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MULTI-WAFER HANDLING SYSTEM

Abstract

A wafer handling device includes multiple quartets of retention fingers, each having a resting flexure at a distal end that is vertically and torsionally compliant, a housing to which the retention fingers are mounted, a first pair of the retention fingers from a first quartet, the first pair configured to rotate to a first angular position to receive a wafer by the resting flexures, a second pair of the retention fingers from the first quartet configured to rotate to the first angular position after the first pair receives the wafer, and configured to vertically move towards the wafer in the first angular position, where the device grips the wafer at a second side by the second pair and at a first side by the first pair, and a bearing to which the housing is mounted for turning the housing to overturn the wafer 180 degrees.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates generally to semiconductor fabrication, and, in particular implementations, to a multi-wafer handling system.

BACKGROUND

[0002] Generally, in modern semiconductor manufacturing, material handling includes the handling of semiconductor substrates in the form of wafers along various steps in the fabrication process. In modern fabrication facilities, many material handling steps are automated using robotic equipment. The handling of wafers in semiconductor manufacturing predominately occurs using material handling robots that transfer individual wafers at different steps in the process. The semiconductor fabrication process typically involves different process modules (PM) to perform various tasks, such as lithography patterning, material deposition, and material removal, among others. Different types of process modules may perform one or more tasks or operations on a wafer. Accordingly, process modules may receive one or more wafers and internally handle the wafer for various operations internal to each process module.

[0003] In addition, a process module may be integrated into a larger process facility having multiple different process modules. Each wafer may undergo multiple processing steps at the different process modules, and may be subject to repeated sets of process steps such that the wafer can be introduced to a given process module multiple times before completion of fabrication. Many semiconductor fabrication facilities have automated carriers that can shuttle one or more wafers between process modules, thereby enabling batch processing of multiple wafers. For example, a wafer carrier holding multiple wafers can be delivered to a given process module where an equipment front end module (EFEM) receives the wafer carrier and transfers each wafer to the process module, typically through a bulkhead of the process module where a corresponding wafer buffer is installed. In many automated semiconductor fabrication facilities, a special EFEM robot is tasked with transferring wafers in this manner for loading into the process module, while internal robots within the process module receive the wafer at the wafer buffer through the bulkhead.

[0004] Furthermore, in some semiconductor fabrication steps, certain backside operations are performed on wafers that involve flipping the wafer over before further processing by a process module. For example, wafer-to-wafer (W2 W) bonding may involve joining two opposite faces of two wafers together. Other types of hybrid integration, such as 3-dimensional (3D) bonding, may also involve flipping the wafer at certain steps, such as for backside grinding and metallization to form contact pads for bonding different parts together, among other steps. In typical semiconductor fabrication systems, wafer flipping is often performed on individual wafers, such as prior to introduction into a process module by an EFEM robot.

[0005] Accordingly, the typical method of flipping or overturning individual wafers can be slow and can add additional process time for wafer handling. Furthermore, an individual wafer flipping station at a process module can take up additional space and can involve additional functionality that is performed by an EFEM robot.

SUMMARY

[0006] In one aspect, a substrate handling device includes multiple quartets of retention fingers, each retention finger having a resting flexure at a distal end, a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive a wafer by the resting flexures of the first pair, and a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair further configured to vertically move towards the wafer in the first angular position. The substrate handling device can be configured to grip the wafer at a second side by the resting flexures of the second pair and at a first side by the resting flexures of the first pair; and a bearing to which the multiple quartets are mounted, the bearing for collectively turning

the multiple quartets to flip the wafer by 180 degrees.

[0007] In another aspect, a method includes rotating a first pair of retention fingers of a first quartet of retention fingers to a first angular position, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, where multiple quartets of retention fingers including the first quartet are mounted in a housing to which each of the retention fingers is respectively mounted at the axis. The method also includes rotating a second pair of retention fingers of the first quartet to a second angular position, the second pair vertically spaced a first distance from the wafer, and receiving a wafer through a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the second pair being free of the passageway in the second angular position, the wafer being received from the first end and supported at a first side of the wafer by the resting flexures of the first pair, the second pair vertically located to face a second side of the wafer opposite the first side. The method still further includes, after the first pair receives and supports the wafer, rotating the second pair to the first angular position and vertically moving the second pair towards the wafer over the first distance in the first angular position to hold the wafer at the second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair; and turning, using a bearing to which the housing is mounted, the housing to overturn the wafer 180 degrees when the wafer is held by the first quartet.

[0008] In still a further aspect, a wafer handling device includes multiple quartets of retention fingers, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, the resting flexure being vertically and torsionally compliant, and a housing to which each of the retention fingers is respectively coupled via the axis; a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the retention fingers having access to the passageway. The wafer handling device also includes a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive, in the passageway by the resting flexures of the first pair, a wafer at a first side of the wafer, and a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position free of the passageway before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair configured to vertically move towards the wafer in the first angular position, where the wafer handling device is configured to grip the wafer at a second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair. The wafer handling device further includes a bearing to which the housing is mounted, the bearing for turning the housing to overturn the wafer by 180 degrees when the wafer is gripped by the first quartet.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a more complete understanding of the present disclosure, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0010] FIG. **1**A is a depiction of a multi-wafer buffer assembly including a rotary stage, in an implementation;

[0011] FIG. **1**B is a depiction of a multi-wafer retaining assembly, in an implementation;

[0012] FIG. **2** is a depiction of a sidewall of a multi-wafer retaining assembly, in an implementation;

[0013] FIG. **3** is a depiction of components with a retention finger assembly, in an implementation;

[0014] FIG. **4** is a depiction of a retention finger assembly, in an implementation;

[0015] FIG. **5** is a depiction of a wafer loading operation, in an implementation;
[0016] FIG. **6** is a depiction of a wafer holding operation, in an implementation;
[0017] FIGS. **7** and **8** are depictions of an edge grip operation, in an implementation;
[0018] FIGS. **9** and **10** are depictions of a wafer grip operation, in an implementation;
[0019] FIG. **11** shows depictions of an edge grip flexure, in an implementation;
[0020] FIG. **12** is a depiction of a wafer resting flexure, in an implementation;
[0021] FIG. **13** is a depiction of a wafer sensing operation, in an implementation; and
[0022] FIG. **14** is a method of flipping wafers using a retaining assembly, in an implementation.

DETAILED DESCRIPTION OF ILLUSTRATIVE IMPLEMENTATIONS

[0023] This disclosure describes a multi-wafer handling system in various implementations.

[0024] In the following description, details are set forth by way of example to facilitate discussion of the disclosed subject matter. It should be apparent to a person of ordinary skill in the field, however, that the disclosed implementations are exemplary and not exhaustive of all possible implementations.

[0025] Throughout this disclosure, a hyphenated form of a reference numeral refers to a specific instance of an element and the un-hyphenated form of the reference numeral refers to the element generically or collectively. Thus, as an example (not shown in the drawings), device “12-1” refers to an instance of a device class, which may be referred to collectively as devices “12” and any one of which may be referred to generically as a device “12”. In the figures and the description, like numerals are intended to represent like elements.

[0026] As noted, the typical method of flipping or overturning individual wafers during semiconductor wafer handling can be slow and can add additional process time for wafer handling, which is not desirable. Typical mechanisms for flipping or overturning wafers can handle individual wafers and have been implemented as a standalone module or as an attachment to a wafer handling robot, such as an EFEM robot. Such individual wafer flipping stations can take up additional space and are associated with additional resources for floor installation and maintenance, which are undesirable aspects. An individual wafer flipping station can involve additional handling functionality that is performed by an EFEM robot, which can add complexity for integration of different systems that also incurs additional resources, which is not desirable. Furthermore, some automated wafer flipping systems use a suction grip, such as a suction cup, that can contaminate a semiconductor substrate with particles, particularly when the suction grip contacts the substrate at a center portion where integrated circuits (IC) on the wafer are located, which is undesirable.

[0027] The multi-wafer handling system described below in further detail can provide certain desirable improvements over typical wafer flipping mechanisms. Certain implementations can be integrated into a bulkhead of a process module, such as at an external wall of the process module that is externally accessible to an EFEM robot that loads wafers into the process module, while the external wall is also internally accessible to handling equipment within the process module. Certain implementations can receive and support multiple wafers and can enable pass-through access for picking and placing a wafer from either side of the multi-wafer handling system. Certain implementations can accordingly be independent of wafer handling equipment associated with a process module. Certain implementations can securely grip multiple wafers individually and flip the multiple wafers together in one operation. Certain implementations can grip wafers at an edge exclusion (EE) portion of a wafer, and so, avoid contacting an IC on the wafer, which also avoids contaminating an IC on the wafer. Certain implementations can grip wafers using a wafer resting flexure that is vertically and torsionally compliant, such that wafers having a bowed condition can be securely gripped and held by the wafer resting flexure. Certain implementations can include an edge grip flexure that contacts a wafer at an edge of the wafer, such as to laterally move the wafer into a desired position.

[0028] Turning now to the drawings, FIG. **1**A is a depiction of a multi-wafer buffer assembly **100** (or simply, buffer assembly **100**) including a rotary stage **102**, in an implementation of the multi-wafer handling system. As shown, buffer assembly **100** further includes a multi-wafer retaining assembly **110** (or simply, retaining assembly **110**) as will be described in further detail with respect to the subsequent figures. As shown, FIG. **1**A is intended to be a schematic illustration that is not necessarily drawn to scale or perspective.

[0029] In buffer assembly **100** in FIG. **1**A, rotary stage **102** is shown with attachment points **102-1**, such as for mounting on a bulkhead of a process module in a semiconductor fabrication facility. It is noted that rotary stage **102** can be configured for compatibility with existing bulkheads and existing attachment points to a given process module, in various implementations, that can vary and can be different. Therefore, the arrangement and shape of rotary stage **102** is shown in an exemplary implementation for descriptive purposes. The bulkhead of the process module may contain a wall opening at an external wall of the process module through which wafers can be introduced into the process module. Rotary stage **102** can accordingly be mounted to the bulkhead at a location of the wall opening, such that the wall opening is aligned with a central passageway **112** (or simply, passageway **112**) that is open at each opposing end of retaining assembly **110**. In this arrangement of retaining assembly **110**, wafers can be introduced, individually or collectively, at each end of central passageway **112** and can be removed, individually or collectively, at each end of central passageway **112**. For example, an external EFEM robot can place individual wafers into central passageway **112**, where the wafer is received by retaining assembly **110**, as will be described in further detail, and can pick individual wafers from central passageway **112**. Similarly, handling equipment within the process module at an opposite end of central passageway **112**, such as another robot or another tool, can pick individual wafers from central passageway **112** and can place individual wafers into central passageway **112**. Furthermore, the openings at each opposing end of central passageway **112** can be accessible for collective pick and place of multiple wafers simultaneously, in a similar manner, since retaining assembly **110** is configured to receive, grip, and retain multiple wafers such that the multiple wafers can be simultaneously flipped together in one operation. It is further noted that, due to the free openings at both ends of central passageway **112** that also do not obstruct pick and place wafer handling equipment on either side of retaining assembly **110**, wafers can be simultaneously loaded into retaining assembly **110** at one end, while being removed from retaining assembly **110** at an opposite end, in various implementations. As will be shown and described with respect to the subsequent figures, the free openings at both ends of central passageway **112** remain free during operation of retaining assembly **110**.

[0030] Also visible in buffer assembly **100** in FIG. **1**A, is a main bearing **104** to which retaining assembly **110** is mounted to enable rotation of retaining assembly **110**. Main bearing **104** can be part of rotary stage **102** that allows retaining assembly **110** to turn about a central axis, such that wafers loaded and secured within retaining assembly **110** can be collectively turned about the central axis, such as by an angular displacement of 180 degrees, which results in flipping the wafers over (e.g., overturning the wafers). It is noted that main bearing **104** can be configured to turn over any desired angular displacement relative to the central axis. In particular implementations, other components of the rotary actuator stage can be integrated into main bearing **104** or be co-housed with main bearing **104** or be mechanically coupled to main bearing **104**. It is further noted that a size or a diameter of main bearing **104**, along with a size of retaining assembly **110**, can be variously dimensioned to handle wafers of different sizes, such as wafers having a diameter of 150 mm, 200 mm, 300 mm, or 450 mm, in different implementations. Furthermore, as will be depicted in the following figures, retaining assembly **110** is configured to handle eight (8) wafers in the implementations shown. However, in various other implementations, the multi-wafer retaining assembly described herein can be configured to handle different numbers of wafers, such as 2, 4, 6, 10, 12, 14, 16, 18, 20, 22, 24 wafers, or another number of wafers. Even though retaining assembly **110** is shown herein configured to handle up to eight (8) wafers, retaining assembly **110** can operate as described when populated with less than eight (8) wafers.

[0031] In FIG. **1**B, multi-wafer retaining assembly **110** is shown in further detail in a dimetric view.

As shown, FIG. 1B is intended to be a schematic illustration that is not necessarily drawn to scale or perspective.

[0032] In FIG. 1B, a base structure of retaining assembly **110** is shown comprising a first base plate **116-1** and a second base plate **116-2** to which a first sidewall **114-1** and a second sidewall **114-2** are attached, thereby forming central passageway **112**. Sidewalls **114** have respective openings in which two retention finger assemblies **120** are mounted that comprise multiple retention fingers **402**, discussed and shown in further detail below with respect to FIG. **4**. Specifically, as shown, a first sidewall **114-1** has a second retention finger assembly **120-2** and a third retention finger assembly **120-3** mounted thereon, while a second sidewall **114-2** has a first retention finger assembly **120-1** and a fourth retention finger assembly obscured from view mounted thereon.

[0033] As shown in FIG. 1B, each retention finger assembly **120** is configured to rotate about an axis **122** and to translate vertically, such that the multiple retention fingers **402** attached to the retention finger assembly **120** rotate and translate vertically simultaneously in unison. Specifically, axis **122** is defined by a corresponding driveshaft that extends and protrudes through first base plate **116-1** and second base plate **116-2**, and that can be rotated or vertically translated. In particular implementations, retention finger assembly **120** is configured to rotate between a first angular position and a second angular position. Specifically, at the first angular position, retention finger assembly **120** protrudes through sidewall **114** into passageway **112** in order to receive or grip a wafer; at the second angular position, retention finger assembly **120** is retracted behind sidewall and does not protrude into passageway **112**. In FIG. 1B, all four retention finger assemblies **120** are depicted in the second angular position, or retracted from passageway **112**. It is noted that retention finger assembly **120** can be configured to rotate to various desired angular positions, in different implementations. In addition to the angular displacement, retention finger assembly **120** is enabled to vertically translate or move, such as by a corresponding vertical translation of the driveshaft associated with axis **122**. Again, in particular, retention finger assembly **120** can be configured to move vertically between a first vertical position and a second vertical position. The first vertical position corresponds vertically to contacting a wafer, such as for gripping the wafer, while the second vertical position corresponds to retracting from the wafer, such as for rotating to the second angular position, as will be explained in further detail.

[0034] As noted, each retention finger assembly **120** has eight (8) retention fingers **402** mounted thereon in an exemplary implementation shown in the figures. Each of the eight (8) retention fingers **402** is configured to respectively contact one wafer and is stacked in a vertically aligned configuration within retention finger assembly **120**. Accordingly, one retention finger **402** from each of the four retention finger assemblies **120** (corresponding to a respective one of axis **122**) collectively form a quartet of retention fingers **402** that contact one wafer, and respectively can provide a slot for the one wafer within passageway **112** when in the first angular position. In this manner, retaining assembly **110** is configured to receive, grip, and flip up to eight (8) individual wafers or other semiconductor substrates.

[0035] As shown in FIG. 1B, various mechatronic components are visible for performing the rotational translation and vertical translation of each of the four retention finger assemblies **120** using a respective driveshaft associated with axis **122**. As noted, mechatronic components for one retention finger assembly **120** are shown together in the sectional view in FIG. **4**. As shown in FIG. 1B, first retention finger assembly **120-1** is coupled to a first driveshaft at axis **122-1** and can be rotated using a first actuator **126-1**. As shown, first actuator **126** is a linear pneumatic actuator with a pivot mechanism that rotates the driveshaft between the first angular position and the second angular position. Various other forms of actuation and angular displacement about axis **122** can be used in different implementations. As shown, linear actuator **126-1** is located at first base plate **116-1**, while at an opposite end of the driveshaft at axis **122-1**, a lift mechanism **124-1** is configured to perform the vertical translation of the driveshaft to vertically move first retention finger assembly **120-1**, such as from the first vertical position to the second vertical position and back to the first vertical position. As shown, lift mechanism **124-1** can include another linear pneumatic actuator. It is noted that different types of actuators and lift mechanisms can be used in various implementations. Also shown in FIG. **1**B is a second retention finger assembly **120-2**, with a linear actuator **126-2** for rotation of second retention finger assembly **120-2** about axis **122-2**, and with a lift mechanism **124-2** for vertical translation of second retention finger assembly **120-2**. Also shown in FIG. **1**B is a third retention finger assembly **120-3**, with a linear actuator **126-3** for rotation of third retention finger assembly **120-3** about axis **122-3**, and with a lift mechanism **124-3** for vertical translation of third retention finger assembly **120-3**. A fourth retention finger assembly with a linear actuator for rotation and with a lift mechanism is at least partially obscured from view in FIG. **1**B but is similarly configured for rotation and vertical translation.

[0036] Although retention finger assemblies **120** can be mounted in retaining assembly **110** in various orientations, it is noted that a particular orientation is shown in FIG. **1**A. Furthermore, although each retention finger assembly **120** can be operated independently, such as with the described components for rotation and vertical translation, a particular operational synchronization can be used in certain implementations. Specifically, third retention finger assembly **120-3** and first retention finger assembly **120-1** are oriented to contact one or more wafers introduced into passageway **112** from a first side of each wafer, and are also configured to operate in unison with each other, such as for rotation and for vertical translation. Commensurately, second retention finger assembly **120-2** and the fourth retention finger assembly are oriented to contact the one or more wafers introduced into passageway **112** from a second side of each wafer, and are also configured to operate in unison with each other, such as for rotation and for vertical translation. In this manner, retaining assembly **110** can operate in a substantially similar manner regardless of rotational orientation of main bearing **104**. In other words, when retaining assembly **110** turns 180 degrees to flip or to overturn the one or more wafers, retaining assembly **110** can operate in the same manner as when turned 0 degrees, as will be described in further detail.

[0037] FIG. **2** is a depiction of sidewall **114-2** of multi-wafer retaining assembly **110**, in an implementation. Specifically, FIG. **2** shows sidewall **114-2** as depicted in FIG. **1**B in isolation, such that fourth axis **122-4** and fourth retention finger assembly **120-4** are visible, along with first axis **122-1** and first retention finger assembly **120-1**. In FIG. **2**, first retention finger assembly **120-1** and a fourth retention finger assembly **120-4** are shown rotated to the second angular position and protrude away from sidewall, such as into central passageway **112**.

[0038] FIG. **3** is a depiction of components **300** with retention finger assembly **120**, in an implementation. FIG. **3** shows a sectional view of one retention finger assembly **120** that is mounted between first base plate **116-1** and second base plate **116-2**, along with related components for rotational and vertical movement. It is noted that retention finger assembly **120** in FIG. **3** can represent any arbitrary one of four retention finger assemblies **120** included with retaining assembly **110**. As shown in FIG. **3**, retention finger assembly **120** is mounted about axis **122** on a driveshaft. First actuator **126** is shown with a pivot mechanism attached to first base plate **116-1** and configured to rotate retention finger assembly **120** about axis **122** from the first angular position to the second angular position. As shown in FIG. **3**, retention finger assembly **120** is at the second angular position. Lift mechanism **124** is shown with a lift actuator **302** that is configured to vertically move retention finger assembly **120** from the first vertical position to the second vertical position.

[0039] FIG. **4** is a depiction of retention finger assembly **120**, in an implementation. FIG. **4** shows further details of retention fingers **402**, of which eight (8) are shown attached to a driveshaft **410** that defines axis **122**. As noted, eight (8) retention fingers **402** are attached to driveshaft **410** rotate and move vertically in unison with driveshaft **410**, and are accordingly fixed to driveshaft **410** in the same manner and orientation. The vertical alignment of the eight retention fingers **402** to each other, as well as a uniform vertical spacing between retention fingers **402**, is also visible in FIG. **4**. As shown, retention finger **402** has a finger body **402-1** in the form of a shaped plate that is penetrated by and affixed to driveshaft **410** at a proximal end of finger body **402-1**. At a distal end of finger body **402-1**, two wafer resting flexures **406** (or simply, resting flexures **406**) are mounted (see also FIGS. **9**, **10**, and **12**). Although two wafer resting flexures **406** are shown included with retention finger **402**, it is noted that different numbers and configurations of resting flexures can be used in various implementations. Wafer resting flexure **406** is attached to finger body **402-1** in an orientation that corresponds to a diameter of a wafer that wafer resting flexure **406** can support and grip, such that wafer resting flexure **406** meets the wafer in a perpendicular orientation to the wafer edge. Specifically, wafer resting flexure **406** includes a stepped portion **406-**S having a flat ledge and a vertical stop for engaging the wafer. In particular implementations, wafer resting flexure **406** is vertically and torsionally compliant in order to provide contact with wafer with a suitable frictional force, such as for gripping wafer during flipping by retaining assembly **110**, including for gripping wafers having a bowed shape, such that the wafer is not planar. For example, vertical bowing with a vertical deviation of up to 1 mm can occur locally where wafer resting flexure **406** contacts the wafer. Accordingly, wafer resting flexure **406** can provide mechanical compliance by vertically and torsionally flexing (e.g., bending and twisting) to effectively grip the wafer. In various implementations, wafer resting flexure **406** can be made from a compliant material having good strength and also superior environmental stability. In particular implementations, the compliant material can be selected from one or more of a variety of polymers, such as acrylonitrile butadiene styrene (ABS), polyether ether ketone (PEEK), ethylene propylene diene monomer (EPDM) rubber, or another suitable polymer. In some implementations, wafer resting flexure **406**, or a portion thereof, may be made using a composite structure with multiple different materials, such as a rigid metal interior portion with a polymer overmold, such as one or more polymers noted above, to provide a degree of vertical and torsional compliance. In some cases, the rigid metal interior portion can be equipped with resting pads that are fastened using one or more fasteners, such that the resting pads are made from a polymer to provide a degree of vertical and torsional compliance. The rigid metal interior portion can be made of a stainless steel or another suitable metal or metal alloy.

[0040] Also shown included with each retention finger **402** is an edge grip flexure **408** shown mounted with each finger body **402-1**. Edge grip flexure **408** is also penetrated by and affixed to driveshaft **410** at a proximal end of edge grip flexure **408**, in a similar manner as finger body **402-1**. At a distal end, edge grip flexure **408** includes a protrusion or a boss **408-1** that has a vertical edge to engage an edge of the wafer, such as to nudge the wafer into a desired aligned position with respect to wafer resting flexure **406** (see also FIGS. **7**, **8**, and **11**). It is noted that edge grip flexure **408** is fixed to driveshaft **410** and can move along with driveshaft **410** in the same manner as retention finger **402**, in particular implementations. Furthermore, driveshaft **410** can have a mechanism to engage and disengage edge grip flexure **408** the wafer, such as when retention finger **402** is rotated to the second angular position (see FIGS. **7** and **8**).

[0041] Referring now to FIGS. **5** and **6**, a depiction of a wafer loading operation **500** and a depiction of a wafer holding operation **600** are respectively shown, in an implementation. FIGS. **5** and **6** show a top view of one slot for a wafer **502** (or a substrate **502**) in passageway **112** of retaining assembly **110**, where wafer **502** is placed between first sidewall **114-1** and second sidewall **114-2**. As noted, the slot for wafer **502** is provided by four retention fingers **402** forming a quartet of retention fingers, each respectively associated with an axis **122** corresponding to a driveshaft **410**. Specifically, first retention finger **402-1** rotates and moves vertically with respect to first axis **122-1**, second retention finger **402-2** rotates and moves vertically with respect to second axis **122-2**, third retention finger **402-3** rotates and moves vertically with respect to third axis **122-3**, and fourth retention finger **402-4** rotates and moves vertically with respect to fourth axis **122-4**. Although each retention finger **402** can be configured to move independently, as noted above, first retention finger **402-1** moves simultaneously in unison with third retention finger **402-3**, while second retention finger **402-2** moves simultaneously in unison with fourth retention finger **402-4**, as shown. Furthermore, assuming a top view in FIG. **5**, first retention finger **402-1** and third retention finger **402-3** are located above wafer **502**, while second retention finger **402-2** and fourth retention finger **402-4** are located below wafer **502**.

[0042] In wafer loading operation **500**, prior to wafer **502** being introduced in passageway **112**, second retention finger **402-2** and fourth retention finger **402-4** are rotated to the first angular position and are vertically moved to the first vertical position, while first retention finger **402-1** and third retention finger **402-3** are rotated to the second angular position and are vertically moved to the second vertical position. In this arrangement, when second retention finger **402-2** and fourth retention finger **402-4** are located below wafer **502**, second retention finger **402-2** and fourth retention finger **402-4** form a tray that can receive wafer **502**, such as placed on second retention finger **402-2** and fourth retention finger **402-4** from either side of passageway **112**. At the same time, first retention finger **402-1** and third retention finger **402-3** are retracted from passageway **112** by rotation to the second angular position, and are elevated above wafer **502** in the second vertical position, thereby providing clearance for wafer **502** to be introduced into the specific slot or tray formed by second retention finger **402-2** and fourth retention finger **402-4**. Wafer **502** can accordingly rest in this configuration on four wafer resting flexures **406** (two each on second retention finger **402-2** and fourth retention finger **402-4**). Then, wafer **502** can be placed in the tray or slot formed by second retention finger **402-2** and fourth retention finger **402-4**, such as by a wafer handling robot, which can release the wafer and retract itself. It is noted that while a single quartet of retention fingers **402** forming one wafer tray or slot is shown in FIG. **5**, in operation of retaining assembly **110**, multiple wafers can be simultaneously be received by respective multiple (e.g., eight (8) as shown in FIG. **1**B) quartets of retention fingers **402** that operate simultaneously in unison, as explained previously.

[0043] Then, in wafer loading operation **500**, first retention finger **402-1** and third retention finger **402-3** can be rotated into the first angular position and then moved (e.g., lowered) to the first vertical position, such that wafer **502** is clamped and gripped by the four (4) retention fingers **402**, such as by the eight (8) wafer resting flexures **406**. The resulting configuration is shown in wafer holding operation **600** in FIG. **6**, in which wafer **502** is held and secured in retaining assembly **110**. In some implementations, in wafer loading operation **500**, one or more edge grip flexures **408** can be activated to nudge wafer **502** to a desired aligned location in passageway **112**, such as aligned to wafer resting flexures **406** (see FIGS. **7** and **8**). In some implementations, the wafer alignment using edge grip flexures **408** can be done after wafer **502** has been gripped from both sides by the eight (8) wafer resting flexures **406**, prior to retaining assembly **110** turning 180 degrees to flip wafer **502** (and other wafers loaded in retaining assembly **110**) over.

[0044] In wafer holding operation **600** shown in FIG. **6**, retaining assembly has been turned 180 degrees to flip wafer **502**, which results in the same configuration, but in which the specific pairs of retention fingers are reversed, as noted by the labeling of retention fingers **402** and sidewalls **114**, which have been reversed from wafer loading operation **500**. Then, the same procedure for wafer loading operation **500** is performed in reverse to enable wafer **502** to be picked by a wafer handling robot, from either side of passageway **112**, and removed from retaining assembly **110**.

[0045] FIGS. **7** and **8** are depictions of an edge grip operation **700-1** and **700-2**, respectively, in an implementation. In FIGS. **7** and **8**, edge grip operation **700** shows a top view in the same orientation as wafer holding operation **600** in FIG. **6** but in a close-up view for improved clarity to show operation of edge grip flexure **408**. In edge grip operation **700**, wafer **502** is secured by a quartet of retention fingers **402**, and thus, is gripped by eight (8) wafer resting flexures **406**, four (4) on a first side of wafer **502**, and four (4) on a second side of wafer **502**. In this state, wafer **502** is ready for flipping over but may not be precisely aligned within the grip of the eight (8) wafer resting flexures **406**.

[0046] In edge grip operation **700-1** in FIG. **7**, edge grip flexure **408** is visible with boss **408-1** at a distal portion that is configured to engage with wafer **502** for alignment purposes. Specifically, in edge grip operation **700-1**, boss **408-1** is shown in a retracted position to provide greater clearance for wafer **502** to be introduced into passageway **112**, even when two (2) of retention fingers **402** are in the first angular position in order to support wafer **502** from below. In various implementations, the clearance between boss **408-1** and an edge of wafer **502** can be less than 5 mm, for example, about 4 mm in particular implementations. After the remaining two (2) retention fingers **402** in the quartet of retention fingers **402** defining the slot for wafer **502** in retaining assembly **110** are turned to the first angular position and lowered to the first vertical position to secure wafer **502**, boss **408-1** can be extended to engage the edge of wafer **502**, as shown in edge grip operation **700-2** in FIG. **8**. In edge grip operation **700-2**, boss **408-1** is extended to engage the edge of wafer **502** and may be configured to have an interference of less than 1 mm with wafer **502**, such as about 0.5 mm in particular implementations. It is noted that edge grip flexure can accordingly be made from a suitably compliant material that nonetheless has sufficient strength or stiffness to nudge wafer **502** into a desired position. It is noted that, since each retention finger **402** can be equipped with edge grip flexure **408**, in the clamped or closed condition of wafer **502** shown in FIGS. **7** and **8**, there can be up to four (4) edge grip flexures **408** that act to nudge wafer **502**, as shown in edge grip operation **700**. In particular implementations, the up to four (4) edge grip flexures **408** can be configured to nudge wafer **502** substantially simultaneously to achieve a desired centering effect on wafer **502**.

[0047] FIGS. **9** and **10** are depictions of a wafer grip operation **900-1** and **900-2**, respectively, in an implementation. In FIGS. **9** and **10**, wafer grip operation **900** shows a lateral view in close up corresponding to the arrangement of retention fingers **402** in wafer holding operation **600** in FIG. **6**. In FIGS. **9** and **10**, a pair of wafer resting flexures **408-2** and **408-3** are thus shown but it will be understood that wafer grip operation **900** is representative for any pair of wafer resting flexures **406**. In wafer grip operation **900**, wafer resting flexure **406-3** is located below wafer **502**, while wafer resting flexure **406-2** is above wafer **502**. In wafer grip operation **900** in FIGS. **9** and **10**, both wafer resting flexures **408-3** and **408-2** are located in the first angular position, while wafer resting flexure **406-3** is in the first vertical position and supports wafer **502**. In wafer grip operation **900-1** in FIG. **9**, wafer resting flexure **406-2** is in the second vertical position, while in wafer grip operation **900-2** in FIG. **10**, wafer resting flexure **406-2** has been lowered to the first vertical position to engage wafer **502**.

[0048] In FIGS. **9** and **10**, further details of wafer resting flexure **406** are visible in operation (see also FIG. **12**). Specifically, using wafer resting flexure **406-2** as an example, a shelf (or tray) portion at a distal end of resting flexure **406-2** is visible and labeled as **406-2**S. Shelf portion **406-2**S has a reduced vertical height as compared with a proximal body portion of resting flexure **406-2** to form the shelf (or tray) to engage wafer **502**, whether from the bottom or from the top of wafer **502**. Shelf portion **406-2**S also includes other features, such as a ramp rest **406-2**R that is angled in a horizontal slope. Ramp rest **406-2**R contacts wafer **502** from a top or bottom surface of wafer **502** and serves to reduce the contact area with wafer **502**, as well as to place the contact area with wafer **502** at an edge portion of wafer **502**, so as to remain in the EE zone of wafer **502** with greater likelihood. Shelf portion **406-2**S also includes one or more detention stops **406-2**D that are vertically angled and have a vertical stop portion at a surface of shelf portion **406-2**S (see also FIG. **12**). Wafer resting flexure **406-3** has corresponding shelf portion **406-3**S, ramp rest **406-3**R, and detention stop **406-3**D.

[0049] In wafer grip operation **900-1** in FIG. **9**, as wafer **502** is placed on shelf portion **406-3**S, such as when wafer **502** is introduced into passageway **112** of retaining assembly **110** in a horizontal direction, wafer **502** may engage vertical ramp portions or vertical stop portions of detention stops **406-3**D that can provide a detention stop. Then, as wafer **502** is lowered into resting flexure **406-3** shelf portion **406-3**S, such as by an external robot tool, the vertical ramp portions can guide the wafer to the vertical stop portions of detention stops **406-3**D as wafer **502** is released and rests on shelf portion **406-3**S, and specifically on ramp rest **406-3**R. At this time, resting flexure

406-2 is still at the second vertical position where a surface of ramp rest **406-2**R has a standoff gap (H) of less than about 5 mm from a top surface of wafer **502**, as shown. In particular implementations, the standoff gap can be less than about 4 mm or less than about 3 mm from the top surface of wafer **502**. Then, as resting flexure **406-2** is lowered onto wafer **502**, as shown in wafer grip operation **900-2** such that the standoff gap H is reduced to zero, in a gripped or clamped state. As shown in wafer grip operation **900-2**, ramp portion **406-2**R may engage with wafer **502** such that ramp portion **406-2**R and ramp portion **406-3**R have an interference with wafer **502** of less than 100 μm, such as about 75 μm in some implementations. This interference results in a bidirectional vertical clamping force on wafer **502** that secures wafer **502**, while detention stops **406-2**D and **406-3**D serve to laterally align wafer **502**. After wafer grip operation **900-2**, edge grip operation **700** may be performed to nudge wafer **502** into a final position, as described above with respect to FIGS. **7** and **8**.

[0050] It is noted that in FIGS. **9** and **10**, wafer **502** is shown as being substantially planar, such as being near perfectly flat. However, it is observed that in certain implementations, such as where multiple layers of different types of semiconductor materials (e.g., conductors, dielectrics, semiconductors) are formed on IC devices on wafer **502**, wafer **502** may exhibit a certain degree of bowing that may be localized at wafer resting flexures **406**. For example, localized variations in wafer height at wafer resting flexures **406** of up to 1,000 μm may be observed. In such cases, wafer resting flexures **406** are configured and fabricated to be compliant, as noted, and can be made with a sufficiently compliant material to sufficiently grip wafer **502** even when locally bowed, such as for safe handling and safe flipping by retaining assembly **110**. Specifically, wafer resting flexures **406** can be designed to deflect under the weight of a standard silicon wafer, such as a 300 mm diameter silicon wafer having a thickness of less than about 1,000 μm, such as 775 μm in particular implementations.

[0051] FIG. **11** shows depictions of edge grip flexure **408**, in an implementation. In FIG. **11**, two views of edge grip flexure **408** are shown from different perspectives. Also visible in FIG. **11** is boss **408-1** at a distal portion of edge grip flexure **408** that can be used to nudge and edge of wafer **502**. At a proximal portion of edge grip flexure **408** an opening **408-2** that is penetrated by driveshaft **410** defining axis **122** is also visible, as explained above with respect to FIGS. **7** and **8**.

[0052] FIG. **12** is a depiction of wafer resting flexure **406**, in an implementation. In FIG. **12**, details of shelf portion **406-**S, including ramp portion **406-**R and detention stop **406-**D are more clearly visible, including the vertical ramp portion and vertical stop portion of detention stop **406-**D, as explained above with respect to FIGS. **9** and **10**.

[0053] In the previous description, mechanical engagement with wafer **502** by various components of retaining assembly **110** are explained in detail. It is noted that additional instrumentation can be used to sense engagement with or a position of wafer **502**. For example, certain sensors may be used at locations where wafer **502** contacts wafer resting flexure **406** and/or edge grip flexure **408**, in some implementations, such as strain gages, piezoelectric sensors, optical sensors, among others. The signals from such sensors can be used to provide feedback to a control system of retaining assembly **110** that controls operation of the four (4) driveshafts **410**, for example. The control system may be so enabled to detect a certain state of individual wafers **502**, such as handled by an individual quartet of retention fingers **402** that form a slot or a tray to receive, grip, rotate, and release wafer **502**. The control system may include a processor having access to memory media storing instructions executable by the processor. The processor and/or instructions can be configured to receive the signals from the instrumentation that interfaces with the one or more sensors.

[0054] FIG. **13** is a depiction of a wafer sensing operation **1300**, in an implementation. As shown and described below, wafer sensing operation **1300** may be performed to detect whether retaining assembly **110** is empty or is loaded with one or more wafers **502**. Furthermore, wafer sensing operation **1300**, as shown and described below, can be performed to detect whether any loaded wafer is out of position, such as to confirm or monitor a place operation or a pick operation performed by an external robot.

[0055] In FIG. **13**, depictions of five (5) wafers **502** indicating five (5) respective sensing conditions are shown as A, B, C, D, E. Each sensing condition can be based on a signal from four (4) of five (sensors) used with retaining assembly **110**, respectively shown by an indicator **1302** that is shown as an empty circle in a normal state and as a solid circle in an error state. The signal shown by indicator **1302** in wafer sensing operation **1300** can be received from four (4) respective optical sensors that are mounted at first base plate **116-1** and second base plate **116-2**, for example, at the locations relative to wafer **502** as shown in FIG. **13**. Specifically, the optical sensors can be line-of-sight sensors, such as with an emitter and a detector, at four corners external to wafer **502** as shown in FIG. **13**. For example, the optical sensors can include laser emitters and photodiode detectors that indicate the normal state when light from a laser emitters reaches a corresponding photodiode detector, and indicate the error state when no light from the laser emitter reaches the corresponding photodiode detector. Because the line-of-sight is vertically arranged to pass by any and all wafers **502** that may be loaded into retaining assembly **110**, the optical sensors can provide collective information about the positional state of wafers **502** loaded into retaining assembly **110**, even when the sensors are not configured to provide specific information about any individual wafer **502**, such as with a distance measurement. Thus even absent any distance measurement to identify any individual wafer, the collective sensor arrangement can identify the sensing conditions A, B, C, D, E depicted in wafer sensing operation **1300**. A further fifth sensor can be centrally located at wafers **502** that can provide a fifth signal indicating whether retaining assembly **110** is empty of wafers **502** or not, (e.g., can indicate whether at least one wafer **502** is loaded into retaining assembly **110**). In wafer sensing operation **1300** shown in FIG. **13**, it can be assumed that the fifth sensor indicates a non-empty condition and is not further considered in the description below.

[0056] As shown in wafer sensing operation **1300** in FIG. **13**, a sensing condition A can indicate a normal placement of all wafers **502** currently loaded into retaining assembly **110**, such that retaining assembly **110** is ready for flipping 180 degrees, as described previously. A sensing condition B can indicate a potential failure of at least one resting flexure **406**, and a location of indicator **1302** can identify which one or more retention fingers **402** is/are the source of the failure that typically occurs during the flipping operation, such as a result of wafer slide out of a single wafer **502**. A sensing condition C can indicate a shallow placement from a direction indicated by the arrow at C, such as after a timeout associated with a place operation by an external robot tool, indicating that at least one wafer **502** was not placed deep enough within passageway **112**. Alternatively, sensing condition C can indicate a valid place operation in progress, such as when sensing condition C is observed during the place operation from the direction indicated by the arrow at C, after which sensing condition A is observed, for example. Similarly, sensing condition D can be observed during a pick operation to remove at least one wafer **502** in a direction shown by the arrow at D and can indicate a valid pick operation in progress, such as when followed by sensing condition A after the pick operation is complete. A sensing condition E can indicate a deep placement from a direction indicated by the arrow at E, such as during or after a place operation by an external robot tool, indicating that at least one wafer **502** was placed too deep within passageway **112**.

[0057] Turning now to FIG. **14**, a method **1400** of flipping wafers using retaining assembly **110** is shown in flowchart format. It is noted that some portions of method **1400** may be omitted or rearranged in certain implementations.

[0058] Method **1400** may begin at step **1402** by rotating a first pair of retention fingers of a first quartet of retention fingers to a first angular position, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, each resting flexure being vertically and torsionally compliant, where multiple quartets of retention fingers including the first quartet are mounted in a housing to which each of the retention fingers is respectively mounted at the axis. At step **1404**, a second pair of retention fingers of the first quartet is rotated to a second angular position, the second pair vertically spaced a first distance from the first pair. At step **1406**, a wafer is received through a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the retention fingers being free of the passageway in the second angular position, the wafer being received from the first end and supported at a first side of the wafer by the resting flexures of the first pair, the second pair vertically located to face a second side of the wafer opposite the first side. At step **1408**, the second pair is rotated to the first angular position. At step **1410**, the second pair is vertically moved towards the wafer in the first angular position to hold the wafer at the second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair. At step **1412**, using a bearing to which the housing is mounted, the housing is turned such that the wafer is flipped 180 degrees when the wafer is held by the first quartet.

[0059] As disclosed herein, a wafer handling device includes multiple quartets of retention fingers, each having a resting flexure at a distal end that is vertically and torsionally compliant, a housing to which the retention fingers are mounted, a first pair of the retention fingers from a first quartet, the first pair configured to rotate to a first angular position to receive a wafer by the resting flexures, a second pair of the retention fingers from the first quartet configured to rotate to the first angular position after the first pair receives the wafer, and configured to vertically move towards the wafer in the first angular position, where the device grips the wafer at a second side by the second pair and at a first side by the first pair, and a bearing to which the housing is mounted for turning the housing to overturn the wafer 180 degrees.

[0060] Example implementations of the disclosure are described below. Other implementations can also be understood from the entirety of the specification as well as the claims filed herein.

[0061] Example 1. A substrate handling device, including: multiple quartets of retention fingers, each retention finger having a resting flexure at a distal end; a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive a wafer by the resting flexures of the first pair; a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair further configured to vertically move towards the wafer in the first angular position, where the substrate handling device is configured to grip the wafer at a second side by the resting flexures of the second pair and at a first side by the resting flexures of the first pair; and a bearing to which the multiple quartets are mounted, the bearing for collectively turning the multiple quartets to flip the wafer by 180 degrees.

[0062] Example 2. The substrate handling device of example 1, where after the multiple quartets are collectively turned, the first pair is configured to vertically move away from the semiconductor substrate in the first angular position and then to rotate to the second angular position, leaving the semiconductor substrate supported by the second pair.

[0063] Example 3. The substrate handling device of one of examples 1 or 2, where the multiple quartets are stacked vertically to each other in a housing that collectively turns the multiple quartets, and each quartet is configured to respectively grip an individual semiconductor substrate when the housing is turned.

[0064] Example 4. The substrate handling device of one of examples 1 to 3, further including: four driveshafts respectively defining four axes of the quartets about which the retention fingers rotate, where the retention fingers are respectively mounted to a driveshaft of the four driveshafts rotate and vertically translate collectively in unison.

[0065] Example 5. The substrate handling device of one of examples 1 to 4, where first two driveshafts corresponding to the first pair of retention fingers are configured to rotate and vertically translate in unison with each other, and second two driveshafts corresponding to the second pair of retention fingers are configured to rotate and vertically translate in unison with each other and independently of the first two driveshafts.

[0066] Example 6. The substrate handling device of one of examples 1 to 5, where each of the retention fingers includes two resting flexures.

[0067] Example 7. The substrate handling device of one of examples 1 to 6, where each resting flexure is vertically and torsionally compliant to hold the wafer when the wafer is not planar.

[0068] Example 8. The substrate handling device of one of examples 1 to 7, where each resting flexure contacts the wafer at an edge exclusion portion of the wafer.

[0069] Example 9. The substrate handling device of one of examples 1 to 8, further including: an edge grip flexure included with a retention finger, the edge grip flexure having a boss for contacting the wafer at an edge surface of the wafer.

[0070] Example 10. A method, including: rotating a first pair of retention fingers of a first quartet of retention fingers to a first angular position, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, where multiple quartets of retention fingers including the first quartet are mounted in a housing to which each of the retention fingers is respectively mounted at the axis; rotating a second pair of retention fingers of the first quartet to a second angular position, the second pair vertically spaced a first distance from the wafer; receiving a wafer through a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the second pair being free of the passageway in the second angular position, the wafer being received from the first end and supported at a first side of the wafer by the resting flexures of the first pair, the second pair vertically located to face a second side of the wafer opposite the first side; after the first pair receives and supports the wafer, rotating the second pair to the first angular position; vertically moving the second pair towards the wafer over the first distance in the first angular position to hold the wafer at the second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair; and turning, using a bearing to which the housing is mounted, the housing to overturn the wafer 180 degrees when the wafer is held by the first quartet.

[0071] Example 11. The method of example 10, further including: after the housing is turned, vertically moving the first pair away from the wafer in the first angular position; and rotating the first pair to the second angular position, leaving the wafer supported by the second pair.

[0072] Example 12. The method of one of examples 10 or 11, where the multiple quartets are stacked vertically to each other in the housing, and each quartet is configured to respectively receive, support, and hold an individual wafer, including holding the individual wafer when the housing is turned.

[0073] Example 13. The method of one of examples 10 to 12, where rotating the first pair of retention fingers further includes: rotating the first pair mounted to a first driveshaft of four driveshafts, the first driveshaft defining the axis, where the retention fingers mounted to the first driveshaft rotate and vertically translate collectively in unison.

[0074] Example 14. The method of one of examples 10 to 13, where each of the retention fingers includes two resting flexures.

[0075] Example 15. The method of one of examples 10 to 14, where each resting flexure is vertically and torsionally compliant to hold the wafer when the wafer is not planar.

[0076] Example 16. The method of one of examples 10 to 15, where the wafer being received from the first end and supported at a first side of the wafer by the resting flexures further includes: contacting the wafer, by the resting flexures, at an edge exclusion portion of the wafer.

[0077] Example 17. The method of one of examples 10 to 16, further including: contacting the wafer at an edge surface of the wafer using an edge grip flexure included with at least one retention finger, the edge grip flexure having a boss for contacting the wafer.

[0078] Example 18. A wafer handling device, including: multiple quartets of retention fingers, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at

a distal end, the resting flexure being vertically and torsionally compliant; a housing to which each of the retention fingers is respectively coupled via the axis; a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the retention fingers having access to the passageway; a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive, in the passageway by the resting flexures of the first pair, a wafer at a first side of the wafer; a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position free of the passageway before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair configured to vertically move towards the wafer in the first angular position, where the wafer handling device is configured to grip the wafer at a second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair; and a bearing to which the housing is mounted, the bearing for turning the housing to overturn the wafer by 180 degrees when the wafer is gripped by the first quartet.
[0079] Example 19. The wafer handling device of example 18, where the multiple quartets are stacked vertically to each other in the housing, and each quartet is configured to respectively receive an individual wafer, including holding the individual wafer when the housing is turned.
[0080] Example 20. The wafer handling device of one of examples 18 or 19, further including: four driveshafts respectively defining four axes of each quartet, where the retention fingers respectively mounted to each driveshaft of the four driveshafts rotate and vertically translate collectively in unison.
[0081] While this disclosure has been described with reference to illustrative implementations, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative implementations, as well as other implementations of the disclosure, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or implementations.

Claims

1. A substrate handling device, comprising: multiple quartets of retention fingers, each retention finger having a resting flexure at a distal end; a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive a wafer by the resting flexures of the first pair; a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair further configured to vertically move towards the wafer in the first angular position, wherein the substrate handling device is configured to grip the wafer at a second side by the resting flexures of the second pair and at a first side by the resting flexures of the first pair; and a bearing to which the multiple quartets are mounted, the bearing for collectively turning the multiple quartets to flip the wafer by 180 degrees.
2. The substrate handling device of claim 1, wherein after the multiple quartets are collectively turned, the first pair is configured to vertically move away from the semiconductor substrate in the first angular position and then to rotate to the second angular position, leaving the semiconductor substrate supported by the second pair.
3. The substrate handling device of claim 1, wherein the multiple quartets are stacked vertically to each other in a housing that collectively turns the multiple quartets, and each quartet is configured to respectively grip an individual semiconductor substrate when the housing is turned.
4. The substrate handling device of claim 3, further comprising: four driveshafts respectively defining four axes of the quartets about which the retention fingers rotate, wherein the retention fingers are respectively mounted to a driveshaft of the four driveshafts rotate and vertically

translate collectively in unison.
5. The substrate handling device of claim 4, wherein first two driveshafts corresponding to the first pair of retention fingers are configured to rotate and vertically translate in unison with each other, and second two driveshafts corresponding to the second pair of retention fingers are configured to rotate and vertically translate in unison with each other and independently of the first two driveshafts.
6. The substrate handling device of claim 1, wherein each of the retention fingers comprises two resting flexures.
7. The substrate handling device of claim 1, wherein each resting flexure is vertically and torsionally compliant to hold the wafer when the wafer is not planar.
8. The substrate handling device of claim 1, wherein each resting flexure contacts the wafer at an edge exclusion portion of the wafer.
9. The substrate handling device of claim 1, further comprising: an edge grip flexure included with a retention finger, the edge grip flexure having a boss for contacting the wafer at an edge surface of the wafer.
10. A method, comprising: rotating a first pair of retention fingers of a first quartet of retention fingers to a first angular position, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, wherein multiple quartets of retention fingers including the first quartet are mounted in a housing to which each of the retention fingers is respectively mounted at the axis; rotating a second pair of retention fingers of the first quartet to a second angular position, the second pair vertically spaced a first distance from the wafer; receiving a wafer through a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the second pair being free of the passageway in the second angular position, the wafer being received from the first end and supported at a first side of the wafer by the resting flexures of the first pair, the second pair vertically located to face a second side of the wafer opposite the first side; after the first pair receives and supports the wafer, rotating the second pair to the first angular position; vertically moving the second pair towards the wafer over the first distance in the first angular position to hold the wafer at the second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair; and turning, using a bearing to which the housing is mounted, the housing to overturn the wafer 180 degrees when the wafer is held by the first quartet.
11. The method of claim 10, further comprising: after the housing is turned, vertically moving the first pair away from the wafer in the first angular position; and rotating the first pair to the second angular position, leaving the wafer supported by the second pair.
12. The method of claim 10, wherein the multiple quartets are stacked vertically to each other in the housing, and each quartet is configured to respectively receive, support, and hold an individual wafer, including holding the individual wafer when the housing is turned.
13. The method of claim 10, wherein rotating the first pair of retention fingers further comprises: rotating the first pair mounted to a first driveshaft of four driveshafts, the first driveshaft defining the axis, wherein the retention fingers mounted to the first driveshaft rotate and vertically translate collectively in unison.
14. The method of claim 10, wherein each of the retention fingers comprises two resting flexures.
15. The method of claim 10, wherein each resting flexure is vertically and torsionally compliant to hold the wafer when the wafer is not planar.
16. The method of claim 10, wherein the wafer being received from the first end and supported at a first side of the wafer by the resting flexures further comprises: contacting the wafer, by the resting flexures, at an edge exclusion portion of the wafer.
17. The method of claim 10, further comprising: contacting the wafer at an edge surface of the wafer using an edge grip flexure included with at least one retention finger, the edge grip flexure having a boss for contacting the wafer.

18. A wafer handling device, comprising: multiple quartets of retention fingers, each retention finger configured to rotate about an axis at a proximal end and having a resting flexure at a distal end, the resting flexure being vertically and torsionally compliant; a housing to which each of the retention fingers is respectively coupled via the axis; a passageway extending centrally through the housing and being open at a first end and a second end of the housing, the retention fingers having access to the passageway; a first pair of the retention fingers from a first quartet of the multiple quartets, the first pair configured to rotate to a first angular position to receive, in the passageway by the resting flexures of the first pair, a wafer at a first side of the wafer; a second pair of the retention fingers from the first quartet, the second pair configured to rotate to a second angular position free of the passageway before the first pair receives the wafer, and to rotate to the first angular position after the first pair receives the wafer, the second pair configured to vertically move towards the wafer in the first angular position, wherein the wafer handling device is configured to grip the wafer at a second side by the resting flexures of the second pair and at the first side by the resting flexures of the first pair; and a bearing to which the housing is mounted, the bearing for turning the housing to overturn the wafer by 180 degrees when the wafer is gripped by the first quartet.
19. The wafer handling device of claim 18, wherein the multiple quartets are stacked vertically to each other in the housing, and each quartet is configured to respectively receive an individual wafer, including holding the individual wafer when the housing is turned.
20. The wafer handling device of claim 19, further comprising: four driveshafts respectively defining four axes of each quartet, wherein the retention fingers respectively mounted to each driveshaft of the four driveshafts rotate and vertically translate collectively in unison.