fold radial symmetry), although in some other implementations, the linear actuators may be arranged in a non-radially symmetric manner.

[0070] It will also be recognized that while the depicted linear actuators 112 have drive motors 124 that are part of the portions of the linear actuators 112 that are mounted to the stationary mount 114, but other implementations may feature linear actuators 112 in which the motors 124 are part of the portions of the linear actuators 112 that are mounted to the movable mount 116 (or which may feature a mix of such linear actuators, e.g., some linear actuators with motors that are part of the portions of the linear actuators that are mounted to the movable mounts and some linear actuators with motors that are part of the portions of the linear actuators that are mounted to the stationary mounts).

[0071] The hexapod mechanism 112 generally has a configuration, shown in more detail in FIGS. 2–4, in which the six linear actuators 122 are grouped into three pairs, with the three pairs of linear actuators 122 being arranged in a circular array about a common center axis. Each pair of linear actuators 122 may be arranged such that the linear actuators 122 in that pair of linear actuators 122 are arranged to extend or retract the movable portions thereof along translation axes that are—at least when the linear actuators 122 are at similar degrees of extension—at oblique angles to a corresponding reference plane that is coincident with the common center axis and located between the linear actuators 122 of that pair of linear actuators 122. Thus, the spacing between the locations where each pair of adjacent linear actuators 122 connect with the stationary mount 114 or the movable mount 116 will be different from the spacing between the locations where that pair of adjacent linear actuators 122 connect with the other of the stationary mount 114 and the movable mount 116.

[0072] In hexapod systems, each linear actuator that is used is configured so as to have at least five degrees of freedom that are unconstrained. This can be accomplished by pivotably connecting one end of each linear actuator with one of the stationary mount or the movable mount using a spherical joint (such as a ball joint) to provide three of the five degrees of freedom and pivotably connecting the other end of each linear actuator with the other of the stationary mount or the movable mount using a universal joint to provide the other two degrees of freedom (or, alternatively, with another spherical joint to provide six degrees of freedom). The use of spherical and universal joints allows for large angular displacements of the linear actuators relative to one or both of the stationary mount and the movable mount in such hexapod systems, providing for a wide range of angular motion. For clarity, the term

2512. For the purposes of illustration, the showerhead 2560 is shown with a significant amount of tilt/misalignment from horizontal. In actual practice, the showerhead 2560 may be configured so as to have a nominally horizontal bottom surface. However, due to assembly and machining tolerances, the showerhead 2560 may nonetheless have some small amount of tilt, e.g., ~0.2° or less. The showerhead is shown floating in space but may, in practice, be supported by one or more other structures, or may be provided as part of the semiconductor processing chamber lid.

[0147] Also visible in FIG. 25 is a pedestal 2506 that is supported by a movable mount 2516 of the pedestal mechanism 2512 which is, in turn, coupled with a stationary mount 2514 thereof by six linear actuators 2522. The pedestal mechanism 2512 in this example is arranged differently than that discussed earlier with respect to other implementations in that the stationary mount 2514 and the movable mount 2516 have their relative positions reversed, but the fundamental operating principles are identical. If desired, the depicted hexapod mechanism may be replaced with one that is more similar to the version depicted in earlier examples (and vice-versa). The stationary mount 2514 is fixedly mounted with respect to the semiconductor processing chamber 2502.

[0148] FIG. 25 also depicts an autocalibration wafer 2564 that is supported by an end effector 2566 of a wafer handling robot that may be used to introduce wafers into, and remove wafers from, the semiconductor processing chamber 2502. A pair of AWC optical sensors 2562 may be mounted so as to be fixed with respect to the semiconductor processing chamber 102; each optical sensor 2562 may emit an optical beam, as discussed above and as indicated by the dotted line spanning from the upper portion to the lower portion of the optical sensor 2562 that is depicted; the other optical sensor 2562 may be positioned on an opposite side of the opening in the semiconductor processing chamber 2502 through which the end effector 2566 transports wafers such that the edge of the wafer(s) break the optical beams of both optical sensors 2562 as they transit through the opening.

[0149] In block 2402, the autocalibration wafer may be placed on the end effector of a wafer handling robot, much in the same manner than a wafer-to-be-processed would be placed on the end effector thereof. In some instances, the autocalibration wafer may be placed on the end effector with the assistance of a fixture that precisely locates the autocalibration wafer in a particular location and orientation with respect to the end effector.

that coincides with the target location of the showerhead. Alternatively, there may be a fiducial, e.g., two intersecting lines, that exists at the target location itself. In another example, an alignment fixture or jig that includes such fiducials may be temporarily placed on the showerhead and precisely positioned with respect to the showerhead using one or more physical alignment features; after such calibration operations are complete, such a fixture may be removed from the showerhead. The image data that is obtained may allow for the determination of the location of the target of interest of the showerhead with respect to the center location of the autocalibration wafer.

[0161] In block 2428, the hexapod mechanism may be controlled so as to move the pedestal, based on the information collected in block 2426, such that an axis that passes through the target location of the pedestal and that is normal to the wafer support surface passes through the target location of the showerhead. In FIG. 34, the target location of the showerhead is indicated by the dash-dot-dash center line that passes through the showerhead 2560. The target location of the showerhead, in this example, coincides with the location where that center axis intersects the underside of the showerhead. Similarly, the target location of the pedestal in this example coincides with the point of intersection between a center axis of the pedestal (shown as a dash-dot-dash centerline that passes through the support column 2508 and the pedestal 2506) with the wafer support surface of the pedestal 2506. In FIG. 35, the pedestal 2506 has been shifted such that the two axes align, e.g., such that the axis that passes through the target location of the pedestal and that is normal to the wafer support surface passes through the target location of the showerhead.

[0162] In block 2430, information indicating the position of the movable mount after the completion of block 2428 may be stored in memory as second position state information, e.g., information that may correspond with the default processing position discussed earlier herein. The pedestal may then, after removal of the autocalibration wafer, be returned to, for example, a default position as shown in FIG. 36. The upper dashed outline of the pedestal 2506 in FIG. 36 represents the location of the pedestal 2506 as defined by the second position and orientation state information, whereas the lower dashed outline of the pedestal 2506 in FIG. 36 represents the location of the pedestal 2506 as defined by the first position and orientation state information.

[0163] Thus, at the conclusion of the operations discussed above with respect to blocks 2402 through 2430, state information may be known for the hexapod-based pedestal system indicating positional

CLAIMS

1. An apparatus comprising:

a pedestal configured to support a semiconductor wafer during wafer processing operations;

a hexapod mechanism that includes:

a movable mount that supports the pedestal;

a stationary mount; and

six independently controllable linear actuators, each linear actuator having a first end pivotably connected with the stationary mount and a second end pivotably connected with the movable mount, wherein the linear actuators support the movable mount relative to the stationary mount.

2. The apparatus of claim 1, wherein the linear actuators are arranged in a trilaterally symmetric manner.

3. The apparatus of either claim 1 or claim 2, wherein:

the six linear actuators are grouped into three sets of two linear actuators, and

the linear actuators in each set of two linear actuators are arranged so as to have first ends that connect with the stationary mount at locations that are closer together than locations where the second sends thereof connect with the movable mount.

4. The apparatus of any of claims 1 through 3, wherein:

each first end of each linear actuator is pivotably connected with the stationary mount by a corresponding spherical joint, universal joint, or biaxial flexure bearing, and

each second end of each linear actuator is pivotably connected with the movable mount by a corresponding spherical joint, universal joint, or biaxial flexure bearing.

5. The apparatus of any of claims 1 through 3, wherein each first end of each linear actuator is pivotably connected with the stationary mount by a corresponding first biaxial flexure bearing.

6. The apparatus of claim 5, wherein each first biaxial flexure bearing includes:

a first portion;

a second portion;

a third portion;

two first bending webs spanning between the first portion and the second portion; and

two second bending webs spanning between the second portion and the third portion, wherein, for each first biaxial flexure bearing:

the second portion thereof is interposed between the first portion thereof and the third portion thereof,

the first portion thereof, the second portion thereof, and the third portion thereof lie along a common axis thereof,

a first gap exists between the first portion thereof and the second portion thereof, and

a second gap exists between the second portion thereof and the third portion thereof.

7. The apparatus of claim 6, wherein, for each first biaxial flexure bearing:

the first bending webs thereof are thin, substantially planar structures aligned with a first reference plane of that first biaxial flexure bearing,

the second bending webs thereof are thin, substantially planar structures aligned with a second reference plane of that first biaxial flexure bearing, and

the first and second reference planes thereof are perpendicular to one another.

8. The apparatus of claim 6 or claim 7, wherein each first biaxial flexure bearing includes a center hole that extends along the common axis of that first biaxial flexure bearing and through the first portion thereof, the second portion thereof, and the third portion thereof.

9. The apparatus of any one of claims 6 through 8, wherein, for each first biaxial flexure bearing:

that first biaxial flexure bearing includes two first through-holes and two second through-holes,

the first bending webs thereof are positioned in between the first through-holes thereof,

the second bending webs thereof are positioned in between the second through-holes thereof,

the first through-holes thereof extend completely through that first biaxial flexure bearing, and

the second through-holes thereof extend completely through that first biaxial flexure bearing.

10. The apparatus of any one of claims 6 through 9, wherein the first bending webs and the second bending webs of each first biaxial flexure bearing extend into the second portion thereof.

11. The apparatus of any one of claims 1 through 10, further comprising a semiconductor processing chamber and a showerhead, wherein:

the wafer support surface of the pedestal is located within the semiconductor processing chamber,

at least a portion of the showerhead is located within the semiconductor processing chamber, and

the stationary mount is fixed with respect to the semiconductor processing chamber.

12. The apparatus of claim 11, further comprising a controller, the controller operatively connected with the six linear actuators and configured to control the linear actuators so as to cause the movable mount to perform, relative to the stationary mount, one or more of: a) translation of the movable mount along an axis that is perpendicular to the wafer support surface of the pedestal, b) rotation of the movable mount about a rotational axis that passes through a target location of the pedestal on which a wafer is to be centered and is perpendicular to the wafer support surface, c) translation of the movable mount along a path so as to orbit an axis that is perpendicular to an underside of the showerhead that faces towards the pedestal and that intersects with a target location of the showerhead, d) tilting of the movable mount such that the wafer support surface of the pedestal is oriented at a non-

zero acute angle to the underside of the showerhead, or e) tilting of the movable mount such that the wafer support surface of the pedestal is oriented at a non-zero acute angle to the underside of the showerhead and such that a maximum acute angle that is formed between the underside of the showerhead and the wafer support surface is defined in a plane that is periodically or continuously caused to change azimuthal direction relative to the pedestal and about an axis that is perpendicular to the underside of the showerhead.

13. The apparatus of claim 12, wherein the controller is further configured to control the linear actuators so as to cause the movable mount to perform two or more of (a) through (e) at least partially simultaneously while the pedestal is supporting a wafer placed thereupon.

14. The apparatus of either claim 12 or claim 13, wherein the controller is further configured to control the linear actuators so as to cause the movable mount to perform two or more of (a) through (e) at least partially sequentially while the pedestal is supporting a wafer placed thereupon.

15. The apparatus of any one of claims 12 through 14, further comprising:

a wafer handling robot configured to extend an end effector thereof into the semiconductor processing chamber; and

an active wafer centering system configured to determine a location of a center of a wafer transported by the end effector relative to the semiconductor processing chamber, wherein:

the controller is further configured to:

i) obtain the location of the center of the wafer as determined by the active wafer centering system,

ii) control the linear actuators so as to cause the target location of the pedestal to be positioned at a location centered beneath the center of the wafer based on the location of the center of the wafer as determined by the active wafer centering system, and

iii) cause the wafer to be transferred to the pedestal after (ii).

16. The apparatus of claim 15, wherein:

the pedestal includes a plurality of lift pins and the apparatus includes a lift pin actuation mechanism that is configured to move the lift pins between an extended state in which the lift pins protrude from the wafer support surface of the pedestal and a retracted state in which the lift pins do not protrude from the wafer support surface, and

the controller is configured to perform (iii) by causing the lift pin actuation mechanism to cause the lift pins to move into the extended state so as to come into contact with the wafer, causing the wafer handling robot to retract the end effector from the space between the wafer and the wafer support surface, and causing the lift pin actuation mechanism to cause the lift pins to move into the retracted state, thereby placing the wafer on the wafer support surface.

17. The apparatus of either claim 15 or claim 16, wherein the controller is further configured to, after (iii), control the linear actuators so as to cause the movable mount to move to an orientation in which the wafer support surface is at a predetermined angle relative to the underside of the showerhead.

18. The apparatus of claim 17, wherein the predetermined angle is 0°.

19. The apparatus of claim 17, wherein the predetermined angle is a non-zero acute angle.