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(54) **PAD CONDITIONING PROCESS CONTROL USING LASER CONDITIONING**

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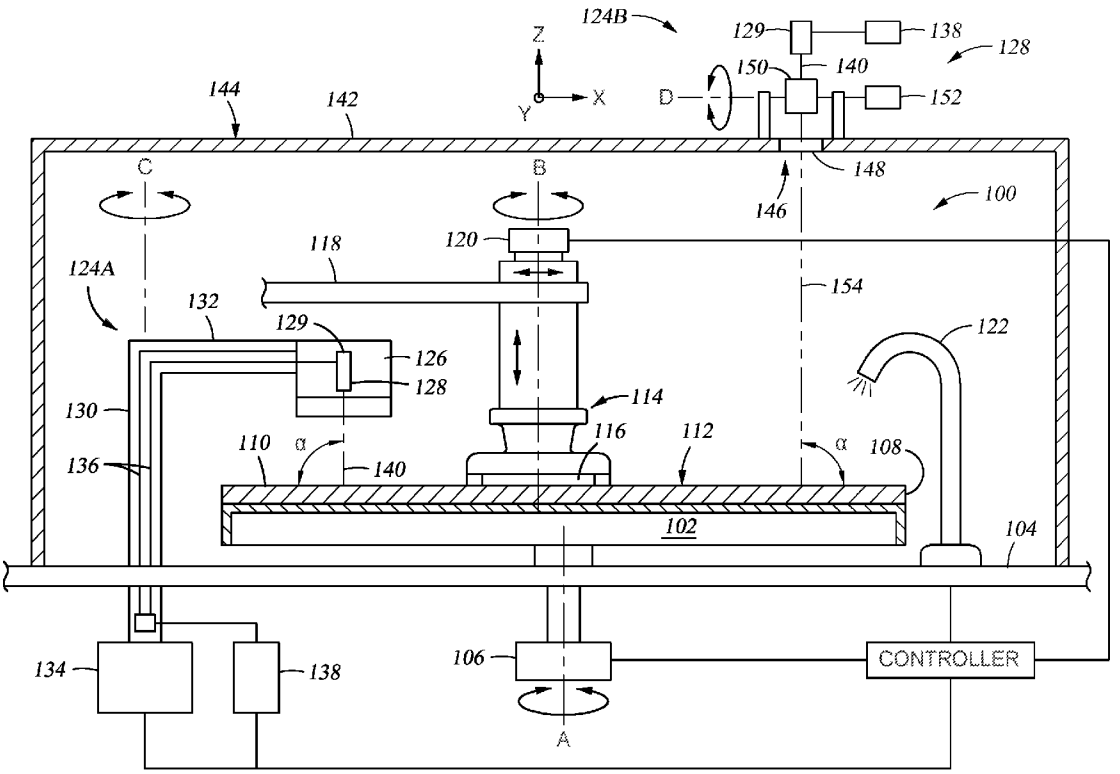
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CPC ***B24B 53/017*** (2013.01); ***B24B 37/042*** (2013.01)

USPC **451/6**; 451/56

(57) **ABSTRACT**

A method and apparatus for conditioning a polishing pad used in a substrate polishing process. In one embodiment, a method for conditioning a polishing pad utilized to polish a substrate is provided. The method includes providing relative motion between an optical device and a polishing pad having a polishing medium disposed thereon, and scanning a processing surface of the polishing pad with a laser beam to condition the processing surface, wherein the laser beam has a wavelength that is substantially transparent to the polishing medium, but is reactive with the material of the polishing pad.



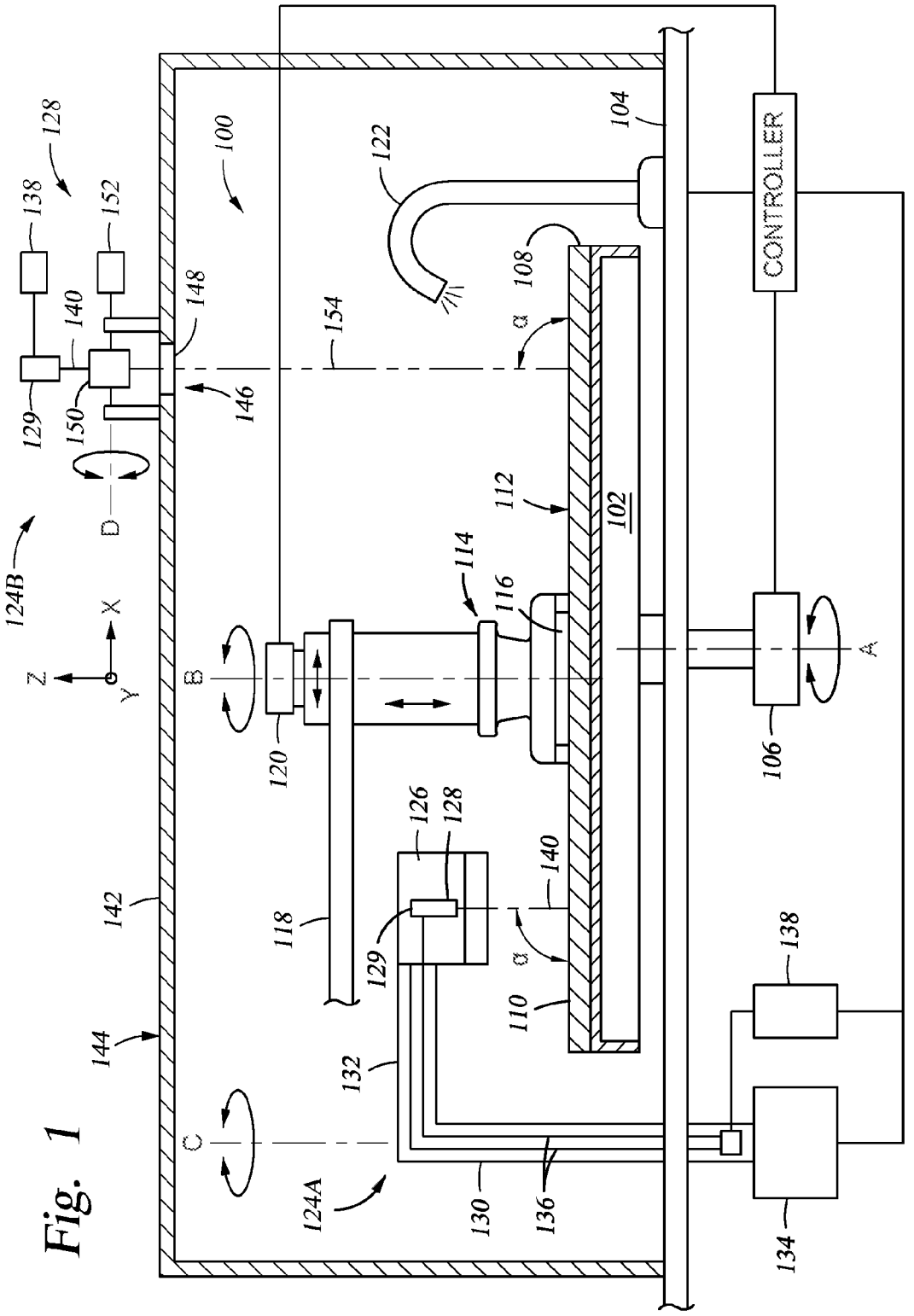

CONTROLLER
100
102
104
106
108
110
112
114
116
118
120
122
124A
124B
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
A
B
C
D
X
Y
Z
α

Fig. 1

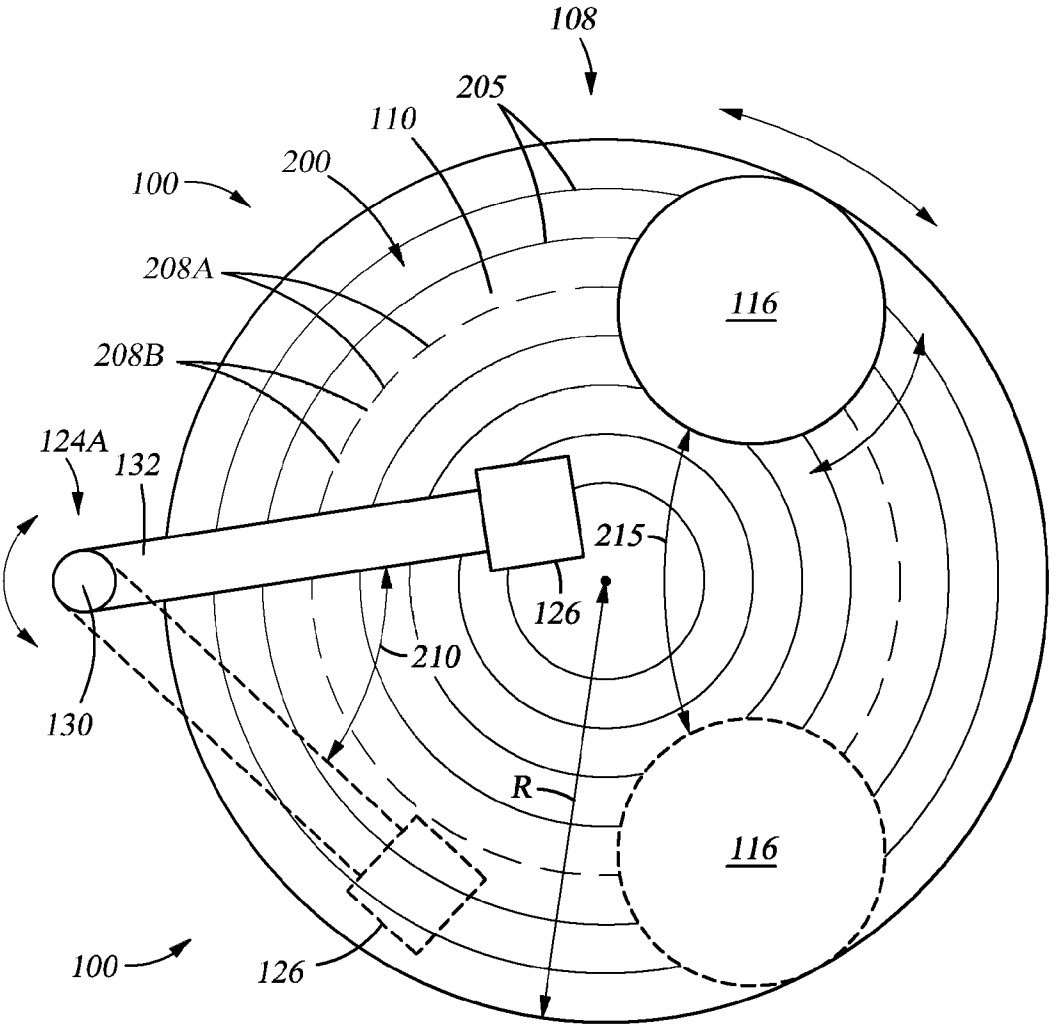

108
205
110
200
100
208A
208B
124A
132
116
215
126
210
130
R
116
100
126

Fig. 2

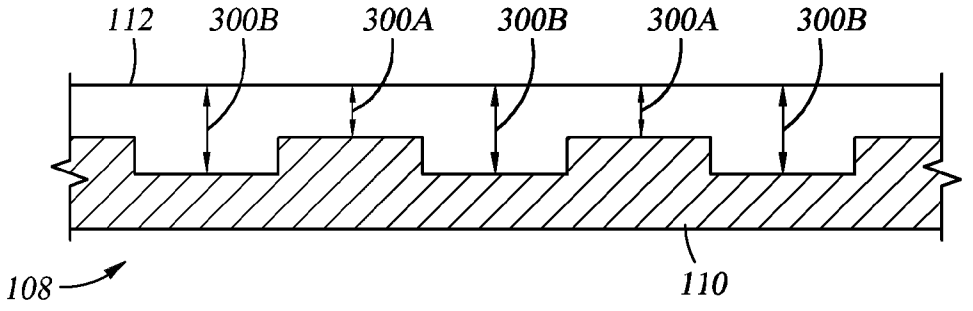

112
300B
300A
300B
300A
300B
108
110

Fig. 3

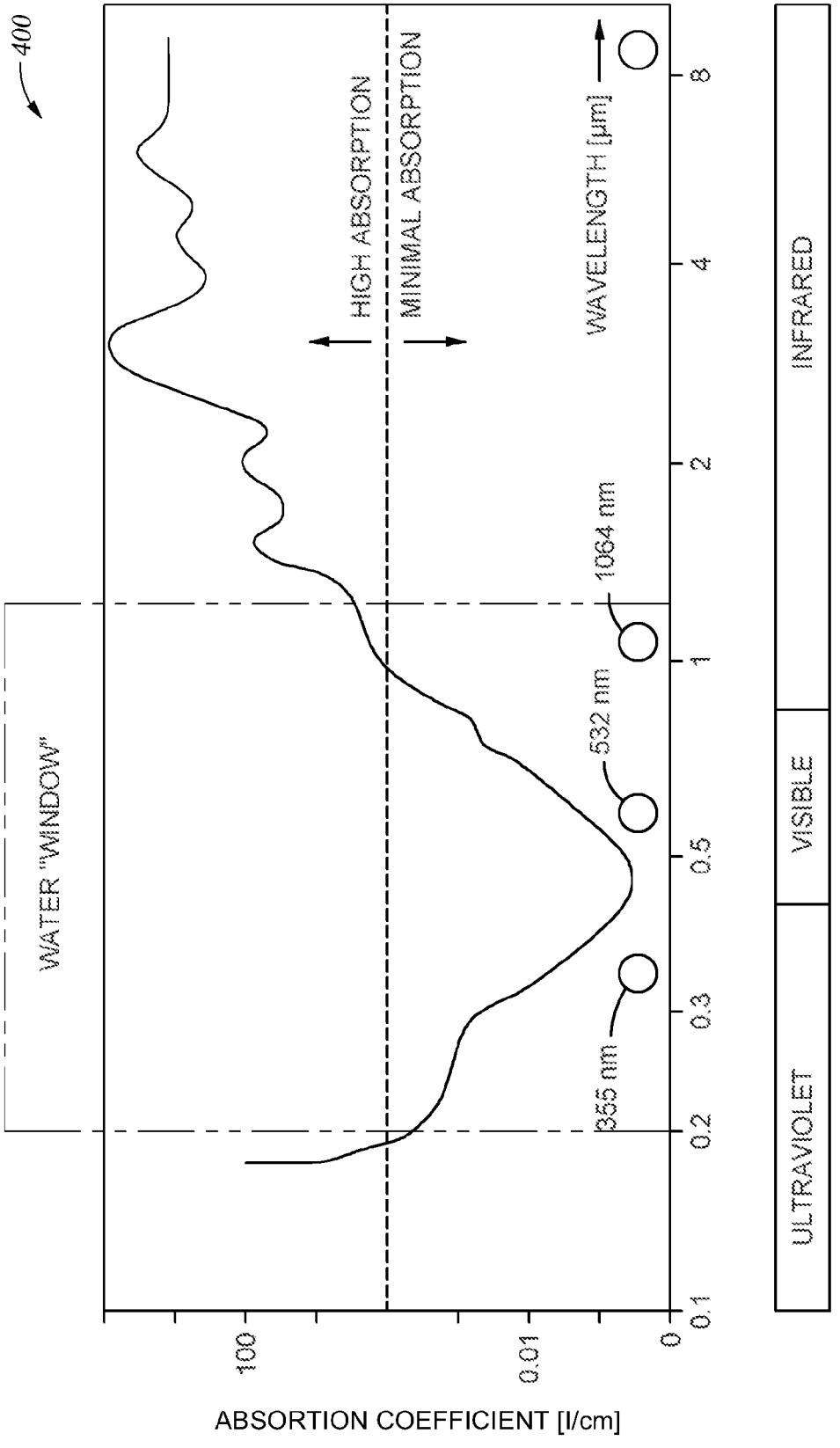

400
WATER "WINDOW"
HIGH ABSORPTION
MINIMAL ABSORPTION
WAVELENGTH [µm]
1064 nm
532 nm
355 nm
ULTRAVIOLET
VISIBLE
INFRARED
ABSORTION COEFFICIENT [l/cm]
100
0.01
0
0.1
0.2
0.3
0.5
1
2
4
8

Fig. 4

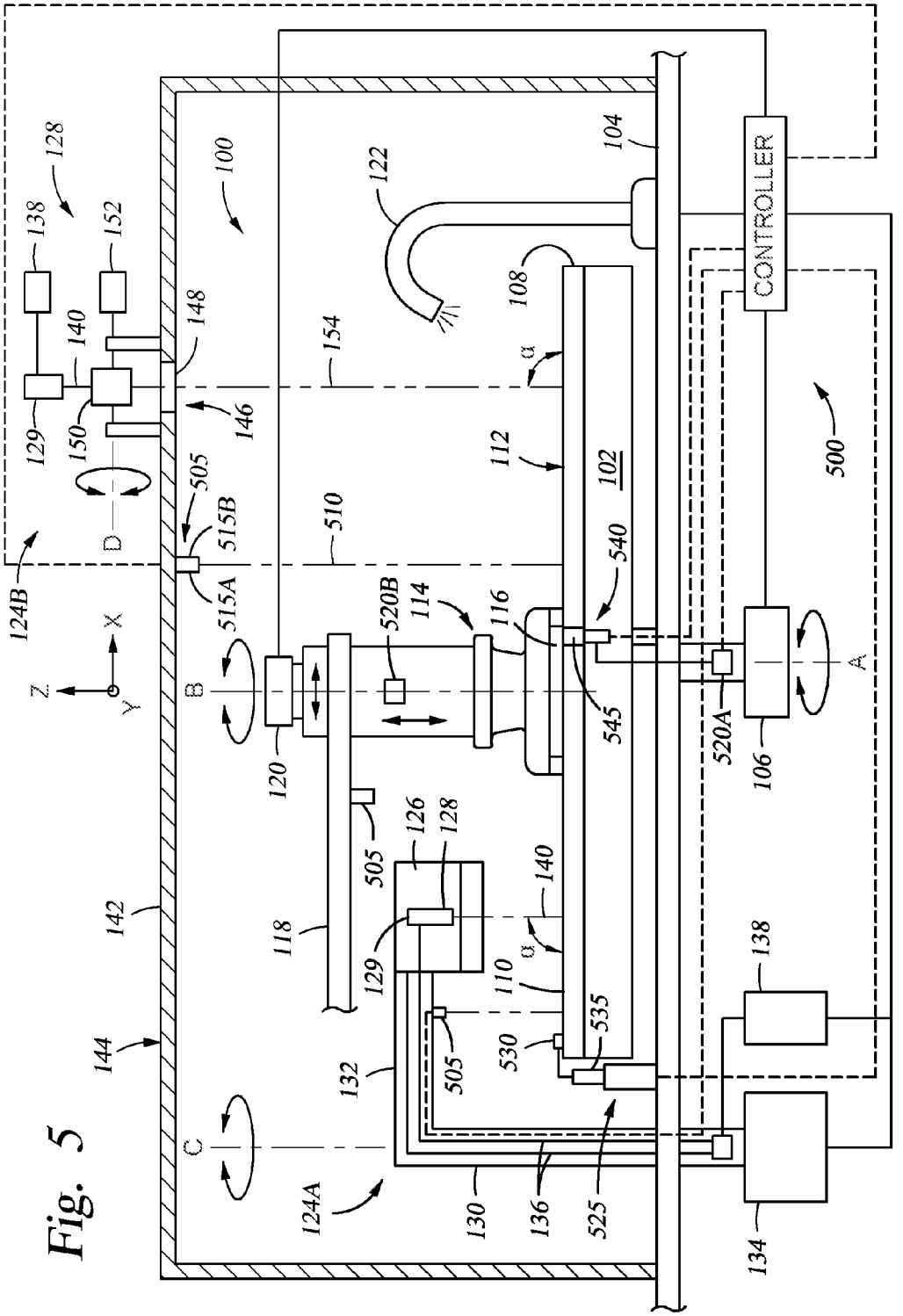

CONTROLLER
100
102
104
106
108
110
112
114
116
118
120
122
124A
124B
126
128
129
130
132
134
136
138
140
142
144
146
148
150
152
154
500
505
510
515A
515B
520A
520B
525
530
535
540
545
A
B
C
D
X
Y
Z
α

Fig. 5

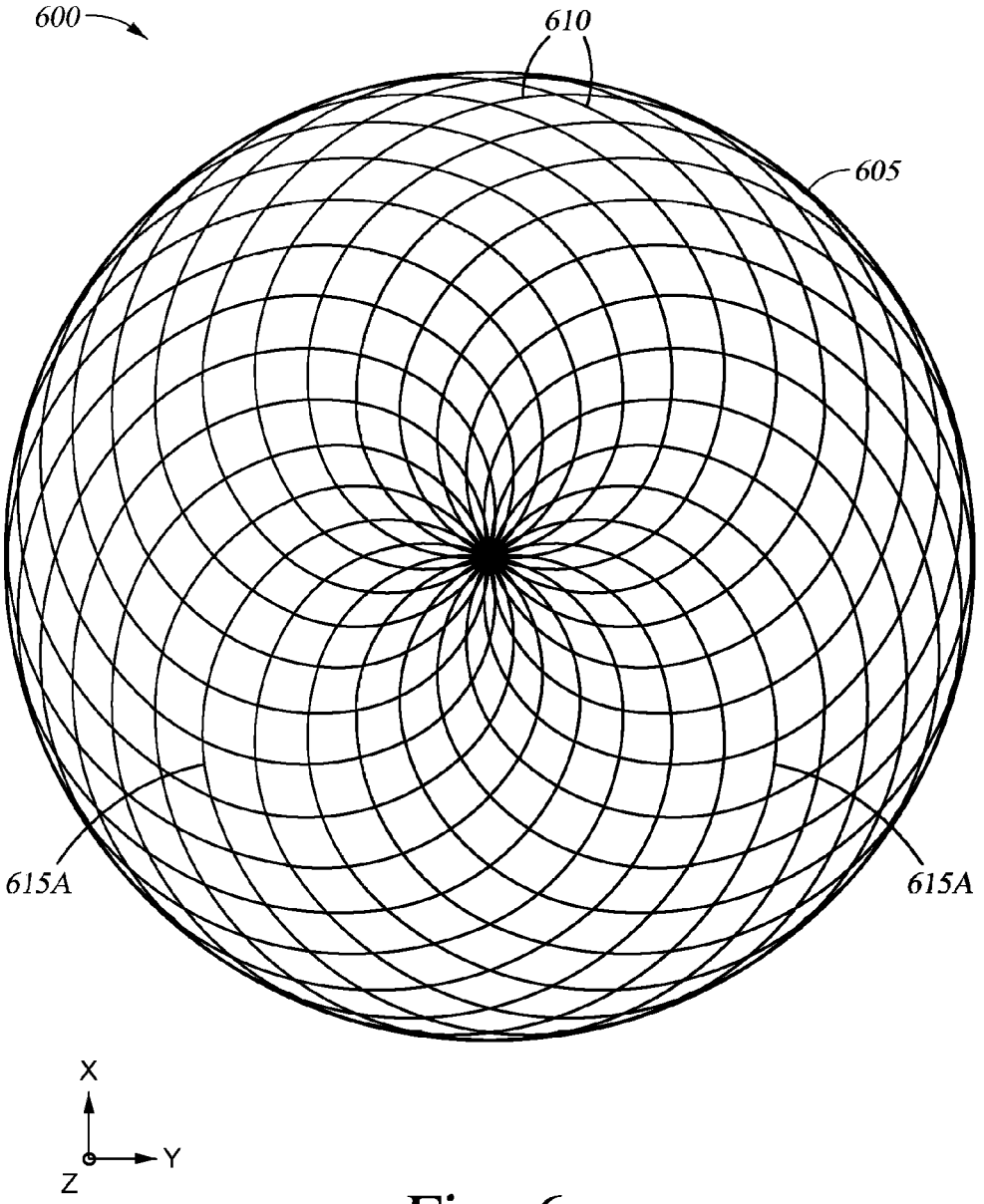


Fig. 6

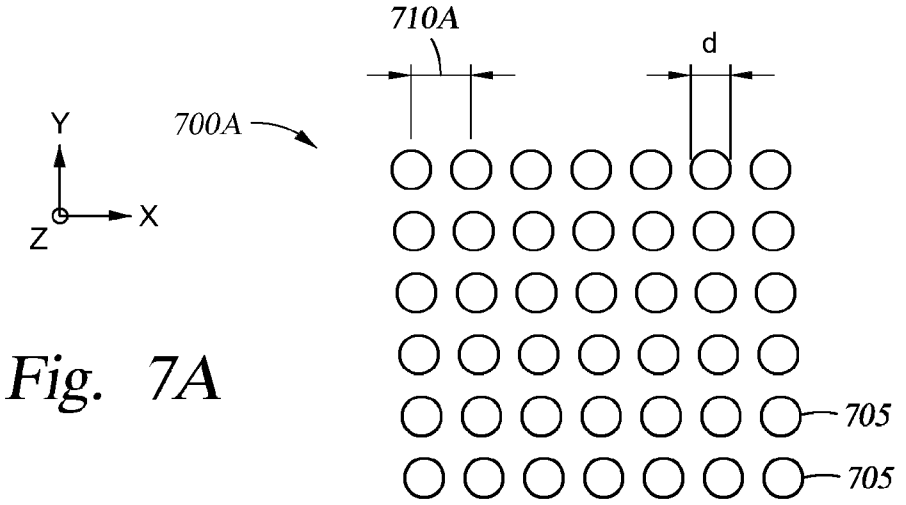


Fig. 7A

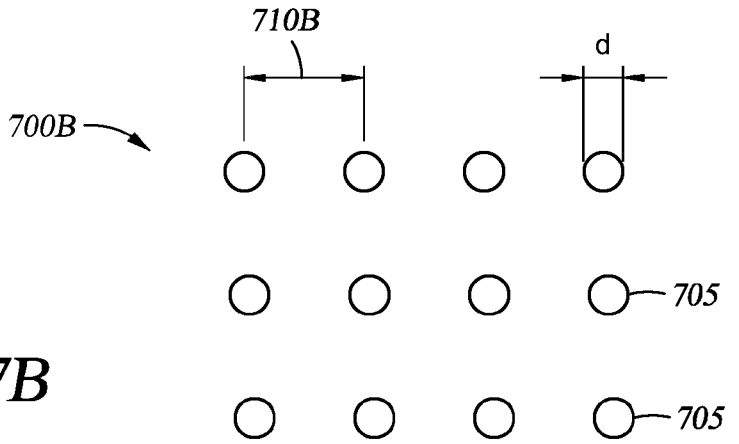


Fig. 7B

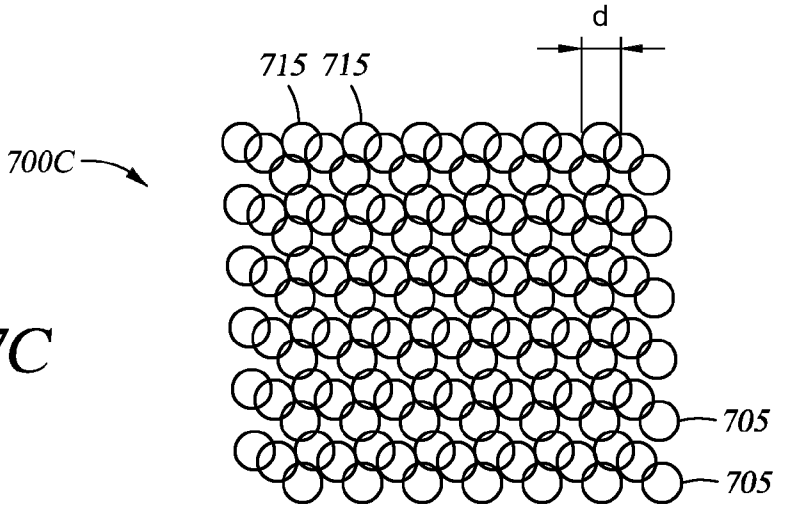


Fig. 7C

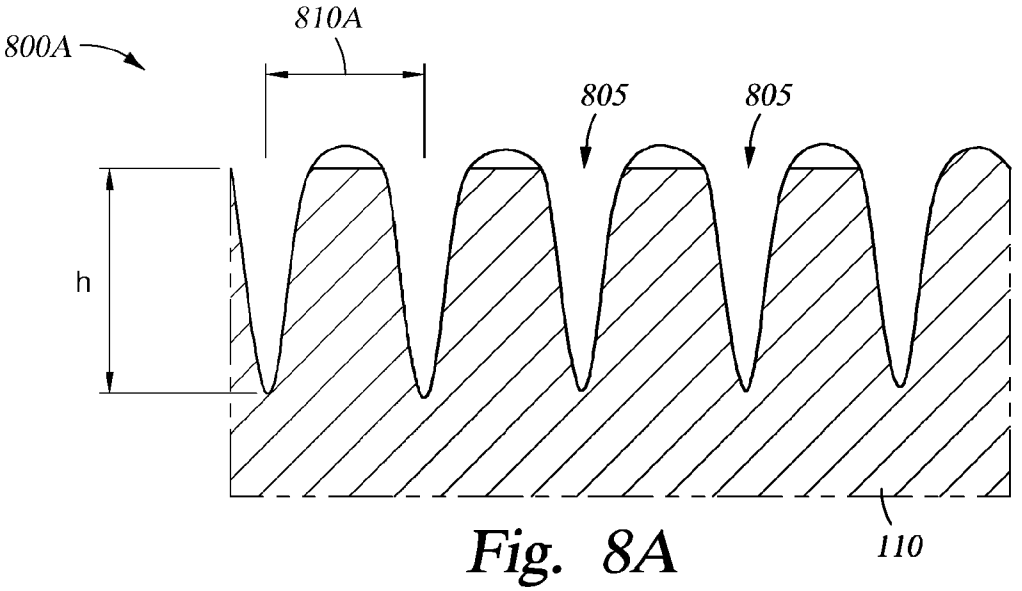


Fig. 8A

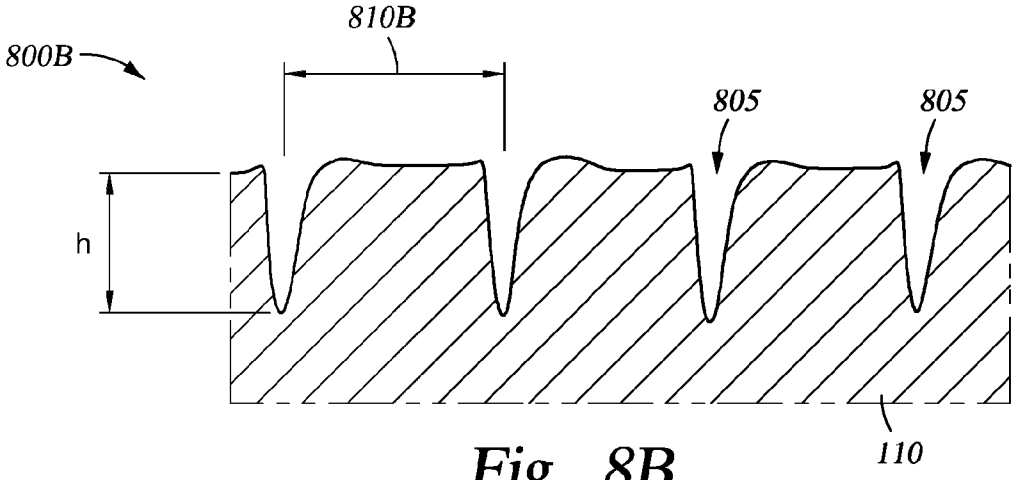


Fig. 8B

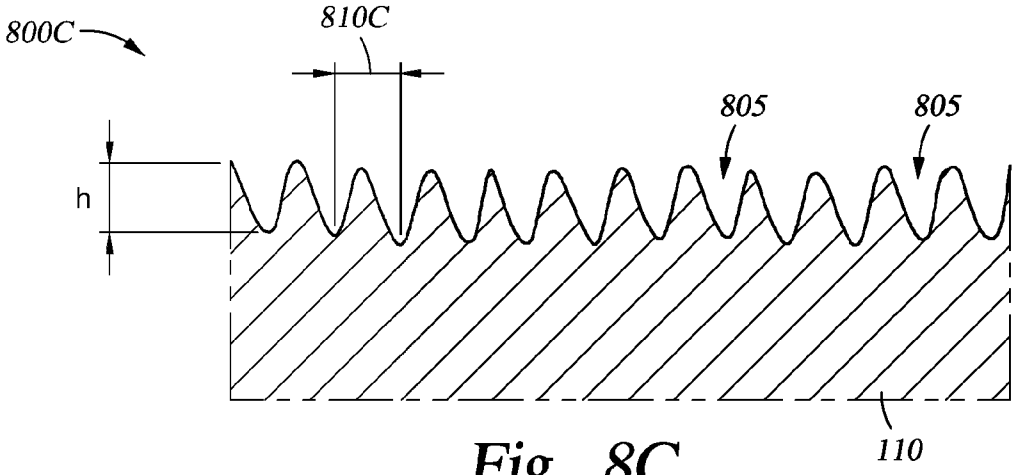


Fig. 8C

Fig. 9A

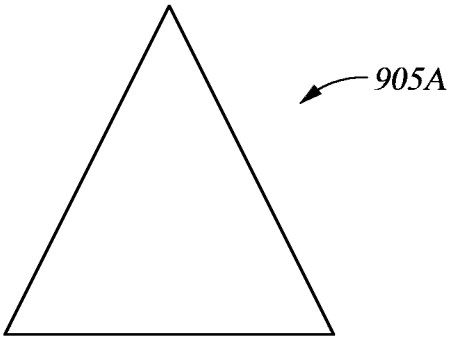


Fig. 9B

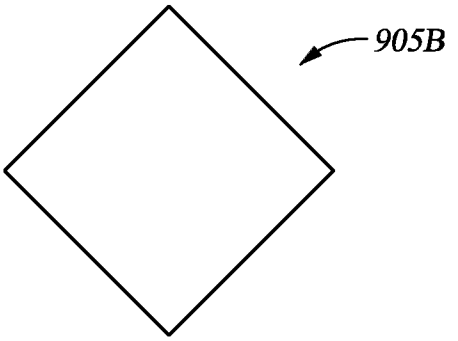


Fig. 9C

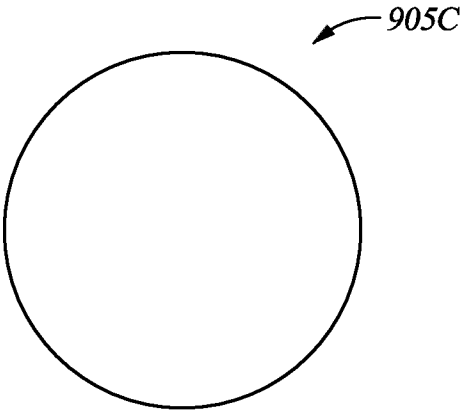
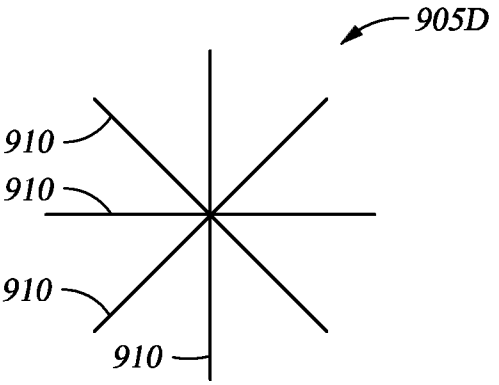


Fig. 9D



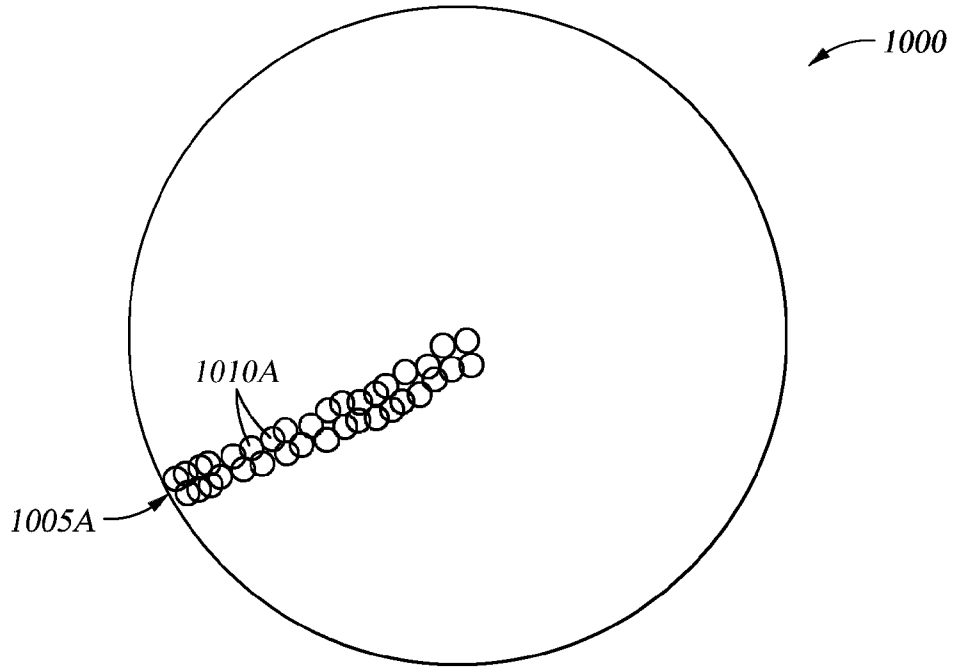


Fig. 10A

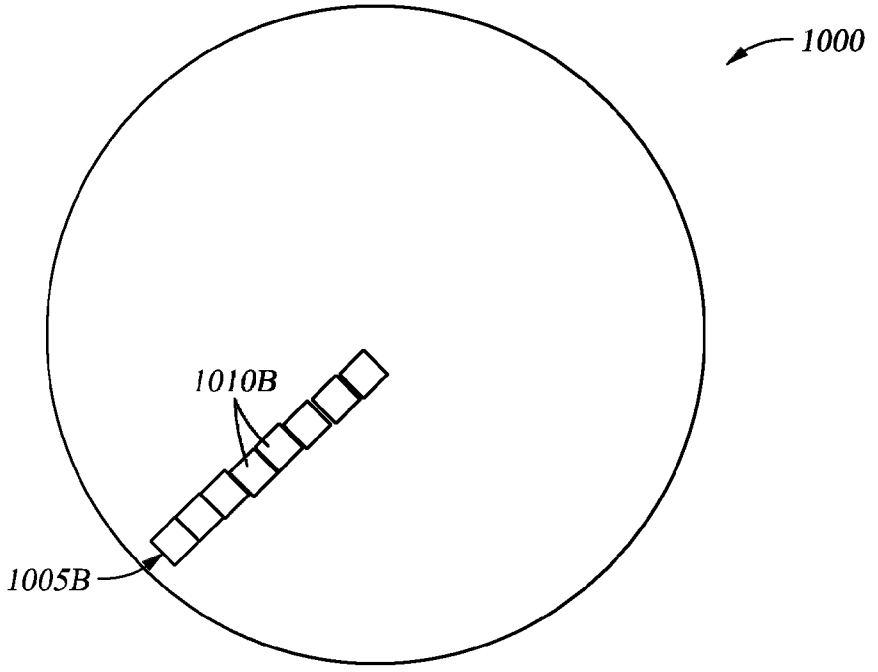


Fig. 10B

PAD CONDITIONING PROCESS CONTROL USING LASER CONDITIONING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. Patent Application Ser. No. 61/780,155 (Attorney Docket No. 020572USAL) filed Mar. 13, 2013, and U.S. Patent Application Ser. No. 61/935,747 (Attorney Docket No. 021012USAL) filed Feb. 4, 2014. Both of the aforementioned patent applications are hereby incorporated by reference herein.

BACKGROUND

[0002] 1. Field

[0003] Embodiments of the present invention generally relate to control methods and apparatus for conditioning a substrate polishing pad using optical conditioning devices, such as laser conditioning devices.

[0004] 2. Description of the Related Art

[0005] In the fabrication of integrated circuits and other electronic devices on substrates, multiple layers of conductive, semiconductive, and dielectric materials are deposited on or removed from a feature side, i.e., a deposit receiving surface, of a substrate. As layers of materials are sequentially deposited and removed, the feature side of the substrate may become non-planar and require planarization and/or polishing. Planarization and polishing are procedures where previously deposited material is removed from the feature side of the substrate to form a generally even, planar or level surface. The procedures are useful in removing undesired surface topography and surface defects, such as rough surfaces, agglomerated materials, crystal lattice damage, and scratches. The procedures are also useful in forming features on a substrate by removing excess deposited material used to fill the features and to provide an even or level surface for subsequent deposition and processing.

[0006] During polishing processes, the polishing surface of the pad that is in contact with the feature side of the substrate experiences a deformation. The deformation includes smoothing of the polishing surface and/or unevenness in the plane of the polishing surface, as well as clogging or blockage of pores in the polishing surface that may lessen the ability of the pad to properly and efficiently remove material from the substrate. Periodic conditioning of the polishing surface is required to maintain a consistent roughness, porosity and/or a generally flat profile across the polishing surface.

[0007] One method to condition the polishing surface utilizes an abrasive conditioning disk that is urged against the polishing surface while being rotated and/or swept across the majority of the polishing surface. The abrasive portion of the conditioning disk, which may be diamond particles or other hard materials, typically cut into the pad surface, which forms grooves in, and otherwise roughens, the polishing surface. However, while the rotation and/or downforce applied to the conditioning disk is controlled, the abrasive portion may not cut into the polishing surface evenly, which creates a difference in roughness across the polishing surface. Additionally, as the cutting action is not readily controlled, the pad lifetime may be shortened. Further, the cutting action of these conditioning devices and systems sometimes produce large asperities in the polishing surface. While the asperities are beneficial in the polishing process, the asperities may break loose during polishing, which creates debris that may contribute to defects in the substrate.

[0008] Therefore, there is a need for an improved pad conditioning process and associated control methods.

SUMMARY

[0009] A method and apparatus for conditioning a polishing pad utilized in a polishing process is provided. In one embodiment, a method for conditioning a polishing pad utilized to polish a substrate is provided. The method includes providing relative motion between an optical device and a polishing pad having a polishing medium disposed thereon, and scanning a processing surface of the polishing pad with a laser beam to condition the processing surface, wherein the laser beam has a wavelength that is substantially transparent to the polishing medium, but is reactive with the material of the polishing pad.

[0010] In another embodiment, a method for polishing a substrate is provided. The method includes urging a substrate against a processing surface of a polishing pad while providing relative movement between the substrate and the polishing pad, providing a polishing medium to the processing surface, monitoring a state of the processing surface during the relative movement, and conditioning the processing surface with an optical device comprising a laser emitter adapted to emit a beam having a wavelength range that is substantially non-reactive with the polishing medium, but is reactive with the polishing pad.

[0011] In another embodiment, a method for conditioning a polishing pad is provided. The method includes scanning a beam relative to a processing surface of the polishing pad having water disposed thereon, the beam having a wavelength range that is non-reactive with the water, but is reactive with the polishing pad, the beam having a wavelength range that is substantially non-reactive with the water, but is reactive with the polishing pad, and conditioning the processing surface of the polishing pad.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] 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.

[0013] FIG. **1** is a partial sectional view of one embodiment of a processing station that is configured to perform a polishing process.

[0014] FIG. **2** is a top plan view of the processing station of FIG. **1**.

[0015] FIG. **3** is a cross-sectional view of a portion of a polishing pad.

[0016] FIG. **4** is a graph showing absorption coefficients for various wavelengths of light.

[0017] FIG. **5** is a partial sectional view of the processing station of FIG. **1** showing a monitoring/feedback system.

[0018] FIG. **6** is a top plan view of a polishing pad showing another embodiment of a patterned processing surface.

[0019] FIGS. **7**A-**7**C are schematic top views of mark arrays that may be formed on a polishing pad.

[0020] FIGS. **8**A-**8**C are schematic cross-sectional views of mark arrays that may be formed on a polishing pad.

[0021] FIGS. **9**A-**9**D are schematic top views of various embodiments of marks that may be formed in or on a polishing pad.

[0022] FIGS. **10**A and **10**B are schematic top views of a polishing pad showing embodiments of a portion of a patterned processing surface.

[0023] 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 disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.

DETAILED DESCRIPTION

[0024] FIG. **1** is a partial sectional view of one embodiment of a processing station **100** that is configured to perform a polishing process, such as a chemical mechanical polishing (CMP) process or an electrochemical mechanical polishing (ECMP) process. The processing station **100** may be a stand-alone unit or part of a larger processing system. Examples of a larger processing system that the processing station **100** may be utilized with include REFLEXION®, REFLEXION® GT, REFLEXION® LK, REFLEXION® LK ECMP™, MIRRA MESA® polishing systems available from Applied Materials, Inc., located in Santa Clara, Calif., although other polishing systems may be utilized, including those from other manufacturers. Other polishing modules, including those that use other types of processing pads, belts, indexable web-type pads, or a combination thereof, and those that move a substrate relative to a polishing surface in a rotational, linear or other planar motion may also be adapted to benefit from embodiments described herein.

[0025] The processing station **100** includes a platen **102** rotatably supported on a base **104**. The platen **102** is operably coupled to a drive motor **106** adapted to rotate the platen **102** about a rotational axis A. The platen **102** supports a polishing pad **108** having a body **110**. The body **110** of the polishing pad **108** may be a commercially available pad material, such as polymer based pad materials typically utilized in CMP processes, or other polishing article suitable for practicing the invention. The polymer material may be a polyurethane, a polycarbonate, fluoropolymers, PTFE, PTFA, polyphenylene sulfide (PPS), or combinations thereof. The body **110** may further comprise open or closed cell foamed polymers, elastomers, felt, impregnated felt, plastics, and like materials compatible with the processing chemistries. While the body **110** may be dielectric, it is contemplated that polishing pads having at least partially conductive polishing surfaces may also benefit from the invention.

[0026] The polishing pad **108** comprises a processing surface **112** which includes a naphthat may include microscopic pore structures. The nap and/or pore structures effect material removal from the feature side of a substrate. Attributes of the processing surface **112**, such as polishing compound retention, polishing or removal activity, and material and fluid transportation, affect the removal rate. In order to facilitate optimal removal of material from the substrate, the processing surface **112** must be periodically conditioned to roughen and/or fully and evenly open the nap or pore structures. When the processing surface **112** is conditioned in this manner, the processing surface **112** provides a uniform and stable removal rate. The roughened processing surface **112** facilitates removal by enhancing pad surface wetability and dispersing polishing compounds, such as, for example, abrasive particles supplied from a polishing compound.

[0027] A carrier head **114** is disposed above the processing surface **112** of the polishing pad **108**. The carrier head **114** retains a substrate **116** and controllably urges the substrate **116** against the processing surface **112** (along the Z axis) of the polishing pad **108** during processing. The carrier head **114** is mounted to a support member **118** that supports the carrier head **114** and facilitates movement of the carrier head **114** relative to the polishing pad **108**. The support member **118** may be coupled to the base **104** or mounted above the processing station **100** in a manner that suspends the carrier head **114** above the polishing pad **108**. In one embodiment, the support member **118** is a circular track that is mounted above the processing station **100**. In another embodiment, the support member **118** is a support arm that couples to a central support member (not shown) that may rotate the support member **118** relative to the processing station **100**.

[0028] The carrier head **114** is coupled to a drive system **120** that provides at least rotational movement of the carrier head **114** about a rotational axis B. The drive system **120** may additionally be configured to move the carrier head **114** along the support member **118** laterally (X and/or Y axes) relative to the polishing pad **108**. In one embodiment, the drive system **120** moves the carrier head **114** vertically (Z axis) relative to the polishing pad **108** in addition to lateral movement. For example, the drive system **120** may be utilized to urge the substrate **116** against the polishing pad **108** in addition to providing rotational and/or lateral movement of the substrate **116** relative to the polishing pad **108**. The lateral movement of the carrier head **114** may be a linear, or an arcing or sweeping motion (shown as **215** in FIG. **2**).

[0029] A fluid applicator **122** is shown positioned over the processing surface **112** of the polishing pad **108**. The fluid applicator **122** is adapted to provide polishing medium, such as polishing fluids or a polishing compound, to at least a portion of the radius of the polishing pad **108**. The polishing fluid or polishing compound may be a chemical solution, a slurry, a cleaning solution, or a combination thereof, consisting primarily of water (e.g., about 70% to about 99%, or greater, content of de-ionized water (DIW)). For example, the medium may be an abrasive containing or abrasive free polishing compound adapted to aid in removal of material from the feature side of the substrate **116**. Reductants and oxidizing agents, such as hydrogen peroxide, may also be added to the medium. Alternatively, the medium may be a rinsing agent, such as DIW, which is used to rinse or flush polishing byproducts from the polishing material of the polishing pad **108**.

[0030] FIG. **1** also shows two distinct embodiments of a conditioning device, shown as a first conditioner device **124**A and a second conditioner device **124**B. One or both of the first conditioner device **124**A and the second conditioner device **124**B may be utilized with the processing station **100**.

[0031] The first conditioner device **124**A generally includes a conditioner head **126** coupled to the base **104** of the processing station **100**. The conditioner head **126** may comprise an optical device **128**. The optical device **128** may be a laser emitter, a lens, a mirror, or other suitable device for emitting, transmitting, or directing a light beam **140** toward the processing surface **112** of the polishing pad **108**. In one embodiment, the optical device **128** comprises a laser emitter

129. The laser emitter 129 may alternatively be located remotely from the first conditioner device 124A. Utilizing this architecture, the optical device 128 comprises optics necessary to deliver the beam 140 to the processing surface 112 of the polishing pad 108. The conditioner head 126 is coupled to a support member 130 by a support arm 132. The support member 130 is disposed through the base 104 of the processing station 100. Bearings (not shown) are provided between the base 104 and the support member 130 to facilitate rotation of the support member 130 about a rotational axis C relative to the base 104. An actuator 134 is coupled between the base 104 and the support member 130 to control the rotational orientation of the support member 130 about the rotational axis C to allow the conditioner head 126 to move in an arc or sweeping motion above the processing surface 112 of the polishing pad 108.

[0032] In one embodiment, the laser emitter 129 is utilized to emit the beam 140 that impinges the polishing pad 108 to condition the processing surface 112. For example, the beam 140 may be utilized to form groove patterns in or on the processing surface 112 of the polishing pad 108. The beam 140 may be a primary beam or the beam 140 may be a secondary beam that is emitted from a reflective component (not shown) that may be part of the optical device 128. The groove patterns provided in or on the processing surface 112 of the polishing pad 108 may be formed on polishing pads that have a relatively flat or planar processing surface, and may also be formed on polishing pads that have a non-planar processing surface. For example, the beam 140 and/or 154 may be utilized to condition polishing pads with a non-planar processing surface without flattening the processing surface.

[0033] The support member 130 may house drive components to selectively control the vertical position (in the Z axis) and/or the angle α of one of the conditioner head 126 and the optical device 128 relative to the plane of the processing surface 112 of the polishing pad 108. The support member 130 and/or the support arm 132 may also contain signal members 136 that are coupled between a signal generator 138 and the optical device 128. The signal generator 138 may be a controllable power supply and the signal members 136 may be wires or optical fibers. The actuator 134 may also provide vertical positioning of the support member 130 (in the Z direction) to provide height control of the conditioner head 126 relative to the polishing pad 108.

[0034] In some embodiments, the actuator 134 may also be used to provide contact between the polishing pad 108 and the conditioner head 126, as well as urge the conditioner head 126 against the processing surface 112 of the polishing pad 108 with a controllable downforce. In one embodiment (not shown), the conditioner head 126 may include a housing that contacts the polishing pad 108 during conditioning. The housing may be coupled to a vacuum device (not shown) and/or a fluid source (not shown) to facilitate removal of materials that are released from the processing surface 112 of the polishing pad 108 during conditioning.

[0035] The second conditioner device 124B is positioned above the processing surface 112 of the polishing pad 108, and, in one embodiment, is supported by a ceiling 142 of an enclosure 144 that at least partially isolates the processing station 100 from the surrounding environment. The second conditioner device 124B includes the optical device 128, which may include the laser emitter 129 and/or optics necessary for delivering a secondary beam 154 generated by the laser emitter 129 to the processing surface 112 of the polishing pad 108 disposed on the platen 102. In one embodiment, the optical device 128 is positioned to direct the secondary beam 154 through an opening 146 formed through the ceiling 142. The opening 146 may include a window 148 that is transparent to the wavelength of the secondary beam 154. The window 148 may be utilized to prevent any polishing debris or gases from exiting the enclosure 144. In this embodiment, the optical device 128 includes the laser emitter 129 and may optionally include a reflective component 150 to scan the secondary beam 154 relative to the processing surface 112 of the polishing pad 108 to condition the processing surface 112 of the polishing pad 108. The reflective component 150 may be a mirror, such as a scanning mirror or a scanning galvo-mirror that is coupled to an actuator 152 to move the reflective component 150 about an axis D (about the X axis). In another embodiment, the reflective component 150 may be configured to rotate about the Y axis (to change the angle α relative to the processing surface 112 of the polishing pad 108) as an alternative to, or in addition to, the movement about the axis D.

[0036] In one embodiment, the laser emitter 129 is adapted to emit the beam 140 as a primary beam that may be directed through the window 148 toward the processing surface 112 of the polishing pad 108 to condition the processing surface 112 of the polishing pad 108, for example, by forming groove patterns in or on the processing surface 112 of the polishing pad 108. In another embodiment, the laser emitter 129 emits the beam 140 toward the reflective component 150 to provide the secondary beam 154 that impinges the polishing pad 108 to condition the processing surface 112 of the polishing pad 108, for example, by forming groove patterns in or on the processing surface 112 of the polishing pad 108.

[0037] FIG. 2 is a top plan view of the processing station 100 of FIG. 1 showing one embodiment of a patterned processing surface 200 on the polishing pad 108. The patterned processing surface 200 facilitates removal of material from a substrate 116 and/or fluid transport during processing. The patterned processing surface 200 may be formed using the first conditioner device 124A and/or the second conditioner device 124B of FIG. 1. The patterned processing surface 200 may include grooves or channels, hereinafter referred to as marks 205 formed in the body 110 to a desired depth.

[0038] Each of the marks 205 may comprise a fluid retaining structure formed in the body 110 of the polishing pad 108 by the optical device 128 of the first conditioner device 124A and/or the second conditioner device 124B of FIG. 1. The marks 205 may be linear or curved, zig-zagged, and may have a radial, grid, spiral or circular orientation on the polishing pad 108. The marks 205 may be intersecting or non-intersecting. Alternatively or additionally, the processing surface 112 of the polishing pad 108 may be embossed.

[0039] In this embodiment, the patterned processing surface 200 includes a plurality of marks 205 that may be substantially concentric. In some embodiments, the marks 205 may be intermittent to form discrete marks 208A separated by non-conditioned areas 208B of the processing surface 112 of the polishing pad 108 (e.g., areas of the processing surface 112 of the polishing pad 108 that are not conditioned by the optical device 128 (shown in FIG. 1)). Each of the marks 208A may be grooves, channels or holes that may comprise a fluid retaining structure formed the body 110 of the polishing pad 108 by the first conditioner device 124A and/or the second conditioner device 124B. The marks 208A may also be linear or curved, zig-zagged, and may have a radial, grid,

spiral or circular orientation on the polishing pad **108**. FIG. **2** also shows the substrate **116** disposed on the processing surface **112** of the polishing pad **108** (partially in phantom) to indicate one embodiment of a polishing sweep pattern **215** of the substrate **116** on the patterned processing surface **200** during polishing.

[0040] Each of the marks **205** and/or marks **208**A may be formed by continuous or intermittent pulsing of the signal generator **138** (shown in FIG. **1**) in order to provide a continuous or intermittent beam (i.e., **140** and/or **154** shown in FIG. **1**) from the optical device **128** (shown in FIG. **1**) directed toward the processing surface **112** of the polishing pad **108**. The marks **208**A may define an array of holes or short, linear or curved channels in the processing surface **112** of the polishing pad **108** as shown in FIG. **2**.

[0041] During conditioning, which may be performed while polishing or between polishing processes, the polishing pad **108** may be rotated at about 0.5 revolutions per minute (rpm) to about 122 rpm while forming the mark and/or groove patterns on the processing surface **112** of the polishing pad **108**. The pattern of marks **205** and/or marks **208**A on the processing surface **112** of the polishing pad **108** may include a pitch of about 50 microns (μm) to about 1000 μm. In one embodiment, at least a portion of the marks **205** and/or marks **208**A formed in the processing surface **112** of the polishing pad **108** may include a width of about 50 μm to about 500 μm. The marks **205** and/or marks **208**A formed in the processing surface **112** of the polishing pad **108** may include a depth of about 5 μm to about 250 μm, such as about 25 μm to about 112 μm. The width and/or depth of the marks **205** and/or marks **208**A formed in the processing surface **112** of the polishing pad **108** may be maintained during the entire lifetime of the polishing pad **108** using the optical device **128**. For example, the optical device **128** may be used to refresh the width and/or depth of the marks **205** and/or marks **208**A during polishing processes, or in between polishing processes. In one embodiment, the optical device **128** is used to refresh the width and/or depth of the marks **205** and/or marks **208**A between each substrate **116** that is polished on the polishing pad **108**, such as after polishing a first substrate and before polishing a second substrate. In another embodiment, the optical device **128** is used to refresh the width and/or depth of the marks **205** and/or marks **208**A, as necessary, which may be subsequent to a polishing process performed on more than one substrate **116** (e.g., two or more substrates).

[0042] In one example of operation of the first conditioner device **124**A, the support member **130** may be rotatable in order to move the conditioner head **126** (with the optical device **128** disposed therein) on the support arm **132** in a sweep pattern **210** across the processing surface **112** of the polishing pad **108**. In one aspect, the rotational movement of the polishing pad **108** during processing is utilized in conjunction with the application of optical energy from the optical device **128** of the first conditioner device **124**A and/or the sweep pattern **210** to form the pattern of marks **205** and/or marks **208**A on the processing surface **112** of the polishing pad **108**. In another aspect, the rotational movement of the polishing pad **108** during processing is utilized in conjunction with the application of optical energy from the optical device **128** of the second conditioner device **124**B.

[0043] FIG. **3** is a cross-sectional view of a portion of a polishing pad **108** showing a graded groove pattern in the processing surface **112** provided by one or both of the first conditioner device **124**A and the second conditioner device **124**B (both shown in FIG. **1**). The graded groove pattern includes first grooves **300**A and second grooves **300**B that are formed by the optical device **128** at a non-uniform depth in the body **110**. For example, when the optical device **128** is a laser device, the power may be pulsed between a low power setting to form the first grooves **300**A at a first, shallower depth, and a high power setting to form the second grooves **300**B at a second, deeper depth. The first grooves **300**A and the second grooves **300**B may be formed as a continuous groove in the processing surface **112**, such as marks **205** shown in FIG. **2**. While not shown, the first grooves **300**A and second grooves **300**B may be formed in an array, such as marks **208**A shown in FIG. **2**.

[0044] Forming groove patterns on polishing pads using laser devices has been used in the manufacture of new polishing pads. In this function, the pad material is generally moisture-free, and lasers with relatively high absorption coefficients are used. Carbon dioxide (CO_2) laser devices with wavelengths of about 10.6 μm (e.g., far infrared spectrum) may be utilized for grooving patterns in this liquid-free medium. However, during conditioning a polishing pad during substrate polishing, the polishing pad is wetted with a polishing fluid or polishing compound, of which water is a main constituent. The use of laser devices having wavelengths that are readily absorbed by the polishing medium (e.g., water), such as 10.6 μm, creates challenges. When the optical energy is absorbed by water in the pad material, heating of the water ensues. The heating of the water may cause the water to boil. As the pad material is generally porous, the boiling of water in pores, or localized areas of pores, may cause ruptures in the pad surface. This rupturing is generally uncontrollable across different areas of the pad surface, and may produce large asperities, as well as a non-uniform grooving pattern across the polishing surface, and, ultimately, unsuitable substrate polishing results.

[0045] Conditioning of the polishing pad **108** utilizing optical devices **128** as described herein may utilize the beams **140** and/or **154** having wavelengths that are not readily absorbed by a polishing medium (e.g., polishing fluid or polishing compound) but are absorbed efficiently by the pad material. Since the polishing medium is substantially transparent to the beams **140** and/or **154**, a direct ablation of the pad material may be realized without the problems encountered from moisture in the pad material, and a controllable groove pattern may be formed in the processing surface **112** of the polishing pad **108** as described herein.

[0046] FIG. **4** is a graph **400** showing absorption coefficients (1/centimeter (cm) or cm^{-1}) for various wavelengths. A "water window" is interposed on the graph **400**. Wavelengths in between about 200 nanometers (nm) and about 1,200 nm show a low absorption coefficient (less than about 1.0/cm) while wavelengths above 1,200 nm have a high absorption coefficient (greater than about 100/cm). Thus, laser devices, such as the laser emitter **129** described in FIG. **1**), having wavelength ranges within the "water window" are utilized with the first conditioner device **124**A and the second conditioner device **124**B, as shown in FIGS. **1**, **2** and **3**.

[0047] Examples of suitable wavelengths for the laser emitter **129** include ultraviolet wavelength ranges (e.g., about 355 nm), visible wavelength ranges (e.g., about 532 nm), near infrared wavelength ranges (e.g., about 1064 nm), and combinations thereof. In one embodiment, the absorption coefficient of the material of the polishing pad **108** is greater than about 1.0/cm, such as about 5.0/cm, or greater, while the

absorption coefficient of the polishing medium is less than about 1.0/cm, such as about 0.5/cm. In one aspect, the wavelengths of the laser emitter **129** are substantially transparent (non-reactive) with the water-based polishing medium and the emitted beam is not significantly affected by the polishing medium. For example, the layer of the polishing medium on the processing surface **112** of the polishing pad **108** is relatively thin, and the emitted beam passes therethrough and onto the processing surface **112** without interacting with the polishing medium. In one embodiment, the emitted beam from the laser emitter **129** passes through air in the space above the processing surface **112** of the polishing pad **108** and is not affected by the polishing medium such that beam properties, such as spot size and/or angle of incidence, are not significantly altered by the polishing medium. In one aspect, the wavelength ranges provided by the laser emitter **129** are substantially non-reactive with a polishing medium utilized in the polishing process but is reactive with the polishing pad material in order to form groove patterns shown and described in FIGS. **2** and **3**. In another aspect, the wavelength ranges provided by the laser emitter **129** are absorbed by polishing pad material in preference to the polishing medium utilized in the polishing process in order to form mark and/or groove patterns shown and described in FIGS. **2** and **3**.

[0048] In another aspect, the primary beam **140** is provided in a wavelength range that is substantially non-reactive with a polishing medium utilized in the polishing process, but is reactive with the polishing pad material, in order to form groove patterns shown and described in FIGS. **2** and **3**.

[0049] "Substantially transparent" may be defined as the incapability of the beam to cause a phase change of the polishing medium under normal operating conditions (i.e., wavelength range of the beam, output power of the beam, spot size of the beam, dwell time of the beam on the polishing pad material, and combinations thereof). "Substantially transparent" may also be defined as the incapability of the beam to cause the polishing medium to heat up and/or boil under normal use in the conditioning process as described herein. For example, the wavelengths of the laser emitter **129** as described herein would not cause a substantial rise in temperature of the polishing medium under normal operating conditions using a pulsed beam and/or short dwell times. "Substantially transparent" may also be defined as the incapability of the polishing medium to affect properties of the beam emitted from the laser emitter **129** under normal use in the conditioning process as described herein. "Substantially non-reactive" may be defined as the incapability of the beam to cause a phase change of the polishing medium under normal operating conditions (i.e., wavelength range of the beam, output power of the beam, spot size of the beam, dwell time of the beam on the polishing pad material, and combinations thereof). "Substantially non-reactive" may also be defined as the incapability of the beam to cause the polishing medium to heat up and/or boil under normal use in the conditioning process as described herein. For example, the wavelengths of the laser emitter **129** as described herein would not cause a substantial rise in temperature of the polishing medium under normal operating conditions using a pulsed beam and/or short dwell times.

[0050] As stated above, periodic conditioning of the polishing pad **108** is needed to refresh the surface of the polishing pad in order to maintain an optimal removal rate. In order to ensure efficient conditioning of the processing surface **112** of the polishing pad **108**, which provides the optimal removal rate, the state of the polishing pad **108** must be monitored, and conditioning and/or polishing processes may be changed based on the state of the polishing pad **108**. In one embodiment, conditioning parameters may be adjusted based on the state of the processing surface **112** of the polishing pad **108** based on input from one or more monitoring devices associated with the processing station **100**. Profilometry (contact or non-contact) and interferometry techniques performed on processed substrates may also be utilized to adjust conditioning parameters.

[0051] Conditioning parameters include the frequency and/or duration of pad conditioning, laser power output, laser pulse time, wavelength, and/or frequency, laser pulse length, spot size (beam diameter), angle of incidence of the beam, and combinations thereof. Some of the conditioning parameters may be utilized as control knobs to maintain consistent or a desired topography of the processing surface **112** of the polishing pad **108**. For example, pulse shape (beam intensity profile) in time and/or the beam intensity profile in space (beam intensity per unit of area) may provide real-time adjustment of the topography control. Adjustment of the conditioning parameters may provide optimal control of asperity count, as well as dimensions and/or shape of the asperities on the processing surface **112** of the polishing pad **108**. In one embodiment, when forming asperities using the laser emitter **129** in a hole drilling mode, where the laser emitter **129** is pulsed to form holes at predetermined pitch and depth over the processing surface **112** of the polishing pad **108**, pitch and/or pulses maybe such that fewer asperities are formed at the edge and center of the pad, while denser and deeper asperties are formed at the mid-radius of the pad. Such a variation in asperity height and density may enable more uniform polishing and improve planarization of substrates.

[0052] FIG. **5** is a partial sectional view of the processing station **100** of FIG. **1** showing various embodiments of monitoring and control systems that enable closed-loop control of the conditioning process and the polishing processes performed thereon. A monitoring/feedback system **500** is shown within the processing station **100**. Components of the monitoring/feedback system **500** may be in communication with the controller for closed-loop control of the processes on the processing station **100**.

[0053] The monitoring/feedback system **500** may include a first monitoring device comprising one or more first sensors **505** disposed on portions of the processing station **100**. Each of the first sensors **505** may be an optical device utilized to view the processing surface **112** of the polishing pad **108**. For example, the first sensors **505** may be coupled to the ceiling **142** of the enclosure **144**, on the support arm **132**, on the support member **118**, and combinations thereof, as well as other locations where the processing surface **112** of the polishing pad **108** may be viewed. One or more of the first sensors **505** may be a camera, or an optical device, such as a laser sensor, which emits a beam **510** that is directed toward the processing surface **112** of the polishing pad **108**. In one example, the first sensor **505** (located on the enclosure **144**) may comprise a transmitter **515**A that emits the beam **510** and a receiver **515**B that receives a reflected beam (not shown). The intensity of the reflected beam may be utilized to provide a real-time metric of the roughness and/or porosity (i.e., topography) of the processing surface **112** of the polishing pad **108**. The roughness and/or porosity metric may be used to determine conditioning parameters that may be adjusted. The first sensors **505** that comprise optical devices may also be

used to determine an average height of the processing surface **112** of the polishing pad **108**, as well as determine depths of the first grooves **300**A and a depth of the second grooves **300**B (both shown in FIG. **3**).

[0054] In one embodiment, one or more of the first sensors **505** may be a camera, such as a CCD camera, or a laser surface scanner, that monitors the processing surface **112** of the polishing pad **108** during conditioning and/or polishing. Images from the first sensors **505** may be sent to the controller and a topographical metric of the processing surface **112** of the polishing pad **108** may be obtained. The topographical metric may be used to determine conditioning parameters that may be adjusted. The topographical metric may include an average height of the processing surface **112** of the polishing pad **108**, as well as depths of the first grooves **300**A and a depth of the second grooves **300**B (both shown in FIG. **3**) that may be used to adjust conditioning parameters.

[0055] Alternatively, one or more of the first sensors **505** may be a capacitive sensor to provide topographical information indicative of the state of the processing surface **112** of the polishing pad **108**. The first sensors **505** utilizing capacitive coupling could also be utilized to detect and measure proximity and/or displacement. First sensors **505** that comprise capacitive sensing devices may also be used to monitor the profile of the polishing pad **108**, such as determining an average height of the processing surface **112** of the polishing pad **108** and/or monitoring the thickness of the polishing pad **108**, as well as determine depths of the first grooves **300**A and a depth of the second grooves **300**B (both shown in FIG. **3**). In one embodiment, thickness information can be used to implement corrective conditioning, such that more conditioning is affected where the polishing pad **108** is thick and less conditioning is affected where the polishing pad **108** is thin to obtain a flat processing surface **112** of the polishing pad **108** with minimal thickness variation. In another embodiment, profile information can be used to determine wear of the processing surface **112** of the polishing pad **108** and conditioning parameters may be adjusted to provide uniform wear across the processing surface **112** of the polishing pad **108**.

[0056] The monitoring/feedback system **500** may include a second monitoring device comprising one or more second sensors **520**A and **520**B. The second sensors **520**A, **520**B may be rotational sensors utilized to sense torque and provide a torque value to the controller. The second sensor **520**A may be a platen rotational sensor utilized to obtain a metric indicative of the force required to rotate the platen **102** and polishing pad **108** during conditioning and/or polishing. The second sensor **520**A may be a torque or other rotational force sensor coupled to the drive motor **106**, or to an output shaft of the drive motor **106**. Likewise, the second sensor **520**B may be coupled to the carrier head **114**. The second sensor **520**B may be a rotational sensor for the carrier head **114** that is utilized to obtain a metric of force required to sweep the carrier head **114** in the polishing sweep pattern **215** (shown in FIG. **2**). The second sensor **520**B may be a torque sensor, a shear force sensor, or other rotational force sensor coupled to the drive system **120**, or an output shaft of the drive system **120**. The second sensors **520**A, **520**B may provide a torque value to the controller, which is utilized to determine conditioning parameters that may be adjusted.

[0057] The monitoring/feedback system **500** may include a third monitoring device, such as a third sensor **525**. The third sensor **525** may comprise a pad surface sensor that reacts based on changes in pad topography. The third sensor **525** may be a friction sensor that includes a pad coupling member **530** and a sensor device **535**. The pad coupling member **530** may be a disk or plate of a material that is utilized to ride on the processing surface **112** of the polishing pad **108** and interacts with the processing surface **112** as the polishing pad **108** rotates. The pad coupling member **530** may move based on unevenness in the processing surface and displacement is sensed by the sensor device **535**. The displacement values are provided to the controller and adjustments to conditioning parameters may be determined and implemented. Alternatively or additionally, the pad coupling member **530** may be urged against the processing surface **112** at a specified load, and displacement values, torque values, or other values based on friction, may be sensed by the sensor device **535**. The displacement values, torque values, or other values are provided to the controller and adjustments to conditioning parameters may be determined and implemented. While the third sensor **525** is shown coupled to the base **104** and is positioned adjacent an edge of the polishing pad **108**, the third sensor **525**, or multiple third sensors **525**, may be coupled to other portions of the processing station **100** to obtain feedback of the state of the polishing pad **108** at different/multiple locations.

[0058] The monitoring/feedback system **500** may include a fourth monitoring device, such as a fourth sensor **540**. The fourth sensor **540** may comprise sensing device that provides a metric of material that remains on the substrate **116** during a polishing process. The fourth sensor **540** may be an eddy current sensor or an optical device, such as a laser emitter and detector, or a light emitting device (e.g., white light source) and detector, that is disposed within the platen **102** beneath a window **545** formed in the polishing pad **108**. The fourth sensor **540** may be used to determine the topography of the substrate **116** during a polishing process, which is an indication of the level of conditioning of the topography of the processing surface **112**. The fourth sensor **540** may be used to determine dishing and/or erosion, which is indicative of over-conditioning of the polishing pad **108**. Thus, real-time adjustment of the conditioning parameters may be provided based on observations of the topography of the substrate **116**.

[0059] In one embodiment, signals from one or more of the sensors **505**, **520**A, **520**B, **525**, and **540** indicating a metric of roughness and/or shear force measurement may be used to increase or decrease the number of pulses to restore surface roughness such that an optimum topography of the processing surface **112** of the polishing pad **108** is maintained. In another embodiment, the pitch of the marks **208**A (shown in FIG. **2**) may be increased or decreased alone, or in combination with, the number of pulses from the laser emitter **129** for more stable polishing performance.

[0060] FIG. **6** is a top plan view of a polishing pad **600** showing another embodiment of a patterned processing surface **605** provided by the methods disclosed herein. In this embodiment, the patterned processing surface **605** is provided by a linear scan of an optical device **128** (shown in FIGS. **1** and **5**) from near a geometric center of the polishing pad **600** to an edge of the polishing pad **600**, and vice versa. For example, the optical device **128** provides a beam (i.e., beam **140** and/or beam **154** shown in FIGS. **1** and **5**) that scans radii of the polishing pad **600** while the polishing pad **600** is rotating. Due to the movement of the polishing pad **600**, the rotational speed is higher at the edge of the polishing pad **600** relative to the rotational speed of the polishing pad **600** at the

center (e.g., where the rotational speed is zero). The result is a spirograph-type pattern on the patterned processing surface **605** as shown in FIG. **6**.

[0061] The patterned processing surface **605** includes a plurality of marks **610**. The depth of the marks **610** and/or the pitch of the marks **610** are determined by one or a combination of scan speed of the beam (**140** and/or **154**), a pulse rate of the beam and the rotational speed of the polishing pad **600**. For example, the spirograph-type pattern of the patterned processing surface **605** includes a plurality of arcs (only arcs **615**A and **615**B are shown) formed by the marks **610**. The arc **615**A may begin at the center of the polishing pad **600** and transition to the arc **6158** near the periphery of the polishing pad **600**, while the arc **6158** ends at the center of the polishing pad **600**. The circular shape of the arcs **615**A, **6158** may be due to the rotational speed of the polishing pad **600**. For example, the arcs **615**A. **615**B may be more elliptical when the rotational speed of the polishing pad **600** is slowed. A similar effect may be provided by varying the scan speed of the beam (**140** and/or **154**) as it traverses the pad radially. Scan speed maybe varied to compensate for varying radial velocity of the polishing pad **600** to maintain a fixed relative speed between the beam and the polishing pad **600** to affect uniform marking depth.

[0062] FIGS. **7**A-**7**C are schematic top views of mark arrays **700**A-**700**C that may be formed on a polishing pad (shown in FIGS. **1**, **2**, **5** and **6**) using the methods as described herein. FIG. **7**A shows a mark array **700**A having a plurality of marks **705** having a substantially uniform outer dimension d as well as a substantially similar pitch **710**A in the X direction. The pitch in the Y direction may be substantially equal to the pitch **710**A. FIG. **7**B shows a mark array **700**B having a plurality of marks **705** with a substantially uniform outer dimension d as well as a substantially similar pitch **710**B in the X direction that is greater than the pitch **710**A. The pitch in the Y direction may be substantially equal to the pitch **710**B. FIG. **7**C shows a mark array **700**C having a plurality of marks **705** having a substantially uniform outer dimension d. However, a pitch of the marks **705** is set such that the marks **705** at least partially overlap and form lines or chains **715** of marks **705**. While the marks **705** in FIGS. **7**A-**7**C are shown as circular, the marks **705** may be one or any combination of shapes, such as circular as shown, rectangles, triangles, linear patterns, and the like. The dimension d may be a diameter in the case of a circular mark, or an outer dimension of other polygonal shapes. The dimension d may be provided by setting a spot size of the beam during conditioning. Spot sizes may be about 20 μm to about 200 μm. Additionally, one or a combination of the dimensions d shown in the mark arrays **700**A-**700**C may be provided as needed to provide a mark array consisting of similar size of marks **705** (e.g., the same dimension d and/or the same pitch) or marks **705** of different sizes and pitches.

[0063] FIGS. **8**A-**8**C are schematic cross-sectional views of mark arrays **800**A-**800**C that may be formed on a body **110** of a polishing pad (shown in FIGS. **1**, **2**, **5** and **6**) using the methods as described herein. FIG. **8**A shows a mark array **800**A having a plurality of marks **805** with a substantially uniform pitch **810**A as well as a substantially uniform height h. FIG. **8**B shows a mark array **800**B having a plurality of marks **805** with a substantially uniform pitch **810**B as well as a substantially similar height h that is less than the height h of the marks **805** shown in FIG. **8**A. FIG. **8**C shows a mark array **800**C having a plurality of marks **805** having a substantially uniform pitch **810**C and a height h. One or a combination of the heights h shown in the mark arrays **800**A-**800**C may be provided as needed to provide a mark array consisting of similar size of marks **805** (e.g., the same height h and/or the same pitch) or marks **805** of different heights h and pitches. The height h may be provided by setting a appropriate number of discreet pulses of the beam during conditioning. Increasing the number of pulses may promote greater mark depth (i.e., height h).

[0064] FIGS. **9**A-**9**D are schematic top views of various embodiments of marks that may be formed in or on a polishing pad (shown in FIGS. **1**, **2**, **5** and **6**) using the methods as described herein. FIG. **9**A depicts a mark **905**A in the form of a triangle; FIG. **9**B depicts a mark **905**B in the form of a rectangle; FIG. **9**C depicts a mark **905**C in the form of a circle; and FIG. **9**D depicts a mark **905**D having a plurality of linear grooves **910**. Although four intersecting grooves **910** are shown, more or less than four may be used. Additionally, the grooves **910** may not intersect. One or a combination of the marks **905**A-**905**D may be used to form patterned processing surfaces on a polishing pad as described herein. Additionally, any of the marks **905**A-**905**D may be sized to have a major dimension from a few millimeters to near the diameter of the polishing pad. For example, the mark **905**A (or the mark **905**B) may be sized such that the corners are adjacent the periphery of the polishing pad. Additional marks (**905**A, **905**B, or combinations of the marks **905**A-**905**D) may be formed within the mark **905**A (or the mark **905**B), or nested over or within the mark **905**A (or the mark **905**B). In another example, the mark **905**D may be formed such that a length of the grooves **910** are substantially equal to the diameter of the polishing pad.

[0065] FIGS. **10**A and **10**B are schematic top views of a polishing pad **1000** showing embodiments of a portion of a patterned processing surface **1005**A, **1005**B thereon, respectively. In FIG. **10**A, the polishing pad **1000** includes a plurality of marks **1010**A formed as circles. In FIG. **10**B, the polishing pad **1000** includes a plurality of marks **1010**B in the form of rectangles. Each of the patterned processing surfaces **1005**A, **1005**B may be formed in or on the entire surface of the polishing pad **1000**, or combinations of each may be used.

[0066] Some or all of the marks **1010**A, **1010**B may partially overlap with other marks **1010**A, **1010**B. In one example, the patterned processing surface **1005**A may consist of the plurality of marks **1010**A that overlap. At least a portion of the marks **1010**A may overlap another adjacent mark **1010**A by about 50%, or greater, along the radius direction. The depth of the marks **1010**A may be about 50 μm, or less. A similar process may be used on the patterned processing surface **1005**B to form an overlap of marks **1010**B as described above in the patterned processing surface **1005**A.

[0067] Another conditioning method includes scanning the beam (**140** and/or **154**) in a radial or a circumferential direction relative to the polishing pad **1000** to achieve different relative velocities between the beam and the polishing pad **1000**. For example, the beam may be scanned in the direction of rotation of the polishing pad **1000** to create marks that are linear or arcing.

[0068] Apparatus and methods for providing a patterned processing surface **200** (FIG. **2**), **605** (FIG. **6**), **1005**A (FIG. **10**A) and **1005**B (FIG. **10**B) on a polishing pad **108** (FIG. **2**), **600** (FIG. **6**) and **1000** (FIGS. **10**A and **10**B) are provided. The patterned processing surface may be formed by a beam and include multiple patterns including lines, arcs or shapes,

marks, objects, and the like, in discrete patterns, repeating patterns, overlapping patterns or marks, and the like. Additionally, apparatus and methods for a monitoring/feedback system **500** for closed-loop control of a CMP system utilizing optical conditioning are provided. The monitoring/feedback system **500** provides control of conditioning parameters to obtain optimal removal rates. The control of the conditioning parameters provides precise topographical control of the processing surface of a polishing pad, which results in lower defect rates, longer pad lifetime, as well as improving throughput.

[0069] While the foregoing is directed to embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof.

What is claimed is:

1. A method for conditioning a polishing pad utilized to polish a substrate, the method comprising:
providing relative motion between an optical device and a polishing pad having a polishing medium disposed thereon; and
scanning a processing surface of the polishing pad with a laser beam to form a groove pattern on the processing surface, wherein the laser beam has a wavelength that is substantially transparent to the polishing medium, but is reactive with the material of the polishing pad.

2. The method of claim **1**, further comprising:
monitoring a state of the processing surface during polishing of a substrate.

3. The method of claim **2**, wherein the state of the processing surface is monitored by at least one sensor.

4. The method of claim **3**, wherein the at least one sensor comprises an optical sensor, a capacitive sensor, a rotational sensor, a shear force sensors an eddy current sensor, and combinations thereof.

5. The method of claim **3**, further comprising:
adjusting conditioning parameters in response to a metric provided by the at least one sensor.

6. The method of claim **5**, wherein the adjusting conditioning parameters includes adjusting a spot size of the beam.

7. The method of claim **5**, wherein the adjusting conditioning parameters includes adjusting a pulse frequency, a number of pulses, and/or a pulse length of the beam.

8. The method of claim **5**, wherein the adjusting conditioning parameters includes adjusting an angle of incidence of the beam relative to the processing surface.

9. The method of claim **5**, wherein the adjusting conditioning parameters includes adjusting an output power of the laser device.

10. A method for polishing a substrate, comprising:
urging a substrate against a processing surface of a polishing pad while providing relative movement between the substrate and the polishing pad;
providing a polishing medium to the processing surface;
monitoring a state of the processing surface during the relative movement; and
conditioning the processing surface with an optical device comprising a laser emitter adapted to emit a beam having a wavelength range that is substantially non-reactive with the polishing medium, but is reactive with the polishing pad.

11. The method of claim **10**, further comprising:
adjusting conditioning parameters based on a metric provided by one or more sensors.

12. The method of claim **11**, wherein the adjusting conditioning parameters includes adjusting a spot size of the beam.

13. The method of claim **11**, wherein the adjusting conditioning parameters includes adjusting a pulse frequency, a number of pulses, and/or a pulse length of the beam.

14. The method of claim **11**, wherein the adjusting conditioning parameters includes adjusting an angle of incidence of the beam relative to the processing surface.

15. The method of claim **11**, wherein the adjusting conditioning parameters includes adjusting an output power of the laser device.

16. A method for conditioning a polishing pad, comprising:
scanning a beam relative to a processing surface of the polishing pad having water disposed thereon, the beam having a wavelength range that is non-reactive with the water, but is reactive with the polishing pad; and
conditioning the processing surface of the polishing pad.

17. The method of claim **16**, further comprising:
monitoring a topography of the processing surface.

18. The method of claim **17**, further comprising:
adjusting conditioning parameters in response to a metric provided by one or more sensors.

19. The method of claim **18**, wherein the adjusting conditioning parameters includes adjusting a spot size of the beam.

20. The method of claim **18**, wherein the adjusting conditioning parameters includes adjusting a pulse frequency, a number of pulses, and/or a pulse length of the beam.

21. The method of claim **18**, wherein the adjusting conditioning parameters includes adjusting an angle of incidence of the beam relative to the processing surface.

22. The method of claim **18**, wherein the adjusting conditioning parameters includes adjusting an output power of the laser device.

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