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**Rangarajan et al.**

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(54) **HIGH THROUGHPUT POLISHING MODULES AND MODULAR POLISHING SYSTEMS**


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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 173 days.

This patent is subject to a terminal disclaimer.


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***B24B 37/04*** (2012.01)
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(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.



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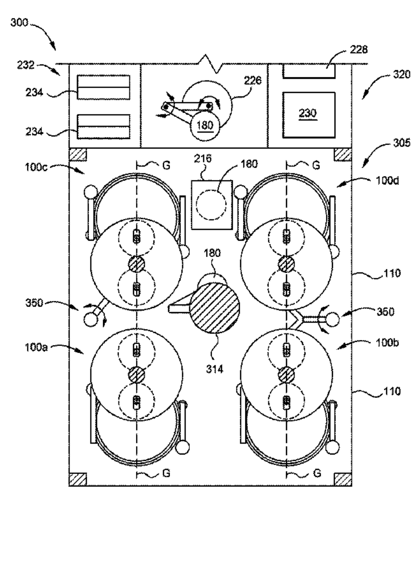
(74) *Attorney, Agent, or Firm* — Patterson + Sheridan, LLP

(57) **ABSTRACT**


Embodiments herein include high throughput density chemical mechanical polishing (CMP) modules and customizable modular CMP systems formed thereof. In one embodiment, a polishing module features a carrier support module, a carrier loading station, and a polishing station. The carrier support module features a carrier platform and one or more carrier assemblies. The one or more carrier assemblies each comprise a corresponding carrier head suspended from the carrier platform. The carrier loading station is used to transfer substrates to and from the carrier heads. The polishing station comprises a polishing platen. The carrier support module, the substrate loading station, and the polishing station comprise a one-to-one-to-one relationship within each of the polishing modules. The carrier
(Continued)

support module is positioned to move the one or more carrier assemblies between a substrate polishing position disposed above the polishing platen and a substrate transfer position disposed above the substrate loading station.

**20 Claims, 15 Drawing Sheets**

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***H01L 21/67*** (2006.01)
***H01L 21/677*** (2006.01)

(52) **U.S. Cl.**
CPC ...... ***B24B 37/345*** (2013.01); ***H01L 21/30625*** (2013.01); ***H01L 21/6719*** (2013.01); ***H01L 21/67219*** (2013.01); ***H01L 21/6776*** (2013.01)

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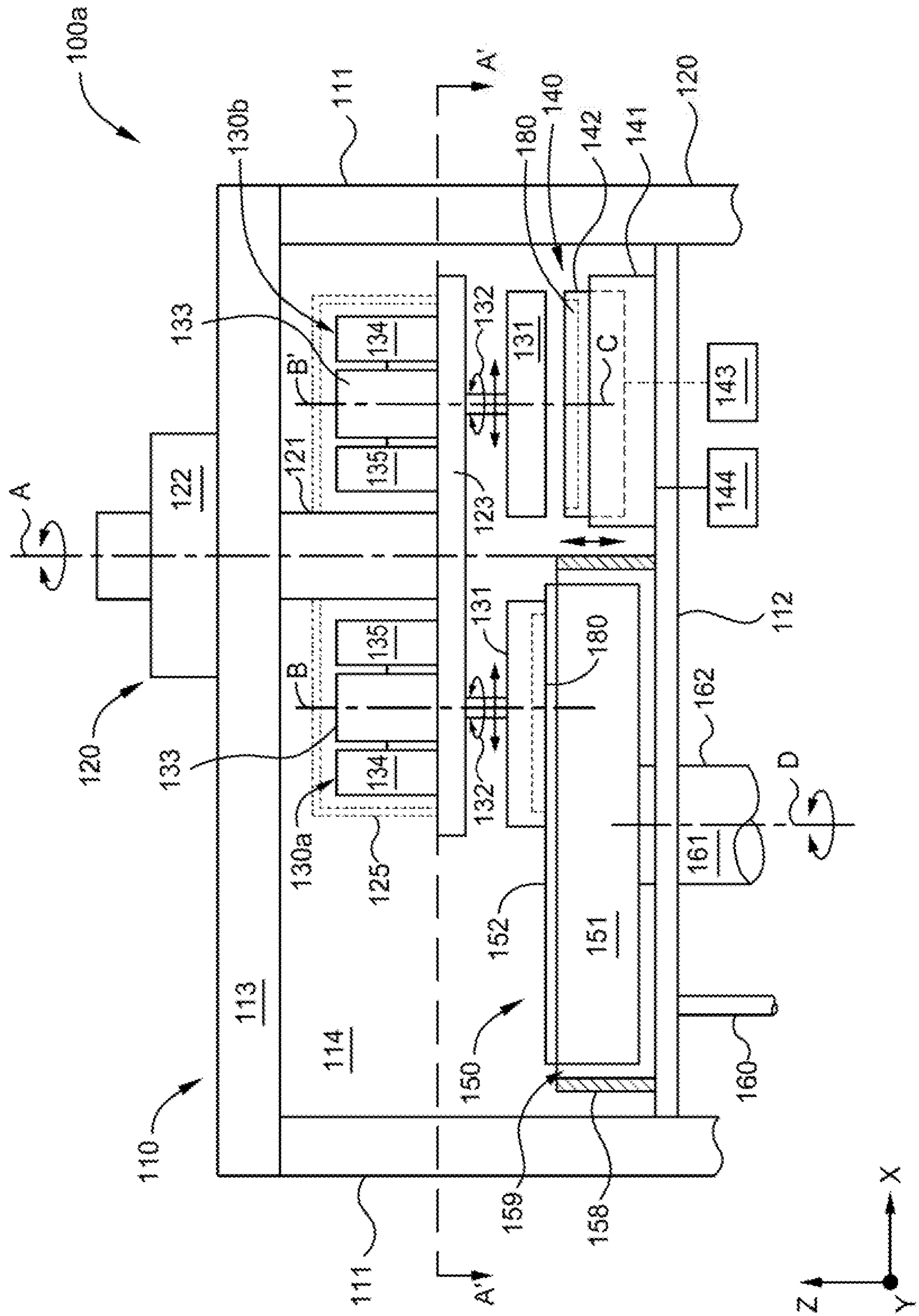

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144
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C
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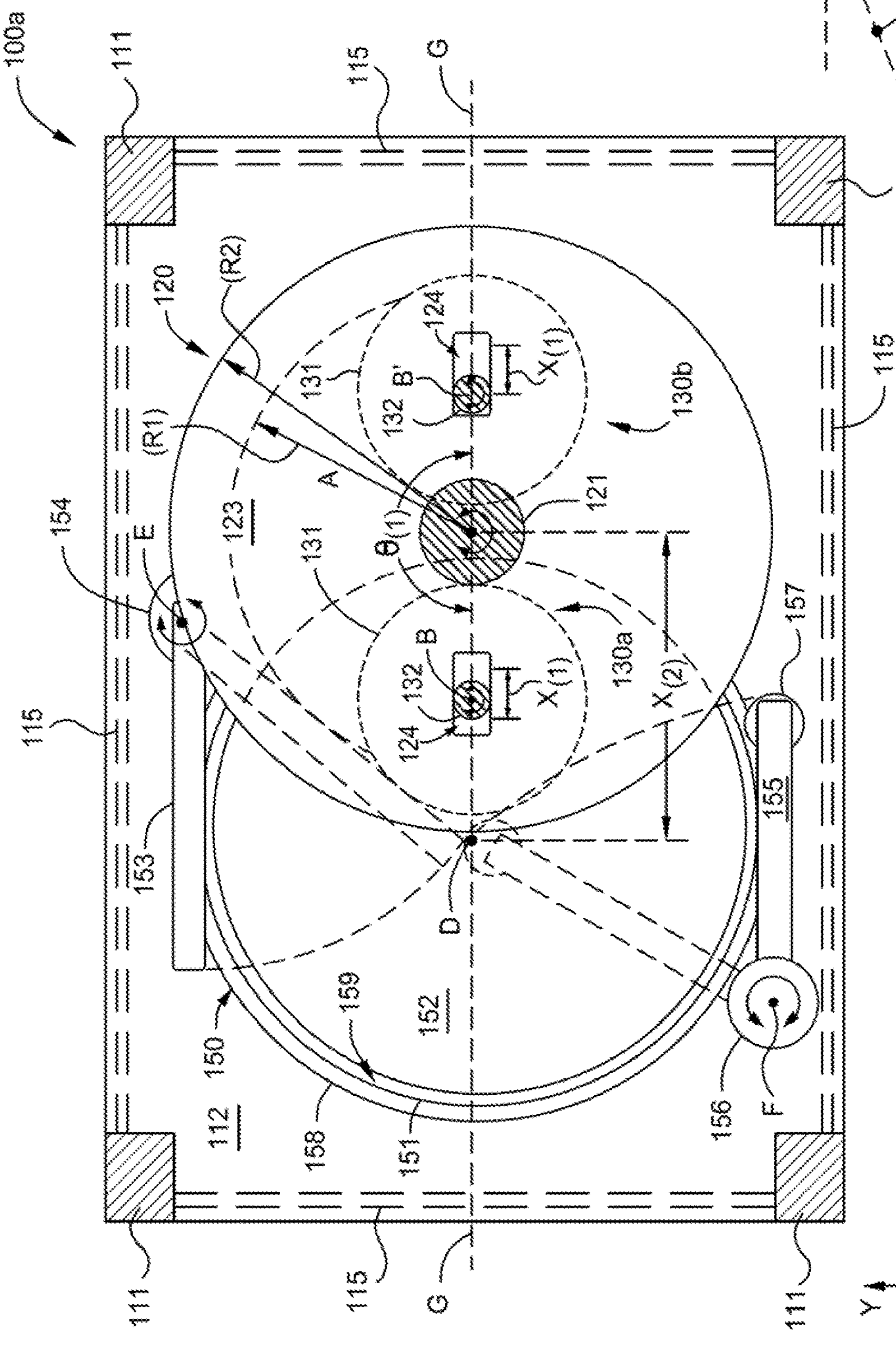
Y
Z


FIG. 1A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154
E
131
B
124
132
X(1)
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FIG. 1B

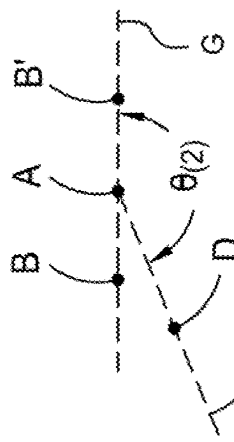
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FIG. 1C

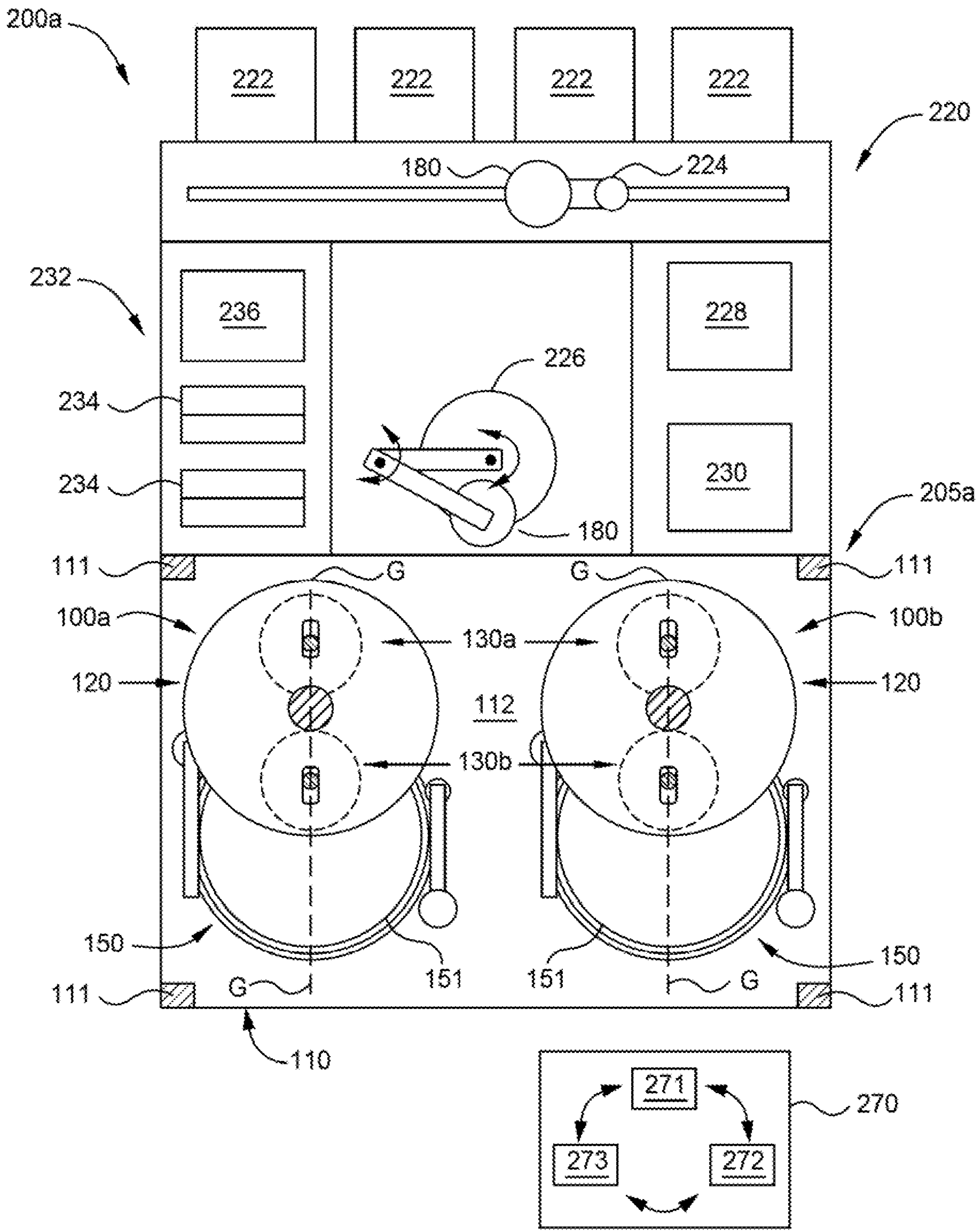
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FIG. 2A

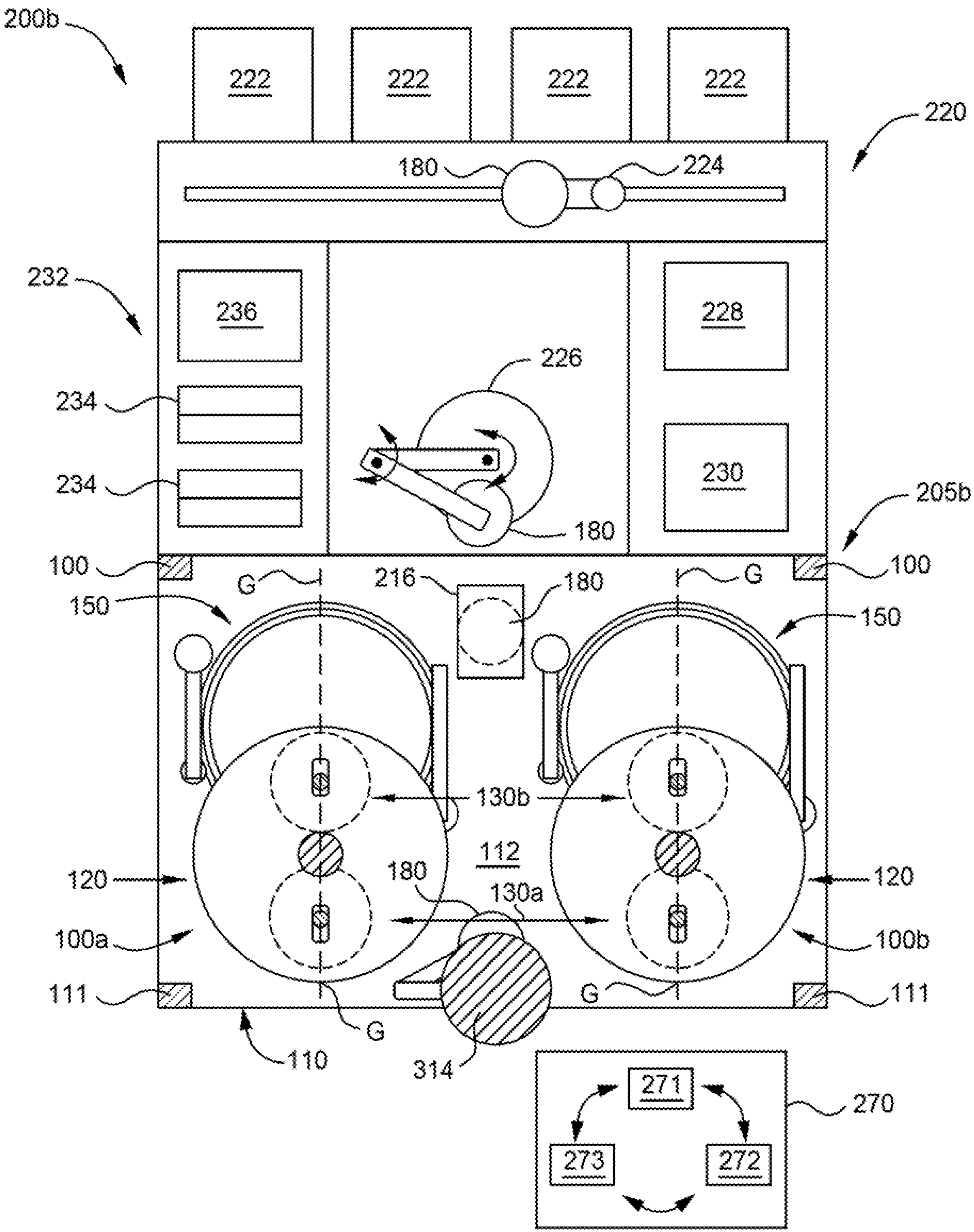
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FIG. 2B

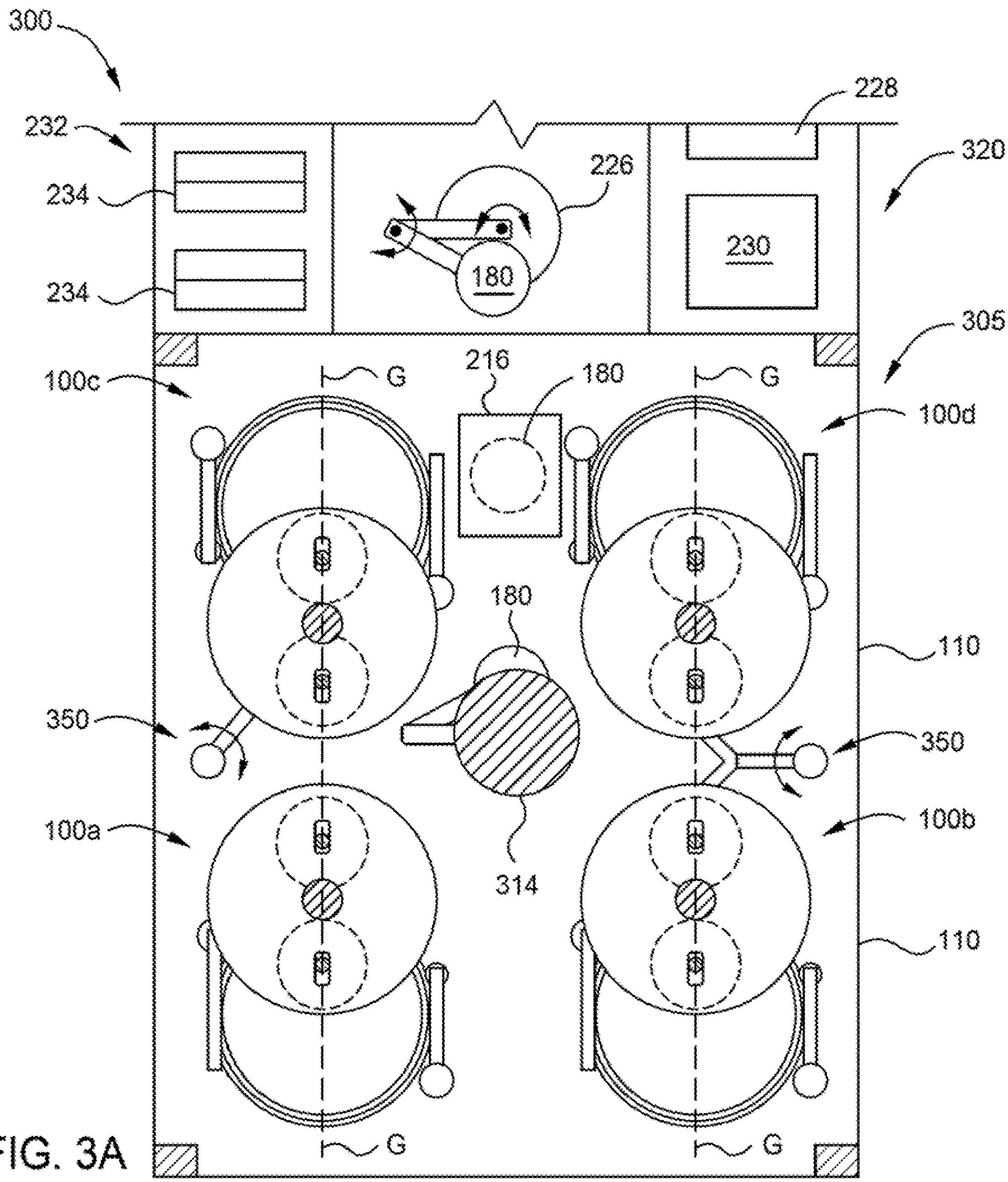
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FIG. 3A

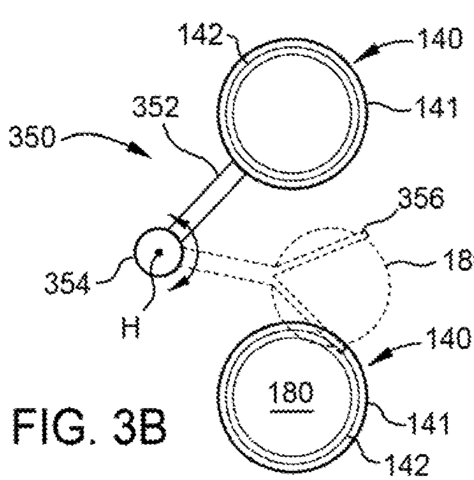
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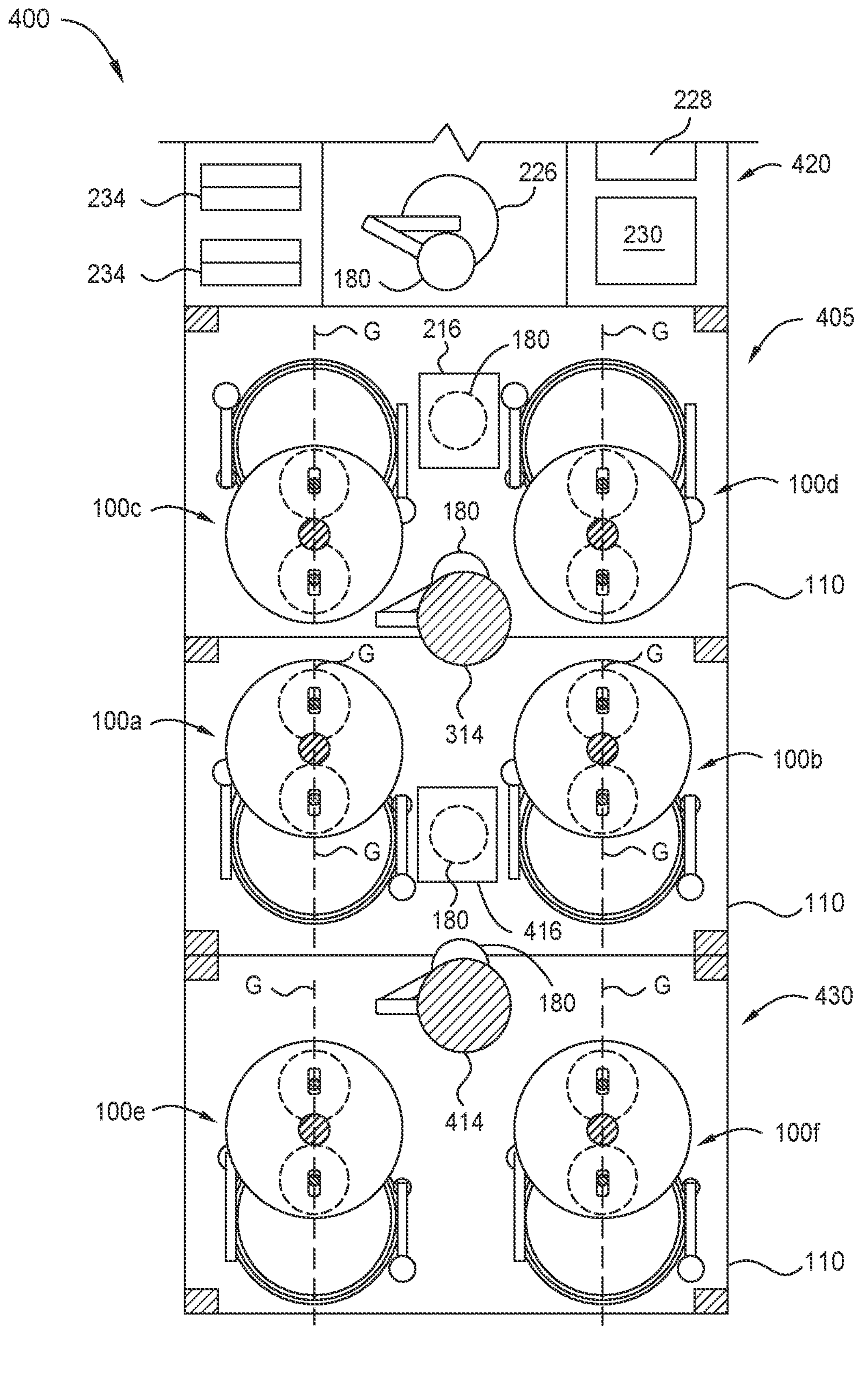
FIG. 3B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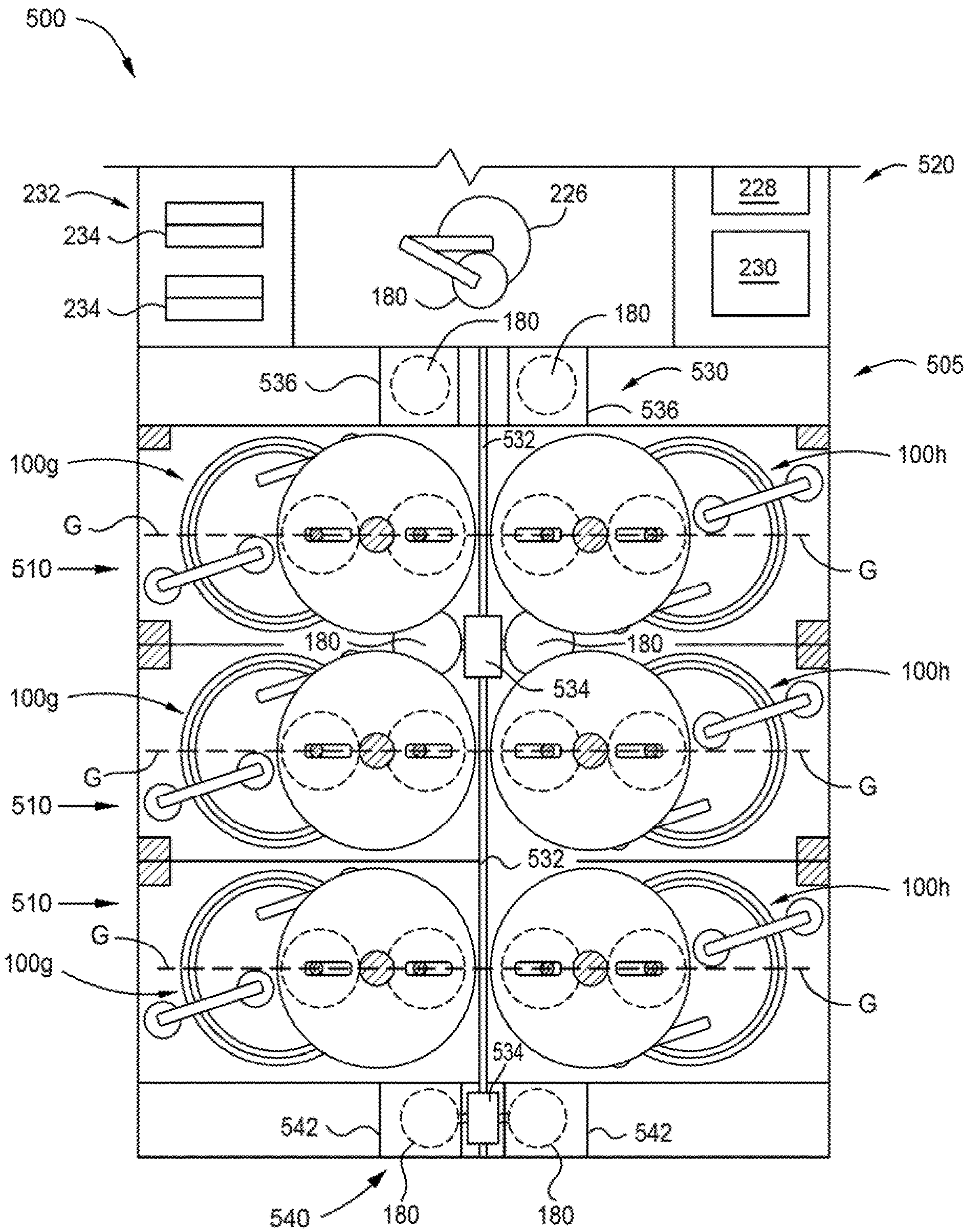
G
180
G
430
100e
414
100f
110

FIG. 4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230
180
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530
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505
532
100g
100h
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180
180
534
100g
100h
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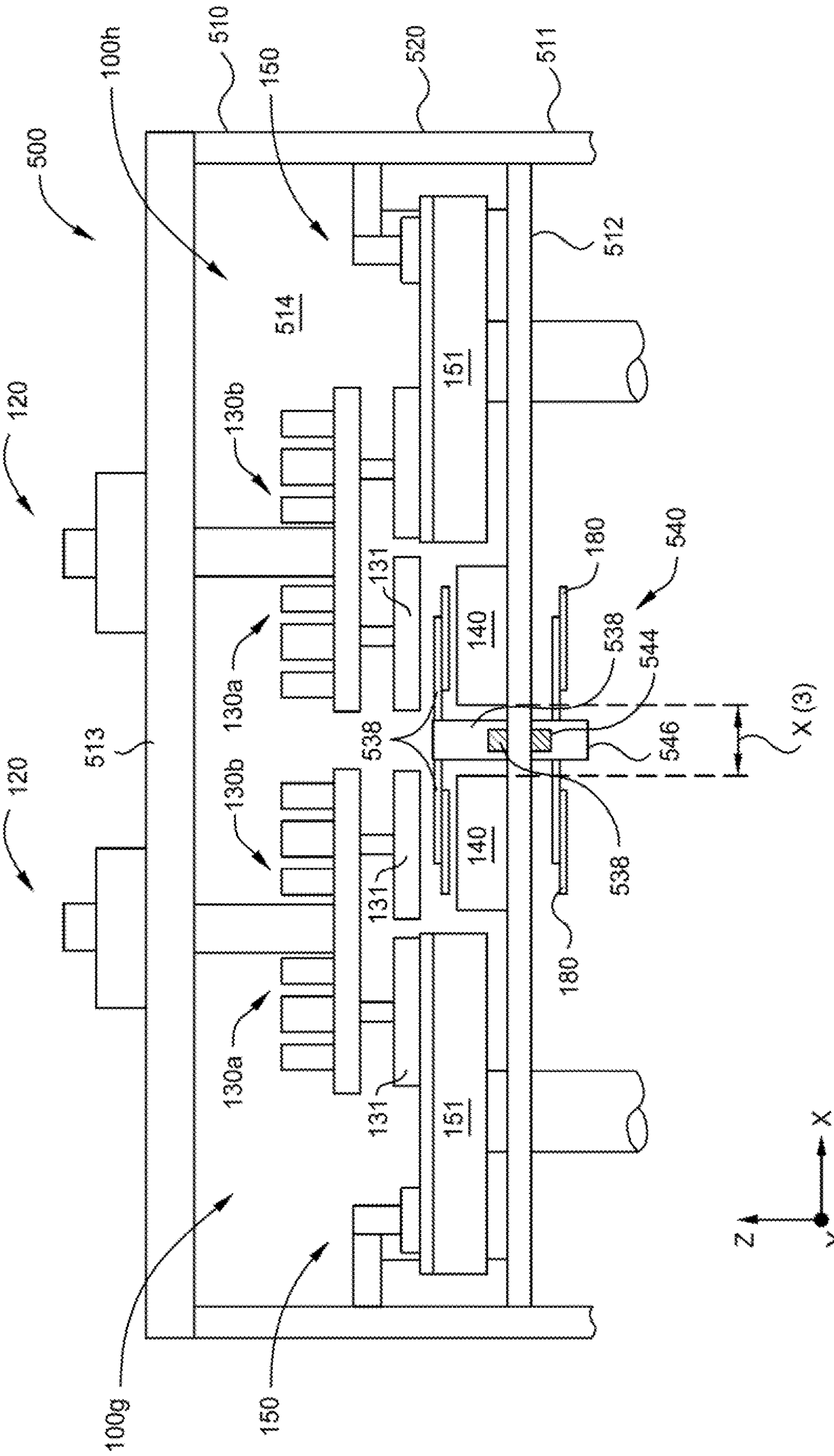
G
100g
G
534
542
542
540
180
180

FIG. 5A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100h
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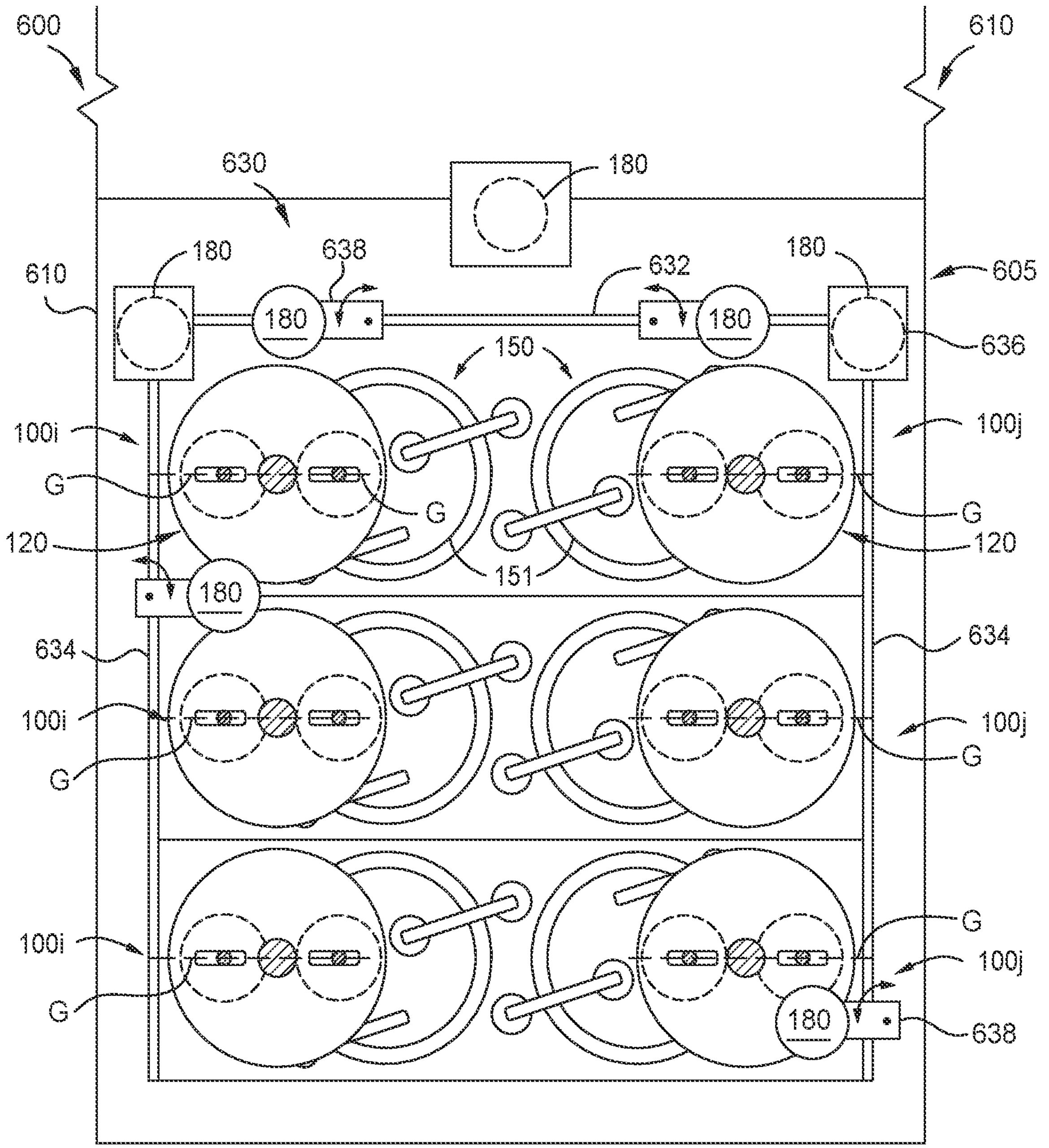
512
514
151
151
130b
130a
130b
130a
131
131
131
140
140
538
538
538
544
546
540
180
180
X (3)
100g
150
Z
X
Y

FIG. 5B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180
636
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100i
100j
G
G
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100j
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100i
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100j
G
180
638

FIG. 6

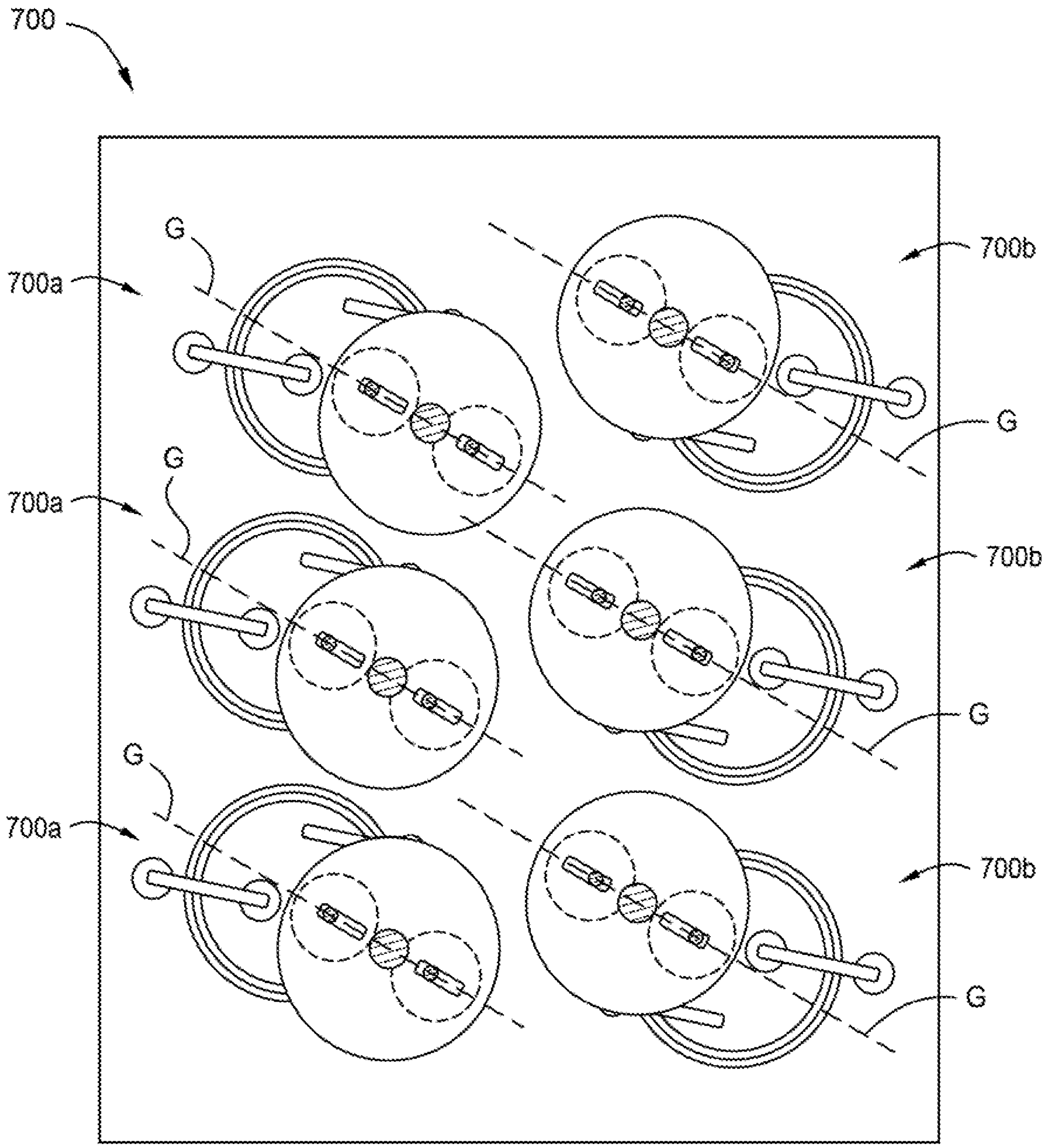



FIG. 7

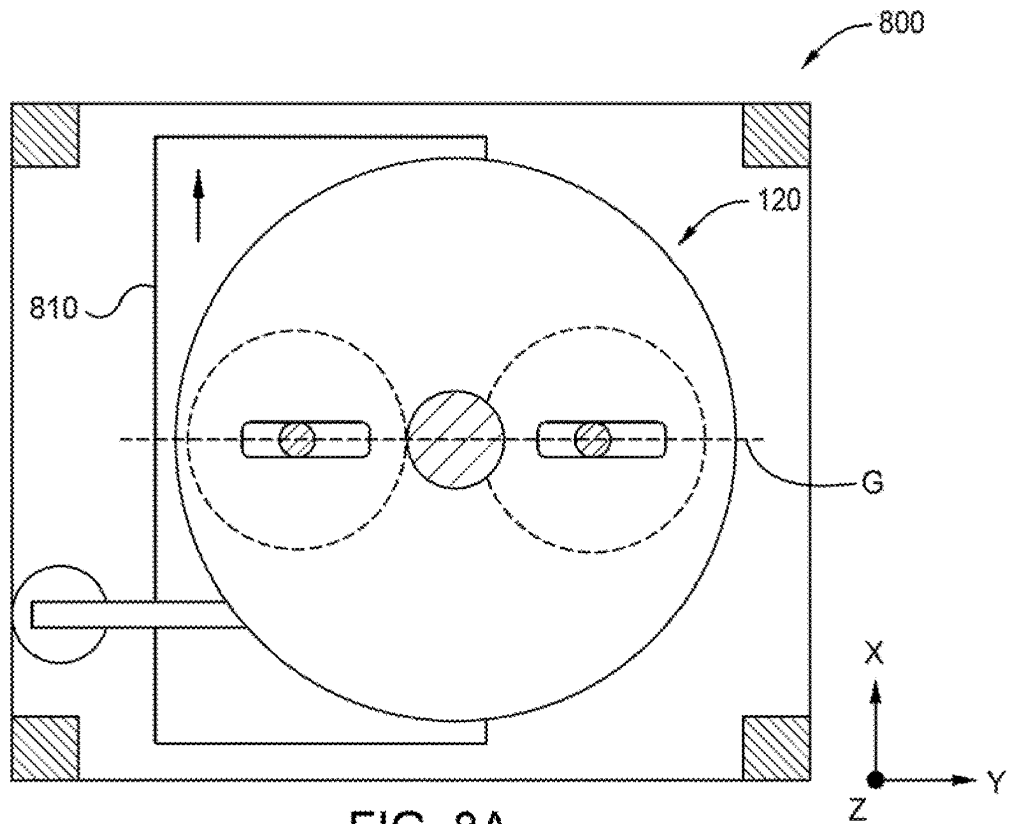



FIG. 8A

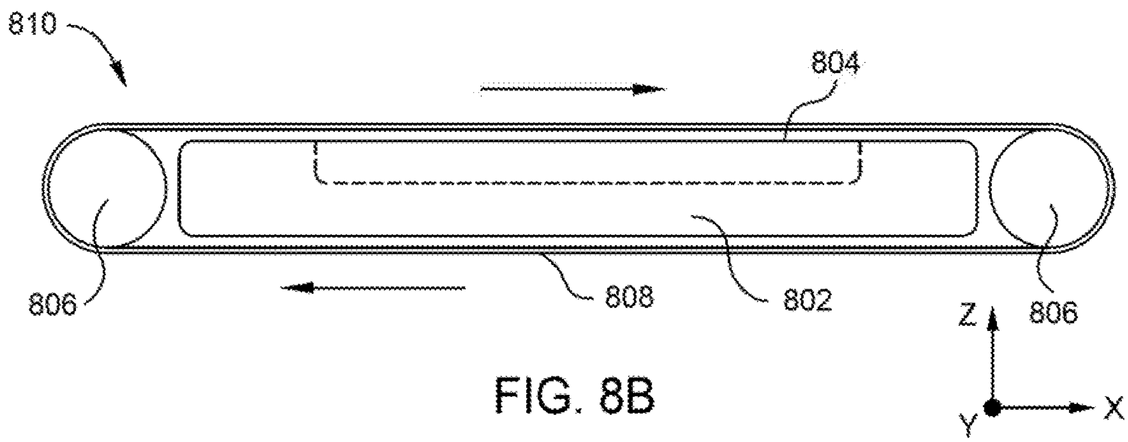



FIG. 8B

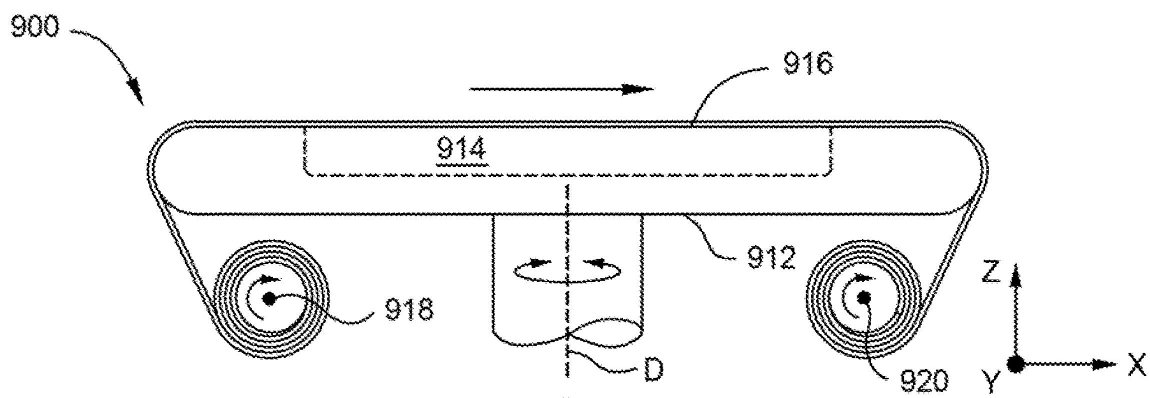



FIG. 9

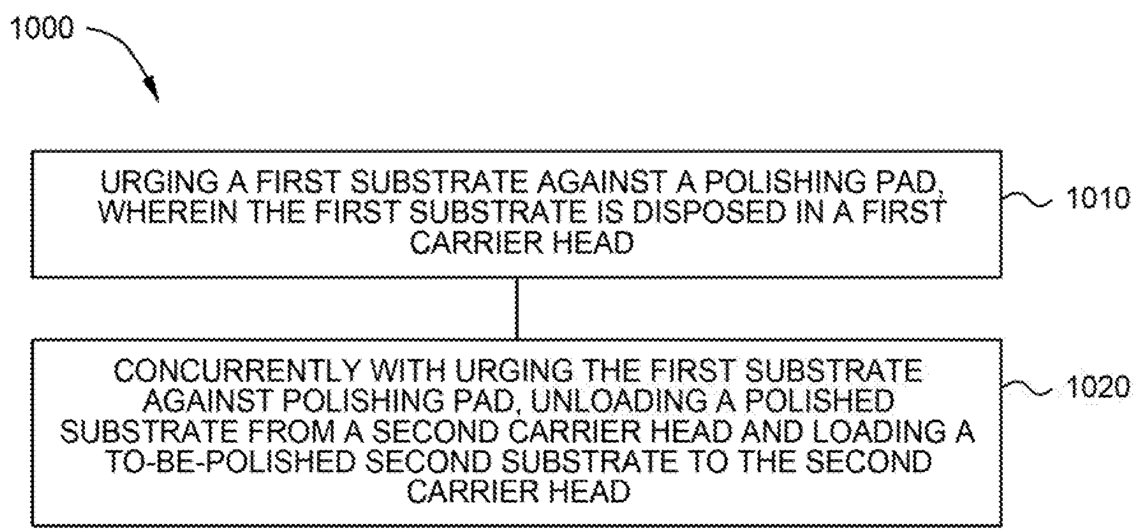
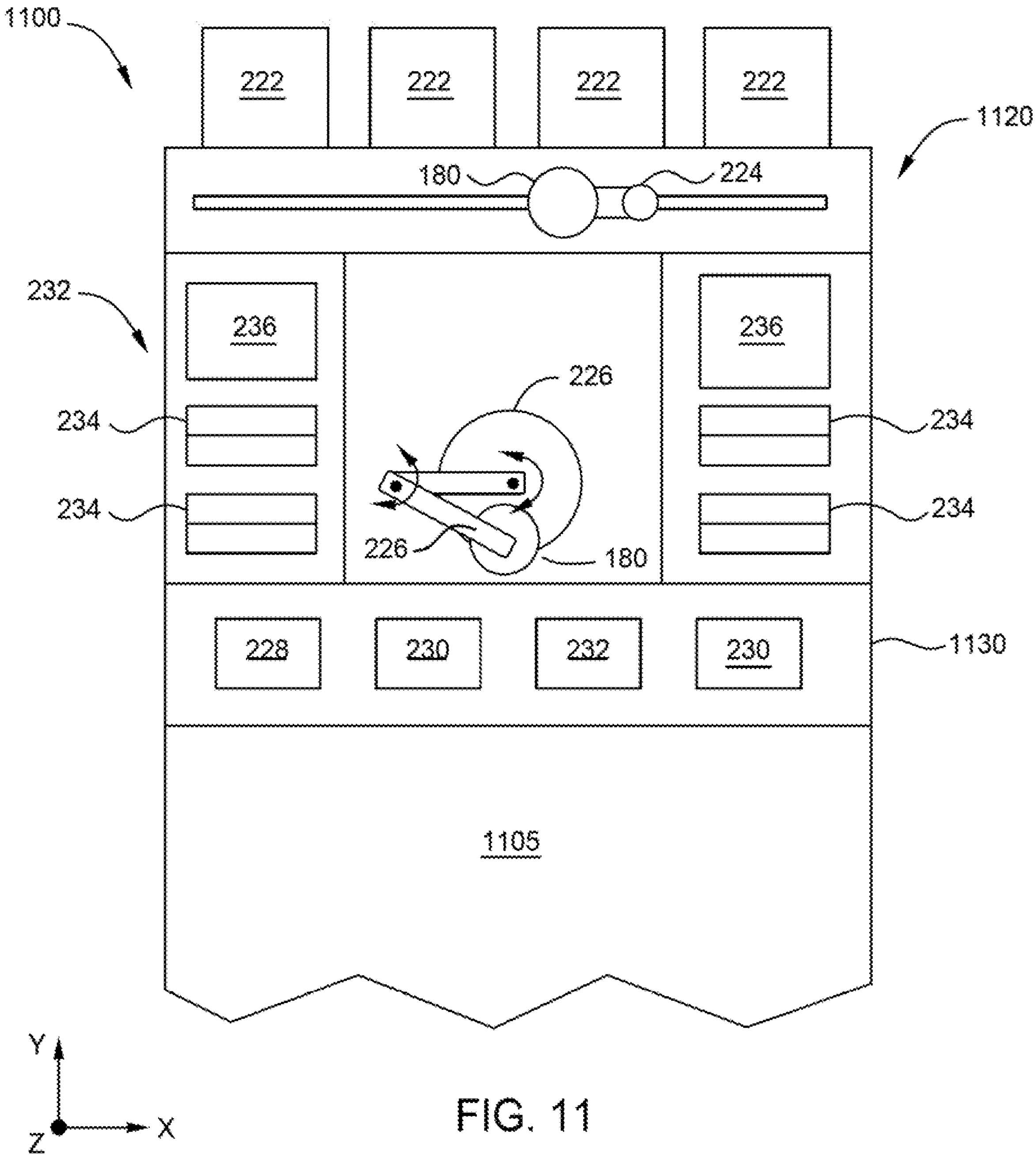

1000
URGING A FIRST SUBSTRATE AGAINST A POLISHING PAD, WHEREIN THE FIRST SUBSTRATE IS DISPOSED IN A FIRST CARRIER HEAD
1010
CONCURRENTLY WITH URGING THE FIRST SUBSTRATE AGAINST POLISHING PAD, UNLOADING A POLISHED SUBSTRATE FROM A SECOND CARRIER HEAD AND LOADING A TO-BE-POLISHED SECOND SUBSTRATE TO THE SECOND CARRIER HEAD
1020

FIG. 10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222
222
222
1120
180
224
232
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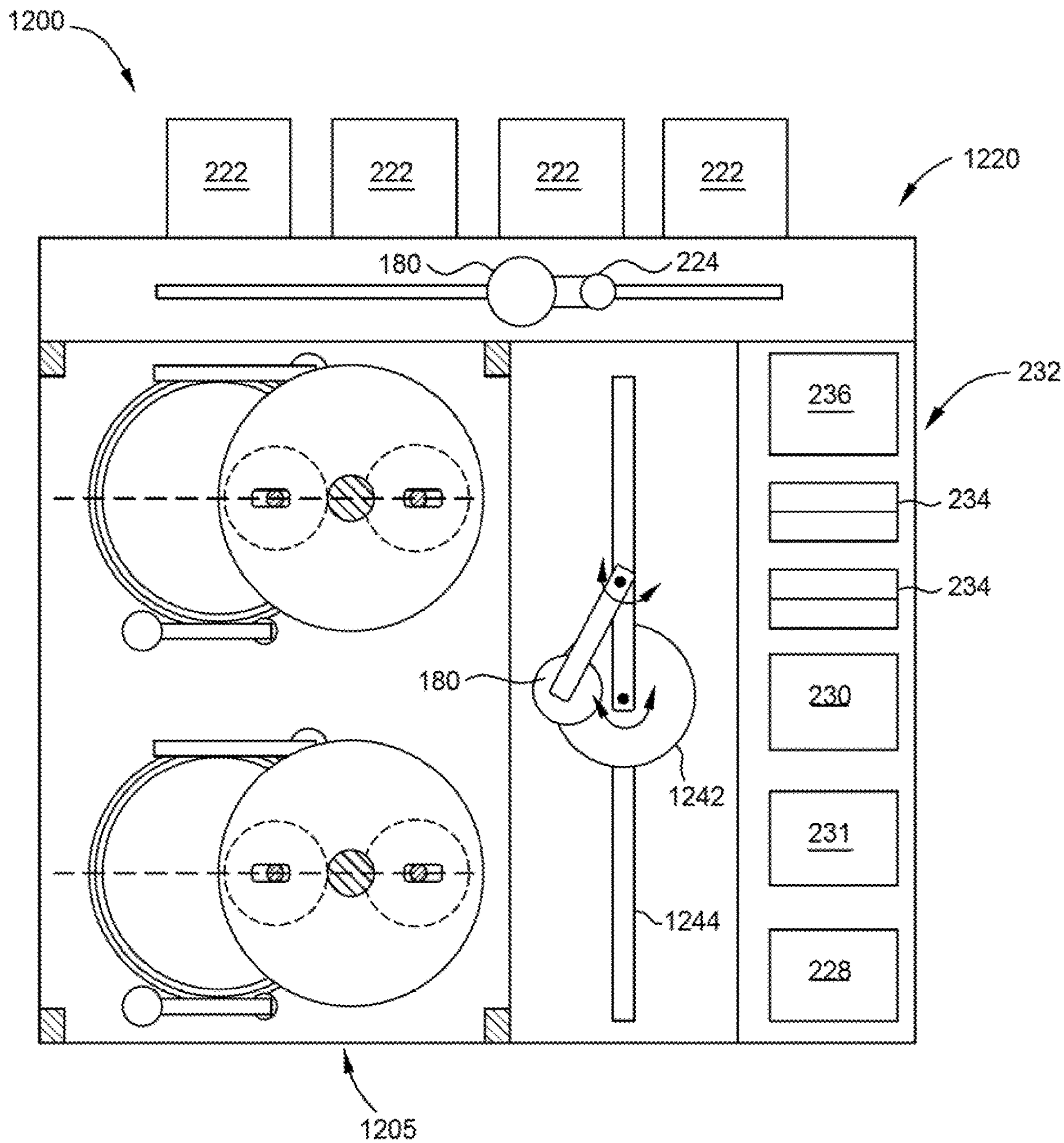
226
180
228
230
232
230
1130
1105
Y
X
Z

FIG. 11


1200
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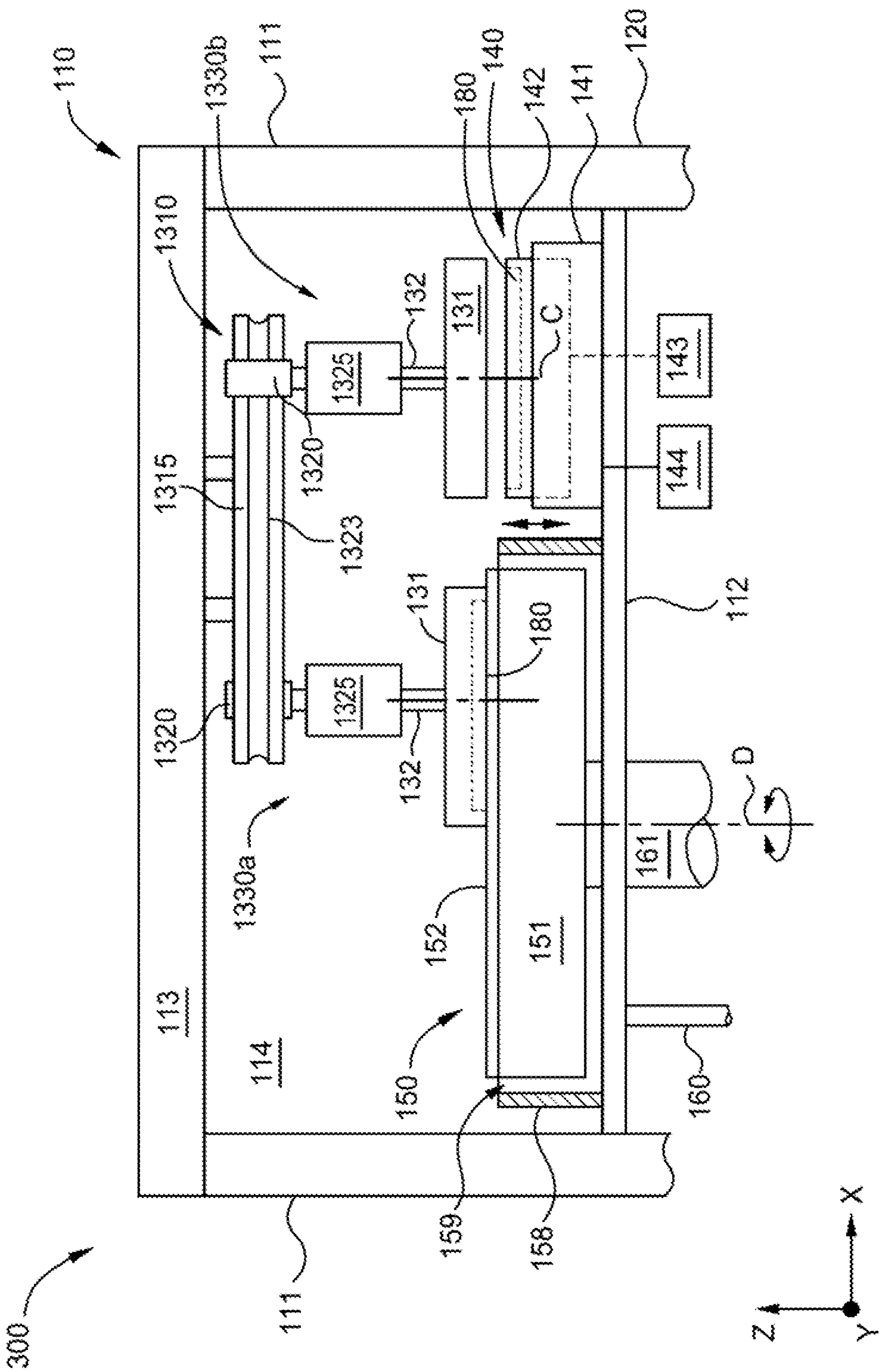
222
222
222
1220
180
224
232
236
234
234
180
230
1242
231
1244
228
1205

FIG. 12



110
1330b
111
120
140
180
142
141
1310
132
131
C
143
144
1325
1320
1315
1323
131
180
1325
1320
132
D
1330a
161
152
151
113
114
150
160
159
158
111
1300
X
Z
Y


FIG. 13

# HIGH THROUGHPUT POLISHING MODULES AND MODULAR POLISHING SYSTEMS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of co-pending U.S. patent application Ser. No. 16/851,012, filed Apr. 16, 2020, which is herein incorporated by reference in its entirety.

## BACKGROUND

### Field

Embodiments described herein generally relate to equipment used in the manufacturing of electronic devices, and more particularly, to a modular chemical mechanical polishing (CMP) system which may be used to polish or planarize the surface of a substrate in a semiconductor device manufacturing process.

### Description of the Related Art

Chemical mechanical polishing (CMP) is commonly used in the manufacturing of high-density integrated circuits to planarize or polish a layer of material deposited on a substrate. In a typical CMP process, a substrate is retained in a carrier head that presses the backside of the substrate towards a rotating polishing pad in the presence of a polishing fluid. Material is removed across the material layer surface of the substrate in contact with the polishing pad through a combination of chemical and mechanical activity which is provided by the polishing fluid and a relative motion of the substrate and the polishing pad. Typically, after one or more CMP processes are complete a polished substrate will be further processed to one or a more post-CMP substrate processing operations. For example the polished substrate may be further processed using one or a combination of cleaning, inspection, and measurement operations. Once the post-CMP operations are complete a substrate can be sent out of a CMP processing area to the next device manufacturing process, such as a lithography, etch, or deposition process.

To conserve valuable manufacturing floor space and reduce labor costs, a CMP system will commonly include a first portion, e.g., a back portion, comprising a plurality of polishing stations and a second portion, e.g., a front portion which has been integrated with the first portion to from a single polishing system. The first portion may comprise one or a combination of post-CMP cleaning, inspection, and/or pre or post-CMP metrology stations. Often the first portion of a CMP system can be customized during the fabrication thereof to more particularly address the needs of specific equipment customers.

For example, a CMP system may be customized to vary the number and arrangement of cleaning, inspection, or metrology stations in response to an intended use of the polishing system, such as for the type of substrate polishing operation intended to be used therewith. The second portion of the CMP system is typically less customizable than the first portion so that the number and arrangement of polishing stations, and the number and an arrangement of substrate handling systems used to transfer substrates therebetween are fixed. Further, the substrate processing throughput in a typical second portion of a multi-platen CMP system is often limited by substrate loading and unloading operations thereinto and/or substrate transfer operations between the platens thereof. Thus, particularly for polishing processes having shorter polishing time requirements, the throughput density (substrates processed per unit time per unit area of manufacturing floor space) of a CMP system will be undesirably limited by the system's substrate loading/unloading and handling configuration.

Accordingly, what is needed in the art are modular CMP systems which may be customized upon customer request. Further needed are modular CMP systems where the individual polishing modules are disposed in such an arrangement that the substrate throughput of the polishing module is not limited by substrate loading and substrate unloading operations respectively thereto and therefrom.

## SUMMARY

The present disclosure is generally related to high throughput density chemical mechanical polishing (CMP) modules and customizable modular CMP systems comprised thereof.

In one embodiment, a polishing module features a carrier support module, a carrier loading station, and a polishing station. The carrier support module features a carrier platform suspended from an overhead support and one or more carrier assemblies. The one or more carrier assemblies each comprise a corresponding carrier head suspended from the carrier platform. The carrier loading station is used to transfer substrates to and from the carrier heads. The polishing station comprises a polishing platen. The carrier support module, the carrier loading station, and the polishing station comprise a one-to-one-to-one relationship within each of the polishing modules. The carrier support module is positioned to move the one or more carrier assemblies between a substrate polishing position disposed above the polishing platen and a substrate transfer position disposed above the carrier loading station.

In another embodiment a modular polishing system includes a first portion and a second portion coupled to the first portion. The second portion features a plurality of polishing modules. At least one of the polishing modules features a carrier support module, a carrier loading station, and a polishing station. The carrier support module features a carrier platform suspended from an overhead support, and one or more carrier assemblies. The one or more carrier assemblies each comprise a corresponding carrier head suspended from the carrier platform. The carrier loading station is used to transfer substrates to and from the carrier heads. The polishing station comprises a polishing platen. The carrier support module, the carrier loading station, and the polishing station comprise a one-to-one-to-one relationship within each of the polishing modules. The carrier support module is positioned to move the one or more carrier assemblies between a substrate polishing position disposed above the polishing platen and a substrate transfer position disposed above the carrier loading station.

In another embodiment a modular polishing system includes a first portion and a second portion coupled to the first portion. The first portion features one of a plurality of system loading stations, one or more substrate handlers, one or more metrology stations, one or more post-CMP cleaning system, one or more location specific polishing (LSP) systems, or a combination thereof. The second portion features a plurality of polishing modules. At least one of the polishing modules features a carrier support module, a carrier loading station, and a polishing station. The carrier support module features a carrier platform suspended from an overhead support, and one or more carrier assemblies. The one or more carrier assemblies each comprise a corresponding carrier head suspended from the carrier platform. The carrier loading station is used to transfer substrates to and from the carrier heads. The polishing station comprises a polishing platen. The carrier support module, the carrier loading station, and the polishing station comprise a one-to-one-to-one relationship within each of the polishing modules. The carrier support module is positioned to move the one or more carrier assemblies between a substrate polishing position disposed above the polishing platen and a substrate transfer position disposed above the carrier loading station.

In some embodiments, one or more of the carrier loading stations of the above described embodiments features a buff platen that may be used to buff, e.g., soft polish, the substrate surface before and/or after the substrate is processed at the polishing station. In some of those embodiments, the buff platen is movable in a vertical direction, i.e., the Z-direction to make room for substrate transfer to and from the carrier loading station using a substrate transfer and/or to facilitate substrate transfer to and from the carrier heads. In some embodiments, one or more of the carrier loading stations is configured as an edge correction station, e.g., to remove material from regions proximate to the circumferential edge of the substrate before and/or after the substrate is processed at the polishing station.

In another embodiment, a polishing module is provided. The polishing module includes a modular frame defining a processing region. Disposed within the polishing region, the polishing module includes a polishing station, a carrier loading station, and a carrier support module. The polishing station includes a polishing platen. In some embodiments, the polishing platen is rotatable about a platen axis. Here, the carrier support module includes a carrier platform having a first substrate carrier and a second substrate carrier suspended therefrom. The carrier platform is rotatable or pivotable about a platform axis to swing the first and second substrate carriers between either a first processing mode or a second processing mode. When in the first processing mode, the first substrate carrier is positioned over the carrier loading station to allow for substrate loading and unloading thereinto and therefrom, and the second substrate carrier is concurrently positioned over the polishing platen to allow for substrate polishing thereon. When in the second processing mode, the second substrate carrier is positioned over the carrier loading station, to allow for substrate loading and unloading thereinto, and the first substrate carrier is concurrently positioned over the polishing platen to allow for substrate polishing thereon.

In some embodiments of the polishing module, the carrier loading station, the carrier platform, the and the polishing platen are disposed in an arrangement where a center of the carrier loading station, the platform axis, and the platen axis are substantially coplanar with one another. In some embodiments, the carrier platform and the polishing platen are disposed in an arrangement where the platform axis and the platen axis are spaced apart by a first distance and a swing radius of one or both of the first and second substrate carriers is about 2.5 times or less than the first distance. In some embodiments, the polishing module includes a plurality of panels vertically disposed between adjacent corners of the modular frame to enclose and isolate the processing region from other portions of a modular polishing system. In those embodiments, one or more of the panels have a slit shaped opening formed therethrough to allow for substrate transfer into and out of the processing region.

In some embodiments of the polishing module, the first and second substrate carriers are suspended from the carrier platform using corresponding first and second carrier shafts. In some of those embodiments, the respective first and second sweep actuators coupled to the first and second carrier shafts are configured to oscillate the first and second shafts between first positions with respect to the platform axis and second positions disposed radially outward from the first positions. In some of those embodiments, the swing radius of the first and second substrate carriers is determined when each of the first and second carrier shafts are disposed in the first positions.

In some embodiments of the polishing module, the carrier loading station includes a substrate buffing station, a substrate carrier cleaning station, a metrology station, a substrate edge correction station, or a combination thereof. In some embodiments, the modular frame includes an overhead support and the carrier platform is suspended from the overhead support. In other embodiments, the modular frame includes a horizontal base and the carrier platform is coupled to a support member extending upwardly from the horizontal base.

In some embodiments, the polishing module further includes a computer readable medium having instructions stored thereon for a substrate processing method. In those embodiments, the method includes urging a first substrate against a polishing pad disposed on the polishing platen where the first substrate is disposed in the first substrate carrier. The method further includes, concurrently with urging the first substrate against the polishing pad, unloading an at-least-partially-polished substrate from the second substrate carrier and loading a to-be-polished second substrate into the second substrate carrier. The at-least-partially-polished substrate and the to-be-polished second substrate are respectively unloaded and loaded using the carrier loading station.

In some embodiments of the polishing module, the instructions for performing the method further include rotating or pivoting the carrier platform about the platform axis to position the second substrate carrier above the polishing platen andurging the second substrate against the polishing pad. Concurrently with urging the second substrate against the polishing pad, the method further includes unloading the first substrate from the first substrate carrier and loading a to-be-polished third substrate into the first substrate carrier. The at-least-partially-polished second substrate and the to-be-polished third substrate are respectively unloaded and loaded using the carrier loading station.

In another embodiment, a polishing module system includes a modular frame defining a processing region. Within the processing region, the polishing module includes two polishing modules. In this embodiment, each of the two polishing modules includes a polishing station, a carrier loading station, and a carrier support module. Each polishing station includes a polishing platen that is rotatable about a platen axis and a carrier support module that includes a first substrate carrier and a second substrate carrier. Here, each carrier support module is configured move the first and second substrate carriers between either a first processing mode or a second processing mode. When in the first processing mode, the first substrate carrier is positioned over the carrier loading station to allow for substrate loading and unloading thereinto and therefrom, and the second substrate carrier is concurrently positioned over the polishing platen to allow for substrate polishing thereon. When in the second processing mode, the second substrate carrier is positioned over the carrier loading station, to allow for substrate loading and unloading thereinto, and the first substrate carrier is concurrently positioned over the polishing platen to allow for substrate polishing thereon.

In some embodiments, the polishing module system further includes a computer readable medium having instructions stored thereon for a substrate processing method. In those embodiments, the method includes urging a first substrate against a polishing pad disposed on the polishing platen where the first substrate is disposed in the first substrate carrier. The method further includes, concurrently with urging the first substrate against the polishing pad, unloading an at-least-partially-polished substrate from the second substrate carrier and loading a to-be-polished second substrate into the second substrate carrier. The at-least-partially-polished substrate and the to-be-polished second substrate are respectively unloaded and loaded to and from the second substrate carrier using the carrier loading station.

In another embodiment, a substrate processing method is provided. The method includes urging a first substrate against a polishing pad, where the polishing pad is disposed on a polishing platen of a polishing module and the first substrate is disposed in a first substrate carrier. Concurrently with urging the first substrate against the polishing pad the method includes unloading, using a carrier loading station, an at-least-partially-polished substrate from a second substrate carrier and loading, using the carrier loading station, a to-be-polished second substrate into the second substrate carrier. In this embodiment, the polishing module includes a modular frame defining a processing region. Within the processing region, the polishing module includes a polishing station, the carrier loading station, and a carrier support module. The polishing station includes a polishing platen having the polishing pad disposed thereon. The polishing platen is rotatable about a platen axis. The carrier support module includes a carrier platform having the first substrate carrier and the second substrate carrier suspended therefrom. Here, the the carrier platform is rotatable or pivotable about a platform axis to swing the first and second substrate carriers between the carrier loading station and the polishing station.

In some embodiments of the substrate processing method, the carrier loading station includes a substrate buffing station, a substrate carrier cleaning station, a metrology station, a substrate edge correction station, or a combination thereof. In some embodiments, the carrier loading station includes a buffing station the method further includes processing the at-least-partially-polished substrate using the buffing station concurrently with urging the first substrate against the polishing pad.

In some embodiments, the substrate processing method further includes rotating or pivoting the carrier platform about the platform axis to position the second substrate carrier above the polishing platen and urging the second substrate against the polishing pad. Concurrently with urging the first substrate against the polishing pad, the method includes unloading an at-least-partially-polished substrate from the second substrate carrier and loading a to-be-polished second substrate into the second substrate carrier. The at-least-partially-polished substrate and the to-be-polished second substrate are respectively unloaded and loaded using the carrier loading station.

In some embodiments of the substrate processing method, the first and second substrate carriers are respectively coupled to first and second carrier shafts and the first and second carrier shafts are disposed through corresponding first and second slot shaped openings formed through the carrier platform. In those embodiments, the method further includes concurrently with urging the first substrate against the polishing pad, oscillating the first carrier shaft between a first position and a second position disposed radially outward from the first position. In some of those embodiments, the method further includes moving the first carrier shaft towards the first position to reduce a swing radius of the first substrate carrier before rotating or pivoting the carrier platform about the platform axis.

In some embodiments of the substrate processing method, the carrier loading station, the carrier platform, the and the polishing platen are disposed in an arrangement where a center of the carrier loading station, the platform axis, and the platen axis are substantially coplanar with one another. In some embodiments, the carrier platform and the polishing platen are disposed in an arrangement where the platform axis and the platen axis are spaced apart by a first distance and a swing radius of one or both of the first and second substrate carriers is about 2.5 times or less than the first distance. In some embodiments, the polishing module includes a plurality of panels vertically disposed between adjacent corners of the modular frame to enclose and isolate the processing region from other portions of a modular polishing system. In those embodiments, one or more of the panels have a slit shaped opening formed therethrough to allow for substrate transfer into and out of the processing region.

In another embodiment, a modular polishing system is provided. The modular polishing system includes a first modular frame defining a first processing region. Disposed in the first processing region, the modular polishing system includes a cleaning system and a first substrate handler. The first substrate handler may be used to transfer substrates from a second processing region to the cleaning system. The modular polishing system further includes one or more second modular frames coupled to the first modular frame. The one or more second modular frames define the second processing region having at at least two polishing modules disposed therein. Each individual polishing module of the at least two polishing modules includes a polishing platen, a carrier loading station, and a substrate carrier transport system for moving a substrate carrier between the polishing platen and the carrier loading station.

In some embodiments of the modular polishing system, the substrate carrier of at least one of the two polishing modules is a first substrate carrier and the at least one polishing module further includes a second substrate carrier. In those embodiments, the substrate carrier transport system is configured to concurrently position the first substrate carrier above the polishing platen and the second substrate carrier above the carrier loading station.

In some embodiments, the modular polishing system further includes a third substrate processing region disposed between the first processing region and the second processing region, the third substrate processing region including one or more processing systems disposed therein. The one or more processing systems include one or more location specific polishing modules, one or more metrology stations, one or more buffing stations, or a combination thereof. In those embodiments, the one or more processing systems in the third processing region are disposed in an arrangement that allows substrates to be directly transferred thereto and therefrom using the first substrate handler. In some of those embodiments, the one or more processing systems comprises a plurality of processing systems, and wherein at least two of the plurality of processing systems are disposed in a vertical arrangement with respect to one another. In some embodiments, the modular polishing system further includes one or more processing systems disposed in the first processing region.

In some embodiments, the modular polishing system further includes a plurality of system loading stations. In those embodiments, the first processing region is disposed between the plurality of system loading stations and the second processing region. In some embodiments, the modular polishing system further includes a plurality of system loading stations. In those embodiments, the first substrate handler is disposed between the cleaning system and second processing region, and wherein at least a portion of the one or more second modular frames is disposed proximate to the plurality of system loading stations.

In another embodiment, a modular system includes a first modular frame defining a first processing region. Disposed in the first processing region, the modular polishing system includes a cleaning system and a first substrate handler. The first substrate handler may be used to transfer substrates from a second processing region to the cleaning system. The modular polishing system further includes one or more second modular frames coupled to the first modular frame. The one or more second modular frames define the second processing region having a second substrate handler disposed therein. The modular polishing system further includes two first polishing modules disposed in the second processing region. Each individual polishing module of the two first polishing modules includes a polishing platen, a carrier loading station, and a substrate carrier transport system for moving a substrate carrier between the polishing platen and the carrier loading station. In this embodiment, the polishing platens and the carrier loading stations of the two first polishing modules are disposed in an arrangement that allows substrates to be directly transferred to and from the carrier loading stations using the second substrate handler.

In some embodiments of the modular system, the two first polishing modules are disposed in a side-by-side arraignment where each of the respective polishing platens thereof are closer to the first processing region than are the respective carrier loading stations thereof. In some embodiments, the substrate carrier of at least one of the two first polishing modules is a first substrate carrier and the at least one first polishing module further includes s a second substrate carrier. In those embodiments, the substrate carrier transport system is configured to concurrently position the first substrate carrier above the polishing platen and the second substrate carrier above the carrier loading station.

In some embodiments, the modular system includes a third substrate processing region disposed between the first processing region and the second processing region and one or more processing systems disposed in the third processing region. Here, the one or more processing systems comprise one or more location specific polishing modules, one or more metrology stations, one or more buffing stations, or a combination thereof. In some of those embodiments, the one or more processing systems comprises a plurality of processing systems and at least two of the plurality of processing systems are disposed in a vertical arrangement with respect to one another.

In some embodiments, the modular polishing system further includes one or more second polishing modules disposed in the second processing region. In those embodiments, each individual second polishing module of the one or more second polishing modules includes a polishing platen, a carrier loading station, and a substrate carrier transport system. In those embodiments, the polishing platens and the carrier loading stations of the two first polishing modules and the one or more second polishing modules are disposed in an arrangement that allows substrates to be directly transferred to and from each of the carrier loading stations thereof using the second substrate handler.

In some embodiments of the modular system, the carrier loading stations of the two first polishing modules and the two second polishing modules define a substrate handling region having the second substrate handler disposed therein. In those embodiments, the second substrate handler is positioned to transfer a substrate from the carrier loading station of any one of the two first polishing modules and the two second polishing modules to the carrier loading station of any other one of the carrier loading stations of the two first polishing modules and the two second polishing modules. In some of those embodiments, the modular system further includes one or more third polishing modules disposed in the second processing region where each individual third polishing module of the one or more third polishing modules comprises a polishing platen, a carrier loading station, and a substrate carrier transport system. In those embodiments, the polishing platens and the carrier loading stations of the one or more third polishing modules are disposed in an arrangement that allows substrates to be directly transferred to and from each of the carrier loading stations thereof using a third substrate handler.

In some embodiments, the polishing system further includes a substrate exchanger disposed between one of the two first polishing modules and one of the one or more second polishing modules. In those embodiments, the carrier loading station the one of the two first polishing modules is a first carrier loading station, a carrier loading station of one of the one or more second polishing modules is a second carrier loading station, and the substrate exchanger is dedicated to moving substrates between the first carrier loading station and the second carrier loading station. In some of those embodiments, the substrate exchanger is movable about an axis to swing a substrate between the first and second carrier loading stations.

In some embodiments, the modular system further includes a plurality of system loading stations, wherein the first processing region is disposed between the plurality of system loading stations and the second processing region. In some embodiments, modular system includes a plurality of system loading stations, where the first substrate handler is disposed between the cleaning system and the second processing region, and at least a portion of the one or more second modular frames is disposed proximate to the plurality of system loading stations.

In another embodiment, a modular polishing system includes one or more first modular frames defining a first processing region. The one or more first modular frames, and thus the first processing region, have a first end and a second end that is opposite to the first end. The modular polishing system further includes a linear substrate handling system and a plurality of polishing module pairs disposed in the first processing region. The linear substrate handling system includes a first linear member extending from a location proximate to the first end to a location proximate to the second end and a first substrate handler movably coupled to the first linear member. Each polishing module pair includes two polishing modules disposed on opposite sides of the linear member. Each polishing module of the two polishing modules includes a polishing platen, a carrier loading station, and a substrate carrier transport system. The polishing platen is disposed distal from the linear member, the carrier loading station is disposed proximate to the linear member, and the substrate carrier transport system may be used to move a substrate carrier between the polishing platen and the carrier loading station.

In some embodiments of the modular polishing system, at least one polishing module of the two polishing modules in a polishing module pair includes a first substrate carrier and a second substrate carrier. In those embodiments, the substrate carrier transport system is configured to concurrently position the first substrate carrier above the polishing platen and the second substrate carrier above the carrier loading station and at least a portion of a substrate moved from the first end towards the second end of the first processing region using the first substrate handler of the linear handling system will pass between the carrier loading station and the second substrate carrier positioned thereabove.

In some embodiments of the modular polishing system, the one or more first modular frames includes a horizontal member defining a lower boundary of the first processing region and the linear substrate handling system further includes a second linear member extending from a location proximate to the first end to a location proximate to the second end and a second substrate handler movably coupled to the second linear member. Typically, in those embodiments, the first linear member is disposed above the horizontal member and the second linear member is disposed below the horizontal member. In some embodiments of the modular polishing system, the one or more first modular frames are coupled to a second modular frame, where the second modular frame defines a second processing region having a cleaning system disposed therein.

In another embodiment, a modular polishing system includes a first modular frame defining a first processing region, a cleaning system disposed in the first processing region, one or more second modular frames coupled to the first modular frame, and a linear substrate handling system. In this embodiment, the one or more second modular frames define a second processing region having a plurality of polishing modules disposed therein. The individual polishing modules each include a polishing platen, a carrier loading station, and a substrate carrier transport system for moving a substrate carrier between the polishing platen and the carrier loading station. Here, the carrier loading stations in each of the plurality of polishing modules are disposed proximate to a perimeter of the second processing region. The linear handling system includes one or more linear members disposed between the carrier loading stations and the perimeter of the second processing region and one or more substrate handlers movably coupled to the one or more linear members.

In another embodiment, a polishing system is provided. The polishing system includes one or more first modular frames defining a first processing region and a plurality of polishing modules disposed in the first processing region. Each individual one of the plurality of polishing modules includes a polishing platen, a carrier loading station, and a carrier transport system for moving a substrate carrier between the polishing platen and the carrier loading station. The polishing system further includes a substrate handling system for transferring a substrate between the carrier loading station of any one of the plurality of polishing modules and the carrier loading station of any other one of the plurality of polishing modules. Here, the any one of the plurality of polishing modules is a first station configured for a first polishing stage of a multi-stage substrate polishing sequence and the any other one of the plurality of polishing modules is a second station configured for a second polishing stage of the multi-stage substrate polishing sequence. In some embodiments of the polishing system the one or more of the carrier loading stations includes a substrate buffing station, a substrate carrier cleaning station, a metrology station, a substrate edge correction station, or a combination thereof.

In some embodiments, the polishing system further includes a plurality of the second stations and a computer readable medium having instructions stored thereon for a substrate processing method. The method includes (a) urging a first substrate against a first polishing pad, (b) determining an available station of the plurality of second stations, (c) transferring the first substrate to the available second station of the plurality of second stations, (d) urging the first substrate against a second polishing pad, and (e) repeating (a)-(d) with a second substrate. Here, the first polishing pad is disposed on the polishing platen of the first station and the second polishing pad is disposed on the polishing platen of the available second station.

In some embodiments of the polishing system, at least one of the plurality of polishing modules includes a first substrate carrier and a second substrate carrier, and the polishing system further includes a computer readable medium having instructions stored thereon for a substrate processing method. The method includes (a) urging a first substrate against a polishing pad disposed on the polishing platen of the at least one polishing module in the presence of a first polishing fluid where the first substrate is disposed in the first substrate carrier, and (b) concurrent with (a), unloading an at least-partially-polished substrate from the second substrate carrier and loading a to-be-polished second substrate into the second substrate carrier.

In some embodiments of the polishing system, the plurality of polishing modules include at least four polishing modules, the carrier loading stations of the at least four polishing modules collectively define a substrate handling region, the substrate handling system includes a substrate handler disposed in the substrate handling region, and the substrate handler is positioned to transfer a substrate from the carrier loading station of any one of the at least four polishing modules to the carrier loading station of any other one of the at least four polishing modules. In some of those embodiments, the substrate handling system further includes a substrate exchanger disposed between two polishing modules of the at least four polishing modules, the carrier loading station of one of the two polishing modules is a first carrier loading station and a carrier loading station of the other of the two polishing modules is a second carrier loading station, and the substrate exchanger is dedicated to moving substrates between the first carrier loading station and the second carrier loading station. In some of those embodiments, the substrate exchanger is movable about an axis to swing a substrate between the first and the second carrier loading stations.

In some embodiments of the polishing system, the substrate carrier of at least one of the plurality of polishing modules is a first substrate carrier and the at least one polishing module further comprises a second substrate carrier, and the carrier transport system of the at least one polishing module is configured to concurrently position the first substrate carrier above the polishing platen and the second substrate carrier above the carrier loading station. In some of those embodiments, the carrier transport system of the at least one of the plurality of polishing modules includes a carrier support module. In some of those embodiments, the carrier support module includes a support member, a carrier platform coupled to the support member, and the first and second substrate carriers, which are suspended from the carrier platform. In other ones of those embodiments, the carrier support module includes a track assembly coupled to an overhead support of the one or more first modular frames, a plurality of carriages coupled to the track assembly, and the first and second substrate carriers respectively coupled to corresponding ones of the plurality of carriages.

In some embodiments of the polishing system, the plurality of polishing modules includes at least two polishing modules disposed in the first processing region. In those embodiments, the polishing system further includes a second modular frame coupled to the first modular frame where the second modular frame defines a second processing region and a post-polishing cleaning system disposed in the second processing region. Here, the substrate handling system includes a substrate handler disposed in the second processing region. The two polishing modules are disposed in an arrangement that allows substrates to be transferred to and from the carrier loading stations thereof using the substrate handler. In some of those embodiments, the polishing system further includes a third processing region disposed between the first processing region and the second processing region and one or more processing systems disposed in the third processing region. Here, the one or more processing systems include one or more location specific polishing modules, one or more metrology stations, one or more buffing stations, or a combination thereof. The one or more processing systems in the third processing region are disposed in an arrangement that allows substrates to be directly transferred thereto and therefrom using the substrate handler.

In another embodiment, a substrate processing method includes (a) urging a first substrate against a first polishing pad, where the first polishing pad is disposed on a polishing platen of a first polishing module of a polishing system. The polishing system includes the first polishing module and a plurality of second polishing modules. Each individual one of the first and second polishing modules includes a polishing platen and a carrier loading station. The first polishing module is configured for a first polishing stage of a multi-stage substrate polishing sequence and the plurality of second polishing modules are each configured for a second stage of the multi-stage substrate polishing sequence. Each of the first and second polishing modules includes a polishing platen, a substrate carrier loading station, and a substrate handling system for transferring a substrate between the carrier loading station of the first polishing module and any one of the plurality of polishing modules and any one of the carrier loading stations of the plurality of second polishing modules. The method further includes (b) determining an available second polishing module of the plurality of second polishing modules, (c) transferring the first substrate to the available second polishing module of the plurality of second polishing modules, (d) urging the first substrate against a second polishing pad in the presence of a second polishing fluid, and (e) repeating (a)-(d) on a second substrate. Here, the second polishing pad is disposed on the polishing platen of the available polishing module.

In some embodiments of the substrate processing method, each individual one of the first and second polishing modules further includes a carrier transport system for moving a substrate carrier between the polishing platen and the carrier loading station.

In some embodiments of the substrate processing method, the first polishing module includes a first substrate carrier and a second substrate carrier. In those embodiments, the method further includes, concurrent with urging the first substrate against the first polishing pad, loading the second substrate into the second substrate carrier. In some of those embodiments, a carrier transport system of the first polishing module includes a carrier support module and the carrier support module includes a support member, a carrier platform coupled to the support member, and the first and second substrate carriers, which are suspended from the carrier platform. In other embodiments, the carrier support module includes a track assembly, a plurality of carriages coupled to the track assembly, and the first and second substrate carriers respectively coupled to corresponding ones of the plurality of carriages.

In some embodiments of the substrate processing method, the first substrate is transferred from the first polishing module to the available second polishing module using a dedicated substrate exchanger disposed therebetween.

In some embodiments of the substrate processing method, the first polishing module and plurality of second polishing modules includes at least four polishing modules, the carrier loading stations of the at least four polishing modules collectively define a substrate handling region, the substrate handling system includes a substrate handler disposed in the substrate handling region, and the substrate handler is positioned to transfer a substrate from the carrier loading station of any one of the at least four polishing modules to the carrier loading station of any other one of the least four polishing modules.

In some embodiments of the substrate processing method, the carrier loading station includes a substrate buffing station, a substrate carrier cleaning station, a metrology station, a substrate edge correction station, or a combination thereof.

## BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

FIG. **1**A is a schematic side view of a polishing module, according to one embodiment, which may be used as one or more of a plurality of polishing modules in one or more of the modular polishing systems described herein.

FIG. **1**B is a top down section view of the polishing module of FIG. **1**A taken along line A'-A'.

FIG. **1**C schematically illustrates an alternate arrangement of the polishing module of FIGS. **1**A-**1**B.

FIG. **2**A-**2**B is a schematic top down sectional views of various embodiments of modular polishing systems each comprising a plurality of the polishing modules set forth in FIGS. **1**A-**1**B.

FIG. **3**A is a schematic top down sectional view of a modular polishing system comprising a plurality of the polishing modules set forth in FIGS. **1**A-**1**B, according to another embodiment.

FIG. **3**B is a schematic top down view of an inter-module substrate exchanger, according to one embodiment, which may be used with any of the modular polishing systems described herein.

FIG. **4** is a schematic top down sectional view of a modular polishing system comprising a plurality of the polishing modules, such as set forth in FIGS. **1**A-**1**B, according to another embodiment.

FIG. **5**A is a schematic top down view of a modular polishing system, according to another embodiment.

FIG. **5**B is a side view of a portion of the modular polishing system shown in FIG. **5**A.

FIG. **6** is a schematic top down sectional view of a modular polishing system, according to another embodiment.

FIG. **7** is a schematic top down section view illustrating an alternate arrangement of polishing modules, according to one embodiment.

FIG. **8**A is a schematic top down sectional view of an alternate embodiment of a polishing module which may be used with any one or combination of the polishing systems set forth in FIGS. **2**-**7**.

FIG. **8**B is a schematic side view of the linear polishing station of FIG. **8**B, according to one embodiment.

FIG. **9** is a schematic side view of an alternate embodiment of a linear polishing station which may be used with any one or combination of the polishing systems set forth in FIGS. **2**-**8**.

FIG. **10** is a diagram illustrating a substrate processing method that may be performed using a modular polishing system described herein, according to one embodiment.

FIG. **11** is a schematic top down sectional view of a modular polishing system, according to another embodiment.

FIG. **12** is a schematic top down sectional view of a modular polishing system, according to another embodiment.

FIG. **13** is a schematic side view of a polishing module, according to another embodiment, which may be used as one or more of a plurality of polishing modules of the modular polishing systems described herein.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

## DETAILED DESCRIPTION

Embodiments of the present disclosure generally relate to chemical mechanical polishing (CMP) systems used in the semiconductor device manufacturing industry. More particularly, embodiments herein relate to high throughput density chemical mechanical polishing (CMP) modules and customizable modular CMP systems comprised thereof.

FIG. **1**A is a schematic side view of a polishing module, according to one embodiment, which may be used as one or more of a plurality of polishing modules of the modular polishing systems described herein. FIG. **1**B is a top down sectional view of FIG. **1**A taken along line A'-A'.

Here, the polishing module **100***a* is disposed within a modular frame **110** and includes a carrier support module **120** comprising a first carrier assembly **130***a* and a second carrier assembly **130***b* where each of the carrier assemblies **130***a, b* includes a corresponding carrier head **131**. The polishing module **100***a* further includes a station for loading and unloading substrates to and from the carrier heads, herein a carrier loading station **140**, and a polishing station **150**. In embodiments herein, the carrier support module **120**, the carrier loading station **140**, and the polishing station **150** are disposed in a one-to-one-to-one relationship within the modular frame **110**. This one-to-one-to-one relationship and the arrangements described herein facilitate the simultaneous substrate loading/unloading and polishing operations of at least two substrates **180** to enable the high throughput density substrate handling methods described herein.

Here, the modular frame **110** features a plurality of vertically disposed supports, herein upright supports **111**, a horizontally disposed tabletop **112**, and an overhead support **113** disposed above the tabletop **112** and spaced apart therefrom. The upright supports **111**, the tabletop **112**, and the overhead support **113** collectively define a processing region **114**. Here, the modular frame **110** has a generally rectangular footprint when viewed from the top down (FIG. **1**B) where four individual ones of the upright supports **111** are respectively coupled to the four outward facing corners of both the tabletop **112** and the overhead support **113**. In other embodiments, the tabletop **112** and the overhead support **113** may be coupled to upright supports **111** at other suitable locations, which have been selected to prevent interference between the upright supports **111** and substrate handling operations. In other embodiments, the modular frame **110** may comprise any desired footprint shape when viewed from the top down.

In some embodiments, the polishing module **100** a further includes a plurality of panels **115** (shown in phantom in FIG. **1**B) each vertically disposed between adjacent corners of the modular frame **110** to enclose and isolate the processing region **114** from other portions of a modular polishing system **100**. In those embodiments, one or more the panels **115** will typically have a slit shaped opening (not shown) formed therethrough to accommodate substrate transfer into and out of the processing region **114**.

Here, the carrier support module **120** is suspended from the overhead support **113** and includes a support shaft **121** disposed through an opening in the overhead support **113**, an actuator **122** coupled to the support shaft **121**, and a carrier platform **123** coupled to, and supported by, the support shaft **121**. The actuator **122** is used to rotate or alternately pivot the support shaft **121**, and thus the carrier platform **123**, about a support shaft axis A in the clockwise and counter-clockwise directions. In other embodiments (not shown), the support shaft **121** may be mounted on and/or coupled to the base **112** to extend upwardly therefrom. In those embodiments, the carrier platform **121** is coupled to, disposed on, and/or otherwise supported by an upper end of the support shaft **121**. In those embodiments, the support shaft **121** may be vertically disposed in an area between the carrier loading station **140** and the polishing station **150** which are described below.

As shown, the carrier platform **123** provides support to the carrier assemblies **130***a, b* and is coupled to an end of the support shaft **121** which is disposed in the processing region **114**. Here, the carrier platform **123** comprises an upper surface and a lower tabletop-facing surface which is opposite of the upper surface. The carrier platform **123** is shown as a cylindrical disk but may comprise any suitable shape sized to support the components of the carrier assemblies **130***a, b*. The carrier platform **123** is typically formed of a relatively light weight rigid material, such as aluminum which is resistant to the corrosive effects of commonly used polishing fluids. Here, the carrier platform **123** has a plurality of openings **124** (FIG. **1**B) disposed therethrough. In some embodiments, the carrier support module **120** further includes a housing **125** (shown in phantom in FIG. **1**A) disposed on the upper surface of the carrier platform **123**. The housing **125** desirably prevents polishing fluid overspray from the polishing process from coming into contact with, and causing corrosion to, the components disposed on or above the carrier platform **123** in a region defined by the housing **125**. Beneficially, the housing **125** also prevents contaminants and/or other defect causing particles from transferring from the components contained therein to the substrate processing regions, which might otherwise cause damage to the substrate surface, such as scratches and/or other defectivity.

As shown, the carrier platform **123** provides support for two carrier assemblies, the first carrier assembly **130***a* and the second carrier assembly **130***b*, so that the carrier support module **120** and the carrier assemblies **130***a, b* are arranged in a one-to-two relationship within the modular frame **110**. Thus, the carrier support module **120**, the carrier assemblies **130***a, b*, the carrier loading station **140**, and the polishing station **150** are arranged in a one-to-two-to-one-to-one relationship within the modular frame **110**. In some embodiments, the carrier support module **120** supports only a single carrier assembly, such as the first carrier assembly **130***a*. In some embodiments, the carrier support module **120** supports not more than two carrier assemblies, such as the first carrier assembly **130***a* and the second carrier assembly **130***b*. In some embodiments, a carrier support module **120** is configured to support not more and not less than the two carrier assemblies **130***a, b*.

Typically, each of the carrier assemblies **130***a, b* comprises a carrier head **131**, a carrier shaft **132** coupled to the carrier head **131**, one or a plurality of actuators, such as a first actuator **133** and a second actuator **134**, and a pneumatic assembly **135**. Here, the first actuator **133** is coupled to the carrier shaft **132** and is used to rotate the carrier shaft **132** about a respective carrier axis B or B'. The second actuator **134** is coupled to the first actuator **133** and is used to oscillate the carrier shaft **132** a distance X(1) between a first position with respect to the carrier platform **121** and a second position disposed radially outward from the first position or to positions disposed therebetween. Typically, the carrier shaft **132** is oscillated during substrate polishing to sweep the carrier head **131**, and thus a substrate **180** disposed therein, between an inner diameter of a polishing pad **152** and an outer diameter of the polishing pad **152** to, at least in part, prevent uneven wear of the polishing pad **152**. Beneficially, the linear (sweeping) motion imparted to the carrier head **131** by oscillating the carrier shaft **132** may also be used to position the carrier head **131** on the polishing pad **152** such that the carrier head **131** does not interfere with the positioning of the polishing fluid dispense arm **153** and/or pad conditioning arm **155** (FIG. 1B). In some embodiments, the linear motion is used to retract the carrier heads **131** towards axis A before the carrier platform **121** is rotated or pivoted. Retracting the carrier heads **131** towards axis A provides a smaller swing radius as the carrier heads **131** are swung about the axis A between the carrier loading station **140** and the polishing station **150**. This smaller swing radius advantageously makes room for the addition of other components to the polishing module **100** if additional components are so desired. In some embodiments, the distance X(1) is between about 5 mm and about 50 mm.

The carrier shafts **132** are disposed through the respective openings **124** (FIG. 1B), here radial slots, disposed through the carrier platform **123**. Typically, the actuators **133** and **134** are disposed above the carrier platform **123** and are enclosed within the region defined by the carrier platform **123** and the housing **125**. The respective positions of the openings **124** in the carrier platform **123** and the position of the carrier shafts **132** disposed through the openings **124** determines a swing radius R(1) of a carrier head **131** as it is moved from a substrate polishing to a substrate loading or unloading position. The swing radius R(1) of a carrier head **131** can determine minimum spacing between polishing modules **100***a* in the modular polishing systems described herein as well as the ability to perform processes in within a processing module that are ex-situ to the polishing process, i.e., not conducted concurrently therewith.

In some embodiments, the swing radius R(1) of a carrier head **131** is not more than about 2.5 times the diameter of a to-be-polished substrate, such as not more than about 2 times the diameter of a to-be-polished substrate, such as not more than about 1.5 times the diameter of a to-be-polished substrate. For example, for a polishing module **100***a* configured to polish a 300 mm diameter substrate the swing radius R(1) of the carrier head **131** may be about 750 mm or less, such as about 600 mm or less, or about 450 mm or less. Appropriate scaling may be used for polishing modules configured to polish other sized substrates. The swing radius R(1) of a carrier head **131** may be more, less, or the same as a swing radius R(2) of the carrier platform **123**. For example, in some embodiments the swing radius R(1) of the carrier head **131** is equal to or less than the swing radius R(2) of the carrier platform **123**.

Here, each carrier head **131** is fluidly coupled to a pneumatic assembly **135** through one or more conduits (not shown) disposed through the carrier shaft **132**. The term "fluidly coupled" as used herein refers to two or more elements that are directly or indirectly connected such that the two or more elements are in fluid communication, i.e., such that a fluid may directly or indirectly flow therebetween. Typically, the pneumatic assembly **135** is fluidly coupled to the carrier shaft **132** using a rotary union (not shown) which allows the pneumatic assembly **135** to remain in a stationary position relative to the carrier platform **123** while the carrier head **131** rotates therebeneath. The pneumatic assembly **135** provides pressurized gases and/or vacuum to the carrier head **131**, e.g., to one or more chambers (not shown) disposed within the carrier head **131**. In other embodiments, one or more functions performed by components of the pneumatic assembly **135** as described herein may also be performed by electromechanical components, e.g., electromechanical actuators.

The carrier head **131** will often feature one or more of flexible components, such as bladders, diaphragms, or membrane layers (not shown) which may, along with other components of the carrier head **131**, define chambers disposed therein. The flexible components of the carrier head **131** and the chambers defined therewith are useful for both substrate polishing and substrate loading and unloading operations. For example, a chamber defined by the one or more flexible components may be pressurized to urge a substrate disposed in the carrier head towards the polishing pad by pressing components of the carrier head against the backside of the substrate. When polishing is complete, or during substrate loading operations, a substrate may be vacuum chucked to the carrier head by applying a vacuum to the same or a different chamber to cause an upward deflection of a membrane layer in contact with the backside of the substrate. The upward deflection of the membrane layer will create a low pressure pocket between the membrane and the substrate, thus vacuum chucking the substrate to the carrier head **131**. During substrate unloading operations, where the substrate is unloaded from the carrier head **131** into the carrier loading station **140**, a pressurized gas may be introduced into the chamber. The pressurized gas in the chamber causes a downward deflection of the membrane to release a substrate from the carrier head **131***a, b* into the carrier loading station **140**.

Here, the carrier loading station **140** is a load cup comprising a basin **141**, a lift member **142** disposed in the basin

141, and an actuator **143** coupled to the lift member **142**. In some embodiments, the carrier loading station **140** is coupled to a fluid source **144** which provides cleaning fluids, such as deionized water, which may be used to clean residual polishing fluids from a substrate **180** and/or carrier head **131** before and/or after substrate polishing. Typically, a substrate **180** is loaded into the carrier loading station **140** in a "face down" orientation, i.e., a device side down orientation. Thus, to minimize damage to the device side surface of the substrate through contact with surfaces of the lift member **142**, the lift member **142** will often comprise an annular substrate contacting surface which supports the substrate **180** about the circumference, or about portions of the circumference, thereof. In other embodiments, the lift member **142** will comprise a plurality of lift pins arranged to contact a substrate **180** proximate to, or at, the outer circumference thereof. Once a substrate **180** is loaded into the carrier loading station **140** the actuator **143** is used to move the lift member **142**, and thus the substrate **180**, in the Z-direction towards a carrier head **131** positioned thereabove for vacuum chucking into the carrier head **131**. The carrier head **131** is then moved to the polishing station **150** so that the substrate **180** may be polished thereon.

In other embodiments, the carrier loading station **140** features buff platen that may be used to buff, e.g., soft polish, the substrate surface before and/or after the substrate is processed at the polishing station. In some of those embodiments, the buff platen is movable in a vertical direction, i.e., the Z-direction to make room for substrate transfer to and from the carrier loading station using a substrate transfer and/or to facilitate substrate transfer to and from the carrier heads **131**. In some embodiments, the carrier loading station **140** is further configured as an edge correction station, e.g., to remove material from regions proximate to the circumferential edge of the substrate before and/or after the substrate is processed at the polishing station **150**. In some embodiment, the carrier loading station **140** is further configured as a metrology station and/or a defect inspection station, which may be used to measure the thickness of a material layer disposed on the substrate before and/or after polishing, to inspect the substrate after polishing to determine if a material layer has been cleared from the field surface thereof, and/or to inspect the substrate surface for defects before and/or after polishing. In those embodiments, the substrate may be returned to the polishing pad for the further polishing and/or directed to a different substrate processing module or station, such as a different polishing module **100** or to an LSP module **230** based on the measurement or surface inspection results obtained using the metrology and/or defect inspection station.

Here, a vertical line disposed through the center C of the carrier loading station **140** is co-linear with the center of a circular substrate **180** (e.g., a silicon wafer when viewed top down). As shown the center C is co-linear with the shaft axis B or B' when a substrate **180** is being loaded to or unloaded from a carrier head **131** disposed thereover. In other embodiments, the center C of the substrate **180** may be offset from the shaft axis B when the substrate **180** is disposed in the carrier head **131**.

The polishing station **150** features a platen **151**, a polishing pad **152**, a polishing fluid dispense arm **153**, an actuator **154** coupled to the fluid dispense arm **153**, a pad conditioner arm **155**, an actuator **156** coupled to a first end of the pad conditioner arm **155**, and a pad conditioner **157**. The pad conditioner **157** is coupled to a second end of the pad conditioner arm **155** that is distal from the first end. To reduce visual clutter the fluid dispense arm **153**, the pad conditioner arm **155**, the actuators **154**, **156** respectively coupled thereto, and the pad conditioner **157** are not shown in FIG. **1**A but are shown in FIG. **1**B. In other embodiments, the fluid dispense arm **153** may be disposed in a fixed position relative to the rotational center of the polishing platen **151**, i.e., disposed in a fixed position relative to the platen axis D. In some embodiments, the fluid dispense arm **153** may be curved so as to avoid interference with the carrier heads **131** as the carrier heads **131** are swung about the support shaft axis A.

Here, the polishing station **150** further includes a fence **158** (shown in cross section in FIG. **1**A) which surrounds the polishing platen **102** and is spaced apart therefrom to define a drainage basin **159**. Polishing fluid and polishing fluid byproducts are collected in the drainage basin **159** and are removed therefrom through a drain **160** in fluid communication therewith. In other embodiments, the fence **158** may comprise one or more sections disposed about, or partially disposed above, respective portions of the polishing platen **102**, and/or may comprises one or more sections disposed between the carrier loading station **140** and the polishing station **150**. Here, the platen **151** is rotatable about a platen axis D which extends vertically through the center of the platen **151**. Here, the polishing station **150** features a single platen **151** so that the carrier support module **120**, the carrier loading station **140**, and the platen **151** are disposed in a one-to-one-to-one relationship.

Typically, the carrier support module **120** and the polishing station **150** are arranged to minimize the footprint of the polishing module **100***a*. For example, in one embodiment a distance X(2) between the support shaft axis A and the platen axis D is not more than 2.5 times the swing radius R(1) of a carrier head **131**, such as not more than 2 times, not more than 1.5 times, or not more than 1.25 times the swing radius R(1) of a carrier head.

Here, the fluid dispense arm **153** is configured to dispense polishing fluids at or proximate to the center of the polishing pad, i.e., proximate to platen axis D disposed therethrough. The dispensed polishing fluid is distributed radially outward from the center of the platen **151** by centrifugal force imparted to the polishing fluid by the rotation of the platen **151**. For example, here the actuator **154** is coupled to a first end of the fluid dispense arm **153** and is used to move the fluid dispense arm **153** about an axis E so that a second end of the fluid dispense arm **153** may be positioned over or proximate to the center of the platen **151** and the polishing pad **152** disposed thereon.

The pad conditioner arm **155** comprises a first end coupled to the actuator **156** and a second end coupled to the pad conditioner **157**. The actuator **156** swings the pad conditioner **157** about an axis F disposed through the first end and simultaneously urges the pad conditioner **157** toward the surface of the polishing pad **152** disposed therebeneath. The pad conditioner **157** is typically one of a brush or a fixed abrasive conditioner, e.g., a diamond embedded disk, which is used to abrade and rejuvenate the polishing surface of the polishing pad **152**.

Here, the pad conditioner **157** is urged against the polishing pad **152** while being swept back and forth from an outer diameter of the polishing pad **152** to, or proximate to, the center of the polishing pad **152** while the platen **151**, and thus the polishing pad **152**, rotate therebeneath. The pad conditioner **157** is used for in-situ conditioning, i.e., concurrent with substrate polishing, ex-situ conditioning, i.e., in periods between substrate polishing, or both. Typically, the pad conditioner **157** is urged against the polishing pad **152** in the presence of a fluid, such as polishing fluid or deionized water, which provides lubrication therebetween. The fluid is dispensed onto the polishing pad **152** near the platen axis D by positioning the fluid dispense arm **153** thereover. Typically, the carrier support module **120** and the polishing station **150** are arranged so that the swing radius R(1) of a carrier head **131** is not within a swing path of one or both of the fluid dispense arm **153** or the pad conditioner **157**. This arrangement beneficially allows for ex-situ conditioning of the polishing pad **152** while the carrier support module **120** pivots the carrier heads **131** between the carrier loading and substrate polishing positions as further described below.

Typically, the carrier support module **120**, the carrier assemblies **130***a, b*, the carrier loading station **140**, and the polishing station **150** are disposed in an arrangement that desirably minimizes the cleanroom footprint of the polishing module **100***a*. Herein, a description of the arrangement is made using the relative positions of the carrier heads **131**, carrier loading station **140**, and platen **151** when the carrier support module **120** is disposed in one of a first or second processing mode and the first and second planes G and G' defined therefrom (plane G is shown in FIGS. **1**B and **1**C, plane G' is shown in FIG. **1**C).

In FIGS. **1**A-**1**B, the carrier support module **120** is disposed in a first processing mode. In the first processing mode the first carrier assembly **130***a* is disposed above the platen **151** and the second carrier assembly **130***b* is disposed above the carrier loading station **140**. I.e., in the first processing mode the carrier head **131** of the second carrier assembly **130***b* is positioned above the carrier loading station **140** to allow for substrate loading and unloading thereinto and therefrom. In a second processing mode (not shown) the carrier platform **123** will be rotated or pivoted an angle ⊖ of 180° about the support shaft axis A and the relative positions of the first carrier assembly **130***a* and the second carrier assembly **130***b* will be reversed. I.e., in the second processing mode the carrier head **131** of the second carrier assembly **130***a* will be positioned above the carrier loading station **140** to allow for substrate loading and unloading thereinto and therefrom.

Herein, the relative positions of the carrier support module **120** and the polishing station **150** are described by reference to the first and second planes G and G' shown in FIGS. **1**B and **1**C. The first plane G is a vertical plane that is orthogonal to the typically horizontal pad mounting surface of the platen **151** and is further defined by the support shaft axis A and a vertical center C of the carrier loading station **140**. Typically, the carrier shaft axes B and B' will be disposed within the first plane G when the carrier support module **120** is disposed in either the first or second processing modes. As shown in FIG. **1**B, the support shaft axis A, the vertical center C, and the platen axis D are co-planar with one another and thus collectively define the first plane G.

In other embodiments, the platen axis D is offset from the first plane G so as to form a second plane G' with the support shaft axis A. The second plane G' is schematically represented in FIG. **1**C. In those embodiments, the first plane G and the second plane G' will typically form an angle θ(2) of 45° or more, such as 60° more, 75° or more, 90° or more, for example 95° or more when the carrier support module **120** is disposed in either of the first or second processing modes.

Beneficially, the polishing module **100***a* described in FIGS. **1**A-**1**C, including alternate embodiments thereof and combinations of alternate embodiments thereof, may be independently manufactured for later integration into a high throughput density customizable modular polishing system. Examples of customizable modular polishing systems which may be formed using the polishing module **100***a* are provided in FIGS. **2**-**7**.

FIG. **2**A is a schematic top down sectional view of a modular polishing system comprising a plurality of the polishing modules set forth in FIGS. **1**A-**1**C, according to one embodiment. Here, the modular polishing system **200***a* features a first portion **220** and a second portion **205***a* coupled to the first portion **220**. The second portion **205***a* includes two polishing modules **100** *a, b* which share a frame **110** including upright supports **111**, a shared tabletop **112**, and a shared overhead support **113**. In other embodiments, each of the polishing modules **100** *a, b* respectively comprise individual frames **110** (such as shown in FIGS. **1**A-**1**B) which are coupled together to form the second portion **205***a*.

Each of the polishing modules **100***a, b* feature a carrier support module **120**, a carrier loading station **140**, and a polishing station **150** disposed in a one-to-one-to-one relationship as shown and described in FIGS. **1**A-**1**C. Each of the polishing stations **150** of the respective polishing modules **100***a, b* features a single platen **151** so that each of the respective polishing modules **100***a, b* comprise a carrier support module **120**, a carrier loading station **140**, and a platen **151** disposed in a one-to-one-to-one relationship as shown and described in FIGS. **1**A-**1**C.

Typically, the polishing module **100***b* is substantially similar to an embodiment of the polishing module **100***a* described in FIGS. **1**A-**1**C, and may include alternate embodiments, or combinations of alternate embodiments, thereof. For example, in some embodiments, one of the two polishing modules, e.g., polishing module **100***a*, is configured to support a longer material removal polishing process while the other polishing module, e.g., **100***b* is configured to support a shorter post-material removal buffing process. In those embodiments, substrates processed on polishing modules **100***a* are then transferred to polishing module **100***b*. Often, the shorter post-material removal buffing process will be a throughput limiting process which will benefit from the throughput increasing two carrier assembly **130***a, b* arrangement described in FIGS. **1**A-**1**C. Thus, in some embodiments, one or more substrate polishing modules within a modular polishing system may comprise a single carrier assembly **130***a* or **130***b* while other polishing modules within the modular polishing system comprise two carrier assemblies **130***a* and **130***b*.

Here, the polishing modules **100***a, b* are disposed in a side-by-side arrangement where the first planes G thereof are generally parallel or substantially parallel with one another, such as within 30° of parallel with one another, within 20° of parallel with one another, or within 10° or parallel with one another. Here, each of the polishing modules **100***a, b* "faces toward" the first portion **220**. As used herein, a polishing module "faces towards" a component or a portion of the modular polishing system **200***a* when the carrier support module **120** and the carrier loading station **140** are closer to that component or portion and the polishing station **150** is farther away. For example, in FIG. **2**A the carrier support modules **120** and the carrier loading stations **140** (shown in FIG. **1**A) of the polishing modules **100***a, b* are closer to the first portion **220** than are the polishing stations **150**.

In another embodiment, such as shown in FIG. **2**B, in second portion **205**B, the polishing modules **100** a, b are oriented to "face away" from the first portion **220**. As used herein, a polishing module "faces away" from a component or a portion of a modular polishing system when the polishing station **150** is closer to the component or portion and the carrier support module **120** is farther away. In some embodiments where the polishing modules **100** *a, b* are oriented to face away from the first portion it may be desirable to use a third robot **314** to facilitate substrate handling. In this embodiment substrates **180** from the first portion **220** are loaded into the transfer station **216** by the second robot **226**. The substrates **180** are then picked up from the transfer station **216** by the third robot **314** to be moved to one of the carrier loading stations **140**.

Typically, the first portion **220** comprises one or combination of a plurality of system loading stations **222**, one or more substrate handlers, e.g., a first robot **224** and a second robot **226**, one or more metrology stations **228**, one or more location specific polishing (LSP) module **230**, and one or more one or more post-CMP cleaning systems **232**. An LSP module **230** is typically configured to polish only a portion of a substrate surface using a polishing member (not shown) that has a surface area that is less than the surface area of a to-be-polished substrate. LSP modules **230** are often used after a substrate has been polished within a polishing module to touch up, e.g., remove additional material, from a relatively small portion of the substrate. In some embodiments one or more LSP modules **230** may be included within the second portion **205** in place of one of the polishing modules **100***a, b*.

In other embodiments the one or more LSP modules **230** may be disposed in any other desired arrangement within the modular polishing systems set forth herein. For example, one or more LSP modules **230** may be disposed between the first portion **220** and the second portion **205**, between adjacently disposed polishing modules **100***a-i* in any of the arrangements described herein, and/or proximate to an end of any of the second portions described herein, the end of the respective second portion being distal from the first portion. In some embodiments, the modular polishing systems may include one or more buffing modules (not shown) which may be disposed in any of the arrangements described above for the LSP module **230**. In some embodiments, the first portion **220** features at least two post-CMP cleaning systems **232** which may be disposed on opposite sides of the second robot **226**.

A post-CMP cleaning system facilitates removal of residual polishing fluids and polishing byproducts from the substrate **180** and may include any one or combination of brush or spray boxes **234** and a drying unit **236**. The first and second robots **224**, **226** are used in combination to transfer substrates **180** between the second portion **205** and the first portion **220** including between the various modules, stations, and systems thereof. For example, here, the second robot **226** is at least used to transfer substrates to and from the carrier loading stations **140** of the respective polishing modules **100***a, b* and/or therebetween.

In embodiments herein, operation of the modular polishing system **200** is directed by a system controller **270**. The system controller **270** includes a programmable central processing unit (CPU) **271** which is operable with a memory **272** (e.g., non-volatile memory) and support circuits **273**. The support circuits **273** are conventionally coupled to the CPU **271** and comprise cache, clock circuits, input/output subsystems, power supplies, and the like, and combinations thereof coupled to the various components of the modular polishing system **200**, to facilitate control thereof. The CPU **271** is one of any form of general purpose computer processor used in an industrial setting, such as a programmable logic controller (PLC), for controlling various components and sub-processors of the processing system. The memory **272**, coupled to the CPU **271**, is non-transitory and is typically one or more of readily available memories such as random access memory (RAM), read only memory (ROM), floppy disk drive, hard disk, or any other form of digital storage, local or remote.

Typically, the memory **272** is in the form of a non-transitory computer-readable storage media containing instructions (e.g., non-volatile memory), which when executed by the CPU **271**, facilitates the operation of the modular polishing system **200**. The instructions in the memory **272** are in the form of a program product such as a program that implements the methods of the present disclosure. The program code may conform to any one of a number of different programming languages. In one example, the disclosure may be implemented as a program product stored on computer-readable storage media for use with a computer system. The program(s) of the program product define functions of the embodiments (including the methods described herein).

Illustrative non-transitory computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM disks readable by a CD-ROM drive, flash memory, ROM chips or any type of solid-state non-volatile semiconductor memory devices, e.g., solid state drives (SSD) on which information may be permanently stored; and (ii) writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or any type of solid-state random-access semiconductor memory) on which alterable information is stored. Such computer-readable storage media, when carrying computer-readable instructions that direct the functions of the methods described herein, are embodiments of the present disclosure. In some embodiments, the methods set forth herein, or portions thereof, are performed by one or more application specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), or other types of hardware implementations. In some other embodiments, the substrate processing and/or handling methods set forth herein are performed by a combination of software routines, ASIC(s), FPGAs and, or, other types of hardware implementations. One or more system controllers **270** may be used with one or any combination of the various modular polishing systems described herein and/or with the individual polishing modules thereof.

FIG. **3**A is a schematic top down sectional view of a modular polishing system comprising a plurality of polishing modules disposed in an alternate arrangement, according to one embodiment. FIG. **3**B is a schematic representation of an inter-module substrate exchanger **350** which may be used with any one or combination of the modular polishing systems described herein. The modular polishing system **300** features a first portion **320** and a second portion **305** coupled to the first portion **320**. The first portion **320** may be substantially the same as the first portion **220** described in FIG. **2** including any one or combination of the features or alternate embodiments thereof.

Here, the second portion **305** features four polishing modules **100***a-d*, a third robot **314** suspended from an overhead support (such as the overhead support **113** described in FIG. **1**) and a transfer station **216**. The polishing modules **100***c, d* are disposed in a side-by-side arrangement facing away from the first portion **320**. For example, in FIG. **3** the polishing stations **150** of each of the respective polishing modules **100***c, d* are closer to the first portion **320** than are the carrier support modules **120** and the carrier loading stations **140**.

Here, the polishing modules **100***c, d* share a frame **110** such as described above in FIG. **2***a* with respect to polishing modules **100***a, b*. In some embodiments, each of the individual polishing modules is disposed within a corresponding frame in a one-to-one arrangement and the individual frames are coupled together to form the second portions described in any of the modular polishing systems set forth herein. In other embodiments, a single frame may be used to support two or more polishing modules, three or more, four or more, five or more, or six or more polishing modules. In some embodiments, individual frames each supporting a different number of polishing modules may be coupled together to form any one or combination of the modular polishing systems set forth herein. For example, an individual frame supporting two polishing modules may be coupled with two individual frames each supporting a single polishing module, with another individual frame supporting two modules, and/or with an individual frame supporting four or more polishing modules to achieve a desired polishing system configuration.

In this embodiment, the polishing modules **100***a, b* are spaced apart from the first portion **320** by the polishing modules **100***c, d*. The polishing modules **100***a, b* are disposed in a side-by-side arrangement each facing towards the polishing modules **100***c, d* to define a substrate transfer region therebetween. The third robot **314** is disposed in the substrate transfer region to facilitate access to the carrier loading stations **140** (as shown in FIG. **1**A) for each of the polishing modules **100***a-d*. The transfer station **216** is disposed in an area between the second robot **226** and the third robot **314**.

Typically, substrates **180** from the first portion **320** are loaded into the transfer station **216** by the second robot **226**. The substrates **180** are then picked up from the transfer station **216** by the third robot **314** to be moved to one of the carrier loading stations **140**. In some embodiments, one or more of the polishing modules **100***a-d* are configured for different polishing processes, such as the material removal and post-material buffing processes described in FIG. **2**A. In those embodiments, the third robot **314** may be used to transfer the substrates **180** between the polishing modules **100***a-d* before transferring the substrate **180** back to the transfer station **216** for pick up by the second robot **226**.

Here, the polishing modules **100***c, d* are disposed in an arrangement where the first planes G thereof are generally parallel with one another, such as described above with respect to the arrangement between polishing modules **100***a, b*. Each of the polishing modules **100***c, d* feature a carrier support module **120**, a carrier loading station **140**, and a polishing station **150** disposed in a one-to-one-to-one relationship. Each of the polishing stations **150** of the respective polishing modules **100***c, d* feature a single platen **151** so that each of the respective polishing modules **100***c, d* comprises a carrier support module **120**, a carrier loading station **140**, and a polishing platen disposed in a one-to-one-to-one relationship. Typically, the polishing modules **100***c, d* are substantially similar to the polishing modules **100***a, b* as described above, including alternate embodiments, or combinations of alternate embodiments, of the features thereof. In some embodiments one or more LSP systems **230** may be included within the second portion **305** in place of one or more of the polishing modules **100***a-d.*

In some embodiments, the modular polishing systems described herein further include a substrate exchanger dedicated to moving substrates between polishing and/or other substrate processing modules, such as the inter-module substrate exchangers **350** shown in FIGS. **3**A-**3**B. In FIG. **3**A, the inter-module substrate exchangers **350** are disposed between adjacent polishing modules, e.g., between the polishing modules **100***a* and **100***c* and between the polishing modules **100***b* and **100***d*. In some embodiments, one or more inter-module substrate exchangers **350** may be used to facilitate a relatively quick substrate transfer between a polishing modules **100** and different type of substrate processing module, such as an LSP module **230** or a buffing module (not shown). In those embodiments, the respective inter-module substrate exchanger **350** is disposed between the polishing module **100** and the different type of substrate processing module positioned adjacent to the polishing module **100**.

In FIG. **3**B, the inter-module substrate exchanger **350** is disposed between the carrier loading stations **140** of two adjacent polishing modules, e.g., the polishing modules **100***a* and *c* shown in FIG. **3**A. Here, the inter-module substrate exchanger **350** features a pivot arm **352**, an actuator **354**, and an end-effector **356**. The actuator **354** is coupled to a first end of the pivot arm **352** and the end-effector **356** is coupled to a second end of the pivot arm **352**. The actuator **354** is used to swing the end-effector **356**, and thus a substrate **180** disposed thereon, about an axis H. Typically, the end-effector **356** is coupled to a vacuum (not shown) which may be used to securely hold the substrate **180** to the end-effector **356** as the substrate **180** is moved between the carrier loading stations **140**.

In some embodiments, the actuator **354** may be movable in the Z-direction to further facilitate substrate handling. The inter-module substrate exchanger **350** beneficially provides fora higher substrate processing throughput by facilitating inter-module substrate transfer, e.g., in a multi-platen polishing processes, without adding to the burden on the other substrate handlers (robots) and/or without the added delay of waiting for a substrate handler to be free. In other words, the inter-module substrate exchangers **350** may be used to improve the overall substrate processing throughput of the modular polishing systems described herein by reducing the number of sequential moves that would otherwise need to be performed by the other substrate handlers (robots).

FIG. **4** is a schematic top down sectional view of a modular polishing system comprising a plurality of polishing modules disposed in an alternate arrangement, according to one embodiment. The modular polishing system **400** features a first portion **420** coupled to a second portion **405**. The first portion **420** may be substantially the same as the first portions **220**, **320** respectively described in FIGS. **2-3** above, including any one or combination of the features or alternate embodiments thereof.

Here, the second portion **405** features polishing modules **100***a-f*, the third robot **314**, the transfer station **216** (hereafter the first transfer station **216**), a fourth robot **414** suspended from an overhead support (such as the overhead support **113** described in FIG. **1**A), and a second transfer station **416**. Here, the polishing modules **100***a-d*, the first transfer station **216**, and the third robot **314** are disposed in the arrangement shown and described in FIG. **3**. The polishing modules **100***e, f* share a frame **110** such as described above with respect to polishing modules **100***a, b* which is coupled to the frame **110** of the polishing modules **100***a, b*. The polishing modules **100***e, f* are disposed in an arrangement where the first planes G thereof are generally parallel with one another, such as described above with respect to the arrangement between polishing modules **100***a, b*. The polishing modules **100***e, f* respectively face towards polishing modules **100***a, b*. The fourth robot **414** is disposed in a region defined by the polishing modules **100***a, b* and the polishing modules **100***e,* *f*. The second transfer station **416** is disposed between the third robot **314** and the fourth robot **414**.

FIG. **5**A is a schematic top down view of modular polishing system, according to another embodiment. FIG. **5**B is a side view of a portion of the modular polishing system shown in FIG. **5**A. Here, the modular polishing system **500** features a second portion **505** coupled to a first portion **520** and a linear substrate handling system **530**. The linear substrate handling system **530** facilitates high throughput substrate handling in the second portion **505**. The first portion **520** may be substantially the same as any one of the first portions **220**, **320**, **420** described in FIGS. **2**-**4** respectively, including any one or combination of the features or alternate embodiments of the features thereof.

The second portion **505** features a plurality of modular frames **510** (shown and labeled in FIG. **5**B) each comprising a pair of polishing modules **100***g, h*. Each modular frame **510** features a plurality of upright supports **511**, a horizontally disposed tabletop **512**, and an overhead support **513** (shown in FIG. **5**B) disposed above the tabletop **512** and spaced apart therefrom. The upright supports **511**, the tabletop **512**, and the overhead support **513** collectively define a processing region **514**.

Here, each of the polishing modules **100***g, h* features a carrier support module **120**, a carrier loading station **140**, and a polishing station **150** disposed in a one-to-one-to-one relationship. Each of the polishing stations **150** of the respective polishing modules **100***g, h* features a single platen **151** so that each of the respective polishing modules **100***g, h* comprises a carrier support module **120**, a carrier loading station **140**, and a platen **151** disposed in a one-to-one-to-one relationship. Typically, the polishing modules **100***g, h* are substantially similar to the polishing modules **100***a-f* as described above, including alternate embodiments, or combinations of alternate embodiments, of the features thereof.

Here, each of the polishing modules **100***g, h* within a pair are arranged so that they face towards one another within the processing region **514** in order to facilitate substrate handling using the linear substrate handling system **530**. As shown, each of the polishing modules **100***g, h* within a modular frame **510** are aligned with one another so that a plane G of the polishing module **100***g* is substantially coplanar with a plane G of the polishing module **100***h*. In other embodiments, the polishing modules **100***g, h* of a pair may be offset from one another so that the planes G of the polishing modules are parallel or substantially parallel, for example within about 10° of parallel.

Here, the linear substrate handling system **530** features a linear member **532**, e.g., such as a track, rail, or belt, and one or more shuttles **534** moveably disposed on or coupled to the linear member **532**. The linear member **532** extends from a first end of the second portion **505** to a location proximate to the second end of the second portion **505** which is opposite of the first end. Here, the first end is proximate to the first portion **520**. Typically, the linear substrate handling system **530** further includes one or more substrate transfer stations **536** disposed in an area between the second robot **226** and the second portion **505** to facilitate transfer of the substrates **180** from the first portion **520** to the shuttles **534**. Here, a shuttle **534** comprises one or more arms **538** (shown in FIG. **5**B) used for retrieving substrates from the transfer stations **536**.

Once one or more substrates **180** are retrieved from the transfer stations **536** the shuttle **534** moves along the linear member **532** to position each of the substrates **180** in a desired carrier loading station **140** of a polishing module **100***g, h*. In some embodiments, at least a portion of the substrates **180** will pass between the carrier loading stations **140** and the respective carrier heads **131** positioned thereabove as the substrates **180** are moved to a desired carrier loading station **140**. This configuration beneficially allows for relatively closer spacing between the polishing modules **100***g, h* than in a modular system using one or more fixed position robots. For example, in some embodiments a distance X(3) between the carrier loading stations **140** of a pair of polishing modules **100***g, h* is not more than 8 times the diameter of a to-be-polished substrate, such as 7 times or less, 6 times or less, example less than 5 times the diameter of a to-be-polished substrate. In some embodiments, the spacing between the support shaft axes A of a pair of polishing modules **100***g, h* is not more than 5 times the diameter of a to-be-polished substrate. For example, for a modular polishing system configured to polishing 300 mm substrate the spacing between the support shaft axes A of a pair of polishing modules **100***g, h* is not more than 1500 mm.

In some embodiments, the linear substrate handling system **530** further includes a substrate return path **540** (shown in part in FIG. **5**B) disposed beneath the tabletop **512**. The substrate return path **540** includes or more assemblies, such as one or more elevators **542**, disposed proximate to the second end of the second portion **505**, a second linear member **544**, such as a track, rail, or belt disposed beneath the tabletop **512**, and a second shuttle **546** disposed on or coupled to the linear member **544**. Typically, once a substrate **180** has completed processing in the second portion **505** a first shuttle **534** will retrieve the substrate **180** from a carrier loading station **140** and transfer the substrate to an elevator **542**. The elevator **542** will move the substrates **180** to a region below the tabletop **512**, where a second shuttle **546** will move the substrate **180** from the elevator **542** to a transfer station (not shown) disposed proximate to the first portion **520** of the processing system where it may be retrieved by the second robot **226** for post-CMP processing therein.

FIG. **6** is schematic top down view of another embodiment of a modular polishing system. Here, the modular polishing system **600** features a second portion **605**, a first portion **620** coupled to the second portion **605**, and a linear transfer system **630**. The second portion **605** features a plurality of polishing modules **100***i, j* arranged in pairs **610**. Each of the polishing modules **100***i, j* feature a carrier support module **120**, a carrier loading station **140** (not shown), and a polishing station **150** arranged in a one-to-one-to-one relationship. Each of the polishing stations **150** of the respective polishing modules **100***i, j* feature a single platen **151** so that each of the respective polishing modules **100***i, j* comprises a carrier support module **120**, a carrier loading station **140**, and a platen **151** disposed in a one-to-one-to-one relationship. Here, the polishing modules **100***i, j* within a pair **610** are arranged to face away from one another so that the respective carrier loading stations **140** thereof are disposed proximate to an outer perimeter of the second portion **605**. Typically, the polishing modules **100***i, j* are substantially similar to the polishing modules **100***a-h* as described above, including alternate embodiments, or combinations of alternate embodiments, thereof.

The linear transfer system **630** features a first linear member **632**, a plurality of second linear members **634** orthogonally disposed to the first linear member **632**, a plurality of transfer stations **636**, and a plurality of shuttles **638**. Examples of suitable linear members **632**, **634** include tracks, rails, belts, or combination thereof. The shuttles **638** may be movably disposed on the linear member **632**, **634** or coupled thereto. Here, one or more of the shuttles **638** comprises a pivot arm. The first linear member **632** is disposed between the polishing modules **100***i, j* and the first portion **620**. The second linear members **634** are respectively disposed between the perimeter of the second portion **605** and the carrier loading stations **140**.

In FIGS. **2**-**6** the modular polishing systems are shown with an even number of polishing modules generally arranged so that the planes G are parallel with or orthogonal to the first end of the second portions thereof. In other embodiments, the modular polishing systems may comprise an odd number of polishing modules, e.g., 1, 2, 3, 5, or more. In some other embodiments, which may be combined with any one or combination of the modular polishing systems described herein the polishing modules are arranged so that the planes G are not generally parallel or orthogonal to the first end of the second portions of the polishing module. For example, in the modular polishing system **700** shown in FIG. **7**, polishing modules **700***a, b* are disposed so that the planes G are between 20° and 70° of from parallel to a first end of the modular polishing system **700**. The polishing modules **700***a, b* may be substantially similar to the polishing modules **100***a-j* described above, including any combination or alternative embodiments of the features thereof.

The polishing modules described in FIGS. **1**A-**1**C and **2**-**7** above typically comprise polishing stations **150** having a rotatable platen **151** having a polishing pad **152** fixedly secured thereto. In other embodiments, one or more of the polishing modules of FIGS. **1**A-**1**C and **2**-**7** may comprise a linear polishing platen, such as set forth in FIGS. **8**A-**8**B and **9** below.

FIG. **8**B is a schematic side view of the linear polishing station **810** of FIG. **8**B. Here, the polishing module **800** features a polishing station **810** which may be used in place of the platen **151** in any one the polishing modules **100***a-j*, and **700***a, b* described above. Here, the linear polishing station **810** comprises a platform **802** having a platen **804** (shown in phantom in FIG. **8**B) disposed therein. The polishing pad **808** is typically a belt, i.e., having an endless perimeter, which is moved in along the X-direction using a plurality of rollers **806** disposed on opposite ends of the platform **820** while a substrate (not shown) is urged thereagainst. The polishing station **810** may be used in place of the platen **151** in any one the polishing modules **100***a-j* and **700***a, b* described above. Here, the plane G of the carrier support module **120** is orthogonal to, or substantially orthogonal e.g., within 20° of orthogonal to the indexing direction of the polishing pad **816**.

FIG. **9** is a schematic side view of an alternate embodiment of a roll-to-roll polishing pad polishing system **900** that is rotatable about the platen axis D. The roll-to-roll system **900** may be used in place of the platen **151** and polishing pad **152** combination in any of the embodiments described above. Here, the roll-to-roll system **900** includes a platform **912** having a platen **914** (shown in phantom) disposed therein, and a roll-to-roll polishing pad **916** disposed between a supply spindle **918** and a take-up spindle **920**. Typically, the polishing pad **916** is indexed in the X-direction between substrate polishing to provide at least a portion of unused polishing pad for the next substrate polishing process.

Beneficially, the polishing modules, the individual components, systems, stations, and robots disposed in the first portions of the modular polishing systems described above, any one or combination of the handling systems set forth above, including individual features or alternative embodiments thereof may be combined in any desired arrangement to provide a customized modular polishing system. The customized modular polishing systems provided are formed of high throughput density polishing modules which lower cost of ownership, maximizes system productivity, and allows flexibility in configurations to meet the specific processing needs of customers using the polishing systems.

FIG. **10** is a diagram illustrating a method **1000** of processing substrates which may be performed using any one of the modular polishing systems set forth herein. Typically, the method **1000** is performed using a polishing module, such as the polishing module **100***a* of FIG. **1**A, which is configured for polishing a first substrate using a first carrier head while concurrently unloading and loading respective polished and to-be-polished substrates from and to a second carrier head.

At activity **1010** the method **1000** includes urging a substrate against a polishing pad in the presence of a polishing fluid. Typically, the substrate is disposed in a first carrier head of a first polishing module. At activity **1020** the method **1000** includes concurrently with urging the first substrate against the polishing pad, unloading an at-least-partially-polished substrate from a second carrier head of the first polishing module, and then loading a to-be-polished second substrate to the second carrier head.

In some embodiments, the method **1000** further includes transferring the at-least-partially-polished substrate to a second polishing module using a substrate exchanger, e.g., the inter-module substrate exchanger **350**, which is disposed between the first polishing module and the second polishing module.

FIG. **11** is a schematic top down view of a modular polishing system **1100**, arranged according to another embodiment. Here, the modular polishing system **1100** features a first portion **1120**, a second portion **1105**, and a third portion **1130** which is disposed between the first portion **1120** and the second portion **1105**. The first portion **1120** may be substantially the same as any of the other first portions described herein and may include any one or combination of the features or alternate embodiments thereof. As shown in FIG. **11**, the first portion **1120** features a plurality of system loading stations **222**, one or more post CMP cleaning systems **232**, a first robot **224** for transferring substrates **180** to and from the plurality of system loading stations **222**, and a second robot **226**. The second portion **1105** generally includes a plurality of polishing modules (not shown) which may be disposed in any of the arrangements described herein. The second portion **1105** may also include one or a combination of a transfer station **216**, one or more third robots **314**, one or more inter-module substrate exchangers **350**, and/or a linear substrate handling system **530**, or alternate embodiments thereof disposed in any of the configurations described herein.

Here, the third portion **1130** includes any one or more or combination of LSP modules **230**, buffing stations **231**, and/or one metrology stations **228**. In some embodiments, one or more of the modules and/or stations are stacked vertically, i.e., in the Z-direction. Typically, the second robot **226** is used to transfer substrates **180** to and from the modules and stations disposed in the third portion **1130** and to and from the polishing modules and/or substrate transfer stations in the second portion **1105**. For example, here the second robot **226** is configured to extend an end-effector having the substrate **180** secured thereto, e.g., by a vacuum, through the third portion **1130** and into the region defined by the second portion **1105** to load and unload the substrate to and from the polishing modules, substrate handling systems, and/or substrate transfer stations disposed therein.

In the modular polishing systems described above the portion of the system comprising the polishing modules **100** are shown as being distal from the system loading stations **222** while the portions of the system comprising the one or more post CMP cleaning systems **232** are shown as being proximate to the system loading stations **222**. However, it is contemplated that the flexibility of the modular systems described herein may be used to facilitate any other desired arrangement of the substrate processing systems, e.g., the polishing, metrology, cleaning, buffing, LSP, loading, and/or handling systems, such as the arrangement of the modular polishing system **1200** shown in FIG. **12**.

FIG. **12** is a schematic top down view of a modular polishing system **1200**, according to another embodiment. Here, the modular polishing system **1200** includes a first portion **1220** and a portion **1205**. The first portion **1220** may include one or combination of a plurality of system loading stations **222**, a plurality of substrate handlers, here a first robot **224** and a second robot **1224**, one or more metrology stations **228**, one or more location specific polishing (LSP) modules **230**, one or more buffing stations **230**, and/or one or more post CMP cleaning systems **232**. The second portion **1205** features a plurality of polishing modules **100** disposed in an arrangement which is substantially the same as the second portion **205** of the modular polishing system **200**. In other embodiments, the second portion **1205** may comprise any one or combination of the arrangements of the second portions of the other modular polishing systems described herein.

As shown in FIG. **12**, at least a part of the second portion **1205** may be disposed proximate to the system loading stations **222** and the first robot **224**. The second robot **1242** may be disposed between the one or more post CMP cleaning systems **232** and the second portion **1205**. Typically, the second robot **1242** is used to transfer substrates to and from the first robot **224** to the second portion **1205**, to and from the one or more post CMP cleaning systems **232** and/or the other modules or systems (**228**, **230**, and/or **231**), and between the second portion **1205** and the one or more post CMP cleaning systems **232** and/or the other modules or systems (**228**, **230**, and/or **231**). In some embodiments, the second robot **1242** is disposed on a rail or track **1244**. In some embodiments, a third portion (not shown), such as the third portion **1130** described in FIG. **11**, may be disposed between the second robot **1242** and the second portion **1205**.

FIG. **13** is a schematic side view of a polishing module **1300**, according to another embodiment, which may be used as one or more of the plurality of polishing modules in any one of the modular polishing systems described herein. The polishing module **1300** is disposed within a modular frame **110** and includes a carrier support module **1310**, a carrier loading station **140**, and a polishing station **150** disposed in a one-to-one-to-one relationship. The modular frame **110**, the carrier loading station **140**, and the polishing station **150** may be substantially the same as those described above with respect to polishing module **100** and may include any one of or combination of the features set forth therein and/or alternate embodiments thereof.

Here, the carrier support module **1310** includes a guide rail assembly **1315** suspended from the overhead support **113**. The guide rail assembly **1315** includes a track assembly **1323**, one or more carriages **1320** coupled to the track assembly **1323**, and one or more corresponding carrier assemblies, here the first and second substrate carrier assemblies **1330***a, b*, respectively coupled to the one or more carriages **1320**.

The guide rail assembly **1315** is generally configured to facilitate loading/unloading of a substrate **180** from a substrate carrier **131** of the second substrate carrier assembly **1330***b* while concurrently polishing a different substrate **180** using the substrate carrier **131** of the first substrate carrier assembly **1330***a*. As shown, the track assembly **1323** comprises a closed loop where each of the carriages **1320** may be controlled to move in synchronization, e.g., driven jointly, or independently thereon. The track assembly **1323** may have any suitable shape to fit within a region defined by the frame **110**, such as a having a substantially circular or rectangular shape when viewed from top down or even a seemingly random shape when viewed from top down. In other embodiments, the track assembly **1323** may comprise a plurality of individual tracks which may be curved, substantially linear, or have any other desired shapes, when viewed from top down.

The substrate carrier assemblies **1330***a, b* may include any one or combination of the features, including alternate embodiments thereof, of the substrate carrier assemblies **130***a, b* of the polishing module **100** at least some of which may be enclosed within corresponding housing **1325** which is respectively coupled to one of the one or more carriages **1320**.

Embodiments, of the modular polishing systems further provide for flexibility in substrate processing sequencing between multiple polishing modules by providing for random (e.g., non-sequential) polishing module access. Random polishing module access desirably improves polishing system throughput by reducing or substantially eliminating substrate processing bottlenecks commonly associated with conventional polishing non-random access polishing systems. For example, in some embodiments a system controller **270** may be used to assign a portion of a substrate processing sequence, such as a second polishing stage of a multi-stage substrate polishing sequence, to a suitably configured polishing module based on the availability thereof. Embodiments herein further provide for substrate handling systems, such as the inter-module substrate exchangers **350**, which advantageously reduce the usage burden on more centrally located substrate handlers, e.g., the substrate handling robots **226**, **314**, and **414**. When the combined, the random polishing module access and the substrate handling systems set forth in the modular polishing systems herein provide for relatively higher substrate throughput density when compared to conventional polishing systems.

In some embodiments, the modular polishing systems and substrate handling systems set forth herein may be configured to facilitate high throughput density substrate processing in a multi-stage substrate polishing process. Typically, to facilitate a multi-stage polishing process one or more polishing stations **150** within a modular polishing system will be differently configured from the other polishing stations **150** thereof. For example, differently configured polishing stations **150** may use different types of polishing pads **152**, different types of pad conditioners **157**, and/or may use one or more different types of polishing fluid during a stage of the substrate polishing process. Typically, the substrate will be polished at a first polishing station for one of the stages in the multi-stage polishing process before being transferred to a second polishing station for a second stage of the multi-stage polishing process. Additional polishing stations may be configured for as many polishing stages as desired.

Beneficially, because of the random polishing module access provided by the substrate handling systems set forth herein, any one of the polishing modules **100** of a modular polishing system may be configured to be used for any desired stage of a multi-stage polishing process. This flexibility for 1-stage, 2-stage, 3-stage, 4-stage or more substrate processing is independent of the location of the correspondingly configured polishing modules within the modular polishing system as the substrate handling systems set forth herein allow for substrate transfer between any of the polishing modules in any desired sequence. In some embodiments, the random polishing module access provided herein may be used to assign a substrate to any desired polishing module configured for the appropriate stage in the multi-stage polishing sequence based on the availability of the polishing module, thus reducing substrate processing bottlenecks often associated with processing duration variability between polishing stations, between polishing stages, and/or between substrates. Thus, the modular polishing systems and substrate processing methods described herein provide for increased utilization of the polishing platens by minimizing the platen down time typically associated with substrate handling operations.

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

The invention claimed is:

**1**. A polishing module, comprising:

a first modular frame defining a first polishing processing region;

a second modular frame defining a second polishing processing region, the second modular frame directly adjacent the first modular frame positioned in a side-by-side arrangement;

a third modular frame defining a third polishing processing region;

a fourth modular frame defining a fourth polishing processing region, the third modular frame directly adjacent the fourth modular frame and positioned together in a side-by-side arrangement, and the third module frame and the fourth modular frame are positioned end-to-end with the first modular frame and the second modular frame;

a polishing station disposed in each of the first polishing processing region, the second polishing processing region, the third polishing processing region and the fourth polishing processing region, the polishing station comprising a polishing platen, wherein the polishing platen is rotatable about a platen axis;

a carrier loading station disposed in each of the first polishing processing region, the second polishing processing region, the third polishing processing region and the fourth polishing processing region;

a substrate handler disposed between each polishing processing region and adjacent each carrier loading station;

a substrate transfer station disposed between the polishing stations of the first and the second polishing processing regions, wherein the substrate handler is configured to transfer substrates between each carrier loading station and the substrate transfer station; and

a carrier support module disposed in each of the first polishing processing region, the second polishing processing region, the third polishing processing region and the fourth polishing processing region, each carrier support module suspended from the first modular frame, the second modular frame, the third modular frame and the fourth modular frame, and each carrier support module comprising a carrier platform comprising a first substrate carrier assembly and a second substrate carrier assembly, wherein:

the carrier platform is rotatable or pivotable about a platform axis by a platform actuator configured to rotate the first and second substrate carrier assemblies between either a first processing mode position or a second processing mode position,

the platform actuator is configured to rotate the carrier platform, the first carrier assembly and the second carrier assembly together, and

each of the first carrier assembly and the second carrier assembly comprise:

a carrier head coupled to a carrier shaft, wherein the carrier head comprises a chamber,

a rotation actuator coupled to the carrier shaft, and configured to rotate the carrier shaft and the carrier head,

a translation actuator, and

a pneumatic assembly that is in fluid communication with the chamber disposed within the carrier head, wherein

the translation actuator is configured to cause the carrier head, the carrier shaft and the rotational actuator to translate in a first direction that extends perpendicular from the platform axis, and

the pneumatic assembly is fluidly coupled to the carrier head, and

in the first processing mode position the first substrate carrier assembly is positioned over the carrier loading station to allow for substrate loading and unloading thereinto and therefrom, and the second substrate carrier assembly is concurrently positioned over the polishing platen to allow for substrate polishing thereon, and

in the second processing mode position the second substrate carrier assembly is positioned over the carrier loading station to allow for substrate loading and unloading thereinto, and the first substrate carrier assembly is concurrently positioned over the polishing platen to allow for substrate polishing thereon.

**2**. The polishing module of claim **1**, further comprising a plurality of panels vertically disposed between adjacent corners of the modular frame to enclose and isolate the first polishing processing region and to enclose and isolate the second polishing processing region, and wherein the one or more of the panels have a slit shaped opening formed therethrough to allow for substrate transfer into and out of the first or second polishing processing region.

**3**. The polishing module of claim **1**, wherein the platform axis and the platen axis are spaced apart by a first distance, and wherein the first distance between the platform axis and the platen axis is not more than 1.25 times a swing radius of the carrier head.

**4**. The polishing module of claim **3**, wherein the first and second substrate carriers are suspended from the carrier platform using corresponding carrier shafts of the first and second carrier assemblies, and wherein the respective first and second translation actuators of the of the first and second carrier assemblies are coupled to the corresponding carrier shafts and are configured to oscillate the corresponding carrier shafts between first positions with respect to the platform axis and second positions disposed radially outward from the first positions.

**5**. The polishing module of claim **4**, wherein the swing radius of the first and second substrate carriers is determined when each of the carrier shafts of the first and second carrier assemblies are disposed in the first positions.

6. The polishing module of claim 1, wherein the carrier loading station comprises a metrology station, a substrate edge correction station, or a combination thereof.

7. The polishing module of claim 1, wherein at least one of the first or second modular frames comprises an overhead support, and wherein the the substrate handler is suspended from the overhead support.

8. The polishing module of claim 1, further comprising a polishing pad disposed on the polishing platen within at least the first polishing processing region or the second polishing processing region, and further comprising a controller configured to perform a method comprising:

retracting the first substrate carrier assembly towards the platform axis before the carrier platform is rotated to the second processing mode position;

urging a first substrate against the polishing pad disposed on the polishing platen, wherein the first substrate is disposed in a carrier head of the first substrate carrier assembly; and

concurrently with urging the first substrate against the polishing pad:

unloading, using the carrier loading station, an at-least-partially-polished substrate from the second substrate carrier assembly; and

loading, using the carrier loading station, a to-be-polished second substrate into a carrier head of the second substrate carrier assembly.

9. The polishing module of claim 8, wherein the controller is configured to cause the polishing module to perform a method comprising:

rotating or pivoting the carrier platform about the platform axis to position the second substrate carrier assembly above the polishing platen, wherein rotating or pivoting the carrier platform comprises retracting the second substrate carrier assembly towards the platform axis;

urging the second substrate against the polishing pad; and

concurrently with urging the second substrate against the polishing pad:

unloading, using the carrier loading station, the first substrate from the first substrate carrier; and

loading, using the carrier loading station, a to-be-polished third substrate into the first substrate carrier.

10. The polishing module of claim 1, wherein the pneumatic assembly is stationary relative to the carrier platform.

11. The polishing module of claim 1, wherein

the carrier loading station comprises a loading station central axis, and

the loading station central axis, the platform axis, the platen axis and the first direction are positioned within a first vertical plane formed within the first modular frame when the first substrate carrier assembly and the second substrate carrier assembly within the first modular frame are positioned in the first processing mode position or the second processing mode position.

12. The polishing module of claim 11, wherein

the first vertical plane is parallel to a second vertical plane, wherein the loading station central axis, the platform axis, the platen axis and first direction within the second modular frame are positioned within the second vertical plane formed within the second modular frame when the first substrate carrier assembly and the second substrate carrier assembly within the second modular frame are positioned in the first processing mode position or the second processing mode position.

13. The polishing module of claim 11, wherein the carrier loading station further comprises a buffing station.

14. The polishing module of claim 1, wherein the translation actuator, and the pneumatic assembly are each coupled to the carrier platform.

15. The polishing module of claim 1, wherein the translation actuator, rotation actuator and the pneumatic assembly are enclosed within a region defined by the carrier platform and a housing.

16. The polishing module of claim 1, wherein the pneumatic assembly in the first carrier assembly and the second carrier assembly is in fluid communication with the carrier head, in their respective carrier assembly, through one or more conduits disposed through the carrier shaft.

17. The polishing module of claim 16, wherein the pneumatic assembly in each of the carrier assemblies is fluidly coupled to their respective carrier head using a rotary union.

18. The polishing module of claim 1, further comprising a computer readable medium having instructions stored therein, which when executed by a processor causes:

the carrier heads to retract towards the platform axis before the carrier platform is rotated to the first processing mode position or the second processing mode position.

19. The polishing module of claim 1, wherein the substrate handler is suspended from a shared overhead support comprising a portion of the first modular frame and the second modular frame or the third modular frame and the fourth modular frame.

20. The polishing module of claim 1, wherein the carrier loading station further comprises a buffing station.

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