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(54) **SUBSTRATE PRECESSION MECHANISM FOR CMP POLISHING HEAD**

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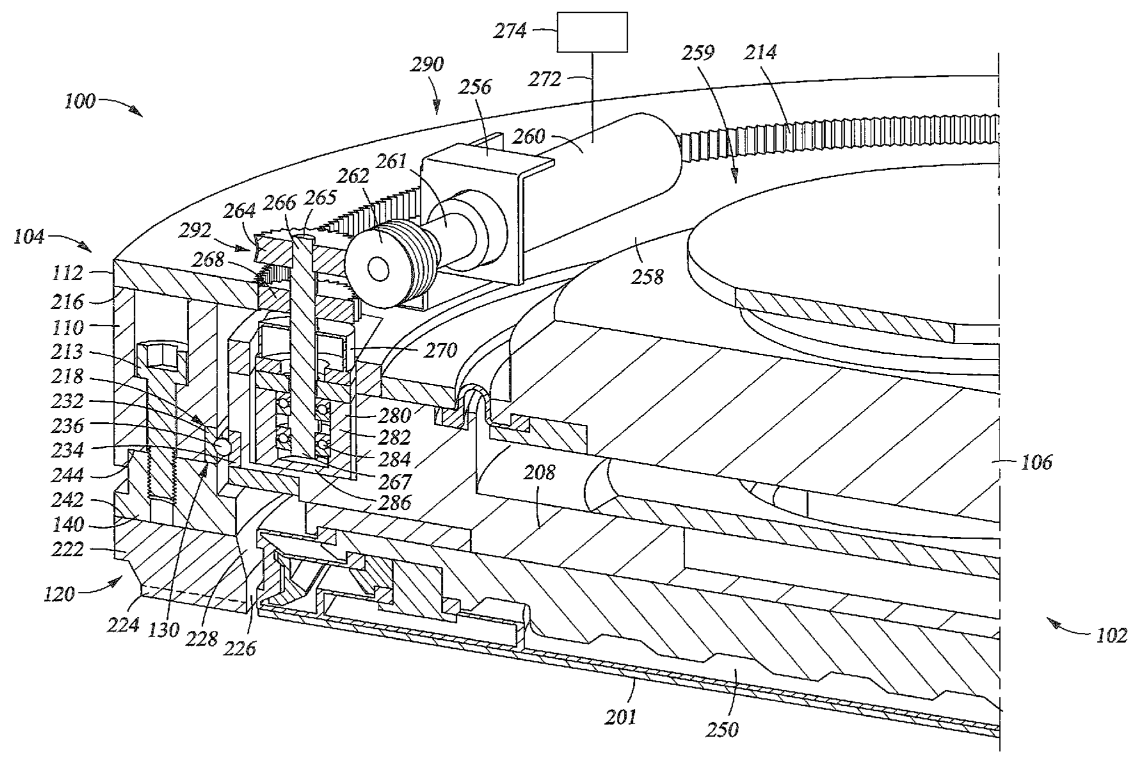
(57) **ABSTRACT**

A substrate precession apparatus for a carrier head is provided. The apparatus enables substrate precession, which is the rotational movement of the substrate relative to the carrier head during polishing of the substrate. The carrier head and a retaining ring assembly may be de-coupled and move independently of one another to promote substrate precession during a CMP process.



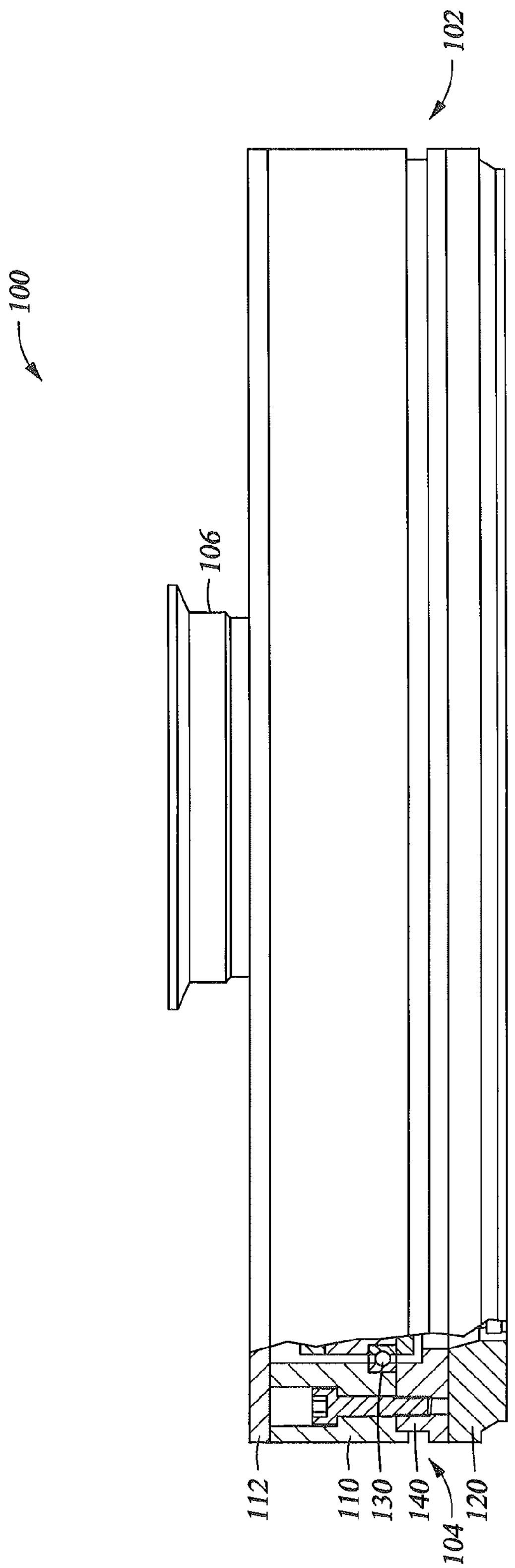


Fig. 1

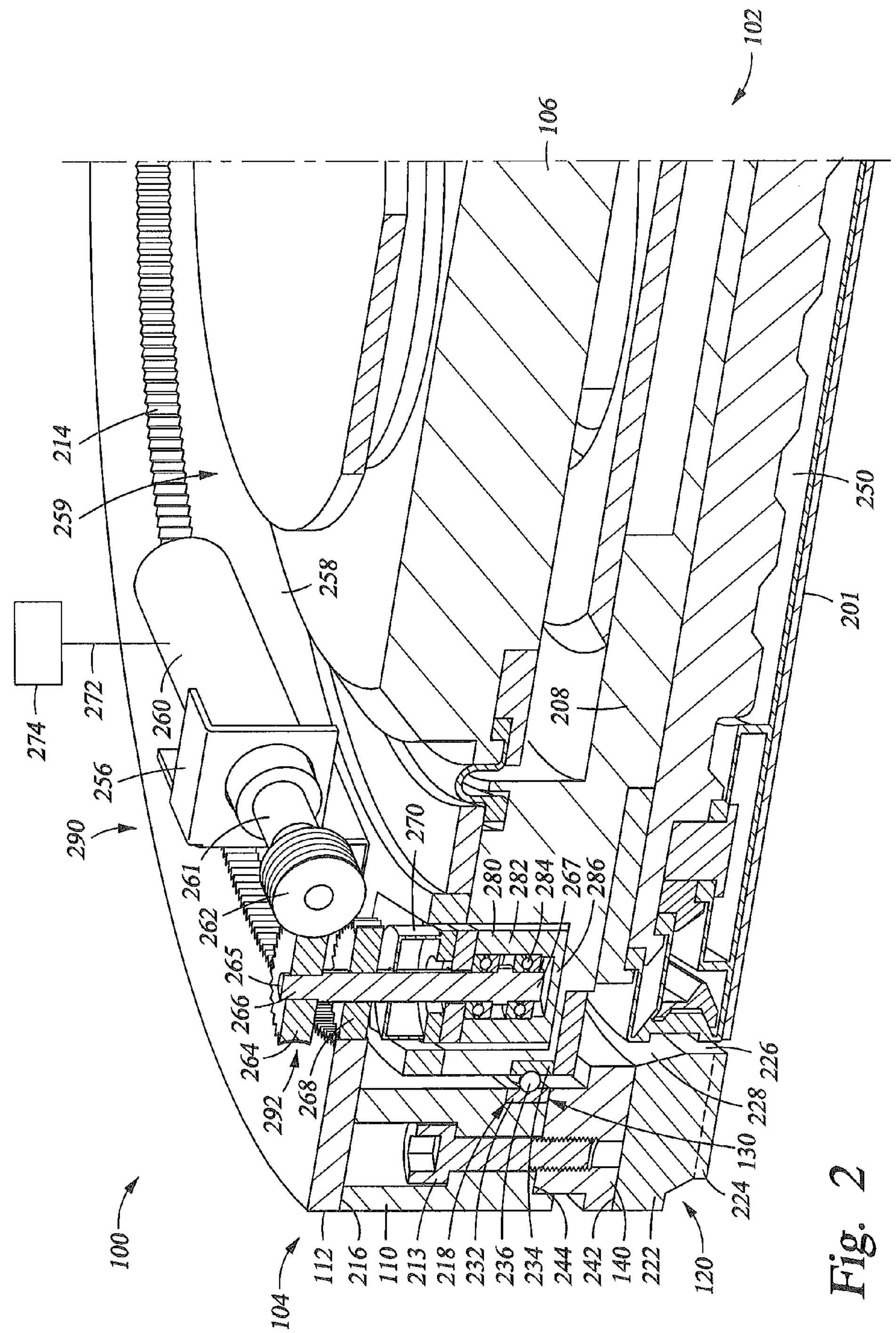

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Fig. 2

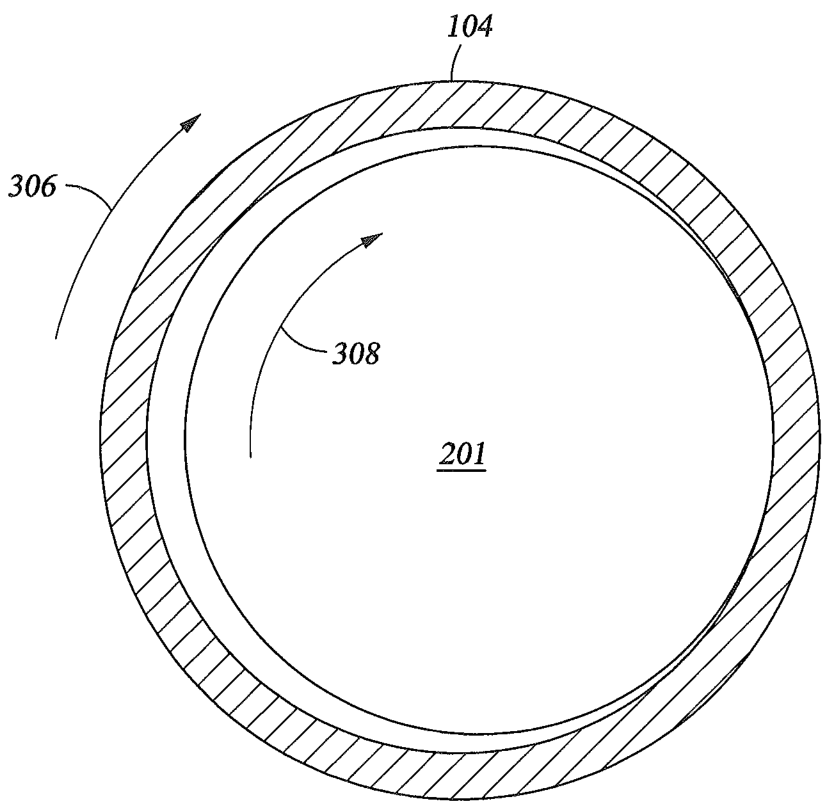

Fig. 3

SUBSTRATE PRECESSION MECHANISM FOR CMP POLISHING HEAD

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] Embodiments described herein generally relate to a chemical mechanical polishing carrier head. More specifically, embodiments described herein relate to a substrate precession mechanism for a carrier polishing head.

[0003] 2. Description of the Related Art

[0004] An integrated circuit is typically formed on a substrate by the sequential deposition of conductive, semiconductive, or insulative layers on a silicon substrate. One fabrication step involves depositing a filler layer over a non-planar surface, and planarizing the filler layer until the non-planar surface is exposed. For example, a conductive filler layer may be deposited on a patterned insulative layer to fill trenches or holes in the insulative layer. The filler layer is then polished until a raised pattern of the insulative layer is exposed. After planarization, portions of the conductive layer remaining between the raised pattern of the insulative layer form vias, plugs, and lines that provide conductive paths between thin film circuits on the substrate. In addition, planarization is needed to planarize the substrate surface for photolithography.

[0005] Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted on a carrier or polishing head of a CMP apparatus. The exposed surface of the substrate is placed against a rotating polishing disk pad or belt pad. The polishing pad may be either a standard pad or a fixed-abrasive pad. A standard pad may have a durable roughened surface, whereas a fixed-abrasive pad may have abrasive particles held in a containment media. The carrier head provides controllable load on the substrate to push the substrate against the polishing pad. The carrier head may have a retaining ring which holds the substrate in place during polishing. A polishing liquid, such as a slurry, including at least one chemically reactive agent and abrasive particles, may be supplied to the surface of the polishing pad during polishing.

[0006] Maintaining a uniform removal profile of the substrate is an important aspect of a CMP process. Maintaining the relatively uniform profile across a surface of the substrate in both the polar and radial directions may be desirable. As such, it may be important to employ methods which reduce localized non-uniformities of the planarization profile.

SUMMARY OF THE INVENTION

[0007] Embodiments described herein generally relate to a substrate precession mechanism for a CMP carrier head. A substrate precession apparatus for a CMP carrier head is provided. The apparatus enables substrate precession, which is the rotational movement of the substrate relative to the carrier head during polishing of the substrate. The carrier head and a retaining ring assembly that may be de-coupled, allowing the carrier head and retaining ring assembly to move independently of one another to promote substrate precession during a CMP process.

[0008] In one embodiment, an apparatus for polishing a substrate is provided. The apparatus comprises a head assembly, and a retaining ring assembly. The retaining ring assembly comprises an internal gear and a bearing disposed between the head assembly and the retaining ring assembly. The bearing is adapted to decouple the retaining ring assembly from the head assembly. A drive assembly adapted to rotate the retaining ring assembly relative to the head assembly is also provided.

[0009] In another embodiment, a retaining ring assembly for a polishing head is provided. The retaining ring assembly comprises a retaining ring having an upper annular portion and a lower annular portion and a carrier ring coupled to the upper annular portion. The retaining ring assembly further comprises a bearing clamp coupled to the carrier ring, the bearing clamp adapted to receive a bearing, and an internal gear coupled to the bearing clamp.

[0010] In yet another embodiment, a method of operating a polishing apparatus is provided. The method comprises providing a polishing head assembly and a retaining ring assembly. The retaining ring assembly is decoupled from the polishing head assembly. The method also provides for rotating the polishing head at a first speed and rotating the retaining ring assembly at a second speed greater than the first speed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, 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 invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0012] FIG. **1** is a partial cut-away view of a carrier head having a de-coupled retaining ring assembly.

[0013] FIG. **2** is a partial perspective view of the carrier head of FIG. **1**.

[0014] FIG. **3** is a schematic bottom view of a retaining ring assembly and a substrate.

[0015] 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

[0016] Embodiments described herein generally relate to a substrate precession mechanism for a CMP carrier head. A substrate precession apparatus for a carrier head is provided. The apparatus enables substrate precession, which is the rotational movement of the substrate relative to the carrier head during polishing of the substrate. A carrier head and a retaining ring assembly may be de-coupled and move independently of one another to promote substrate precession during a CMP process.

[0017] Generally, varying pressures may be applied to various radial zones of a membrane member to create a backside pressure that may chuck a substrate to the CMP head. Varying the pressures may across the zones provides for a predetermined removal profile in each radial zone. However, adjusting the pressures in the radial zones does not completely adjust for non-uniformities in a polar direction. A non-uniformity of the membrane member may cause a non-uniform removal profile in the substrate. As such, providing "polar asymmetry" in the polishing process may remove or reduce the effect of local non-uniformities in the removal profile.

[0018] Embodiments described herein are generally provided with regard to polishing 300 mm substrates. However, embodiments described herein may be adapted to polishing substrates of other sizes, such as 100 mm or 450 mm substrates. The CMP head which may be adapted to benefit from the embodiments described herein is the TITAN HEAD™ or TITAN CONTOUR, available from Applied Materials, Inc., Santa Clara, Calif. However, it is contemplated that carrier heads available from other manufacturers may be adapted to employ the embodiments described herein.

[0019] FIG. **1** is a partial cut-away view of a conventional carrier head **100**. The carrier head **100** includes a housing **106**, a head assembly **102**, and a retaining ring assembly **104**. The housing **102** may generally be circular in shape and may be connected to a drive shaft (not shown) to rotate therewith during polishing. There may be passages (not shown) extending through the housing **102** for pneumatic control of the carrier head **100**. The carrier head **100** also includes a retaining ring assembly **104** which includes a retaining ring **120**, a carrier ring **140**, a bearing clamp **110**, and an internal gear **112**. A bearing **130** may de-couple the head assembly **102** from the retaining ring assembly **104**.

[0020] FIG. **2** is a partial perspective view of the carrier head **100** of FIG. **1** having a head assembly **102** and a decoupled retaining ring assembly **104**. The head assembly **102** may comprise the housing **106** which may generally be circular in shape and may be connected to a drive shaft (not shown) to rotate therewith during polishing. There may be passages (not shown) extending through the housing **106** for pneumatic control of the carrier head **100**. A carrier body **208** may be flexibly coupled to the housing **106** and co-rotate with the housing **106**. The carrier body **208** may also be coupled to a flexible membrane **250** that may be adapted to chuck a substrate **201** during a CMP process. The flexible membrane **250** may define a plurality of pressurizable chambers for chucking the substrate **201**.

[0021] As previously described, the retaining ring assembly **104** may comprise a retaining ring assembly **120**, carrier ring **140**, a bearing clamp **110**, and an internal gear **112**. The carrier ring **140** may be a substantially ring-like structure. The carrier ring **140** may have an annular upper portion **244** and an annular lower portion **242**. The annular upper portion **244** may be disposed adjacent to and below the bearing clamp **110**. The annular lower portion **242** may be disposed adjacent to and above the retaining ring **120**. The carrier ring **140** may have a recess or hole disposed therethrough to accommodate a fastening apparatus, such as a screw or bolt (not shown), to couple the bearing clamp **110**, carrier ring **140**, and retaining ring **120**.

[0022] The retaining ring **120** may be formed from two rings, a lower annular ring **224** and an upper annular ring **222**. The lower annular ring **224** and upper annular ring **222** may be coupled together. When the lower annular ring **224** and the upper annular ring **222** are joined, the two rings have substantially the same dimensions at the inner and outer diameters on their adjacent surfaces such that the lower annular ring **224** and the upper annular ring **222** form a flush surface where they are joined.

[0023] In embodiments configured for 300 mm substrates, the substrate **201** may have an outer diameter of about 11.811 in. In one embodiment, an inner diameter of the lower annular ring **224** may be between about 11.830 in and about 11.870 in, such as 11.852 in. In this embodiment, a gear ratio between the substrate **201** outer diameter and the lower annular ring **224** inner diameter may be about 0.99654. In another embodiment, the inner diameter of the lower annular ring **224** may be between about 11.890 in and about 11.950 in, such as about 11.912 in. In this embodiment, a gear ratio between the substrate **201** outer diameter and the lower annular ring **224** inner diameter may be about 0.99152.

[0024] In certain embodiments, the lower annular ring **224** and upper annular ring **222** may be attached by a bonding material (not shown) at their adjacent surfaces. The interface between the lower annular ring **224** and the upper annular ring **222** may prevent trapping of a slurry material in the retaining ring **120**. The bonding material may be an adhesive material, such as a slow-curing or fast-curing epoxy. A high temperature epoxy may resist degradation of the bonding material due to high heat during the CMP process. In certain embodiments, the epoxy includes polyamide and aliphatic amines.

[0025] The upper annular ring **222** may have an inner surface **228** which may be adapted to couple with and provide support to the flexible membrane **250**. The upper annular ring **222** may be formed from a material that may be more rigid than the lower annular ring **224**, such as a metal, e.g. stainless steel, molybdenum, aluminum, ceramic materials, or other exemplary materials.

[0026] The lower annular ring **224** may be disposed adjacent to and below the upper annular ring **222**. The lower annular ring **224** may have a substrate retaining surface **226** which may be adapted to retain the substrate **201** during the CMP process. The lower annular ring **224** may be formed from a material that is chemically inert in a CMP process, such as a plastic, for example, polyphenylene sulfide (PPS). The lower annular ring **224** may also be adapted to provide durability and a low wear rate. The lower annular ring **224** may be sufficiently compressible so that contact of the substrate **201** edge against the lower annular ring **224** does not cause the substrate **201** to chip or crack. However, the lower annular ring **224** should not be so elastic that downward pressure on the retaining ring **120** causes the lower annular ring **224** to extrude during the CMP process.

[0027] The bearing clamp **110** may be substantially ring-like. The bearing clamp **110** may be disposed adjacent to and above the annular upper portion **244** of the carrier ring **140**. The bearing clamp **110** may be coupled to the carrier ring **140** by a fastener **213**, such as a screw or bolt. The bearing clamp **110** may be formed from a material such as a metal, e.g. stainless steel, molybdenum, aluminum, ceramic materials, or other exemplary materials. An upper portion **216** of the bearing clamp **110** may provide support for the internal gear **112**. The bearing clamp **110** may comprise a plurality of holes (not shown) which may be aligned with a plurality of holes (not shown) of the internal gear **112**. A bearing receiving region **218** may be adapted to receive a bearing **130**.

[0028] The bearing **130** may be coupled between the bearing clamp **110** and heads body **208**. The bearing **130** may comprise a first annular surface **232** which may be coupled to and disposed adjacent to the bearing receiving region **218** of the bearing clamp **110**. A second annular surface **234** may be coupled to and disposed adjacent to the carrier body **208**. A plurality of ball bearings **236** may be disposed between the first annular surface **232** and the second annular surface **234** and may be adapted to decouple the head assembly **102** from the retaining ring assembly **104**. The bearing **130** may provide an additional degree of rotational freedom to the carrier head **100**. The additional degree of rotational freedom allows the retaining ring assembly **104** to rotate independently of the head assembly **102**.

[0029] The internal gear **112** may be substantially ring-like. The internal gear **112** may be formed from a material such as a metal, e.g. stainless steel, molybdenum, aluminum, ceramic materials, or other exemplary materials. The internal gear **112** may be disposed adjacent to and coupled with an upper portion **216** of the bearing clamp **112**. The plurality of holes (not shown) may be disposed through the internal gear **112** and adapted to receive the fastener (not shown) which may be adapted to secure the internal gear **112** to the bearing clamp **110**. A plurality of teeth **214** may comprise an interior surface of the internal gear **112**.

[0030] In certain embodiments, a drive assembly **290** may be configured to provide rotational motion to the retaining ring assembly **104** independent of rotation of the head assembly **102**. The drive assembly **290** includes a cover ring **258**, a bracket **256**, a actuator **260**, a spindle **261**, and a worm drive **262**. The drive assembly **290** actuates a transmission **292** which may cause the retaining ring assembly **104** to rotate relative to the head assembly **102**.

[0031] The cover ring **258** may be disposed adjacent to and above a portion of the carrier body **208**. The cover ring **258** may be coupled to the carrier body **208** such that the cover ring **258**, and elements coupled thereto, move in the same rotational manner as the head assembly **102**. The bracket **256** may be disposed above and coupled to a top surface **259** of the cover ring **258**. The bracket **256** may be adapted to support the actuator **260** in a fixed position. The actuator **260**, such as an air motor, may be coupled to a pressure source **274** via a transport line **272**. The pressure source **274** may be adapted to provide a pressurized gas or fluid via the transport line **272** to the actuator **260**. A spindle **261** extends from the actuator **260** and a worm drive **262** may be coupled to the spindle **261**. The actuator **260** generally imparts rotational movement to the spindle **261** and causes the worm drive **262** to rotate.

[0032] The transmission **292** may be actuated by the worm drive **262**. The transmission **292** comprises a worm gear **264**, a spur gear **268**, a drive shaft **266**, and a shaft encoder **270**. The worm gear **264** may be disposed around a first end **265** of the drive shaft **266**. The worm gear **264** may be coupled to the worm drive **262** and adapted to translate the rotational movement of the worm drive **262** to the drive shaft **266**. The spur gear **268** may be disposed around the drive shaft **266** below the worm gear **264** at a region **269** substantially parallel to the teeth **214** of the internal gear **112**. The spur gear **268** may translate rotational movement of the drive shaft **266** to the internal gear **112**. Thus, the retaining ring assembly **104** may be rotated independently from the rotation of the head assembly **102**.

[0033] The shaft encoder **270** may be disposed below the spur gear **268** on the drive shaft **266**. The shaft encoder **270**, such as an electro-mechanical device, may convert the rotational motion of the drive shaft **266** to an analog or digital code. The shaft encoder **270** may be coupled to a controller (not shown) which may be coupled to the actuator **260**. The controller may be adapted to control the rotational speed at which the retaining ring **104** is rotated relative to the head assembly **102**.

[0034] A housing assembly **280** may be disposed in a portion of the carrier body **208** and may be adapted to receive the drive shaft **266**. The housing assembly **280** may have a bottom **286** and a plurality of side walls **282**. A second end **267** of the drive shaft **266** may be disposed within the housing assembly **280**. A plurality of bearings **284** may also be disposed within the housing assembly **280**. The plurality of bearings **284** may be disposed between the sidewalls **282** of the housing assembly **280** and the drive shaft **266**. The plurality of bearings **284** may couple the drive shaft **266** to the housing assembly **280** and allow for rotational movement of the drive shaft **266** relative to the housing assembly **280**.

[0035] In certain embodiments, the retaining ring assembly **104** may be driven at a speed greater than the rotational speed of which the head assembly **102** may be rotated. For example, during a 60 second CMP polishing process, the head assembly **102** may be rotated at a speed achieving about 60 rpm to about 120 rpm. In this example, the rotational speed of the retaining ring assembly **104** may be greater than the rotational speed of the polishing head which may encourage substrate precession. It is contemplated that the retaining ring assembly **104** may be rotated in the same of opposite direction relative to the rotational direction of the head assembly **102**. Moreover, the substrate precession may be affected by the rotational direction of a polishing pad against which the substrate **201** is polished.

[0036] FIG. **3** is a schematic bottom view of the retaining ring assembly **104** and substrate **201**. The inner diameter of the retaining ring assembly **104** may be greater than the outer diameter of the substrate **201**. A rotation direction **306** of the retaining ring assembly **104** encourages substrate **201** rotation **308** in a direction relative to a head assembly (not shown), such as head assembly **102** (See FIG. **2**). The rotation **308** of the substrate **201** relative to the head assembly may be defined as substrate precession as previously discussed.

[0037] A previously described, substrate precession is the degree of rotation or slip experienced by the substrate **201** relative to the membrane **250** on the head assembly **102**. It is believed that encouraging substrate precession may "average out" any potential local non-uniformities in a substrate removal profile over a given polishing time. It is believed that the polar asymmetry created by substrate precession results in an averaging effect with regard to local non-uniformities in the membrane **250** or the polishing pad. The local non-uniformities may result in a non-planar removal profile and therefore it may be advantageous to reduce the effects of the local non-uniformities.

[0038] It is also believed that substrate precession may be dictated by the relationship between the substrate **201** outer diameter and the retaining ring assembly **104** inner diameter. The relationship between the substrate **201** outer diameter and the retaining ring assembly **104** inner diameter may be described in terms of a gear ratio. A smaller gear ratio between the retaining ring assembly **104** inner diameter and the substrate **201** outer diameter will result in increased substrate precession.

[0039] It is further believed that driving the retaining ring assembly **104** at a speed greater than a speed of the head assembly **102** may further encourage substrate precession. In one embodiment, a head assembly **102** rotational speed of about 60 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.852 in may provide about 90° of substrate precession. In another embodiment, a head assembly **102** rotational speed of about 90 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.852 in may provide about 135° of substrate precession. In another embodiment, a head assembly **102** rotational speed of about 120 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.852 in may provide about 100° of substrate precession. The gear ratio of the above embodiments may be about 0.99654. In the aforementioned embodiments, the retaining ring assembly **104** maybe co-rotated or counter-rotated at a rotational speed greater than the rotational speed of the head assembly **102**.

[0040] In one embodiment, a head assembly **102** rotational speed of about 60 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.912 in may provide about 180° of substrate precession. In another embodiment, a head assembly **102** rotational speed of about 90 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.912 in may provide about 270° of substrate precession. In another embodiment, a head assembly **102** rotational speed of about 120 rpm in combination with a retaining ring assembly **104** inner diameter of about 11.912 in may provide about 360° of substrate precession. The gear ratio of the above embodiments may be about 0.99152. In the aforementioned embodiments, the retaining ring assembly **104** maybe co-rotated or counter-rotated at a rotational speed greater than the rotational speed of the head assembly **102**.

[0041] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

1. An apparatus for polishing a substrate, comprising:
a head assembly;
a retaining ring assembly comprising:
an internal gear; and
a bearing disposed between the head assembly and the retaining ring assembly, wherein the bearing is adapted to decouple the retaining ring assembly from the head assembly; and
a drive assembly adapted to rotate the retaining ring assembly relative to the head assembly.

2. The apparatus of claim **1**, wherein the head assembly further comprises:
a housing;
a carrier body; and
a flexible membrane.

3. The apparatus of claim **1**, wherein the head assembly further comprises a cover plate coupled to the drive assembly.

4. The apparatus of claim **1**, further comprising:
a transmission comprising:
a first gear;
a second gear;
a shaft encoder; and
a drive shaft.

5. The apparatus of claim **4**, wherein the first gear is rotatably coupled to the drive assembly.

6. The apparatus of claim **4**, wherein the second gear is rotatably coupled to the internal gear.

7. The apparatus of claim **4**, wherein the first gear and the second gear are coupled to the drive shaft.

8. The apparatus of claim **1**, wherein the drive assembly comprises:
an actuator;
a spindle coupled to the actuator; and
a worm drive coupled to the spindle.

9. The apparatus of claim **8**, wherein the actuator is an air motor.

10. The apparatus of claim **1**, wherein the internal gear comprises a plurality of teeth.

11. The apparatus of claim **1**, wherein an inner diameter of the retaining ring assembly is between about 11.830 in and about 11.870 in.

12. The apparatus of claim **1**, wherein an inner diameter of the retaining ring assembly is between about 11.890 in and about 11.950 in.

13. A retaining ring assembly for a polishing head, comprising:
a retaining ring having an upper annular portion and a lower annular portion;
a carrier ring coupled to the upper annular portion;
a bearing clamp coupled to the carrier ring, the bearing clamp adapted to receive a bearing; and
an internal gear coupled to the bearing clamp.

14. The apparatus of claim **13**, wherein the bearing decouples the retaining ring assembly from a polishing head assembly.

15. A method of operating a polishing apparatus, comprising:
providing a polishing head assembly and a retaining ring assembly, wherein the retaining ring assembly is decoupled from the polishing head assembly;
rotating the polishing head at a first speed; and
rotating the retaining ring assembly at a second speed greater than the first speed.

16. The method of claim **15**, wherein the first speed is between about 60 rpm and about 120 rpm.

17. The method of claim **15**, wherein the polishing head assembly and the retaining ring assembly are rotated in the same direction.

18. The method of claim **15**, wherein the polishing head assembly and retaining ring assembly are rotated in opposite directions.

19. The method of claim **15**, wherein a rotation direction of the polishing head assembly and a rotation direction of a polishing pad are the same.

20. The method of claim **15**, wherein the rotation direction of the polishing head assembly and a rotation direction of a polishing pad are opposite.

* * * * *