



(19) **United States**

(12) **Patent Application Publication**
Schieve et al.

(10) **Pub. No.: US 2004/0177813 A1**

(43) **Pub. Date: Sep. 16, 2004**

(54) **SUBSTRATE SUPPORT LIFT MECHANISM**

(57) **ABSTRACT**

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(21) Appl. No.: **10/387,619**

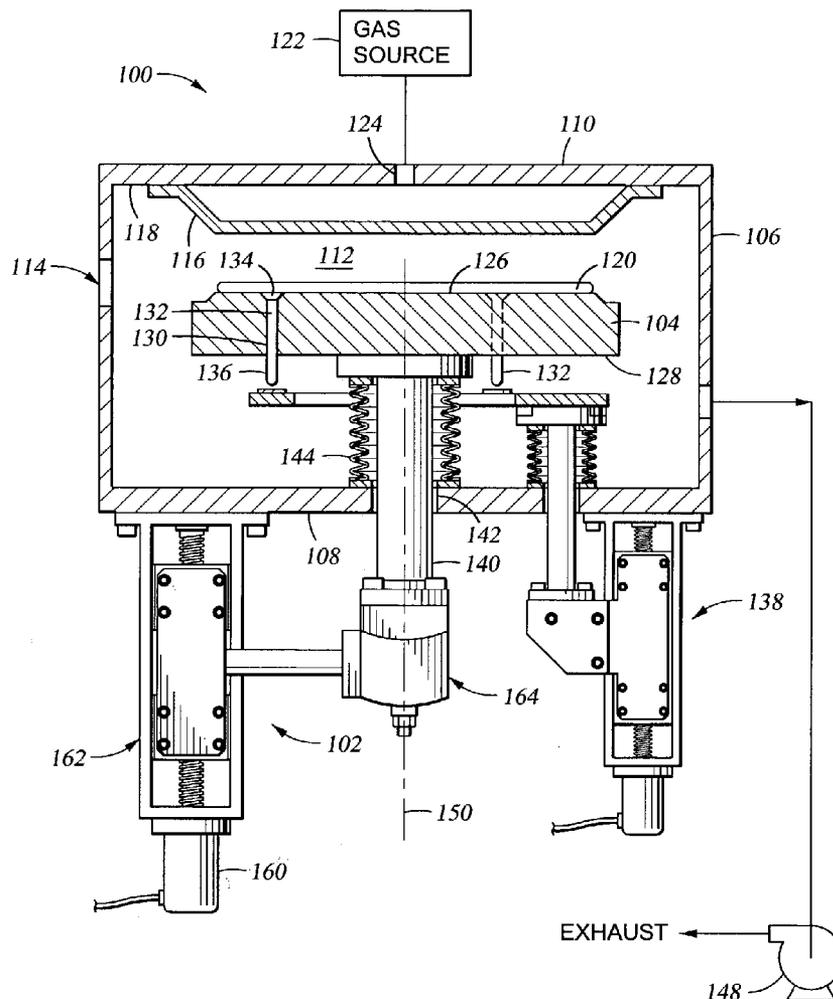
(22) Filed: **Mar. 12, 2003**

Publication Classification

(51) **Int. Cl.⁷ C23C 16/00**

(52) **U.S. Cl. 118/728**

An apparatus for positioning a substrate support within a processing chamber is provided. In one embodiment, an apparatus for positioning a substrate support includes a gimbal mechanism having radially aligned clamping that substantially prevents movement from a pre-defined plane of a substrate support coupled to the gimbal mechanism during clamping. In another embodiment, an apparatus for positioning a substrate support includes substrate support disposed in a processing chamber. A stem, coupled to the substrate support, extends through the processing chamber and is coupled to a gimbal assembly. The gimbal assembly has a radial clamping mechanism is adapted to adjust a planar orientation of the substrate support about a plurality of axes without exerting rotational moments on the substrate support during clamping. A bearing assembly, having a first carriage block and a second carriage block, is coupled to the gimbal assembly. An actuator is coupled to at least one of the carriage blocks and is adapted to control the elevation of the substrate support within the processing chamber.



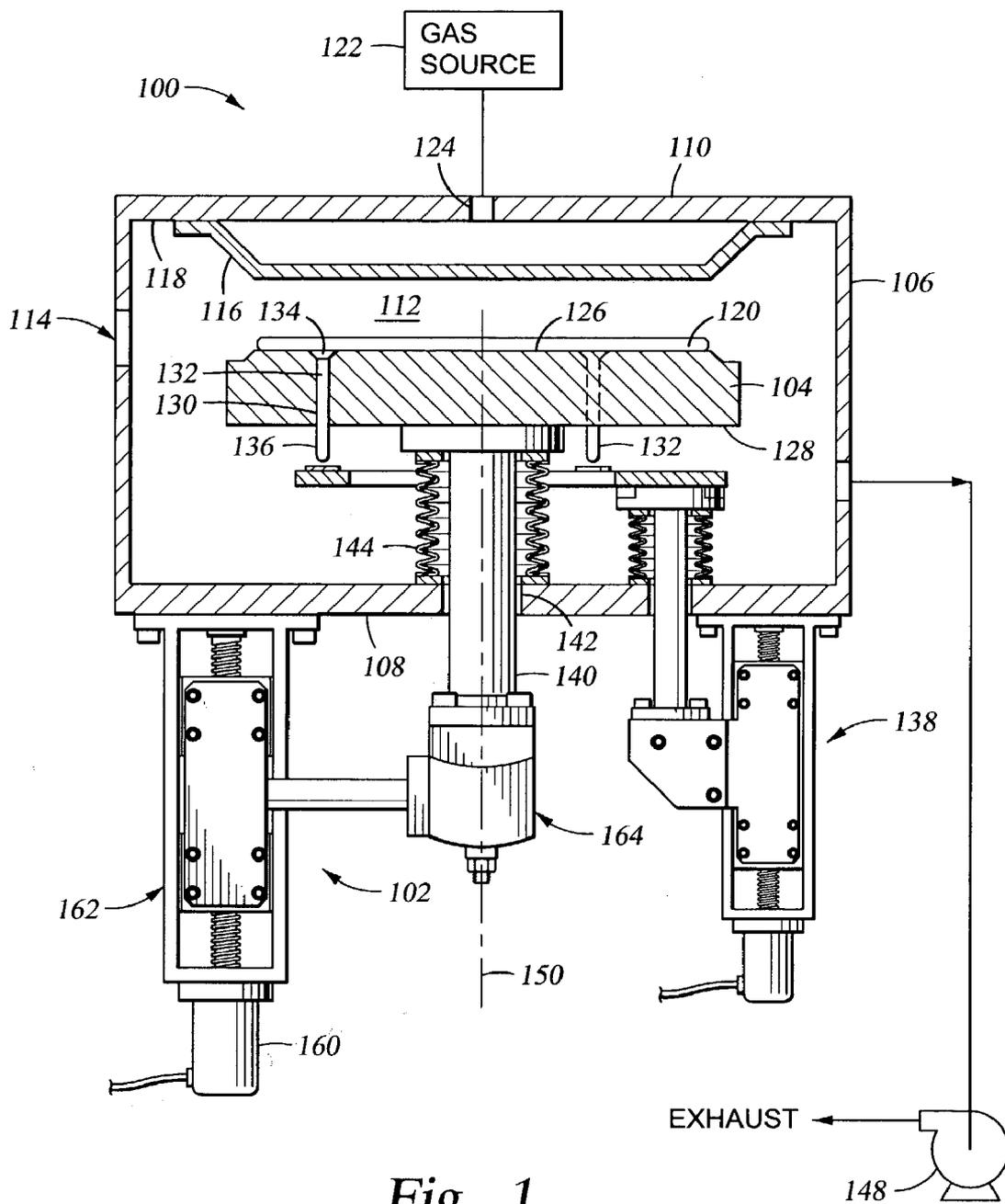


Fig. 1

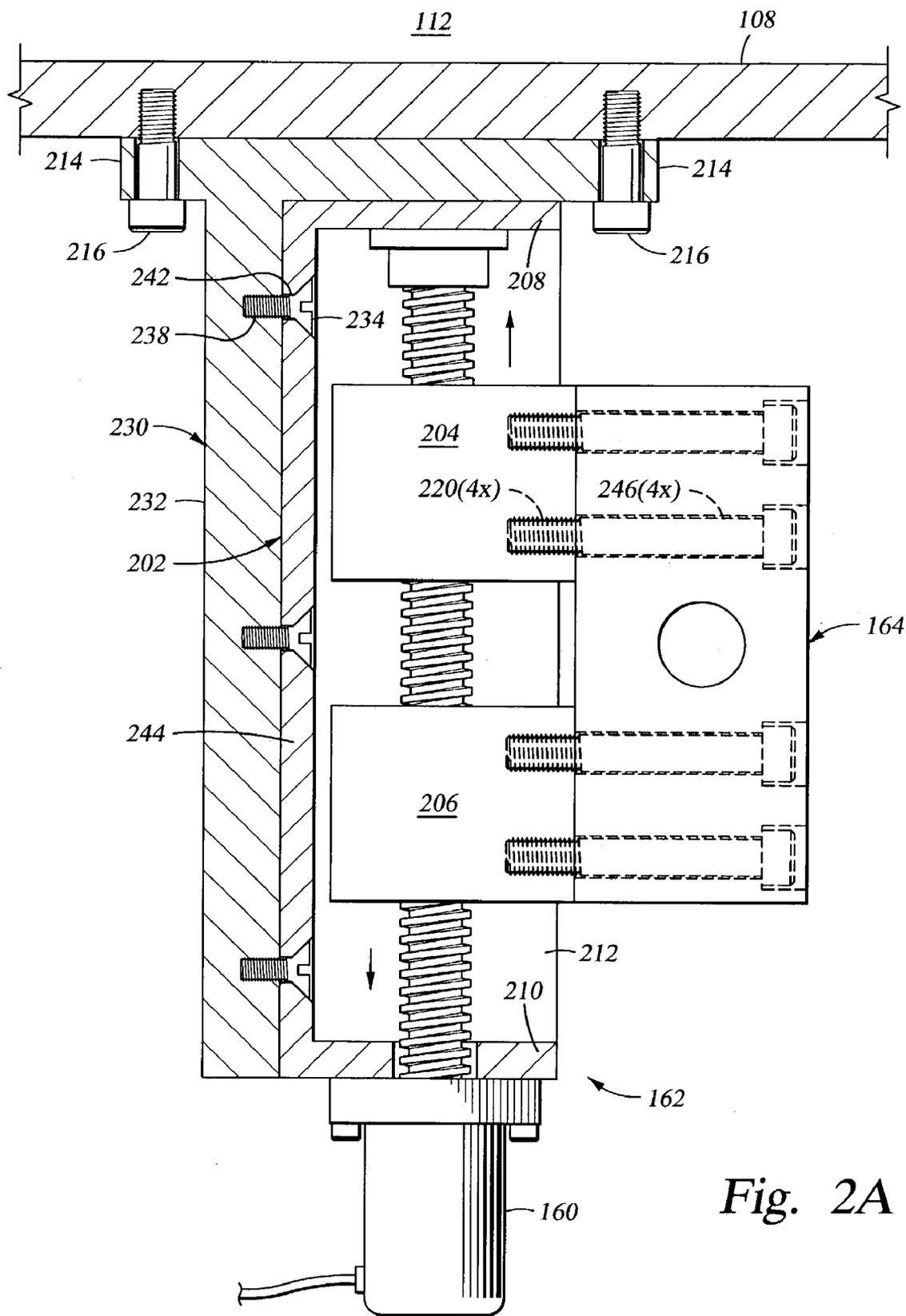


Fig. 2A

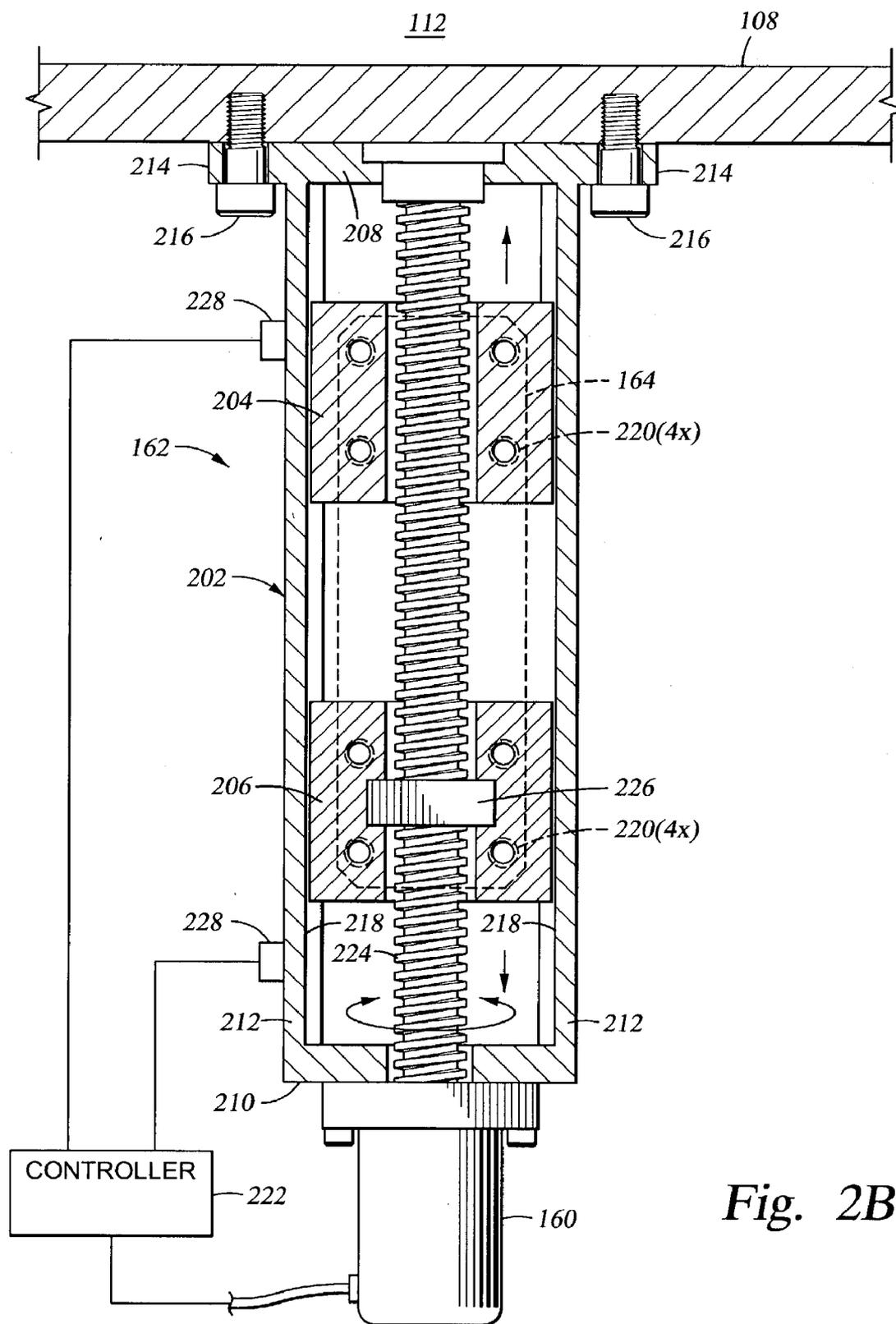


Fig. 2B

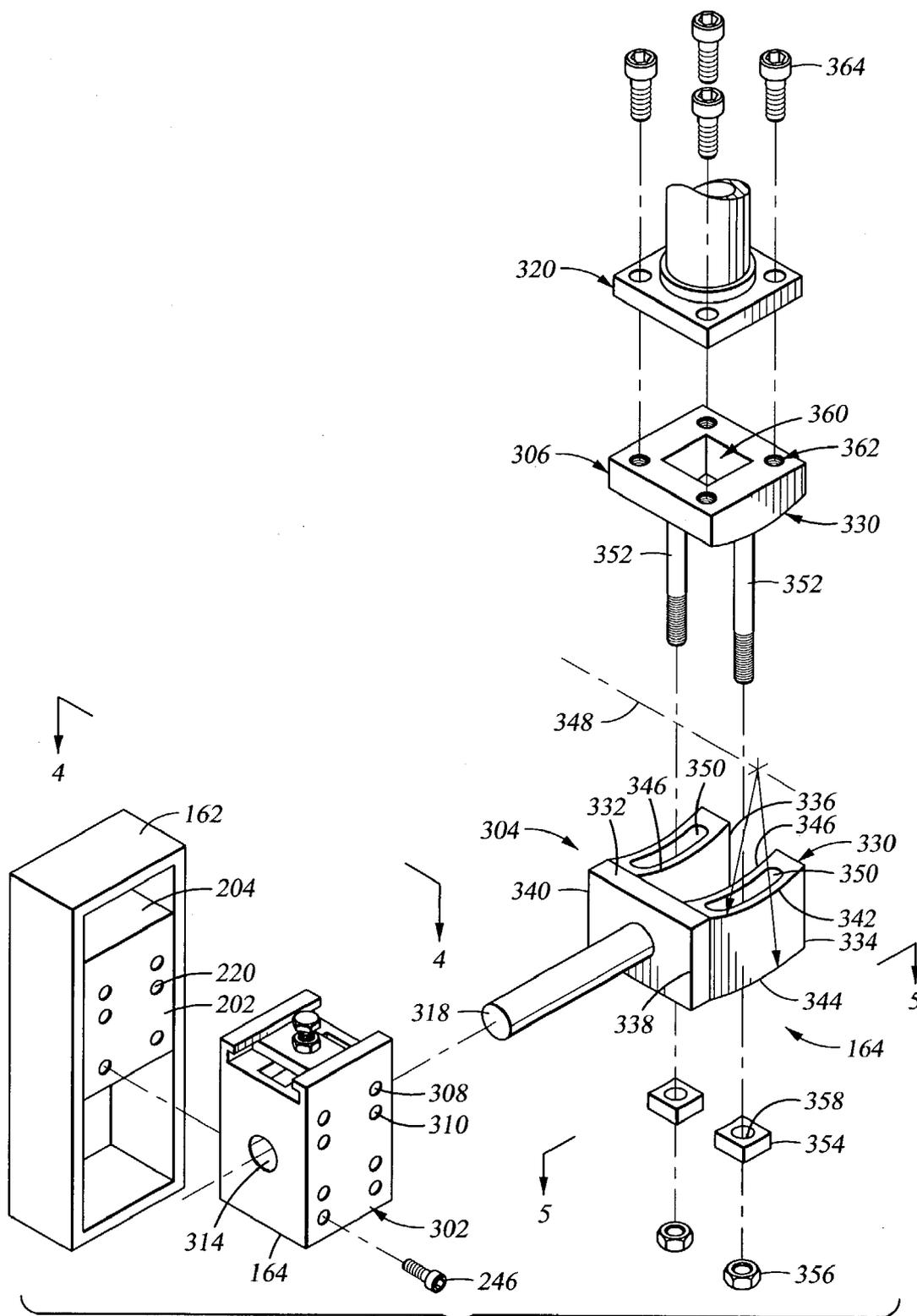


Fig. 3

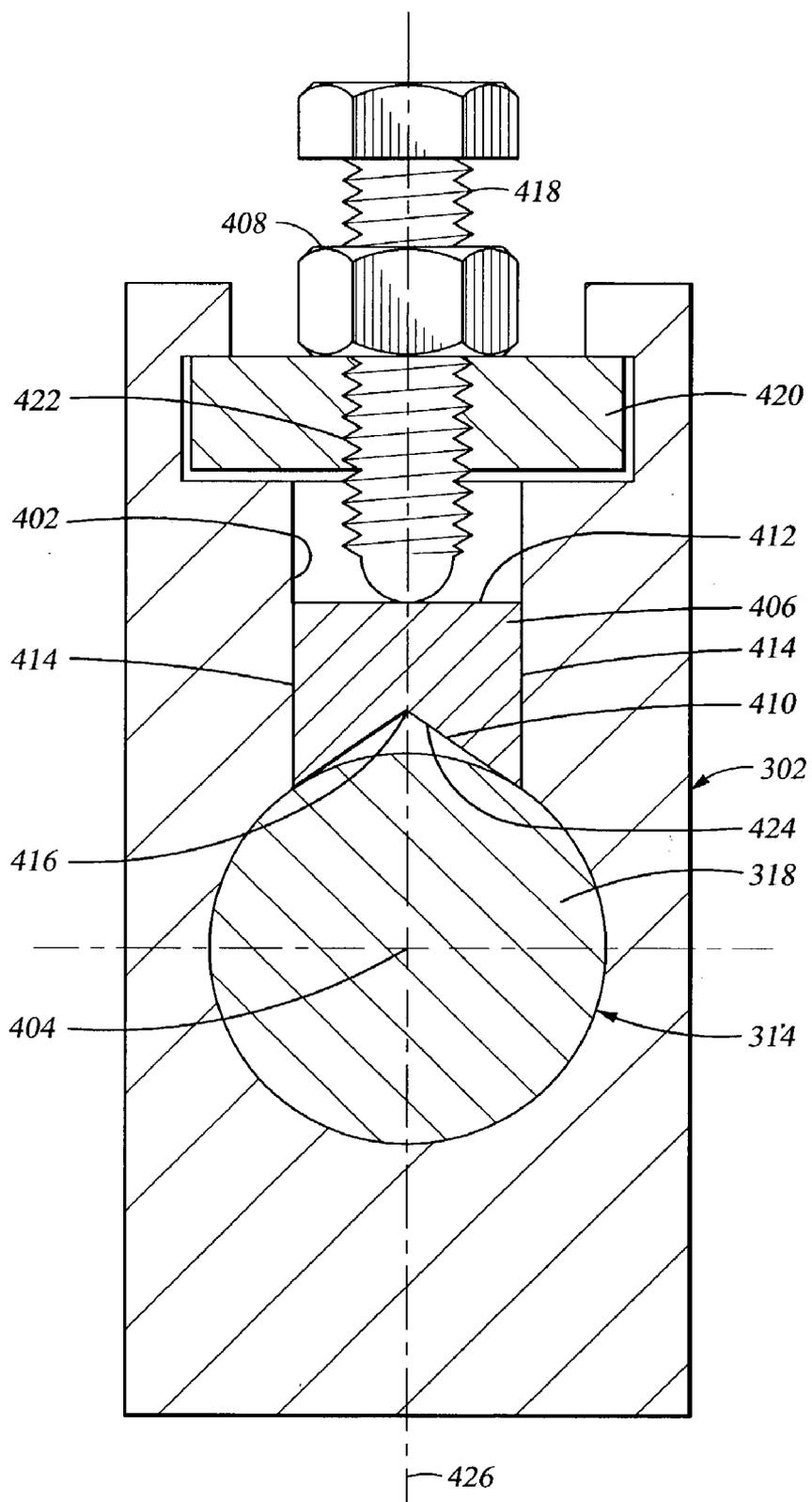


Fig. 4

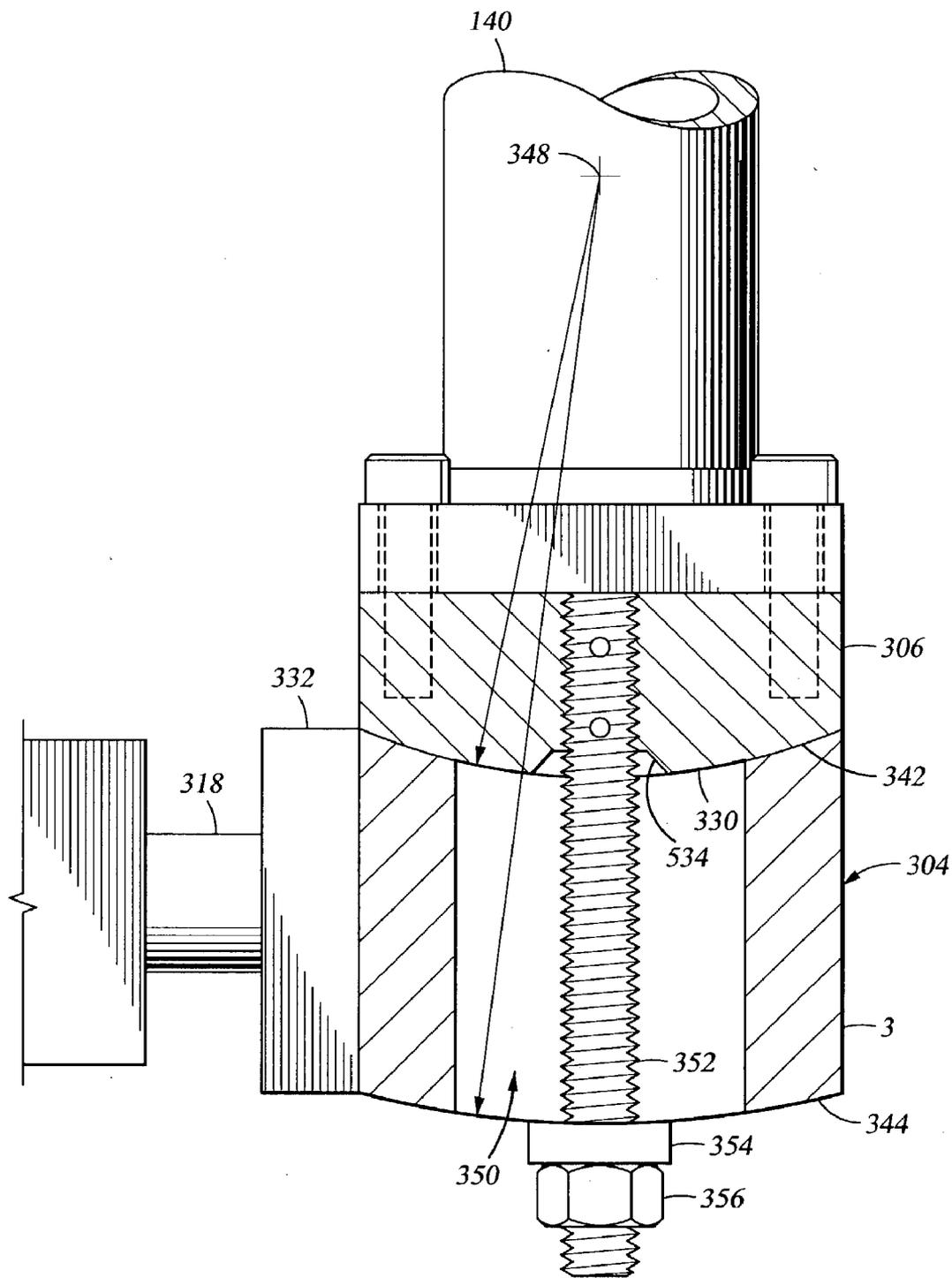


Fig. 5

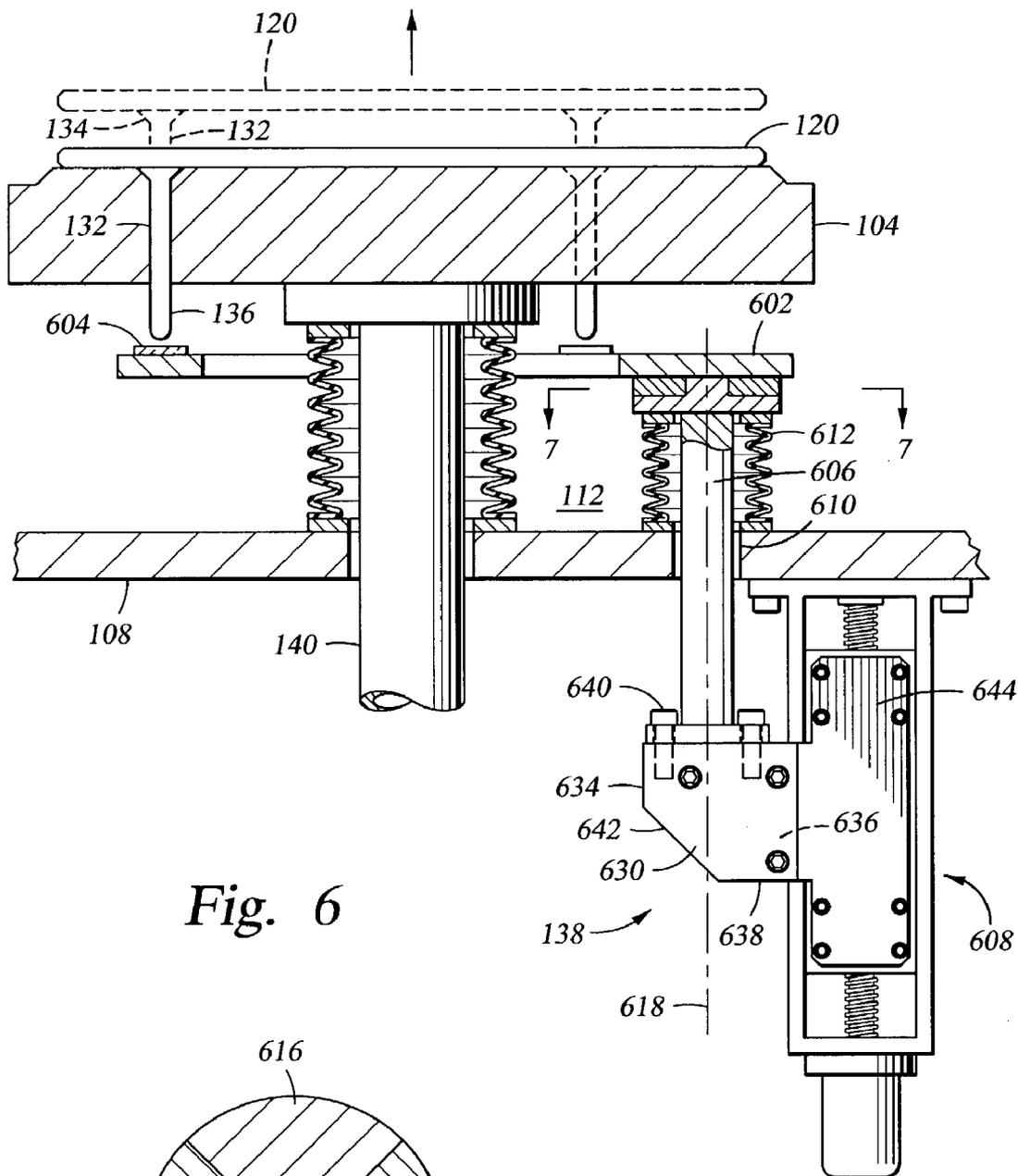


Fig. 6

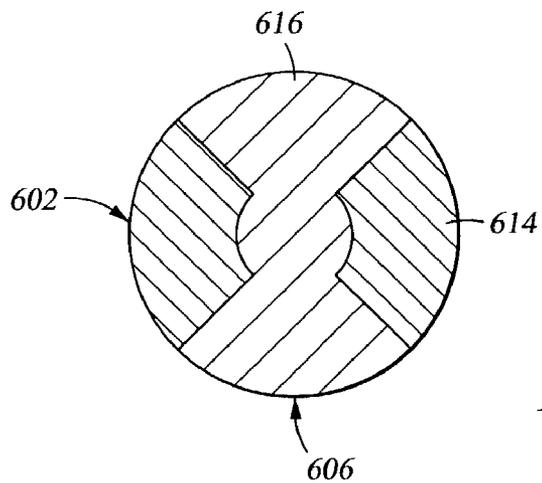


Fig. 7

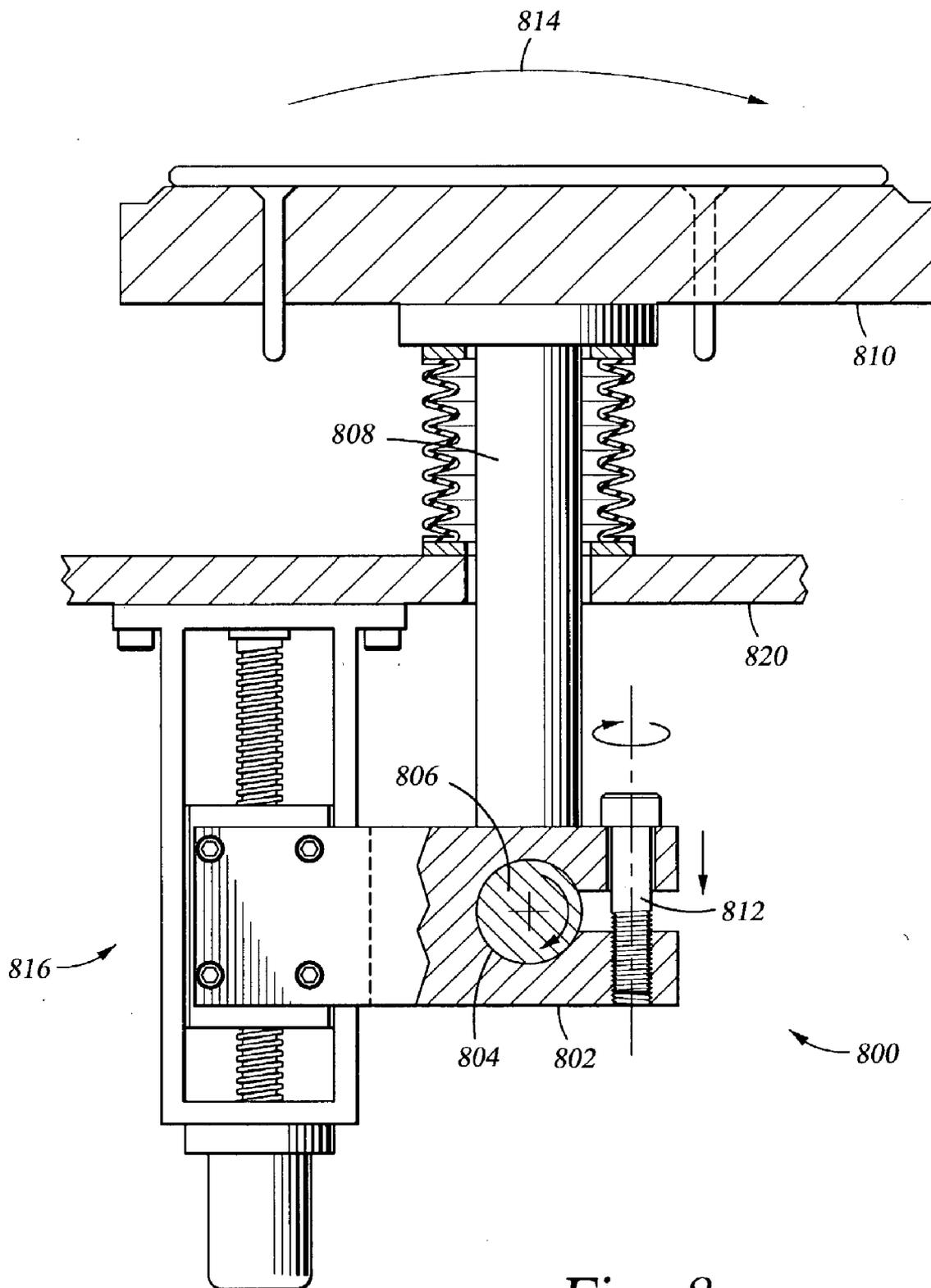


Fig. 8
(PRIOR ART)

SUBSTRATE SUPPORT LIFT MECHANISM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] Embodiments of the present invention generally relate to a lift mechanism for controlling the position of a substrate support in a processing chamber.

[0003] 2. Description of the Related Art

[0004] Many semiconductor processing operations, for example, chemical vapor deposition, physical vapor deposition and etch, among others, are performed in a vacuum environment. Typically, a substrate is positioned on a movable substrate support disposed within a processing chamber. The elevation of the substrate support is controlled by a lift mechanism so that the substrate may be disposed at a lower position within the processing chamber to facilitate substrate transfer and an elevated position that typically enhances substrate processing. As the spacing between the top of the processing chamber and the substrate seated on the substrate support may be 200 mils or closer when in the elevated position, the parallelism between the top of the processing chamber and the substrate support is a major attribute in maintaining process uniformity across the width of the substrate and ensuring process repeatability between substrates. For example, if one edge of the substrate is closer to the top of the processing chamber than another edge of the substrate, gases flowing between the substrates and the top of the processing chamber will be inclined to disadvantageously flow predominantly through the portion of the gap having the widest spacing, resulting in process non-uniformity across the width of the substrate. Additionally, variations in the distance between the substrate and the top of the processing chamber will typically result in process non-uniformity in plasma enhanced processes. As the intensity of the plasma formed between the substrate and the top of the processing chamber is dependent on the strength of the electrical field defined between the substrate support and the top of the processing chamber, which in turn is dependent on the distance between the substrate support and the top of the processing chamber. If this distance is not uniform, the plasma will not be uniform across the width of the substrate support and will contribute to process non-uniformity. Additionally, in the extreme cases, if the plane of the substrate support is not orientated perpendicular to the center line of the chamber, the plane of a wafer supported thereon may be skewed relative to the plane of operation of a transfer robot utilized to transfer the substrate to and from the processing chamber. In such instances, the end effector of the transfer robot may inadvertently collide with the substrate, causing particular generation and possibly knocking the substrate out of alignment. Moreover, if the lift pin mechanism is not parallel with the substrate support, the lift pins utilized to space the substrate from the substrate support may not extend uniformly through the substrate support, thereby causing the substrate to be supported in a skewed position that may lead to damage during transfer with the transfer robot as described above.

[0005] Typically, most substrate supports are coupled to their lift mechanisms by a mechanism in a manner that allows for the plane of the substrate support to be adjusted perpendicular to the center line of the processing chamber. However, many of the adjustment mechanisms utilized to

level the substrate support are difficult to secure in a desired position. Furthermore, most adjustment mechanisms do not provide against drift during the securing procedures that is detrimental to systems requiring close parallelism tolerancing.

[0006] FIG. 8 depicts one embodiment of a conventional clamping arrangement 800 that is commonly utilized in a processing chamber 820 to couple a substrate support 810 to a lift mechanism 816. The clamping arrangement 800 typically has a clamp block 802 having a hole 804 disposed therethrough. The hole 804 accepts a shaft 806 extending from a lower portion of a stem 808 supporting the substrate support 810. Thus, as the orientation of the shaft 806 within the clamp block 806 is adjusted, the angle of the plane of the substrate support may be adjusted about the center line of the shaft 806.

[0007] A disadvantage of such a clamping arrangement 800 is that a clamp screw 812 utilized to clamp hole 804 around the shaft 806 imparts a tangential force upon the shaft 802, thus exerting a rotational moment upon the substrate support 810 as shown by arrow 814. Thus, as the substrate support 810 is being clamped into position, the clamping force, tangential to the shaft 806, causes the parallelism of the substrate support 810 to disadvantageously draft away from a predefined, desired position.

[0008] Therefore, there is a need for an apparatus for controlling the position of a substrate support.

SUMMARY OF THE INVENTION

[0009] An apparatus for positioning a substrate support within a processing chamber is provided. In one embodiment, an apparatus for positioning a substrate support includes a gimbal mechanism having radially aligned clamping that substantially prevents movement from a pre-defined plane of a substrate support coupled to the gimbal mechanism during clamping. In another embodiment, an apparatus for positioning a substrate support includes substrate support disposed in a processing chamber. A stem, coupled to the substrate support, extends through the processing chamber and is coupled to a gimbal assembly. The gimbal assembly has a radial clamping mechanism that is adapted to adjust a planar orientation of the substrate support about a plurality of axes without exerting rotational moments on the substrate support during clamping. A bearing assembly, having a first carriage block and a second carriage block, is coupled to the gimbal assembly. An actuator is coupled to at least one of the carriage blocks and is adapted to control the elevation of the substrate support within the processing chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] A more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof that are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0011] FIG. 1 is a simplified sectional view of a semiconductor processing chamber having a substrate support lift assembly of the present invention;

[0012] FIGS. 2A-B are sectional side and front views of one embodiment of a bearing assembly;

[0013] FIG. 3 is an exploded view of one embodiment of a gimbal assembly;

[0014] FIG. 4 is a sectional view of a gimbal assembly taken along section lines 4-4 of FIG. 3;

[0015] FIG. 5 is a sectional view of a gimbal assembly taken along section line 5-5 of FIG. 3;

[0016] FIG. 6 is a sectional view of one embodiment of a lift pin actuation mechanism;

[0017] FIG. 7 is a sectional view of the lift pin actuation mechanism taken along section line 7-7 of FIG. 6; and

[0018] FIG. 8 is a sectional view of a conventional clamping arrangement utilized to couple a substrate support to a lift mechanism.

[0019] To facilitate understanding, identical reference numerals have been used, wherever possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0020] FIG. 1 is a simplified sectional view of a semiconductor processing chamber 100 having a substrate support lift assembly 102 for controlling the elevation of a substrate support 104 disposed within the processing chamber 100. Examples of processing chambers that may be adapted to benefit from the invention include WzX® and TxZ™ metal chemical vapor deposition chambers, both available from Applied Materials, Inc. located in Santa Clara, Calif. Although one embodiment of the substrate support lift assembly is illustrated coupled to a chemical vapor deposition chamber, the substrate support lift assembly may be utilized in other processing chambers such as physical vapor deposition chambers, etch chambers, ion implant chambers, rapid thermal anneal chambers, among other chambers wherein parallelism of the substrate support and a lid of the chamber is desirable.

[0021] The processing chamber 100 typically includes sidewalls 106 and a bottom 108 that support a lid 110 to define an interior volume 112 of the processing chamber. The processing chamber 100 is typically fabricated from a monolithic block of aluminum or welded from stainless steel plates. At least one wall 108 of the processing chamber 100 includes a substrate access port 114 to facilitate entry and egress of substrates from the processing chamber 100.

[0022] An exhaust port 146 is typically disposed in the sidewalls 106 or bottom 108 of the processing chamber 100 and is coupled to a pumping system 148. The pumping system 148 generally includes various pumping components such as throttle valves and turbomolecular pumps to evacuate and maintain the interior volume 112 of the processing chamber 100 at a predefined pressure during processing.

[0023] The lid 110 of the processing chamber 100 is typically removable to allow access to the interior volume 112 of the processing chamber 100. A showerhead 116 is coupled to an interior side 118 of the lid 110 to facilitate uniform distribution of process gases within the processing chamber 100 and across the surface of a substrate 120 positioned on the substrate support 104 during processing.

One example of suitable showerhead is described in U.S. patent application Ser. No. 09/603,117, filed Jun. 22, 2000, which is hereby incorporated by reference in its entirety.

[0024] A gas source 122 is typically coupled to the processing chamber 100 to provide process and other gases to the interior volume 112. In one embodiment, the lid 110 includes an inlet 124 through which process and/or other gases are provided from the gas source 122 to a plenum defined between the showerhead 116 and the interior surface 112 of the lid 110. The plenum allows the process and other gases provided into the interior volume 112 of the processing chamber 100 to spread across the backside of the showerhead 116, thereby enhancing uniformity of gas distribution through the showerhead 116 and across the substrate 120.

[0025] The substrate support 104 is disposed in the interior volume 112 of the processing chamber 100 and may be controlled in elevation along a central axis 150 between a processing position approximate the showerhead 116 and a lower transfer position aligned with the access port 114. The substrate support 104 may be a susceptor, heater, vacuum chuck, an electrostatic chuck or other platform for supporting the substrate 120 during processing or transfer. The substrate support 104 may be fabricated from ceramic, aluminum, stainless steel or other materials compatible with processing temperatures and chemistries. Two examples of substrate supports which may be adapted to benefit from the invention are described in U.S. patent application Ser. No. 09/596,854, filed Jun. 19, 2000 and U.S. patent application Ser. No. 10/055,634, filed Jan. 22, 2002, both of which are hereby incorporated by reference in their entireties.

[0026] The substrate support 104 has an upper surface 126 that supports the substrate 120 and an opposing lower surface 128 facing the chamber bottom 108. A plurality of holes 130 (one is shown in FIG. 1) are formed through the substrate support 104 and are adapted to receive lift pins 132 utilized to space the substrate 120 from the upper surface 126 during substrate transfer. The lift pins 132 typically have a flared first end 134 that is flush with, or slightly recessed from, the upper surface 126 of the substrate support 104 and a second end 136 that extends beyond the lower surface 128 of the substrate support 104.

[0027] The second end 136 of the lift pins 132 may be selectively actuated by a lift pin actuation mechanism 138. The lift pin actuation mechanism 138 displaces the second end 136 of the lift pins 132 toward the lower surface 128 of the substrate support 104, thereby causing the flared first end 134 of the lift pins 132 to project above the upper surface 126 to space the substrate 120 from the substrate support 104. One lift pin mechanism that may be adapted to benefit from the invention is described in U.S. patent Ser. No. 09/698,814 filed Oct. 26, 2000, which is hereby incorporated by reference in its entirety.

[0028] A stem 140 is disposed through an aperture 142 formed in the bottom 108 of the processing chamber 100 and connects the substrate support 104 to the substrate support lift mechanism 102. The stem 140 is typically hollow and/or includes passages formed therethrough to facilitate coupling of power leads, sensors, control lines, fluid lines and other utilities (not shown) from the substrate support 104 to the exterior of the processing chamber 100. A bellows 144 is typically provided circumscribing the stem 140 to provide a

flexible seal that facilitates elevation control of the substrate support **104** without vacuum leakage from the interior volume **112** of the processing chamber **100**.

[0029] The substrate support lift mechanism **102** is configured to allow the substrate support **104** to be adjusted along five axes and typically includes an actuator **160**, a bearing assembly **162** and a gimbal assembly **164**. In one embodiment, the bearing assembly **162** is coupled to the exterior side of the chamber bottom **108**. The gimbal assembly **164** is coupled between the stem **140** and the bearing assembly **162** and is driven by the actuator **160** to control the elevation of the substrate support **104**.

[0030] FIGS. 2A-B are sectional side and front views of one embodiment of the bearing assembly **162**. The bearing assembly **162** is mounted to the chamber bottom **108** by a mounting bracket **230**. The mounting bracket **230** includes a base **214** coupled to the chamber bottom **108** by a plurality of fasteners **216**. A mounting flange **232** extends from the base **214** and is coupled to the bearing assembly **162** by a plurality of fasteners **234**.

[0031] The bearing assembly **162** includes a rectangular frame **202** and at least two carriage blocks **204**, **206**. The rectangular frame **202** has a first end **208** adapted for coupling to the chamber bottom **108** separated from a second end **210** by two longitudinal members **212**. A center member **244** is coupled between the two longitudinal members **212** to form a c-section. The center member **244** provides geometrical stability of the two longitudinal members **212**. The center member **244** includes a plurality of mounting holes **242** through which the plurality of fasteners **234** pass through and thread into a threaded hole **238** formed in the mounting flange **232** of the mounting bracket **230**.

[0032] The facing surfaces of the longitudinal members include bearing surfaces **218** between which the carriage blocks **204**, **206** ride. The bearing surfaces **218** may be an integral part of the longitudinal members **212** or may alternatively be a separate outer race of a bearing that facilitates movement of the blocks **204**, **206** along the frame **202**.

[0033] The bearing surfaces **218** and the carriage blocks **204**, **206** form the inner and outer race for a plurality of bearings (not shown) disposed between the carriage blocks **204**, **206** and the frame **202**. The bearings may be ball, pin or tapered and are typically captured to recirculate about each carriage block **204**, **206**. Each carriage block **204**, **206** includes a plurality of mounting holes **220** to facilitate coupling the bearing assembly **162** to the gimbal assembly **164**. In the embodiment depicted in FIGS. 2A-B, each carriage block **204**, **206** includes four mounting holes **220** that are threaded to accept a fastener **246** (shown in phantom in FIG. 2A) utilized to secure the bearing assembly **162** and gimbal assembly **164**.

[0034] The actuator **160** is typically mounted to the second end **210** of the frame **202** but may alternatively be mounted in other configurations that allow the actuator **160** to control the position of the carriage blocks **204**, **206** relative to the frame **202**. The actuator **160** may be an electric motor, air motor, pneumatic cylinder, hydraulic cylinder, solenoid, ball screw, lead screw or other motion device adapted to control the linear position of the carriage blocks **204**, **206**. The actuator **160** is coupled to a controller **222** that controls the

actuator's motion. In the embodiment depicted in FIG. 2B, the actuator **160** is a stepper motor or server motor that drives a lead screw **224**. The lead screw **224** passes through a thrust nut **226** disposed or otherwise coupled to the second carriage block **206**. As the actuator **160** controllably rotates the lead screw **224**, the lead screw **224** imparts a force on the nut **226** held stationary in the second carriage block **206** that causes the nut **226** and carriage block **206** to move along the frame **202**.

[0035] One or more sensors **228** are typically coupled to the substrate support lift assembly **102** to provide positional feedback to the controller **222** indicative of the elevation of the substrate support **104** within the processing chamber **100**. The sensors **228** may include LVDT sensors, proximity sensors, read switches, Halifax switches, proximity switches, limit switches, motor encoders and the like. In the embodiment depicted in FIG. 2B, the sensors **228** comprise a first proximity switch and a second proximity switch coupled to the frame **202** of the bearing assembly **162**. As the carriage blocks **204**, **206** move between first and second ends **208**, **210** of the frame **202**, the presence of at least one of the carriage blocks **204**, **206** adjacent the proximity switch (e.g., sensor **228**) changes the state or output of that switch, thereby indicating the arrival of the substrate support **104** to a predefined position. The position of the sensors **228** on the frame **202** is adjustable so that the stroke of the substrate support **104** may be set within a predefined range of motion and adjust to a predefined elevation within the processing chamber **100**. By incorporating two carriage blocks **202**, **206** within the frame **202**, the vacuum forces that act upon the substrate support **104** within the internal volume **112** of the processing chamber **100** which result in high torsional loads on the lift assembly that are distributed over larger load bearing surface areas, dramatically minimizing overall mechanical deflection, and thereby advantageously maintaining the parallelism of the substrate support **104** and the showerhead **116**. This dual carriage bearing assembly **162** provides about a four-fold improvement in lateral deflection over conventional single carriage bearing assemblies.

[0036] FIG. 3 depicts an exploded view of one embodiment of the gimbal assembly **164**. The gimbal assembly **164** includes a clamp block **302**, a yoke **304** and a gimbal base **306**. The clamp block **302** is typically fabricated from aluminum or another suitable material and includes a plurality of mounting holes **308** utilized to couple the gimbal assembly **164** to the carriage blocks **204**, **206**. In the embodiment depicted in FIG. 3, each of the mounting holes **308** includes a counterbore **310** adapted to receive the head of each fastener **246** (one is shown in FIG. 3) which threads into a respective one of the mounting holes **220** formed in the carriage blocks **204**, **206**.

[0037] The clamp block **302** includes a clamping aperture **314** formed therein. The clamping aperture **314** is adapted to receive a post **318** extending from the yoke **304** to secure the orientation of the yoke **304** within the clamp block **302** while allowing axial and rotational adjustment of the post **318** relative to the clamping aperture **314**.

[0038] FIG. 4 is a sectional view of the clamp block **302** depicting one embodiment of the clamping aperture **314**. The clamping aperture **314** is typically formed at least partially through the clamp block **302** in an orientation

substantially perpendicular to the central axis 150 of the substrate support 104. A slot 402 is formed at least partially through the clamp block 302 in communication with the clamping aperture 314. The slot 402 is typically radially aligned with a center 404 of the clamping aperture 314. The slot 402 is adapted to receive a plunger 406 that may be urged through the slot 406 against the post 318 of the yoke 304, thereby fixing the position and rotational orientation of the yoke 304 relative to the clamp block 302. The plunger 406 may be urged against the post 318 and yoke 304 through any suitable means, including screws, motors, solenoids, over center clamps, clamps, electrostatic force, and the like.

[0039] In the embodiment depicted in FIG. 4, the clamp block 302 includes a first surface 410 disposed opposite a second surface 412 and separated by lateral surfaces 414. The lateral surfaces 414 are typically configured to guide the plunger 406 within the slot 402 so that a center 416 of the first surface 410 is urged into radial engagement with the post 318. A fastener 418 is disposed through a threaded hole 422 formed in a web 420 that bounds the end of the slot 402 opposite the clamping aperture 314. As the fastener 418 is threaded through the web 420, an end of the fastener 418 in contact with the post 318 urges the plunger 406 against the post 318 of the yoke 304, thereby securely clamping the post 318 in the aperture 314 of the clamp block 302. A jam nut or equivalent fixing method may be utilized to prevent the fastener 418 from backing out of the web 420 and allowing the post 318 to move. As the plunger 406 remains radially aligned with the aperture 314 and post 318 of the yoke 304 along an imaginary line 426 defined by the center of the aperture 314 and passing through the center of the slot 402, the clamping force is radially aligned and prevents the generation torque during clamping, advantageously preventing the yoke 304 from rotating relative to the clamp block 302 during clamping. Additionally, the angular orientation of the yoke 302 is advantageously maintained during clamping which preserves the parallelism of the substrate support 104 to the showerhead 116 within the processing chamber 100 during clamping.

[0040] To further prevent torque generation during clamping that could cause the yoke 304 to rotate relative to the clamp block 302, a clamping surface 424 of the plunger 406 may be configured to contact the post 318 at two locations. For example, the clamping surface 424 of the plunger 406 may include a "V" configuration, a step, depression, a radius or a curved surface configured to mate with the post 318 at at least two locations equidistance from the center.

[0041] Returning to FIG. 3, the yoke 304 is typically fabricated from aluminum or other suitable rigid material and includes a bifurcated end 330 extending from the post 318. The bifurcated end 330 includes a cross member 332 centered on the post 318 and arranged in a substantially perpendicular orientation relative to the center axis of the post 318. A first mounting flange 334 is formed on a first end 338 of the cross member 332. A second mounting flange 336 is formed on a second end 340 of the cross member 332 and is typically oriented parallel with the central axis of the post 318.

[0042] Each mounting flange 334, 336 includes an upper side 342 and a lower side 344 separated by facing inner lateral sides 346. The lateral sides 346 of the adjacent mounting flanges 334, 336 define a space between the

mounting flanges 334, 336 configured to allow routing of the various conduits and wires routed out of the stem 140.

[0043] In one embodiment, the upper side 342 of each flange 334, 336 is accurate to facilitate adjusting the orientation of the gimbal base 306 seated on the mounting flange 334, 336. In the embodiment depicted in FIG. 3, the curvature of the upper side 342 typically has a radius of about 305 to about 304 mm relative to an axis 348 oriented substantially perpendicular to an offset from the central axis of the post 318. The lower side 334 of each mounting flange 334, 336 is typically convex and configured to have a radius defined from the axis 348.

[0044] Each mounting flange 334, 336 includes a slot 350 formed therethrough between the upper and lower sides 342, 344. The slot 350 is configured to accept a fastener or stud 352 extending from the gimbal base 306. A clamping block 354 is typically disposed on the portion of the stud 352 extending through the lower side 344 of the mounting flanges 334, 336. A nut 356 is threaded onto each of the studs 352 and may be tightened to urge a bottom surface 370 of the gimbal base 306 against the upper side 342 of the mounting flanges 334, 336. A contact surface 358 of the clamping block 354 typically is configured with the same radius as the lower side 344 of the mounting flanges 334, 336 to maintain axial tension on the studs 352 that substantially eliminates lateral drift of the studs 352 along the lower side 344 of the mounting flanges 334, 336 as the nuts 356 are tightened. Advantageously, this arrangement for coupling the gimbal base 306 to the yoke 304 allows the support surface of the substrate support 104 to be adjusted about an axis 348 perpendicular to the central axis of the yoke 304 and secured in that position without inducing any lateral forces on the stud that could compromise the parallelism of the substrate support 104 and the showerhead 116.

[0045] FIG. 5 is a sectional view of the yoke 304 and gimbal base 306. To further enhance the precision of the alignment between the gimbal base 306 and the yoke 304, the bottom surface 370 of the gimbal base 306 that engages the upper side 342 of each mounting flange 334, 336 is configured to contact the upper side 342 of the mounting flanges 334, 336 in two places. For example, in the embodiment depicted in FIG. 5, a stepped depression 534 is formed in the bottom surface 370 around each stud 352. The stepped depressions 534 provide dual contact points that are symmetrical about the studs 352, thus preventing the gimbal base 306 from rocking on the yoke 304 as the nuts 356 are tightened and thereby maintaining the desired planar orientation of the substrate support 104 during clamping.

[0046] Referring additionally to FIG. 3, the gimbal base 306 is typically configured with a slot or central aperture 360 to facilitate routing of the various conduits and wires exiting the stem 140. The gimbal base 306 also includes a plurality of mounting holes 362 formed therein that respectively accept a plurality of fasteners 364 (one of which are shown in FIG. 3) that thread into a threaded hole 534 formed in a base plate 320 of the stem 140 thereby coupling the gimbal base 306 to the stem 140. The mounting holes 362 include a counter bore 530 having that allows the fasteners 364 to seat below the bottom surface 370 of the gimbal base 306. Holes 532 formed in the yoke 304 substantially align with the counter bores 530 and are of sufficient diameter that allows passage of the fasteners 364 through the yoke 304

and into the gimbal base 306 through a range of angular orientation between the yoke 304 and into the gimbal base 306, thereby allowing the substrate support 104 to be removed after angular alignment of the substrate support 104. The holes 532 may optionally be part of the slot 350. As the gimbal assembly 164 is not susceptible to drift due to the axial and radial loading of the clamping mechanisms, the base plate 320 of the stem 140 may be unfastened from the gimbal base 306 to facilitate removal, surface and/or replacement of the substrate support 104 without having to realign the substrate support 104 relative to the plane of the lid 110 and showerhead 116 upon re-installation of the substrate support 104.

[0047] FIG. 6 depicts one embodiment of the lift pin actuation mechanism 138. The lift pin actuation mechanism 138 typically includes an annular lift plate 602 that is disposed below the second end 136 of the lift pins 132 and circumscribes the stem 140. The lift plate 602 is typically fabricated from aluminum and may include a plurality of ceramic contact pads 604 adapted to contact the lift pins 134 as the lift plate 602 is actuated toward the substrate support 104.

[0048] In one embodiment, the lift pin actuation mechanism 138 includes a lift plate 602 coupled by an actuation rod 606 to an actuator assembly 608. In order to minimize deflection between the lift plate 602 and rod 606, the mating surfaces of the lift plate 602 and rod 606 include a plurality of mating wedge-shaped keys 614, 616 (seen in FIG. 7). The keys 614, 616 are typically configured to expand and create an interference fit at processing temperatures, thus eliminating movement between the lift plate 602 and rod 606 associated with part tolerancing. One example of a lift plate and rod coupled in a similar arrangement is described in U.S. patent application Ser. No. 09/652,727, filed Oct. 31, 2000, which is hereby incorporated by reference in its entirety.

[0049] The rod 606 extends through an aperture 610 formed in the bottom 108 of the process chamber 100 and is coupled to the actuator assembly 608. A bellows 612 is typically disposed around the rod 606 to provide a flexible seal between the processing chamber 100 and the pin lift actuation mechanism 138 to prevent leakage into the chamber while facilitating actuation of the lift pins 132.

[0050] The actuator assembly 608 is typically coupled between the rod 606 and the chamber bottom 108 to control the elevation of the lift plate 602 and lift pins 132. The actuator assembly 608 may include solenoids, gear motors or other actuator suitable for controllably actuating the shaft in an axial direction. In one embodiment, the actuation assembly 608 is similar to the bearing assembly and actuator described above.

[0051] A spar 630 is utilized to couple the rod 606 to the actuator assembly 608. The spar is typically fabricated from aluminum or other suitably rigid material. The spar 630 includes a mounting side 632 and an opposing lower side 638 separated by first and second lateral sides 634, 636. The mounting side 632 of the spar 630 is coupled to the rod 606 by a plurality of fasteners 640. The second lateral side 636 is typically coupled to a bearing assembly 644 of the actuator assembly 608. The lower side 638 may include a chamfer 642 at the junction of the first lateral side 634 and the lower side 638.

[0052] The lateral sides 634, 636 are typically longer than the mounting side 632 to minimize deflection of the actua-

tion mechanism 138 due to vacuum forces acting upon the annular plate 602 disposed within the chamber 100. To further stiffen the spar 630, the lower side 638 typically extends from the second lateral side 636 beyond a center line 618 of the rod 606 before the chamfer 642. As the rigidity of the spar 630 is superior to conventional L-shaped brackets commonly used in conventional designs, the reduced deflection of the lift pin actuation mechanism 138 enhances the planarity between the plate 602 and the substrate support 104, thereby allowing the substrate 102 to retain its parallelism to the substrate support 104 when spaced therefrom by the lift pins 132 displaced by the plate 602.

[0053] As discussed above, maintaining the parallelism between the lid 110 and the upper support surface 126 of the substrate support 104 is important for maintaining process uniformity and repeatability. The invention also improves the parallelism of the substrate 120 when spaced from the substrate support 104 that minimizes particular generation or wafer damage during robotic wafer exchange. In one aspect of the invention, the substrate support lift assembly 102 experiences reduced torsional deflection when the substrate support 104 is exposed to a vacuum within the processing chamber 100. In another aspect of the invention, the spaced bearing surfaces of the carriage blocks 204, 206 maintains parallelism of the substrate support 104 to the lid 110 as the substrate support 104 is moved between the elevated and lowered position. Additionally, the dual carriage blocks 204, 206 minimize deflection of the lift 102 thereby maintaining the desired planar orientation of the substrate support 104 when the substrate support 104 is subjected to vacuum forces. In another aspect of the invention, the lift pin actuation mechanism 138 is configured to minimize deflection under vacuum loading of the lift mechanism 138 to enable simultaneous contact and substantially equal displacement of the lift pins, resulting in enhanced parallelism of the substrate and substrate support when spaced apart to facilitate wafer exchange with a robotic mechanism while minimizing the probability of inadvertent wafer to robot contact due to misalignment and/or deflection issues.

[0054] While the foregoing is directed to the preferred embodiment of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An apparatus for positioning a substrate support, comprising:

- a yoke having at least a first slot formed therethrough;
- a gimbal base having a first surface adapted to support the substrate support and an opposing second surface; and
- a first threaded member disposed through the first slot and axially urging the yoke and gimbal base against each other.

2. The apparatus of claim 1, wherein the yoke and gimbal base further comprise mating accurate surfaces.

3. The apparatus of claim 2, wherein the first threaded member is radially aligned with the mating curved surfaces.

4. The apparatus of claim 3, wherein the mating curved surface of the gimbal base further comprises a stepped recess.

5. The apparatus of claim 1, wherein the yoke further comprise:

- a post; and
- a connecting member coupled to the post;
- a first flange coupled to a first end of the connecting member, the first slot defined between a first side supporting the gimbal base and an opposing second side of the first flange;
- a second flange coupled to a first end of the connecting member;
- a second slot defined between a first side of the second flange that supports the gimbal base and an opposing second side; and
- a second threaded member disposed through second slot and axially urging the yoke and gimbal base against each other.

6. The apparatus of claim 5, wherein the first side of the first flange is curved.

7. The apparatus of claim 5, wherein the first side of the first flange has a radius of curvature between about 305 to about 304 mm.

8. The apparatus of claim 7, wherein the second side of the first flange is curved concentrically to the first side.

9. The apparatus of claim 1 further comprising:

- a clamp block having a clamping aperture receiving a post extending from the yoke.

10. The apparatus of claim 9, wherein the clamp block further comprises:

- a slot formed at least partially through the clamp block and communicating with the clamping aperture; and
- a plunger disposed in the slot and movable in a direction radially aligned with a center of the clamping aperture.

11. The apparatus of claim 10, wherein the plunger includes a contact surface that, when urged against the post, does not exert a rotational moment force upon the post.

12. The apparatus of claim 10, wherein the clamp block further comprises:

- a web disposed over the slot opposite the clamping aperture; and
- member disposed through the web and radially aligned with the center of the clamping aperture, the member adapted to urge the plunger against the post.

14. The apparatus of claim 1 further comprising:

- a bearing assembly having a first carriage block and a second carriage block, and coupled to the clamp block; and
- an actuator coupled to at least one of the carriage blocks and adapted to control the linear position of the carriage blocks along the bearing assembly.

15. An apparatus for positioning a substrate support, comprising:

- a gimbal assembly comprising:
 - a clamp block;
 - a yoke coupled to the clamp block, the yoke positional along and rotational about a first axis relative to the clamp block; and

- a gimbal base coupled to the yoke and adapted to support the substrate support, the gimbal base movable about a second axis orthogonal to the first axis; and

- a bearing assembly having a first carriage block and a second carriage block, the bearing assembly coupled to the clamp block; and

- an actuator coupled to at least one of the carriage blocks and adapted to control the linear position of the carriage blocks along the bearing assembly.

16. The apparatus of claim 15, wherein the clamp block further comprises:

- a clamping aperture formed therein for receiving a post extending from the yoke.

17. The apparatus of claim 16, wherein the clamp block further comprises:

- a slot formed at least partially through the clamp block and communicating with the clamping aperture; and
- a plunger disposed in the slot and movable in a direction radially aligned with a center of the clamping aperture.

18. The apparatus of claim 17, wherein the plunger includes a contact surface that, when urged against the post, does not exert a rotational moment force upon the post.

19. The apparatus of claim 17, wherein the clamp block further comprises:

- a web disposed over the slot opposite the clamping aperture; and
- member disposed through the web and radially aligned with the center of the clamping aperture, the member adapted to urge the plunger against the post.

20. The apparatus of claim 17, wherein the yoke further comprises:

- at least one flange;
- a slot formed through the flange;

- a gimbal base having a first surface adapted to support the substrate support and an opposing second surface disposed against the flange; and

- a member disposed through first slot and urging the yoke and gimbal base against each other along axis of the member.

21. The apparatus of claim 1, wherein the second surface of the yoke and gimbal base contact along a curved surface.

22. The apparatus of claim 21, wherein the member is radially aligned relative to the curved surface.

23. The apparatus of claim 22, wherein the second surface of the gimbal base has a stepped recess formed therein.

24. The apparatus of claim 15, wherein the yoke further comprise:

- a post; and
- a connecting member coupled to the post;
- a first flange coupled to a first end of the connecting member, the first slot defined between a first side supporting the gimbal base and an opposing second side of the first flange;
- a second flange coupled to a first end of the connecting member;

a second slot defined between a first side of the second flange that supports the gimbal base and an opposing second side; and

a second threaded member disposed through second slot and axially urging the yoke and gimbal base against each other.

25. The apparatus of claim 24, wherein the first side and the second side of the first flange are curved concentrically.

26. The apparatus of claim 25 further comprising:

a spacer disposed on the stud and having a first curved surface; and

a nut threaded on the stud and adapted to urge the first curved surface of the spacer disposed against the second side of the first flange.

27. An apparatus for positioning a substrate support, comprising:

a processing chamber;

a substrate support disposed in the chamber body;

a stem coupled to the substrate support and extending through a first hole formed in the chamber body;

a gimbal assembly coupled to the stem and adapted to adjust a planar orientation of the substrate support, the gimbal assembly comprising:

a) a yoke having at least first slot formed therethrough;

b) a gimbal base having a first surface adapted to support the substrate support and an opposing second surface; and

c) a first threaded member disposed through first slot and axially urging the yoke and gimbal base against each other;

a bearing assembly having a first carriage block and a second carriage block, the bearing assembly coupled to the gimbal assembly; and

an actuator coupled to at least one of the carriage blocks and adapted to control the elevation of the substrate support within the processing chamber.

28. The apparatus of claim 27, wherein the yoke and gimbal base contact along a curved surface.

29. The apparatus of claim 28, wherein the first threaded member is radially aligned with the curved surface.

30. The apparatus of claim 28, wherein the second surface of the gimbal base has a stepped recess formed therein.

31. The apparatus of claim 27, wherein the yoke further comprise:

a post; and

a connecting member coupled to the post;

a first flange coupled to a first end of the connecting member, the first slot defined between a first side supporting the gimbal base and an opposing second side of the first flange;

a second flange coupled to a first end of the connecting member;

a second slot defined between a first side of the second flange that supports the gimbal base and an opposing second side; and

a second threaded member disposed through second slot and axially urging the yoke and gimbal base against each other.

32. The apparatus of claim 31, wherein the first side and the second side of the first flange are curved concentrically.

33. The apparatus of claim 32 further comprising:

a spacer disposed on the first threaded member and having a first curved surface; and

a nut threaded on the first threaded member and adapted to urge the first curved surface of the spacer disposed against the second side of the first flange.

34. The apparatus of claim 27, wherein the gimbal assembly further comprises:

a clamp block coupled to the yoke, the yoke positional along and rotational about an axis relative to the clamp block.

35. An apparatus for positioning a substrate support, comprising:

a processing chamber;

a substrate support disposed in the chamber body;

a plurality of lift pin disposed through the substrate support and having an end extending below the substrate support;

a stem coupled to the substrate support and extending through a first hole formed in the processing chamber;

a gimbal assembly coupled to the stem and adapted to adjust a planar orientation of the substrate support;

a bearing assembly having a first carriage block and a second carriage block, the bearing assembly coupled to the gimbal assembly;

an actuator coupled to at least one of the carriage blocks and adapted to control the elevation of the substrate support within the processing chamber;

an annular plate circumscribing the stem;

a rod coupled to the lift plate and extending through a second hole formed in the processing chamber;

a lift pin actuator assembly adapted to urge the plate against and displace the lift pins; and

a spar coupling the rod to the lift pin actuator assembly, the spar comprising:

a mounting surface coupled to the rod;

a lower surface disposed opposite the mounting surface; and

a first lateral side and a second lateral side extending between the mounting surface and the lower surface, the second lateral side coupled to the lift pin actuator assembly, the lateral sides having a length greater than mounting surface.

36. The apparatus of claim 35, wherein the lower surface of the spar extends from the second lateral side to a position beyond the center line of the rod.

37. The apparatus of claim 35, wherein the rod further comprises wedges interleaved with mating wedges of the plate.

38. The apparatus of claim 35, wherein the gimbal assembly further comprises:

- a clamp block;
- a yoke coupled to the clamp block, the yoke positional along and rotational about a first axis relative to the clamp block; and
- a gimbal base coupled to the yoke and adapted to support the substrate support, the gimbal base movable about a second axis orthogonal to the first axis; and
- a first threaded member disposed through a slot formed in the yoke and axially urging the yoke and gimbal base against each other.

39. The apparatus of claim 38, wherein the yoke and gimbal base contact along a curved surface.

40. The apparatus of claim 39, wherein the first threaded member is radially aligned with the curved surface.

41. The apparatus of claim 39, wherein the gimbal base further comprises a stepped recess formed in a surface contacting the yoke.

42. The apparatus of claim 38, wherein the yoke further comprise:

- a post;
- a connecting member coupled to the post;
- a first flange coupled to a first end of the connecting member, the first slot defined between a first side supporting the gimbal base and an opposing second side of the first flange;
- a second flange coupled to a first end of the connecting member;
- a second slot defined between a first side of the second flange that supports the gimbal base and an opposing second side; and
- a second threaded member disposed through second slot and axially urging the yoke and gimbal base against each other.

43. The apparatus of claim 42, wherein the first side of the first flange is curved.

44. The apparatus of claim 39, wherein the first curved surface has a radius of curvature between about 305 to about 304 mm.

45. The apparatus of claim 44, wherein the second side of the first flange is curved concentrically to the first side.

46. The apparatus of claim 38, wherein the clamp block further comprises:

- a clamping aperture formed therein for receiving a post extending from the yoke.

47. The apparatus of claim 46, wherein the clamp block further comprises:

- a slot formed at least partially through the clamp block and communicating with the clamping aperture; and
- a plunger disposed in the slot and movable in a direction radially aligned with a center of the clamping aperture, wherein the plunger includes a contact surface that, when urged against the post, does not a moment force upon the post.

48. The apparatus of claim 47, wherein the clamp block further comprises:

- a web disposed over the slot opposite the clamping aperture; and
- member disposed through the web and radially aligned with the center of the clamping aperture, the member adapted to urge the plunger against the post.

49. An apparatus for positioning a substrate support, comprising:

- a processing chamber;
- a substrate support disposed in the chamber body;
- a stem coupled to the substrate support and extending through a first hole formed in the chamber body;
- a gimbal assembly coupled to the stem and adapted to adjust a planar orientation of the substrate support about 5 axes;
- a bearing assembly having a first carriage block and a second carriage block, the bearing assembly coupled to the gimbal assembly; and

an actuator coupled to at least one of the carriage blocks and adapted to control the elevation of the substrate support within the processing chamber.

50. The apparatus of claim 49, wherein the gimbal assembly further comprises:

- a yoke having at least first slot formed therethrough;
- a gimbal base having a first surface adapted to support the substrate support and an opposing second surface; and
- a first threaded member disposed through first slot and axially urging the yoke and gimbal base against each other.

51. The apparatus of claim 50, wherein the yoke and gimbal base contact along a curved surface.

52. The apparatus of claim 51, wherein the first threaded member is radially aligned with the curved surface.

53. The apparatus of claim 51, wherein the second surface of the gimbal base has a stepped recess formed therein.

54. The apparatus of claim 49, wherein the yoke further comprise:

- a post; and
- a connecting member coupled to the post;
- a first flange coupled to a first end of the connecting member, the first slot defined between a first side supporting the gimbal base and an opposing second side of the first flange;
- a second flange coupled to a first end of the connecting member;
- a second slot defined between a first side of the second flange that supports the gimbal base and an opposing second side; and
- a second threaded member disposed through second slot and axially urging the yoke and gimbal base against each other.

55. The apparatus of claim 54, wherein the first side and the second side of the first flange are curved concentrically.

56. The apparatus of claim 55 further comprising:

a spacer disposed on the first threaded member and having a first curved surface; and

a nut threaded on the first threaded member and adapted to urge the first curved surface of the spacer disposed against the second side of the first flange.

57. The apparatus of claim 49, wherein the gimbal assembly further comprises:

a clamp block;

a yoke coupled to the clamp block, the yoke positional along and rotational about a first axis relative to the clamp block; and

a gimbal base coupled to the yoke and adapted to support the substrate support, the gimbal base movable about a second axis orthogonal to the first axis.

58. The apparatus of claim 57, wherein the gimbal base further comprises:

a plurality of holes formed therein having a counter bore that substantially aligns with a passage formed through the yoke.

59. Apparatus for positioning a substrate support, comprising:

a gimbal assembly providing freedom of movement about perpendicular axes, the gimbal assembly including two clamps, each adjustable to prevent movement about one axis by a clamping force applied through that axis.

60. The apparatus of claim 59, wherein the gimbal assembly further comprises:

a clamp block;

a yoke coupled to the clamp block, the yoke being positioned along and rotational about one of the axes relative to the clamp block;

a gimbal base connected to support the substrate support and movably mounted in the yoke for rotation about the other of the axes relative to the yoke.

61. The apparatus of claim 60, wherein movement about each axis is prevented by the force of clamp held by a fastener applied through the axis.

62. The apparatus of claim 50, wherein the gimbal base further comprises:

a plurality of holes formed therein having a counter bore that substantially aligns with a passage formed through the yoke.

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