein the step of treating the wafers includes performing a chemical vapor deposition process.

14. A wafer carrier for a CVD reactor comprising a plate of a non-metallic refractory material having oppositely-facing upstream and downstream surfaces, the plate having a central region and a peripheral region, the plate having wafer-holding features adapted to hold a plurality of wafers exposed at the upstream surface of the plate in the peripheral region, wherein the plate is a unitary slab consisting essentially of silicon carbide.

15. A wafer carrier as claimed in claim 14 wherein the wafer carrier has a spindle connection adapted to engage a spindle of a CVD reactor so as to mechanically connect the plate with the spindle.

16. A wafer carrier as claimed in claim 15 wherein the spindle connection is adapted to removably engage the spindle.

17. A wafer carrier as claimed in either claim 1 or claim 16, wherein the downstream surface faces in a downstream direction, and wherein the spindle connection includes a socket having a hole with an open end facing in the downstream direction.

18. A wafer carrier as claimed in claim 17 wherein the upstream surface faces in an upstream direction, and wherein the hole is tapered such that a diameter of the hole decreases progressively in the upstream direction.

19. A wafer carrier as claimed in claim 14 further comprising a hub formed separately from the plate, the hub being attached to the plate in the central region, the hub having a spindle connection adapted to engage a spindle of a CVD reactor so as to mechanically connect the plate with the spindle.

20. A wafer carrier as claimed in claim 19 wherein the hub is formed at least in part from a material other than silicon carbide.

21. A wafer carrier as claimed in either claim 8 or claim 20, wherein the hub is formed at least in part from one or more metals.

22. A wafer carrier as claimed in claim 21 wherein said one or more metals are selected from the group consisting of molybdenum, tungsten, rhenium, combinations thereof, and alloys thereof.

23. A wafer carrier as claimed in claim 21 wherein the hub includes an insert at least partially defining the spindle connection, the insert being formed from an insert material softer than said one or more metals.

24. A wafer carrier as claimed in claim 23 wherein the insert material consists essentially of graphite.

25. A wafer carrier as claimed in either claim 8 or claim 20, wherein the hub comprises an insert at least partially defining the spindle connection, and wherein the plate includes an opening in the central region, the insert being received within the opening.

26. A wafer carrier as claimed in claim 25 wherein the insert is press fit into the opening.

27. A wafer carrier as claimed in claim 25, wherein the insert is formed from graphite.

28. A wafer carrier as claimed in claim 25 wherein the opening in the central region extends between the upstream and downstream surfaces.

29. A wafer carrier as claimed in claim 28 further including a cap at least partially overlying a portion of the upstream surface of the plate in the central region.

30. A wafer carrier as claimed in claim 29 wherein the cap is formed from silicon carbide.

31. A wafer carrier as claimed in claim 29 wherein the cap is secured to the insert.

32. A wafer carrier as claimed in claim 31 wherein the cap and the insert each include threads thereon, the threads of the cap being configured to engage the threads of the insert.

33. A wafer carrier as claimed in either claim 1 or claim 19, wherein the hub is removably attached to the plate.

34. A wafer carrier as claimed in either claim 1 or claim 19, wherein the hub includes an upstream hub element, at least a part of the upstream hub element overlying a portion of the upstream surface of the plate in the central region and a downstream hub element, at least a part of the downstream hub element overlying a portion of the downstream surface of the plate in the central region so that at least a part of the central region of the plate is clamped between the upstream and downstream hub elements.

35. A wafer carrier as claimed in claim 34 wherein the plate has a central bore extending between the upstream and downstream surfaces in the central region, and at least one of the hub elements projects into the central bore.

36. A wafer carrier as claimed in either claim 1 or claim 14, wherein the plate is substantially circular.

37. A wafer carrier for a CVD reactor comprising:

(a) a plate having oppositely-facing upstream and downstream surfaces, the plate having a central region and a peripheral region, the plate having wafer-holding features adapted to hold a plurality of wafers exposed at the upstream surface of the plate in the peripheral region; and

(b) a gas flow facilitating element projecting from the upstream surface of the plate in the central region.

38. A wafer carrier as claimed in claim 37 wherein the plate has a central axis and the gas flow facilitating element has a perimeter surface in the form of a surface of revolution about the central axis.

39. A wafer carrier as claimed in claim 37 wherein the gas flow facilitating element has a perimeter surface having a generally concave profile.

40. A wafer carrier as claimed in claim 37 wherein the gas flow facilitating element has a perimeter surface having a generally convex profile.

41. A wafer carrier as claimed in claim 37 wherein the gas flow facilitating element has a height of less than one centimeter.

42. Chemical vapor deposition apparatus comprising a reaction chamber, a spindle mounted within the reaction chamber for rotation about an axis extending generally in an upstream to downstream direction, an injector head for introducing one or more reaction gases into the reaction chamber, the apparatus further comprising a wafer carrier as claimed in claim 37, the wafer carrier being adapted to mount to the spindle with the upstream surface of the plate facing toward the injector head and with the gas flow facilitating element lying along the axis; wherein the apparatus is configured to direct the one or more reaction gasses in the downstream direction toward the wafer carrier and the gas flow facilitating element.