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(54) **METHOD AND APPARATUS FOR SUBSTRATE NOTCH SENSING ON CMP HEAD FOR LOCAL PLANARIZATION**

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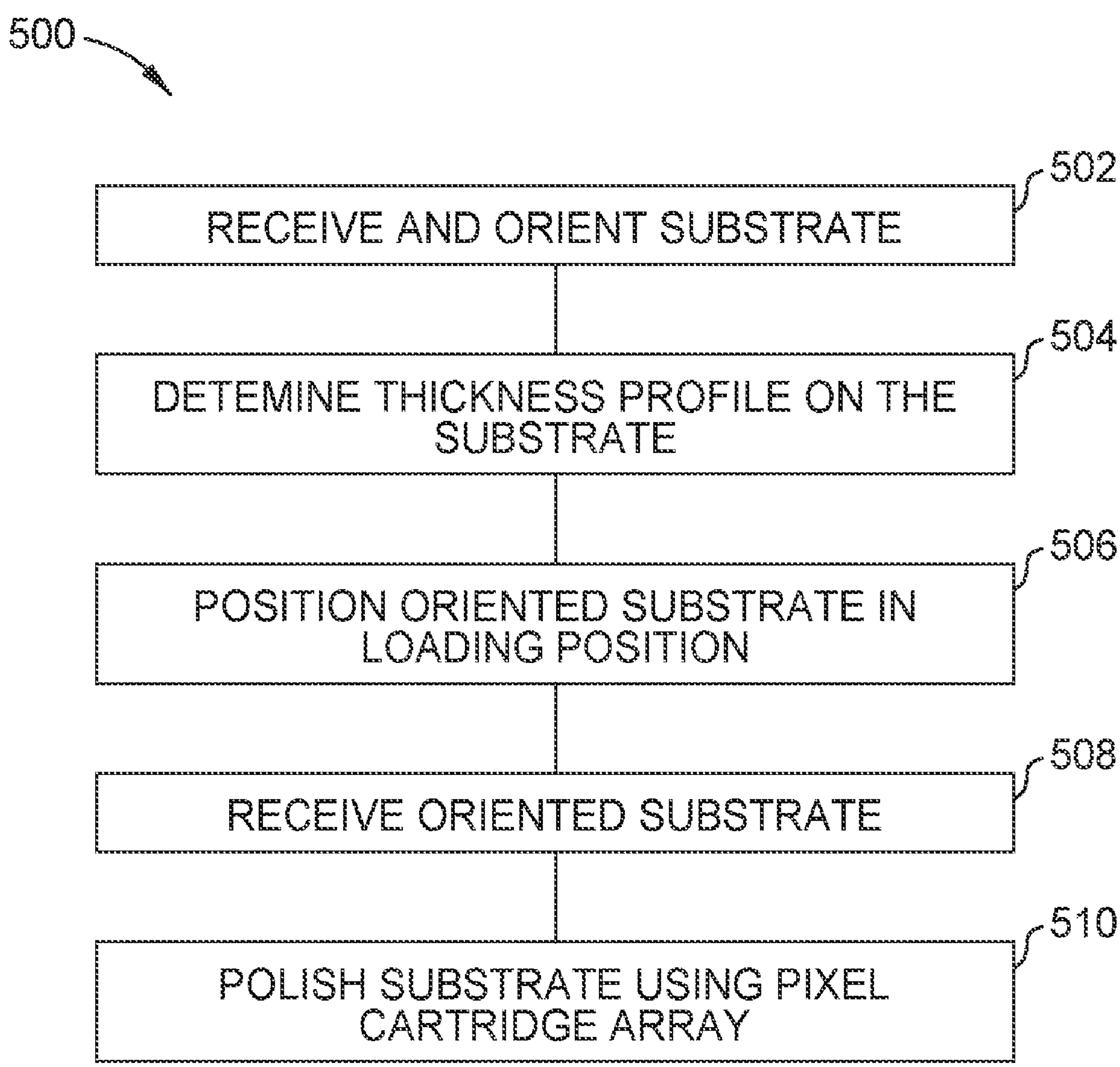
(57) **ABSTRACT**

Embodiments of the disclosure provided herein include systems and methods for correcting thickness asymmetry of a substrate during chemical mechanical polishing. The system includes a carrier head with a pixel cartridge array disposed within a carrier head body and a membrane adjacent to the pixel cartridge array, a notch sensor array disposed on a carrier ring, and a controller coupled to the pixel cartridge array and the notch sensor array. The controller is configured to receive and orient a substrate such that the substrate is an oriented substrate, determine a thickness profile on the oriented substrate, position the oriented substrate in a loading position, receive the oriented substrate, and polish the oriented substrate use the pixel cartridge array. The pixel cartridge array is configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.



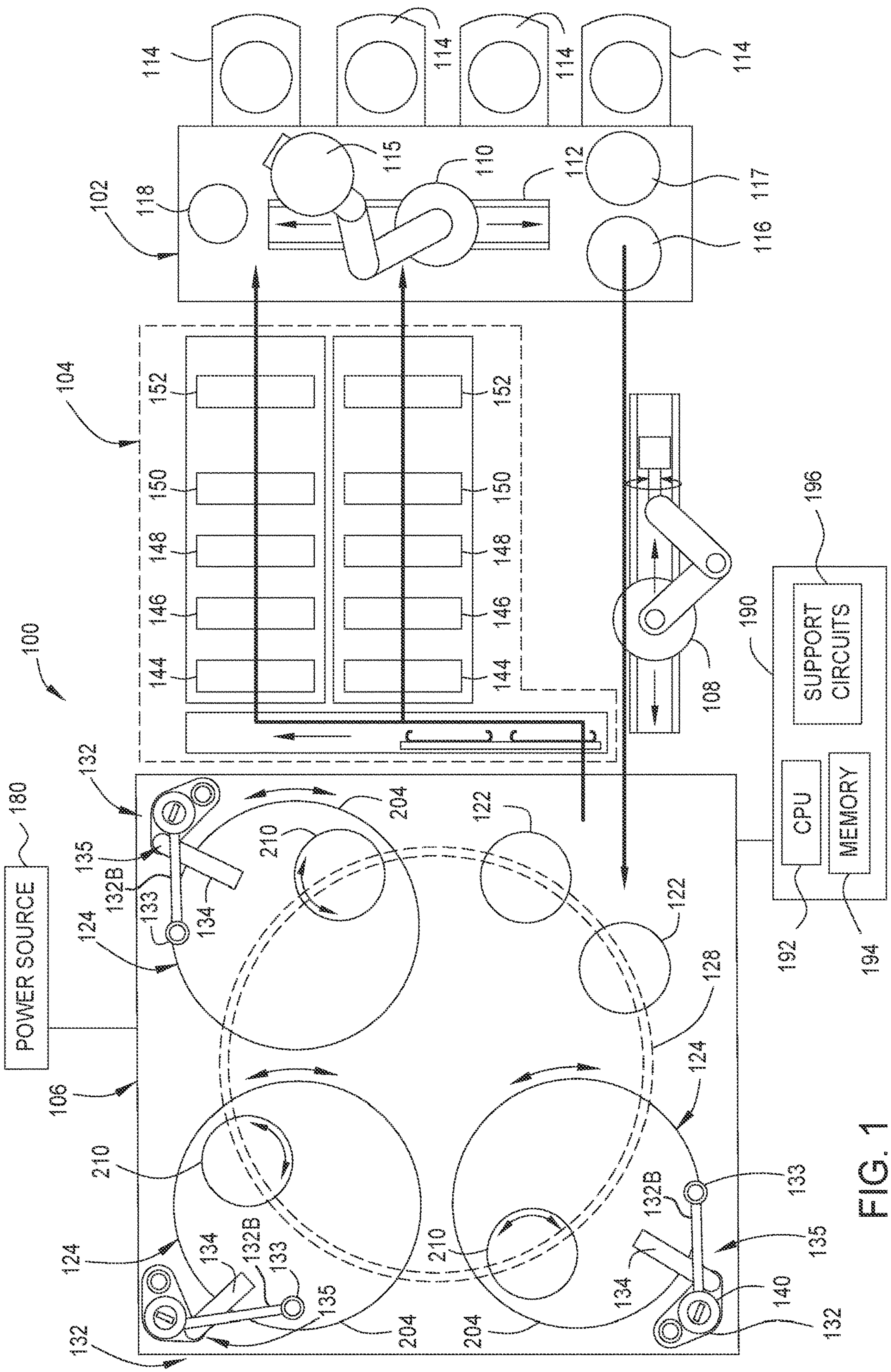

100
102
104
106
108
110
112
114
115
116
117
118
122
124
128
132
132B
133
134
135
140
144
146
148
150
152
180
190
192
194
196
204
210
POWER SOURCE
CPU
MEMORY
SUPPORT CIRCUITS

FIG. 1

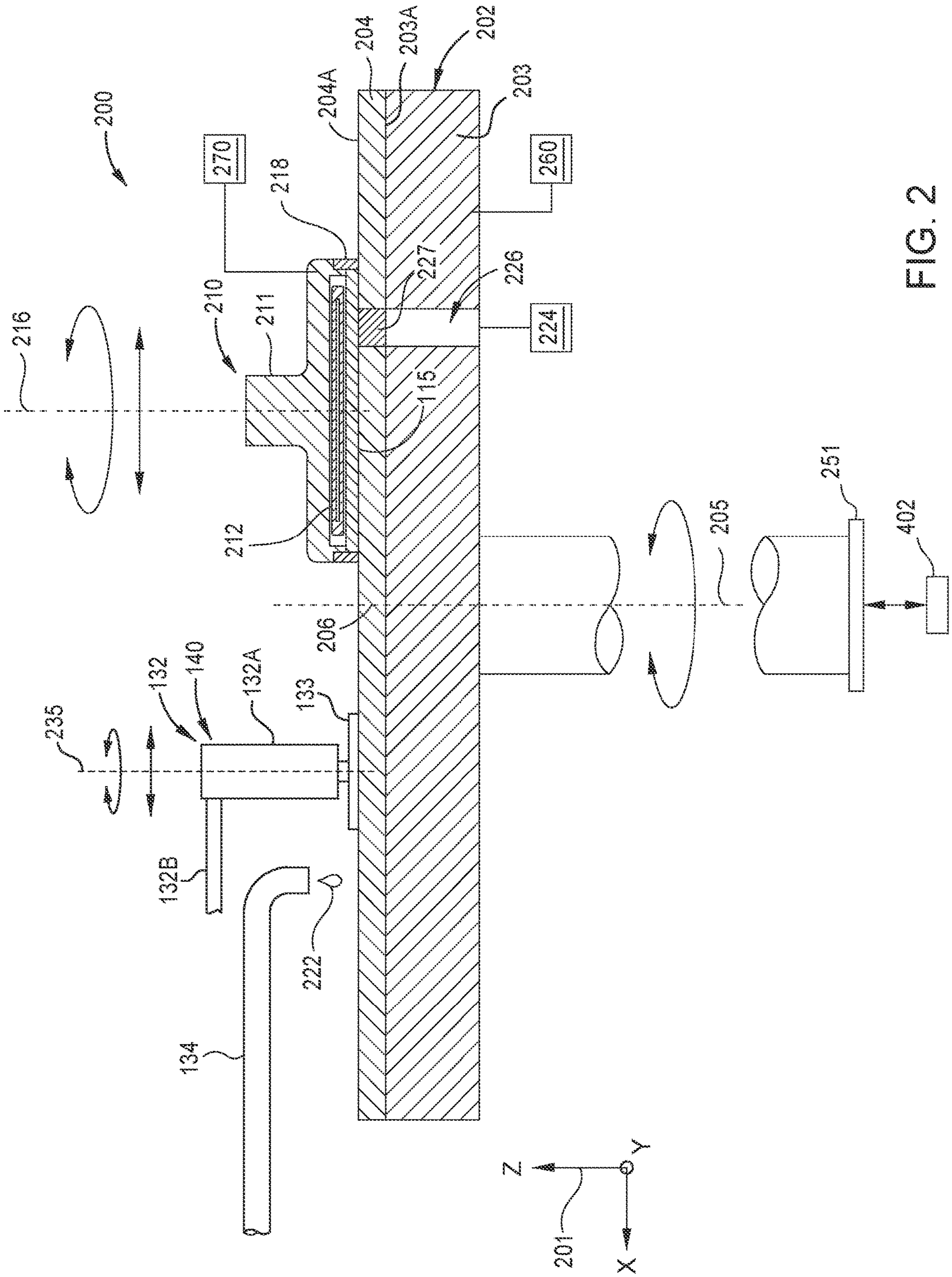

200
202
203
203A
204
204A
205
206
210
211
212
115
216
218
222
224
226
227
235
251
260
270
402
132
132A
132B
133
134
140
201
X
Y
Z

FIG. 2

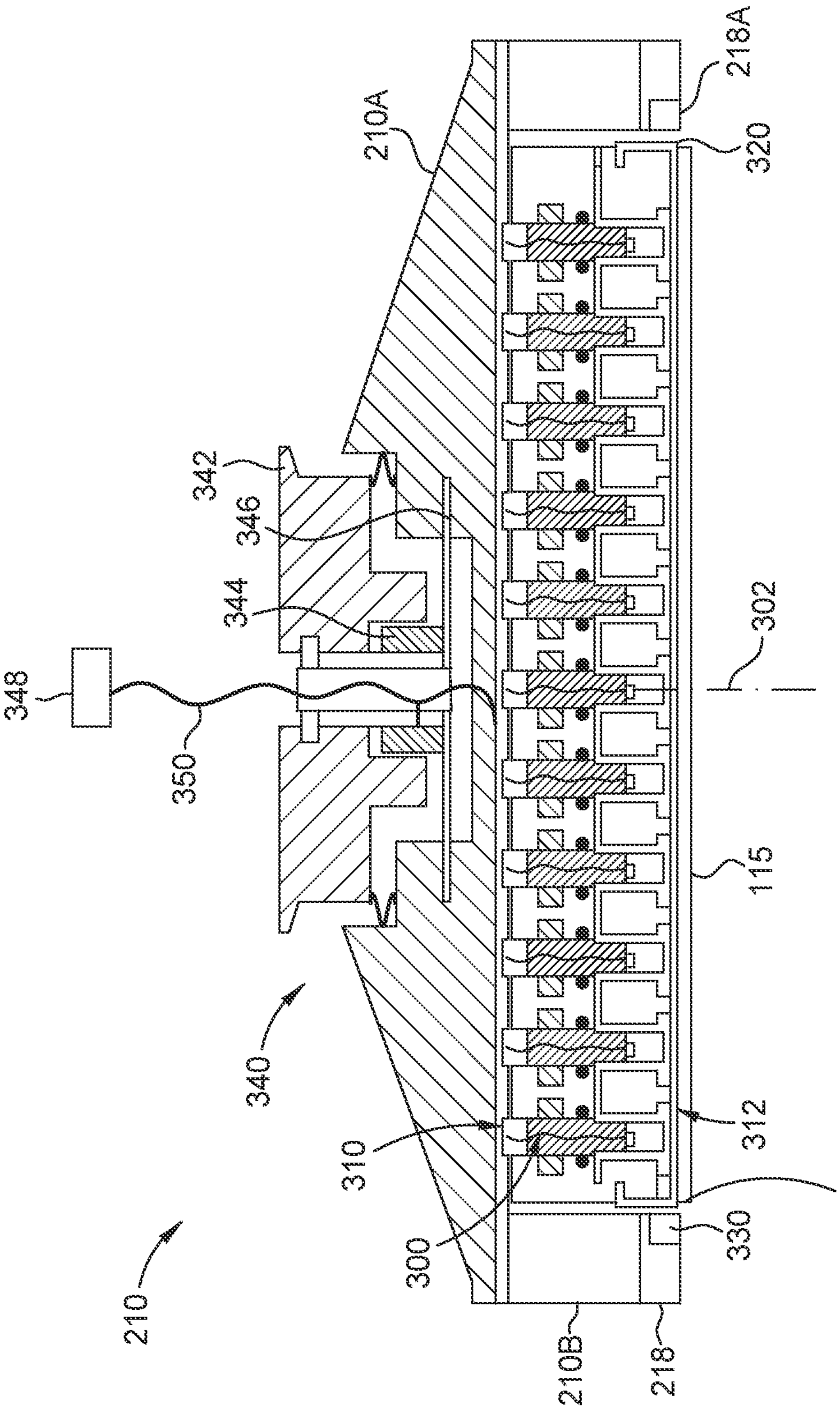

218A
210A
320
342
346
344
348
302
350
115
340
312
310
115A
300
330
210
210B
218

FIG. 3A

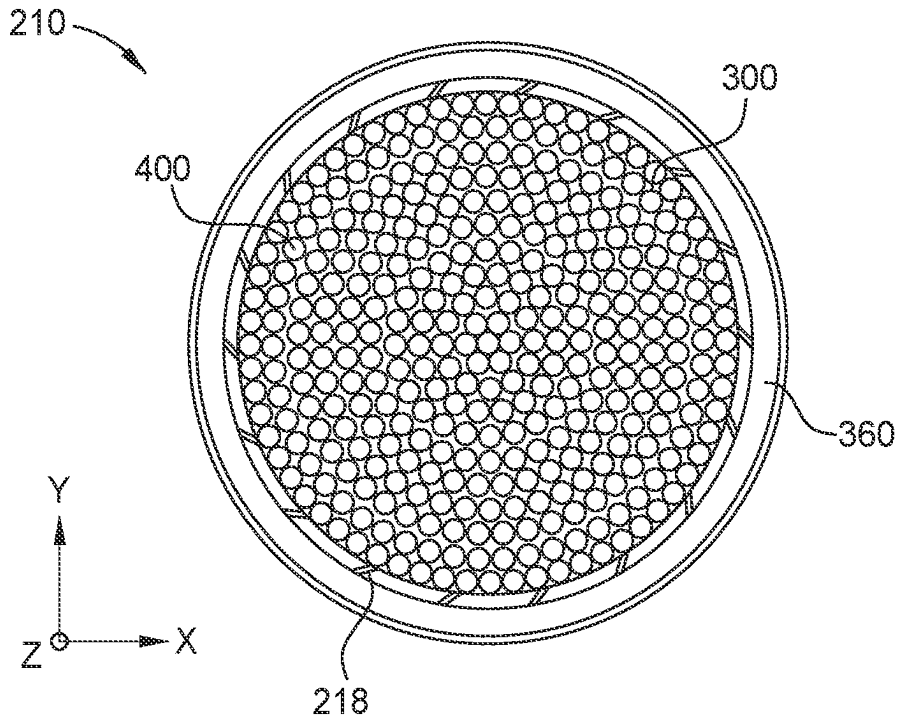

210
300
400
360
Y
Z
X
218

FIG. 3B

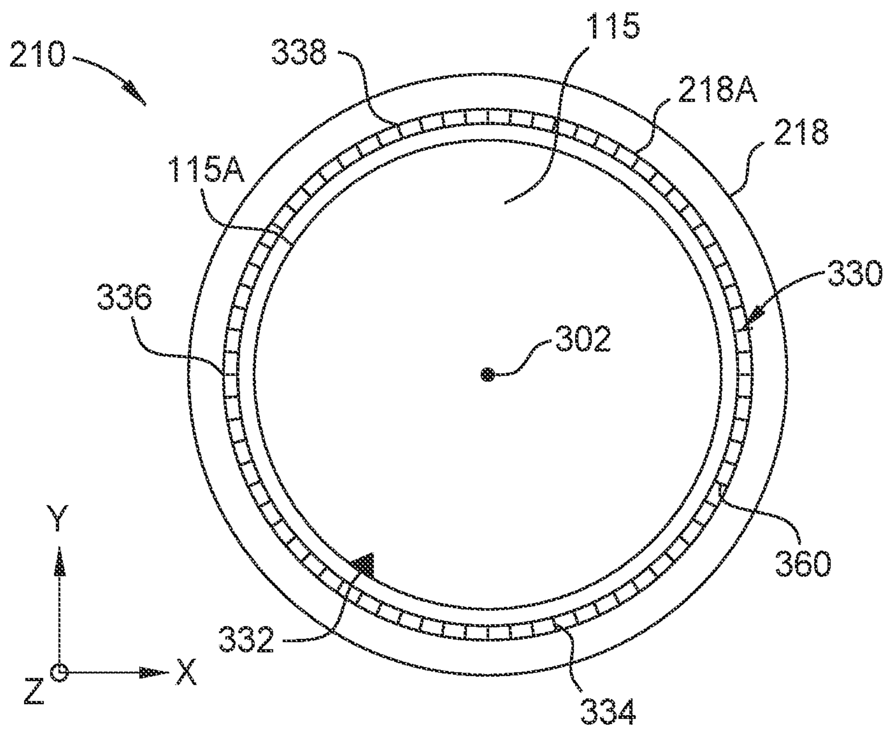

210
338
115
218A
218
115A
330
336
302
Y
360
332
Z
X
334

FIG. 3C

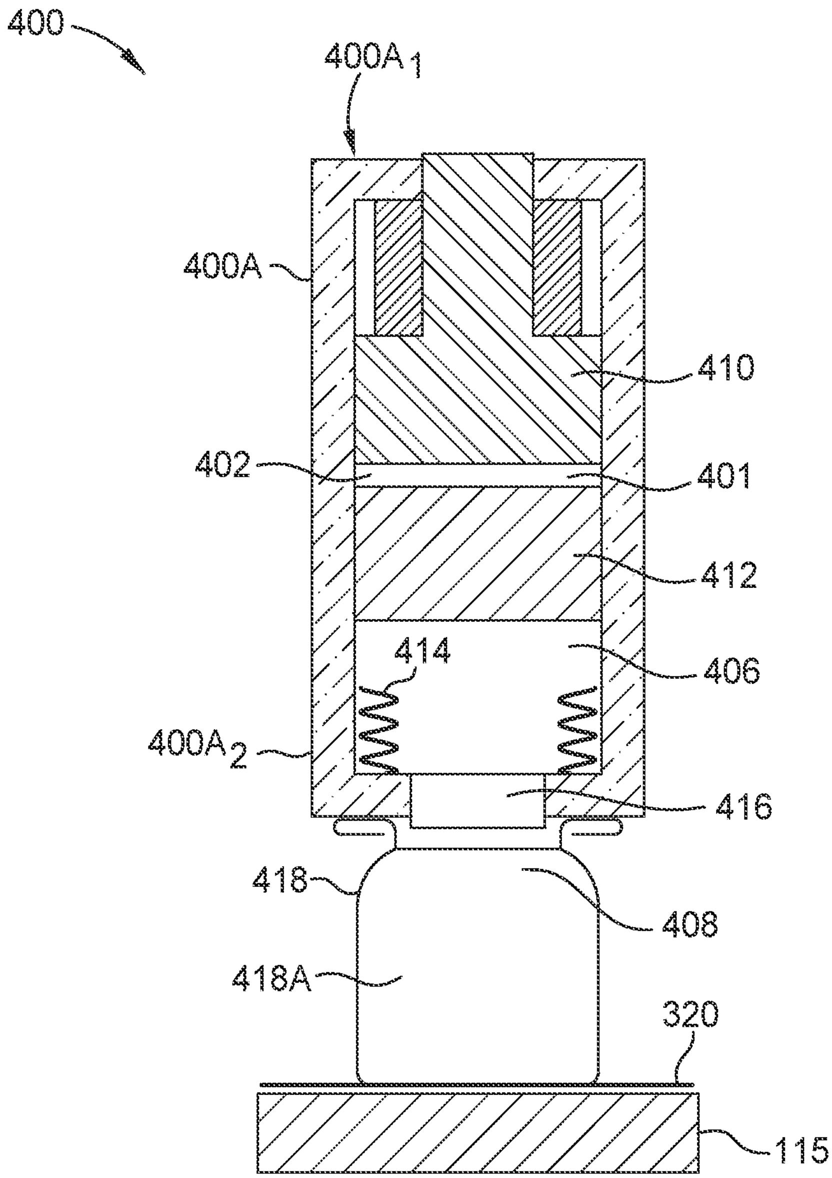

400
$400A_1$
400A
410
402
401
412
414
406
$400A_2$
416
418
408
418A
320
115

FIG. 4

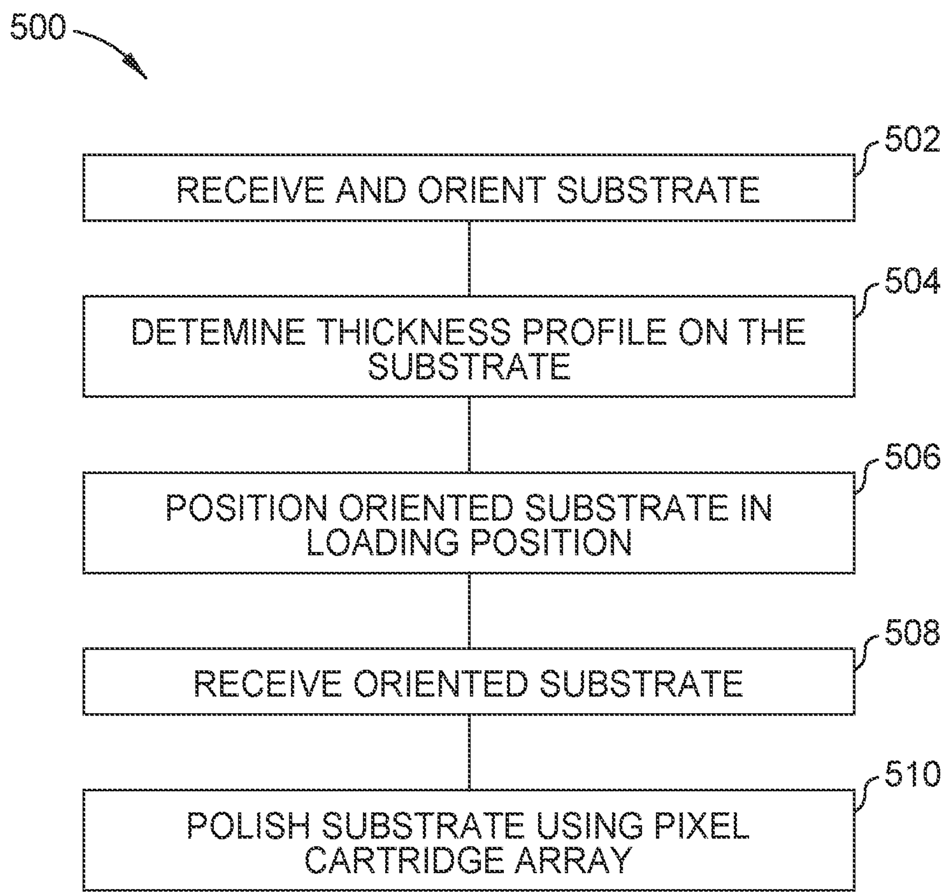

500
RECEIVE AND ORIENT SUBSTRATE
502
DETEMINE THICKNESS PROFILE ON THE SUBSTRATE
504
POSITION ORIENTED SUBSTRATE IN LOADING POSITION
506
RECEIVE ORIENTED SUBSTRATE
508
POLISH SUBSTRATE USING PIXEL CARTRIDGE ARRAY
510

FIG. 5

METHOD AND APPARATUS FOR SUBSTRATE NOTCH SENSING ON CMP HEAD FOR LOCAL PLANARIZATION

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to semiconductor manufacturing. More specifically, the embodiments of the present disclosure generally relate to correcting thickness asymmetry of a substrate during chemical mechanical polishing.

Description of the Related Art

[0002] 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. A CMP process includes contacting the material layer to be planarized with a polishing pad and moving the polishing pad, the substrate, or both, to create relative movement between the material layer surface and the polishing pad, in the presence of a polishing fluid including abrasive particles, chemically active components, or both.

[0003] One common application of a CMP process in semiconductor device manufacturing is planarization of a bulk film, for example pre-metal dielectric (PMD) or interlayer dielectric (ILD) polishing, where underlying two or three-dimensional features create recesses and protrusions in the to be planarized material surface. This planarization method typically requires that the substrate be mounted on a carrier head. The exposed surface of the substrate, the surface with the layer deposition, is typically placed against a rotating polishing pad. The carrier head provides a controllable load on the substrate to urge it against the polishing pad. A polishing slurry with abrasive particles is typically supplied to the surface of the polishing pad and spreads in between the substrate and the polishing pad. The polishing pad and the carrier head each rotate at a constant rotational speed and the abrasive slurry removes material from one or more of the layers. Material is removed in a planar fashion and the material removal process is symmetric about a central axis. The symmetric removal process may be problematic because a substrate having an asymmetrically non-uniform thickness profile will remain asymmetric after the CMP process is complete. For example, the asymmetric thickness of the substrate may result in the circuits formed on a surface of the substrate having a different RC time constant for the integrated circuits in devices formed on opposing sides of the same surface of the substrate, due to the ICs formed on the thinner edge of the substrate having less metal than the ICs formed on the thicker edge of the substrate. The resulting integrated circuits will have processing speeds that vary based on the corresponding substrate thickness. Thus, the variance in RC time constants results in devices of varying quality, which is not desirable. Although described as on opposing sides or edges, the location of the thinnest and thickest sides or areas of the substrate may be in other locations of the substrate.

[0004] Accordingly, there is a need in the art for correcting asymmetry in substrates during chemical mechanical polishing.

SUMMARY

[0005] Embodiments described herein generally relate to systems and methods used for correcting thickness asymmetry of a substrate during chemical mechanical polishing.

[0006] In an embodiment, a chemical mechanical polishing system is provided. The polishing system includes a carrier head including a carrier head body, a pixel cartridge array disposed within the carrier head body, and a membrane adjacent to the pixel cartridge array, a carrier ring configured to couple with the carrier head, a notch sensor array disposed on the carrier ring, and a controller coupled to the pixel cartridge array and the notch sensor array. The controller is configured to receive and orient a substrate such that the substrate is an oriented substrate, determine a thickness profile on the oriented substrate, position the oriented substrate in a loading position, receive the oriented substrate, and polish the oriented substrate use the pixel cartridge array. The pixel cartridge array is configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.

[0007] In another embodiment, a carrier head for chemical mechanical polishing is provided. The carrier head includes a carrier head body configured to couple with a carrier ring, a pixel cartridge array disposed within the carrier head body, a membrane adjacent to the pixel cartridge array, a controller coupled to the pixel cartridge array. The controller is configured to receive and orient a substrate such that the substrate is an oriented substrate, determine a thickness profile on the oriented substrate, position the oriented substrate in a loading position, receive the oriented substrate, and polish the oriented substrate use the pixel cartridge array. The pixel cartridge array is configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.

[0008] In yet another embodiment, a method of processing a substrate is provided. The method includes ding receiving and orienting a substrate such that the substrate is an oriented substrate, determining a thickness profile on the oriented substrate, positioning the oriented substrate in a loading position, receiving the oriented substrate, and polishing the oriented substrate using a pixel cartridge array, the pixel cartridge array configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] 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 exemplary embodiments of the present disclosure and are therefore not to be considered limiting of its scope, as the present disclosure may admit to other equally effective embodiments.

[0010] FIG. **1** illustrates a schematic top view of a chemical mechanical polishing system, according to certain embodiments.

[0011] FIG. **2** illustrates a schematic sectional view of a polishing station, according to certain embodiments.

[0012] FIG. **3**A illustrates a schematic, cross-sectional side view of a pad conditioner head, according to certain embodiments.

[0013] FIG. **3**B illustrates a schematic, bottom view of the pad conditioner head of FIG. **3**A, according to certain embodiments.

[0014] FIG. **3**C illustrates a schematic, bottom view of the pad conditioner head of FIG. **3**A, according to certain embodiments.

[0015] FIG. **4** illustrates a schematic, cross-sectional side view of a pixel cartridge, according to certain embodiments.

[0016] FIG. **5** illustrates a flow diagram for a method of planarizing a substrate, according to certain embodiments.

[0017] 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

[0018] Embodiments of the present disclosure generally relate to semiconductor manufacturing. More specifically, the embodiments of the present disclosure generally relate to correcting thickness asymmetry of a substrate during chemical mechanical polishing.

[0019] Symmetric removal during chemical mechanical polishing (CMP) may problematic because a substrate having an asymmetrically non-uniform thickness profile will remain asymmetric after the CMP process is complete. For example, the asymmetric thickness of the substrate may result in the circuits formed on a surface of the substrate having a different RC time constant for the integrated circuits in devices formed on opposing sides of the same surface of the substrate, due to the ICs formed on the thinner edge of the substrate having less metal than the ICs formed on the thicker edge of the substrate. The resulting integrated circuits will have processing speeds that vary based on the corresponding substrate thickness. As such, precise, localized planarization is needed to remove excess material, e.g., areas of higher thickness, from the substrate.

[0020] The present disclosure provides for systems and methods to improve planarization of a substrate by improved localized planarization. Specifically, the present disclosure provides a carrier head including a pixel cartridge array configured to apply localized pressure to a membrane of the carrier head according to the angular position of the substrate. The angular position of the substrate is determined by a notch sensor array configured to determine the angular position of a notch in the substrate. The pressure applied by the pixel cartridge array varies depending on the region of the substrate to be planarized. The pixel cartridge array, in conjunction with the notch sensor array, allows for precise, local planarization of regions of the substrate as determined by recipe and substrate thickness.

[0021] FIG. **1** is a top plan view illustrating one embodiment of a chemical mechanical polishing (CMP) system **100** that can be adapted to perform a polishing process on a substrate using a polishing pad described herein, which can be used to improve the polishing process results achieved on the substrate over conventional polishing processes. The CMP system **100** includes a factory interface module **102**, a cleaner **104**, and a polishing module **106**. A wet robot **108** is provided to transfer substrates **115** between the factory interface module **102** and the polishing module **106**. The wet robot **108** may also be configured to transfer the substrates **115** between the polishing module **106** and the cleaner **104**. The factory interface module **102** includes a dry robot **110** which is configured to transfer the substrates **115** between one or more cassettes **114**, one or more metrology stations **117**, and one or more transfer platforms **116**. In some embodiments, as shown in FIG. **1**, four substrate storage cassettes **114** are shown. The dry robot **110** within the factory interface **102** has sufficient range of motion to facilitate transfer between the four cassettes **114** and the one or more transfer platforms **116**. Optionally, the dry robot **110** may be mounted on a rail or track **112** to position the robot **110** laterally within the factory interface module **102**. The dry robot **110** is also configured to receive the substrates **115** from the cleaner **104** and return the clean polished substrates to the substrate storage cassettes **114**.

[0022] Still referring to FIG. **1**, the polishing module **106** includes a plurality of polishing stations **124** on which the substrates **115** are polished while being retained in a carrier head **210**. The polishing stations **124** are sized to interface with one or more carrier heads **210** so that polishing of a substrate **115** may occur in a single polishing station **124**. The carrier heads **210** are coupled to a carriage (not shown) that is mounted to an overhead track **128** that is shown in phantom in FIG. **1**. The overhead track **128** allows the carriage to be selectively positioned around the polishing module **106** which facilitates positioning of the carrier heads **210** selectively over the polishing stations **124** and load cup **122**. In some embodiments, as shown in FIG. **1**, the overhead track **128** has a circular configuration which allows the carriages retaining the carrier heads **210** to be selectively and independently rotated over and/or clear of the load cups **122** and the polishing stations **124**.

[0023] In some embodiments, as shown in FIG. **1**, three polishing stations **124** are shown located in the polishing module **106**. At least one load cup **122** is in the corner of the polishing module **106** between the polishing stations **124** closest to the wet robot **108**. The load cup **122** facilitates transfer between the wet robot **108** and the carrier heads **210**.

[0024] Each polishing station **124** includes a polishing pad **204** having a polishing surface (e.g., a polishing surface **204**A in FIG. **2**) capable of polishing a substrate **115**. Each polishing station **124** includes one or more carrier heads **210**, a conditioning assembly **132** and a polishing fluid delivery module **135**. During the operation of the polishing assembly **200**, the pad **204** is subject to compression, shear and friction, which produce heat and wear, as a slurry and substrate are urged against the polishing surface **204**A by the one or more carrier heads **210**. The slurry and abraded material from the substrate and pad are pressed into the surface and pores of the pad material, which causes the pad material, and pores formed in the pad material to become matted and even partially fused. These effects created at the polishing surface **204**A are sometimes referred to as "glazing," and reduce the pad's ability to have a desirable polishing rate and provide fresh slurry to the substrate during processing. In some embodiments, the conditioning assembly **132** may comprises a conditioning disk **133** of a pad conditioning assembly **140**, which dresses the polishing surface of the polishing pad **204** by removing polishing debris, remove any "glazing" formed on the polishing pad **204**, which occurs after extended use of the pad. Generally, the bottom surface of the conditioning disk **133** contacts and abrades the polishing surface **204**A of the polishing pad **204** during a pad conditioning process. During a pad conditioning process, the arm **132**B of the pad conditioning assembly **140**, provides translational motion to the conditioning disk **133** so that the conditioning disk **133** may contact and abrade the entire polishing surface of the polishing pad **204**. A typical pad conditioning process includes applying a down force to the conditioning disk **133** relative to the polishing surface **204**A of the polishing pad **204** in a range between about 0.1 psi and about 30 psi, such as, between about 0.7 psi to about 2.0 psi, to achieve an down force of between about 3 and 6 pounds. During a pad conditioning process the conditioning disk **133** is rotated about the axis **235** at a rotation speed of typically between about 30 RPM to about 120 RPM, for example, between about 30 RPM to about 100 RPM, or even between about 40 RPM to about 70 RPM, while a rotational actuator causes the conditioning arm **132**B to cause the conditioning disk **133** to translate across the polishing surface **204**A of the polishing pad **204** as the polishing pad **204** is being rotated about the axis **216** at a rotation speed of typically between about 20 RPM to about 120 RPM, for example, between about 40 RPM to about 85 RPM. The abrasive action applied by the conditioning disk **133** to the surface of the polishing pad **204** will intentionally cause damage to the polishing layer material at the polishing surface **204**A to assure that any "glazing" and other unwanted debris is removed. The pad conditioning process can also be used to open pores formed in the polishing pad **204**, when they are present at or near in the polishing surface **204**A.

[0025] Referring to FIG. **2**, the conditioning disk **133** typically has a plurality of abrasive regions (not shown) on its lower face, in which abrasive particles (e.g., diamond or silicon carbide particles) are secured. The abrasive particles are disposed on a surface of a backing plate portion of the conditioning disk **133** to provide a structure capable of enabling the removal of the material on the polishing surface **204**A of the polishing pad **204**. The abrasive particles can be attached to the lower surface of the conditioning disk **133** by way of known electroplating and/or electrodeposition processes, or by way of organic binding, brazing or welding processes. Each individual abrasive particle can have one or more cutting points, ridges or mesas. In some configurations, the abrasive diamond particles are between 60 micrometers (μm) and 250 μm in size, which can provide superior conditioning of the material used in 3D printed polishing pads, e.g., a low wear rate while maintaining uniform surface roughness across the pad.

[0026] In other embodiments, the polishing fluid delivery module **135** may comprise a fluid delivery arm **134** to deliver a slurry. Each polishing station **124** comprises a pad conditioning assembly **132**. In some embodiments, the fluid delivery arm **134** is configured to deliver a fluid stream (e.g., a fluid **222** in FIG. **2**) to a polishing station **124**. The polishing pad **204** is supported on a platen (e.g., a platen **202** in FIG. **2**) which rotates the polishing surface during processing. The platen **202** includes a body **203** that has a pad supporting surface **203**A. The CMP system **100** is coupled with a power source **180**.

[0027] In some embodiments, the substrates **115**, such as a silicon wafer having one or more layers deposited thereon, are loaded into the CMP system **100** via a cassette **114**. During processing, the factory interface module **102** extracts the substrate **115** from the cassette **114** to begin processing while a controller **190** coordinates operations of the CMP system **100**. The dry robot **110** within the factory interface module **102** then transfers the substrate **115** to the metrology station **117**, which in some cases measures a thickness profile of the substrate **115**. The dry robot **110** then transfers the substrate **115** to the transfer platforms **116**, and the wet robot **108** transfers the substrates through subsequent processing components including the CMP system **100**.

[0028] The substrate **115** is then transferred by the wet robot **108** to a load cup **122** so that a carrier head **210** can pick-up and transport the substrate **115** to each of the one or more polishing stations **124** to undergo a CMP process according to the polishing parameters selected. Each polishing station includes a polishing pad **204** secured to a rotatable platen **202**. Different types of polishing pads **204** may be used at different polishing stations **124** to control the material removal of the substrate **115**.

[0029] During CMP, the controller **190** controls aspects of the polishing stations **124**. In some embodiments, the controller **190** is one or more programmable digital computers executing digital control software. The controller **190** can include a processor **192** situated near the polishing apparatus, e.g., a programmable computer, such as a personal computer. The controller can include a memory **194** and support circuits **196**. The controller **190** can, for example, coordinate contact between the substrate **115** and the polishing pad **204** at differing rotational speeds such that a selective removal profile is aligned with indices of residue locations on the substrate **115**, such as an asymmetric thickness profile of the substrate **115**. Aligning these profiles ensures the thickest part of the substrate **115** has the most material removed and reduces the asymmetry of the substrate **115** during polishing. The controller **190** may include a plurality of separate controllers that are connected via network.

[0030] After polishing in at least one of the polishing stations **124**, the carrier head **210** (FIG. **2**) transports the substrate **115** to the load cup **122**, and then the wet robot **108** transports the substrate **115** from the load cup **122** to a cleaning chamber in the cleaner **104**, where slurry and other contaminants that have accumulated on the substrate surface during polishing are removed. In the embodiment depicted in FIG. **1**, the cleaner **104** includes two pre-clean modules **144**, two megasonic cleaner modules **146**, two brush box modules **148**, a spray jet module **150**, and two dryers **152**. The dry robot **110** then removes the substrate **115** from the cleaner **104** and transfers the substrate **115** to the metrology station **117** to be measured again. In certain embodiments, the post-polish layer measurements can be used to adjust the polishing process parameters for a subsequent substrate. Finally, the dry robot **110** returns the substrate **115** to one of the cassettes **114**.

[0031] FIG. **2** depicts a schematic sectional view of a polishing station **124** of the CMP system **100** from FIG. **1** that comprises a polishing assembly **200** having a polishing pad **204** formed according to embodiments described herein. In particular, FIG. **2** shows how a carrier head **210** is positioned relative to the polishing pad **204**. A coordinate system **201**, having an x-axis, a y-axis, and a z-axis, shows the orientation of the different components of the polishing assembly **200** in this and subsequent figures. The coordinate system **201** shows positive directions of the x, y, and z-axes and positive direction for rotation about the z-axis, which is in a counter-clockwise direction. The opposite directions (not shown) are negative directions.

[0032] In some embodiments, the polishing pad **204** is secured to the pad supporting surface **203**A of the platen **202** using an adhesive layer **220** (FIG. 3A), such as a pressure sensitive adhesive (PSA) layer, as shown in FIG. 3A, disposed between the polishing pad **204** and the pad supporting surface **203**A of the platen **202**. In some embodiments, the PSA layer can include a rubber resin, acrylic or silicone containing material.

[0033] The carrier head **210**, facing the platen **202** and the polishing pad **204** mounted thereon, includes a flexible diaphragm **212** configured to impose different pressures in different regions of the flexible diaphragm **212** against a surface of a substrate **115** that is disposed between the carrier head **210** and the polishing pad **204**. The carrier head **210** includes a carrier ring **218** surrounding the substrate **115**, which holds the substrate in place. The carrier head **210** rotates about a carrier head axis **216** while the flexible diaphragm **212** urges a to-be-polished surface of the substrate **115**, such as a device side of the substrate **115**, against a polishing surface **204**A of the polishing pad **204**. During polishing, a downforce on the carrier ring **218** urges the carrier ring **218** against the polishing surface **204**A to improve the polishing process uniformity and prevent the substrate **115** from slipping out from under the carrier head **210**.

[0034] In some embodiments, the polishing pad **204** rotates about a platen axis **205**. The polishing pad **204** has a polishing pad axis **206** that is typically collinear with the platen axis **205**. In some embodiments, the polishing pad **204** rotates in the same rotational direction as the rotational direction of the carrier head **210**. For example, the polishing pad **204** and carrier head **210** both rotate in a counter-clockwise direction. As shown in FIG. **2**, the polishing pad **204** has a surface area that is greater than the to-be-polished surface area of the substrate **115**. However, in some embodiments, the polishing pad **204** has a surface area that is less than the to-be-polished surface area of the substrate **115**.

[0035] In some embodiments, an endpoint detection (EPD) system **224** detects reflected light that is directed towards the substrate **115** from a light source, through a platen opening **226** and an optically transparent window feature **227** of the polishing pad **204** disposed over the platen opening **226**, and then back through these components to a detector (not shown) within the EPD system **224** during processing to detect properties of a layer formed on a surface of the substrate during polishing. The EPD system **224** can allow a thickness and/or residue location measurement, of the substrate **115** to be taken while the polishing assembly **200** is in use. In some embodiments, an eddy current probe is used to measure the thickness of conductive layers formed on a region of a surface of the substrate **115** by the comparison of the relative angle and position of the notch of the substrate **115**, or carrier head **210**, to the EPD system **224** within the platen **202**.

[0036] During polishing, a fluid **222** is introduced to the polishing pad **204** through the fluid delivery arm **134** portion of the polishing fluid delivery module **135**, which is positioned over the polishing surface **204**A of the polishing pad **204**. In some embodiments, the fluid **222** is a polishing fluid, a polishing slurry, a cleaning fluid, or a combination thereof. In some embodiments, the polishing fluid may include water based chemistries that include abrasive particles. The fluid **222** may also include a pH adjuster and/or chemically active components, such as an oxidizing agent, to enable CMP of the material surface of the substrate **115** in conjunction with the polishing pad **204**. The fluid **222** removes material from the substrate as the carrier head **210** urges the substrate against the polishing pad **204**.

[0037] FIG. 3A illustrates a schematic, cross-sectional side view of an embodiment of the carrier head **210** with the carrier ring carrier ring **218**. FIG. 3B is a schematic, bottom view of the carrier head **210** with the carrier ring carrier ring **218**. FIG. 3C is a schematic, bottom view of the carrier head **210** with a substrate mounted, e.g., substrate **115**. As shown in FIG. 3A, the carrier head **210** includes a pixel cartridge array **300** disposed within a carrier head body **210**A enclosed by sidewalls **210**B and concentric to a head center axis **302**. The pixel cartridge array **300** includes a cartridge top end **310** and a cartridge bottom end **312**. The cartridge bottom end **312** is adjacent to and may contact a membrane **320**. The membrane **320** is configured to contact the substrate **115** during polishing. The carrier ring **218**, disposed adjacent to the cartridge bottom end **312**, includes notch sensors **330** configured to detect the presence of a notch **332** (FIG. 3C) in the substrate **115**. The notch sensors **330** may be disposed on an inner edge **218**A of the carrier ring **218**, adjacent to the membrane **320** and the substrate **115**. The notch **332** is on an outer edge **115**A of the substrate **115** and may be at least 1.25 mm deep into the substrate. The notch **332** may have any desired profile, e.g., as viewed from the top or bottom of the substrate **115**, such as a triangular, rectangular, or circular profile, though the notch **332** is shown to have a triangular cross-sectional profile. The cross-sectional size and depth of the notch **332** is dependent on the type of notch sensors **330** used.

[0038] The carrier head **210** may also include a gimbal assembly **340** in an upper portion of the carrier head body **210**A. The gimbal assembly **340** may include a spindle adaptor **342**, electromagnet **344**, and a flexure gimbal **346** each configured to actuate the carrier head **210** with respect to the head center axis **302**, e.g., along the head center axis **302** or in a direction normal to the head center axis **302**. The carrier head **210** may also include slip rings **348** to accommodate a coupling cable **350** which couples the pixel cartridge array **300** to the controller **190**.

[0039] As shown in FIG. 3B, the pixel cartridge array **300** may be centered about the head center axis **302** and may expand an entire surface of the membrane **320**. The pixel cartridge array **300** may include a circular array of pixel cartridges **400** (FIG. 4), such as about **100** pixel cartridges, such as **110**, such as **120**, or more. The pixel cartridge array **300** may be actuated by the controller **190** such that a portion or portions of the pixel cartridge array **300**, exerts higher or lower pressure on the membrane **320**. This allows for portions of the substrate **115** to be planarized more precisely.

[0040] As shown in FIG. 3C, the notch sensors **330** may be part of a notch sensor array **360** that is disposed on the inner edge **218**A of the carrier ring **218**. In operation, the substrate **115** may be mounted into or disposed over the membrane **320** and the pixel cartridge array **300**. The substrate **115** includes a notch **332** on an outside edge **115**A adjacent to the inner edge **218**A of the carrier ring **218** and the notch sensor array **360**. The notch **332** is placed into the substrate **115** at a predetermined angular position. This angular position is stored into the controller **190** and recalled during processing of the substrate **115**. Each of the notch sensors **330** of the notch sensor array **360** may be coupled to the controller **190** and configured to detect the notch **332**. For example, the notch sensors **330** may be capacitive sensors that continuously detect the notch **332** by emitting an electric field from a sensing end of the sensor and detecting disturbances, e.g., the notch **332**, in the emitted electric field. The notch sensors **330**, when configured as capacitive sensors, may detect the position of the notch **332** within +/−1 degree. As the substrate **115** rotates, the notch sensor array **360** detects if the notch **332** is present at a certain angular position, e.g., at a first notch sensor **334** of the notch sensor array **360**, the pixel cartridge array **300** may be actuated according to a recipe stored in the controller **190**. As the angular position changes, e.g., the notch **332** is detected at a second notch sensor **336** of the notch sensor array **360**, the pixel cartridge array **300** is actuated to adjust for the angular position according to the recipe. Similarly, as the angular position changes again, e.g., the notch **332** is detected at a third notch sensor **338** of the notch sensor array **360**, the pixel cartridge array **300** is actuated to adjust for the new angular position according to the recipe. The continuous monitoring and detection of the notch **332** of the substrate **115** allows the pixel cartridge array **300** to adjust pressure on the membrane **320**, increasing or decreasing pressure on desired portions of the substrate **115**, resulting in precise, local planarization of the substrate **115**.

[0041] FIG. **4** illustrates a schematic, cross-sectional side view of a pixel cartridge **400**, which may be used in the pixel cartridge array **300** as described above. The pixel cartridge **400** includes a cartridge body **400**A, with a top portion **400**A_1 and bottom portion **400**A_2, and an inner volume **402** having an upper volume **404** and a lower volume **406**. An electromagnet **410** is disposed within the inner volume **402** and defines a top end of the upper volume **404** with a permanent magnet **412** defining a bottom end of the upper volume **404**. The permanent magnet **412** defines a top end of the lower volume **406** and the bottom portion **400**A_2 defines a bottom end of the lower volume **406**. A spring **414** is disposed within the lower volume **406** and may contact the permanent magnet **412**. The bottom portion **400**A_2 includes a through-hole **416** that fluidly couples the lower volume **406** to an inner balloon volume **418**A of a balloon **418** connected to an outer surface of the bottom portion **400**A_2. The lower volume **406** and the inner balloon volume **418**A then define a gaseous volume **408**. The gaseous volume **408** may include any suitable gas, such as air or nitrogen, and is sealed from the environment by the balloon **418** and the cartridge body **400**A.

[0042] The electromagnet **410** is coupled to the controller **190** through the top portion **400**A_1 by a coupling cable (not shown) on an end opposite the permanent magnet **412**. In operation, the controller **190** energizes the electromagnet **410** to either attract or repulse the permanent magnet **412**, changing the volume of the lower volume **406**. As the gaseous volume **408** is constant, the change in the lower volume **406** results in an equal, but opposite, change in the inner balloon volume **418**A. For example, if the electromagnet **410** is energized to repulse the permanent magnet **412**, the lower volume **406** decreases, resulting in an increase in the inner balloon volume **418**A, which expands the balloon **418** and applies increased localized pressure to the membrane **320**. The added localized pressure to the membrane **320** is then conveyed to the substrate **115**. Similarly, if the electromagnet **410** is energized to attract the permanent magnet **412**, the lower volume **406** increases, creating a vacuum and resulting in a decrease in the inner balloon volume **418**A, which contracts the balloon **418**. The contraction of the balloon **418** reduces localized pressure to the membrane **320** and, subsequently, the substrate **115**.

[0043] FIG. **5** illustrates a flow chart for an asymmetric polishing method **500** that can be performed in a polishing system, such as the CMP system **100** illustrated in FIG. **1**. While the method described in relation to FIG. **5** primarily focuses on the operations used to perform an asymmetric polishing process, this shortened list of operations is not intended to be limiting as to the scope of the disclosure described herein since other polishing process operations may inserted before, during or after the operations discussed in relation to the asymmetric polishing method **500** without deviating from the basic scope of the disclosure provided herein. In one example, as briefly discussed above, one or more cleaning processes may be performed on a substrate in the cleaner **104** within the CMP system **100** after the asymmetric polishing method **500** has been performed on a substrate. In another example, one or more additional polishing processes (i.e., asymmetric polishing process or conventional symmetric polishing processes) may also be performed on a substrate on the same or a different polishing pad **204** within the CMP system **100** using the same carrier head **210** before or after performing the asymmetric polishing method **500**.

[0044] At operation **502**, a substrate **115** is removed from the cassette **114** by the dry robot **110** and positioned in the pre-aligner **118**. The pre-aligner **118** is then used to determine the orientation of the substrate **115** by detecting one or more features formed on a surface of the substrate **115**, such as the notch **332**. The pre-aligner **118** then positions the substrate **115** in a desired angular orientation so that the dry robot **110** can then receive an oriented and pre-aligned substrate **115**.

[0045] At operation **504**, the oriented and pre-aligned substrate **115** is then removed from the pre-aligner **118** by the dry robot **110** and positioned in the metrology station **117**. As discussed above, the metrology station **117**, is then used to measure a thickness profile of the substrate **115** and determine the orientation of the thickness profile in relation to the one or more features formed on a surface of the substrate **115**, such as the notch **332**. During operation **504**, the controller **190** receives the measurements and the orientation of the thickness profile from the metrology station **117**. The controller **190** can then use the measurement and substrate orientation information to coordinate the asymmetric polishing processes performed in subsequent operations.

[0046] In some embodiments, operations **502** and **504** are performed in the same chamber, and thus a separate pre-aligner **118** may not be necessary since the metrology station **117** includes one or more substrate orientation detection elements.

[0047] At operation **506**, the oriented, pre-aligned and thickness profile measured substrate **115** is then transferred by the dry robot **110** to a transfer platform **116**, and the wet robot **108** then transfers the substrate **115** to a load cup **122**. Based on the known orientation, alignment and thickness profile of the substrate **115**, the substrate **115** is then positioned in a desired position and orientation in the load cup **122** so that a carrier head **210** can pick-up the substrate **115** in a known angular orientation. In some embodiments, the pre-alignment step(s) performed during operation **502** are configured to align and position the substrate **115** such that the subsequent transferring steps performed by the dry robot **110** and wet robot **108** cause the angular alignment of the substrate **115** to end up in a desired orientation in the load cup **122**. The ability of the carrier head **210** to receive the substrate **115**, having a known thickness profile, in a known and desirable orientation enables the subsequent asymmetric polishing process at operation **510** to be performed on the desired regions of the substrate **115** in one or more of the polishing stations **124**.

[0048] At operation **508**, the carrier head **210** then picks-up the oriented and aligned substrate **115** from its known position within the load cup **122** and transfers the substrate **115** to a surface **204**A of a polishing pad **204** in a polishing station **124** so that the subsequent asymmetric polishing process at operation **510** can be performed. Prior to or during operation **508**, one or more carrier head **210** orientation detecting elements are used to assure that the angular orientation of the carrier head **210** relative to the load cup **122** and position of the one or more features formed on a surface of the substrate **115**, such as the notch **332**, are known and oriented correctly. In some embodiments, the carrier head **210** includes an encoder, position flag or other orientation detecting element(s) that are coupled to an actuator (not shown), which when working together allows the carrier head **210** to be oriented in a known and desired angular orientation when it picks-up the aligned and oriented substrate **115** from the load cup **122**.

[0049] At operation **510**, the controller **190** then coordinates the relative motion of the carrier head **210** to the substrate **115** to perform the processing steps used to perform an asymmetric polishing process. For example, the notch sensors **330** of the notch sensor array **360** disposed on the carrier ring **218** send information to the controller **190** regarding the angular position of the notch **332** on the substrate **115**. The controller **190** then actuates the desired pixel cartridge **400** of the pixel cartridge array **300**, as determined by the thickness profile and recipe stored in the controller **190**. For example, regions of higher thickness of the substrate **115** may require more pressure exerted on the membrane **320** by the pixel cartridge array **300** than regions of lower thickness. The controller **190** may then determine the amount and location of the pixel cartridge **400** relative to the pixel cartridge array **300** and the angular location from the notch **332**. For example, the controller **190** may determine that a region of higher thickness on the substrate **115** requires a set of **10** pixel cartridges **400** to apply increased pressure at a region **180** degrees from the notch **332**. The controller **190** may actuate the set of **10** pixel cartridges **400** to apply a uniform pressure in that region. Alternatively, the controller **190** may actuate the set of **10** pixel cartridges **400** to apply a non-uniform pressure, e.g. a gradient or other desired pressure profile, to the region. As the angular position of the substrate **115** changes relative to the carrier head **210**, the controller **190** adjusts the pixel cartridge array **300** according to the recipe and the received position information from the notch sensor array **360** indicating the angular location of the notch **332**.

[0050] The methods disclosed herein comprise one or more steps or actions for achieving the methods. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims. Further, the various operations of methods described above may be performed by any suitable means capable of performing the corresponding functions. The means may include various hardware and/or software component(s) and/or module(s), including, but not limited to a circuit, an application specific integrated circuit (ASIC), or processor. Generally, where there are operations illustrated in figures, those operations may have corresponding counterpart means-plus-function components with similar numbering.

[0051] The present disclosure provides for systems and methods to improve planarization of a substrate by improved localized planarization. Specifically, the present disclosure provides a carrier head including a pixel cartridge array configured to apply localized pressure to a membrane of the carrier head according to the angular position of the substrate determined by a notch sensor array configured to determine the angular position of a notch in the substrate. The pressure applied by the pixel cartridge array varies depending on the region of the substrate to be planarized. The pixel cartridge array, in conjunction with the notch sensor array, allows for precise, local planarization of regions of the substrate as determined by recipe, substrate thickness, and location on the substrate.

[0052] When introducing elements of the present disclosure or exemplary aspects or embodiments thereof, the articles "a," "an," "the" and "said" are intended to mean that there are one or more of the elements.

[0053] The terms "comprising," "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0054] The term "coupled" is used herein to refer to the direct or indirect coupling between two objects. For example, if object A physically touches object B and object B touches object C, the objects A and C may still be considered coupled to one another-even if objects A and C do not directly physically touch each other. For instance, a first object may be coupled to a second object even though the first object is never directly in physical contact with the second object.

[0055] 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.

What is claimed is:

1. A chemical mechanical polishing system, comprising:
- a carrier head comprising a carrier head body, a pixel cartridge array disposed within the carrier head body, and a membrane adjacent to the pixel cartridge array;
- a carrier ring configured to couple with the carrier head;
- a notch sensor array disposed on the carrier ring; and
- a controller coupled to the pixel cartridge array and the notch sensor array, the controller configured to:
  - (a) receive and orient a substrate such that the substrate is an oriented substrate;
  - (b) determine a thickness profile on the oriented substrate;
  - (c) position the oriented substrate in a loading position;
  - (d) receive the oriented substrate; and
  - (e) polish the oriented substrate use the pixel cartridge array, the pixel cartridge array configured to apply

pressure on a membrane of a carrier head in a chemical mechanical polishing system.

2. The chemical mechanical polishing system of claim **1**, wherein the pixel cartridge array comprises a plurality of pixel cartridges, each of the pixel cartridges comprising an electromagnet and a permanent magnet.

3. The chemical mechanical polishing system of claim **1**, wherein polishing the oriented substrate comprises using the notch sensor array to determine an angular position of the oriented substrate using a notch in the oriented substrate.

4. The chemical mechanical polishing system of claim **1**, wherein the pixel cartridge array is configured to apply pressure on the membrane based on the angular position of the oriented substrate.

5. The chemical mechanical polishing system of claim **1**, wherein the pressure applied by the pixel cartridge array is adjusted based on the thickness profile on the oriented substrate.

6. The chemical mechanical polishing system of claim **1**, wherein the pressure applied by the pixel cartridge array is non-uniform.

7. The chemical mechanical polishing system of claim **1**, wherein the pixel cartridge array comprises at least 100 pixel cartridges.

8. A carrier head for chemical mechanical polishing, comprising:

a carrier head body configured to couple with a carrier ring;

a pixel cartridge array disposed within the carrier head body;

a membrane adjacent to the pixel cartridge array;

a controller coupled to the pixel cartridge array, the controller configured to:

(a) receive and orient a substrate such that the substrate is an oriented substrate;

(b) determine a thickness profile on the oriented substrate;

(c) position the oriented substrate in a loading position;

(d) receive the oriented substrate; and

(e) polish the oriented substrate use the pixel cartridge array, the pixel cartridge array configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.

9. The carrier head of claim **8**, wherein the pixel cartridge array comprises a plurality of pixel cartridges, each of the pixel cartridges comprising an electromagnet and a permanent magnet.

10. The carrier head of claim **9**, wherein polishing the oriented substrate comprises using the electromagnet of at least one of the pixel cartridges of the pixel cartridge array to apply pressure to the membrane based on the angular orientation of the substrate.

11. The carrier head of claim **8**, wherein the pixel cartridge array is configured to apply pressure on the membrane based on the angular position of the oriented substrate.

12. The carrier head of claim **8**, wherein the pressure applied by the pixel cartridge array is adjusted based on the thickness profile on the oriented substrate.

13. The carrier head of claim **8**, wherein the pressure applied by the pixel cartridge array is non-uniform.

14. The carrier head of claim **8**, wherein the pixel cartridge array comprises at least 100 pixel cartridges.

15. A method of processing a substrate, comprising:

(a) receiving and orienting a substrate such that the substrate is an oriented substrate;

(b) determining a thickness profile on the oriented substrate;

(c) positioning the oriented substrate in a loading position;

(d) receiving the oriented substrate; and

(e) polishing the oriented substrate using a pixel cartridge array, the pixel cartridge array configured to apply pressure on a membrane of a carrier head in a chemical mechanical polishing system.

16. The method of claim **15**, wherein the pixel cartridge array comprises a plurality of pixel cartridges, each of the pixel cartridges comprising an electromagnet and a permanent magnet.

17. The method of claim **15**, wherein polishing the oriented substrate comprises using a notch sensor array to determine an angular position of the oriented substrate using a notch in the oriented substrate.

18. The method of claim **15**, wherein the pixel cartridge array is configured to apply pressure on the membrane based on the angular position of the oriented substrate.

19. The method of claim **15**, wherein the pressure applied by the pixel cartridge array is adjusted based on the thickness profile on the oriented substrate.

20. The method of claim **15**, wherein the pressure applied by the pixel cartridge array is non-uniform.

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