

CLAIMS

1. An apparatus for transferring wafers from processing station to processing station in a multi-station semiconductor processing chamber, the apparatus comprising:

5 a rotational indexer~~for simultaneously moving multiple wafers between equidistantly spaced locations along a circular path when the wafers are placed upon the rotational indexer and the rotational indexer is activated~~, the rotational indexer including:

~~a base;~~

10 ~~a first motor;~~

~~a second motor;~~

a rotatable first hub;

15 N indexer arm assemblies, each indexer arm assembly including a) a wafer support and b) an indexer arm having a proximal end fixedly connected with the rotatable first hub and a distal end ~~rotatably connected with that supports~~ the wafer support for that indexer arm; and

an actuation mechanism, wherein:

20 ~~the first motor is configured to rotate the first hub about a center axis of the first hub and relative to the base,~~

~~the second motor is configured to provide rotational input to the actuation mechanism,~~

each wafer support is configured to support a semiconductor wafer when the semiconductor wafer is placed on that wafer support,

N is an integer greater than or equal to two,

25 each wafer support is configured to be rotatable relative to the indexer arm ~~of the corresponding indexer arm assembly~~ and about a corresponding rotational axis located at the distal end of the indexer arm that supports~~of that wafer support,~~

30 ~~the rotational axis of each wafer support is located so as to pass through a center of a corresponding one of the wafers when the wafer supports are supporting the wafers, and~~

35 the actuation mechanism includes an array of linkages that are ~~is configured to cause the~~ rotate each wafer supports ~~of the indexer arms to simultaneously rotate by the same amounts, in the same rotational directions, and~~ about the corresponding rotational ~~axes~~axis

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~~of the wafer supports and~~ relative to the indexer arms, ~~and responsive to rotation of: the first motor without rotation of the second motor, the second motor without rotation of the first motor, or the first motor and the second motor such that the actuation mechanism actuates~~

the rotatable first hub and the indexer arm assemblies fixedly connected thereto are configured to rotate about a center axis.

2. The apparatus of claim 1, wherein:

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the actuation mechanism includes a rotatable second hub that is configured to ~~be rotatable~~ rotatable about the center axis ~~of the~~ relative to the rotatable first hub ~~responsive to actuation by the second motor~~, and

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each indexer arm assembly further includes one of the linkages, each linkage including a tie-rod with a proximal end that is rotatably connected with the rotatable second hub by a first rotatable interface and a distal end that is rotatably connected with the wafer support of ~~that~~ the corresponding indexer arm assembly by a second rotatable interface, wherein the actuation mechanism and indexer arm assemblies are configured such that relative rotation between the rotatable first hub and the rotatable second hub about the center axis causes the tie-rods to translate in a generally, predominantly radial manner relative to the center axis, thereby causing each tie-rod to rotate the wafer support to which that tie-rod is rotatably connected ~~to rotate~~ relative to the indexer arms and about the rotational axis of that wafer support.

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3. The apparatus of claim 2, wherein:

the rotatable first hub and the rotatable second hub are configured to be rotatable relative to each other from a first relative rotational position to a second relative rotational position,

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each of the wafer supports, when the rotatable first hub and the rotatable second hub are in the first relative rotational position, is in a third relative rotational position with respect to the rotatable first hub,

each of the wafer supports, when the rotatable first hub and the rotatable second hub are in the second relative rotational position, is in a fourth relative rotational position with respect to the rotatable first hub,

the third relative rotational positions and the fourth relative rotational positions are $360^\circ/N$ out of phase with one another.

4. The apparatus of claim 2, wherein:

the rotatable first hub and the rotatable second hub are configured to be rotatable relative to each other from a first relative rotational position to a second relative rotational position,

N equals 4,

each of the wafer supports, when the rotatable first hub and the rotatable second hub are in the first relative rotational position, is in a third relative rotational position with respect to the rotatable first hub,

each of the wafer supports, when the rotatable first hub and the rotatable second hub are in the second relative rotational position, is in a fourth relative rotational position with respect to the rotatable first hub,

the third relative rotational positions and the fourth relative rotational positions are 90° out of phase with one another.

5. The apparatus of claim 4, wherein:

the proximal end of each tie-rod has an uppermost surface directly above the first rotatable interface for that tie-rod,

each first rotatable interface is horizontally spaced apart from the nearest other first rotatable interface by a first distance,

each tie-rod includes an offset region extending between a first longitudinal distance from a rotational center of the first rotatable interface for that tie-rod and a second longitudinal distance from the rotational center of the first rotatable interface for that tie-rod,

the first longitudinal distances are less than the first distances and the second longitudinal distances are greater than the first distances, and

the offset region of each tie-rod has a lowermost surface that is higher than the uppermost surface of the distal end of the tie-rod from an adjacent indexer arm assembly, thereby allowing the distal end of the tie-rod from the adjacent indexer

arm assembly to pass underneath that tie-rod when the rotatable first hub and the rotatable second hub are in the first relative rotational position.

5 6. The apparatus of claim 4, further comprising a stop mechanism, wherein the stop mechanism is configured to limit relative rotational motion between the rotatable first hub and the rotatable second hub to between 90° and 95°.

10 47. The apparatus of claim 2, wherein at least one of the indexer arms, the tie-rods, and/or the wafer supports are/is made of a ceramic material.

15 58. The apparatus of claim 47, wherein:

 each indexer arm assembly includes a third rotatable interface that rotatably connects the wafer support for that indexer arm assembly with the indexer arm for that indexer arm assembly, and

 the first rotatable interfaces, the second rotatable interfaces, and the third rotatable interfaces are all ceramic ball bearings.

20 ~~6. The apparatus of claim 3, wherein:~~

~~there are four indexer arm assemblies,~~

~~each of the wafer supports, when the first hub and the second hub are in the first relative rotational position, is in a third relative rotational position with respect to the first hub,~~

~~each of the wafer supports, when the first hub and the second hub are in the second relative rotational position, is in a fourth relative rotational position with respect to the first hub,~~

~~the third relative rotational positions and the fourth relative rotational positions are 90° out of phase with one another.~~

30 ~~7. The apparatus of claim 6, further comprising a stop mechanism, wherein the stop mechanism is configured to limit relative rotational motion between the first hub and the second hub to between 90° and 95°.~~

~~8. The apparatus of claim 6, wherein:~~

~~the proximal end of each tie rod has an uppermost surface directly above the first rotatable interface for that tie rod,~~

~~each first rotatable interface is horizontally spaced apart from the nearest other first rotatable interface by a first distance,~~

5 ~~each tie rod includes an offset region extending between a first longitudinal distance from a rotational center of the first rotatable interface for that tie rod and a second longitudinal distance from the rotational center of the first rotatable interface for that tie rod,~~

10 ~~the first longitudinal distances are less than the first distances and the second longitudinal distances are greater than the first distances, and~~

~~the offset region of each tie rod has a lowermost surface that is higher than the uppermost surface of the distal end of the tie rod from an adjacent indexer arm assembly, thereby allowing the distal end of the tie rod from the adjacent indexer arm assembly to pass underneath that tie rod when the first hub and the second hub~~
15 ~~are in the first relative rotational position.~~

~~9. The apparatus of claim 3, wherein:~~

20 ~~each of the wafer supports, when the first hub and the second hub are in the first relative rotational position, is in a third relative rotational position with respect to the first hub,~~

~~each of the wafer supports, when the first hub and the second hub are in the second relative rotational position, is in a fourth relative rotational position with respect to the first hub,~~

25 ~~the third relative rotational positions and the fourth relative rotational positions are $360^\circ/N$ out of phase with one another.~~

9. The apparatus of claim 2, further comprising:

a first motor configured to cause the rotatable first hub to rotate when actuated;

30 a second motor configured to cause the rotatable second hub to rotate when actuated; and

a controller having a memory and one or more processors, wherein:

the memory and the one or more processors are communicatively connected,

35 the one or more processors are configured to control the first motor and the second motor, and

the memory stores computer-executable instructions for controlling the one or more processors to cause one or more of the first motor, the second motor, and the first motor and the second motor to be selectively actuated to cause:

5 the rotatable first hub and the indexer arm assemblies to rotate such that each wafer support moves from a corresponding one of the processing stations to a neighboring processing station of the processing stations,

10 first relative rotational motion between the rotatable first hub and the actuation mechanism such that each wafer support rotates about the rotational axis of that wafer support and relative to the rotatable first hub by a first amount in a first direction during movement from processing station to processing station, while the wafer supports are resident at each processing station, or during both
15 movement from processing station to processing station and while the wafer supports are resident at each processing station, and

20 second relative rotational motion between the rotatable first hub and the actuation mechanism such that each wafer support rotates about the rotational axis of that wafer support and relative to the rotatable first hub by a first amount in a second direction opposite the first direction during movement from processing station to processing station, while the wafer supports are resident at each processing station, or during both movement from processing station to processing station and while the wafer supports are resident at
25 each processing station.

10. The apparatus of claim 2, wherein each tie rod has an internal gas flow passage that is configured to flow gas from the proximal end thereof to the distal end thereof when the gas is introduced at the proximal end thereof.

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4011. The apparatus of claim 1, wherein:

the rotatable first hub includes a separate mounting interface for each indexer arm assembly;

each mounting interface includes a tensionable interface and three conical recesses arranged around the tensionable interface;

5 a sphere is nestled in each conical recess; and
each indexer arm includes:

an aperture through which a portion of the tensionable interface of a corresponding mounting interface of the mounting interfaces protrudes, and

10 three grooves radiating outward relative to the aperture, wherein
each of the spheres of the corresponding mounting interface is also nestled
in a corresponding groove of that indexer arm, ~~wherein and~~ the tensionable
interface ~~s are each~~ of the corresponding mounting interface is configured to
compress the spheres of the corresponding mounting interface between a
15 corresponding one of the indexer arms ~~and a the~~ corresponding ~~one of the~~
mounting interfaces.

1112. The apparatus of claim 1011, wherein the tensionable interface associated
with each indexer arm comprises a threaded component and a spring that is
20 configured to compress that indexer arm against the spheres interposed between
that indexer arm and the mounting interface that connects that indexer arm with the
rotatable first hub when the threaded component is ~~tightened and~~ placed in tension
and provides a compressive load to the spring.

13. The apparatus of claim 12, wherein, for each indexer arm:

25 the corresponding aperture is located in the proximal end of the indexer arm,
the indexer arm is fixedly connected with the rotatable first hub by way of
the corresponding mounting interface, and
each mounting interface fixedly connects the corresponding indexer arm with
the rotatable first hub such that a) the corresponding indexer arm and the rotatable
30 first hub can undergo different amounts of thermal expansion without direct sliding
contact between the indexer arm and the rotatable first hub and b) the
corresponding indexer arm is held fixedly in place relative to the rotatable first hub,
at least in part, by the compression exerted on the indexer arm by the threaded

component and the spring of the tensionable interface of the corresponding mounting interface.

~~12~~14. The apparatus of claim 1, further comprising:

- 5 a motor housing containing the first motor and the second motor and supporting the rotatable first hub via a first hub rotational interface; and
- a z-axis drive system configured to translate the motor housing along a vertical axis responsive to actuation of the z-axis drive system.

10 15. The apparatus of claim 1, wherein each indexer arm has an internal gas flow passage that is configured to flow gas from the proximal end thereof to the distal end thereof when the gas is introduced at the proximal end thereof.

15 16. The apparatus of claim 1, wherein the actuation mechanism is configured to simultaneously rotate the wafer supports about their corresponding rotational axes relative to the indexer arms when actuated.

~~13~~17. A system comprising:

- the apparatus of claim 1; and
- 20 a semiconductor processing chamber housing, the semiconductor processing chamber housing having N processing stations, wherein:
- each processing station includes a pedestal configured to support a semiconductor wafer, and
- the apparatus is configured to transfer semiconductor wafers from
- 25 pedestal to pedestal within the semiconductor processing chamber housing.

30 ~~14. The system of claim 13, wherein the processing stations are configured for performing a semiconductor processing operation selected from the group consisting of: deposition operations, etch operations, curing operations, and heat treatment operations.~~

~~15. The system of claim 13, further comprising a controller having a memory and one or more processors, wherein:~~

~~the memory and the one or more processors are communicatively connected,~~

~~the one or more processors are configured to control the first motor and the second motor, and~~

5 ~~the memory stores computer-executable instructions for controlling the one or more processors to cause one or more of the first motor, the second motor, and the first motor and the second motor to be selectively actuated to cause:~~

10 ~~the first hub and the indexer arm assemblies to rotate such that each wafer support moves from a corresponding one of the processing stations to a neighboring processing station of the processing stations,~~

15 ~~first relative rotational motion between the first hub and the actuation mechanism such that each wafer support rotates about the rotational axis of that wafer support and relative to the first hub by a first amount in a first direction during movement from processing station to processing station, while the wafer supports are resident at each processing station, or during both movement from processing station to processing station and while the wafer supports are resident at each processing station, and~~

20 ~~second relative rotational motion between the first hub and the actuation mechanism such that each wafer support rotates about the rotational axis of that wafer support and relative to the first hub by a first amount in a second direction opposite the first direction during movement from processing station to processing station, while the wafer supports are resident at each processing station, or during both movement from~~
25 ~~processing station to processing station and while the wafer supports are resident at each processing station.~~

30 ~~16. The system of claim 15, wherein $N = 4$ and the memory stores further computer-executable instructions for controlling the one or more processors to cause the first motor to rotate the first hub by 90° in the first direction while not providing rotational input to the actuation mechanism with the second motor.~~

~~17~~18. A method for handling wafers in a semiconductor processing apparatus, the method comprising:

35 a) picking up at least one plurality of wafers ~~up~~ off of ~~a one or more~~ corresponding ~~plurality of~~ pedestals of a plurality of wafer pedestals using an indexer having a corresponding plurality of wafer supports, each wafer support rotatably

mounted to a distal end of an indexer arm of the indexer and configured to support the wafer from below and each indexer arm fixedly mounted to a rotatable first hub of the indexer, ~~wherein the wafers are supported by the wafer supports;~~

5 b) rotating the rotatable first hub and the indexer arms about a first rotational axis to move each wafer support from a position above each of the pedestals to a position above ~~an adjacent~~ one of the other pedestals;

c) placing ~~the each wafers of the at least one wafer~~ onto the pedestals underneath that wafer after (b); and

10 d) rotating each wafer support of the wafer supports ~~relative to the indexer arms and~~ about a corresponding rotational ~~axes~~axis of that wafer supports in between (a) and (c) to cause that wafer support to rotate from a first rotational orientation relative to the indexer arms to a second rotational orientation relative to the indexer arms, wherein the rotational axis of each wafer support ~~passes through the center of the wafer supported by that wafer support when the wafers are supported by the~~ is located at the distal end of the indexer arm having that wafer supports.

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19. The method of claim 18, wherein the rotating of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports and the rotating of the rotatable first hub and the indexer arms about the first rotational axis is performed using no more than two rotational inputs.

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20. The method of claim 18, wherein the rotating of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports occurs concurrently with rotating the rotatable first hub and the indexer arms about the first rotational axis.

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21. The method of claim 20, wherein the rotating of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports starts and ends concurrently with starting and ending the rotation of the rotatable first hub and the indexer arms about the first rotational axis.

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22. The method of claim 21, wherein the rotating of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports

occurs at the same rotational rate as the rotating of the rotatable first hub and the indexer arms about the first rotational axis.

23. The method of claim 18, further comprising simultaneously rotating each wafer support of the wafer supports from the second rotational orientation relative to the indexer arms to the first rotational orientation relative to the indexer arms while the wafer supports are not supporting any wafers.

24. The method of claim 18, wherein the rotating of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports is executed by:

- (1) ending the rotation of the rotatable first hub and the indexer arms before starting the rotation of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports,
- (2) starting the rotation of the rotatable first hub and the indexer arms after ending the rotation of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports,
- (3) starting the rotation of the rotatable first hub and the indexer arms after starting the rotation of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports, or
- (4) starting the rotation of the rotatable first hub and the indexer arms before starting the rotation of the wafer supports relative to the indexer arms and about the corresponding rotational axes of the wafer supports.

~~18~~25. The method of claim ~~17~~18, wherein the indexer has four indexer arms and (b) comprises rotating the rotatable first hub and the indexer arms by 90° in a first rotational direction and (d) comprises rotating the wafer supports relative to the indexer arms by 90° in a second rotational direction opposite the first rotational direction.

26. The method of claim 18, further comprising flowing a purge gas to the distal ends of the indexer arms and to rotatable interfaces located at the distal ends of the indexer arms that rotatably support the wafer supports relative to the indexer arms.

5 27. The method of claim 18, wherein:

the indexer includes a rotatable second hub that is configured to rotate about the first rotational axis;

each indexer arm is part of a corresponding indexer arm assembly; and

10 each indexer arm assembly includes a corresponding tie-rod with a proximal end that is rotatably connected with the rotatable second hub by a corresponding first rotatable interface and a distal end that is rotatably connected with the wafer support rotatably mounted to the indexer arm of that indexer arm assembly by a corresponding second rotatable interface, wherein (d) is performed by causing relative rotation between the rotatable first hub and the rotatable second hub about
15 the first rotational axis that causes the tie-rods to translate in a predominantly radial manner relative to the first rotational axis, thereby causing each tie-rod of the tie rods to rotate the wafer support to which that tie-rod is rotatably connected relative to the indexer arms and about the rotational axis of that wafer support.

20 ~~19. The apparatus of claim 11, wherein, for each indexer arm:~~

~~the corresponding aperture is located in the distal end of the indexer arm,~~

~~the indexer arm is fixedly connected with the first hub by way of the corresponding mounting interface,~~

25 ~~each mounting interface fixedly connects the corresponding indexer arm with the first hub such that a) the corresponding indexer arm and the first hub can undergo different amounts of thermal expansion without direct sliding contact between the indexer arm and the first hub and b) the corresponding indexer arm is held fixedly in place relative to the first hub, at least in part, by the compression exerted on the indexer arm by the threaded component and the spring of the~~
30 ~~tensionable interface of the corresponding mounting interface.~~

2028. The method of claim 1718, further comprising:

heating the indexer arms from a first temperature to a second temperature such that there is a different amount of thermal expansion in the indexer arms as compared with the rotatable first hub, wherein each indexer arm of the indexer arms is fixedly mounted to the rotatable first hub of the indexer by a mounting interface such that a) the corresponding that indexer arm and the rotatable first hub can are able to undergo different amounts of thermal expansion without direct sliding contact between the that indexer arm and the rotatable first hub and b) the that corresponding indexer arm is held fixedly in place relative to the rotatable first hub, at least in part, by the compression exerted on the that indexer arm by a threaded component and a spring of a tensionable interface of the corresponding mounting interface.

29. The method of claim 28, wherein the rotatable first hub is made from an aluminum or a steel and the indexer arms are made from a ceramic material.

30. The method of claim 28, wherein, for each indexer arm of the indexer arms, a corresponding set of three spheres is interposed between that indexer arm and a mounting plate of the mounting interface for that indexer arm.

31. The method of claim 18, wherein the rotating in (d) of each wafer support of the wafer supports about a corresponding rotational axis of that wafer support in between (a) and (c) is done simultaneously.