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(54) **CMP PAD CONDITIONERS AND
ASSOCIATED METHODS**

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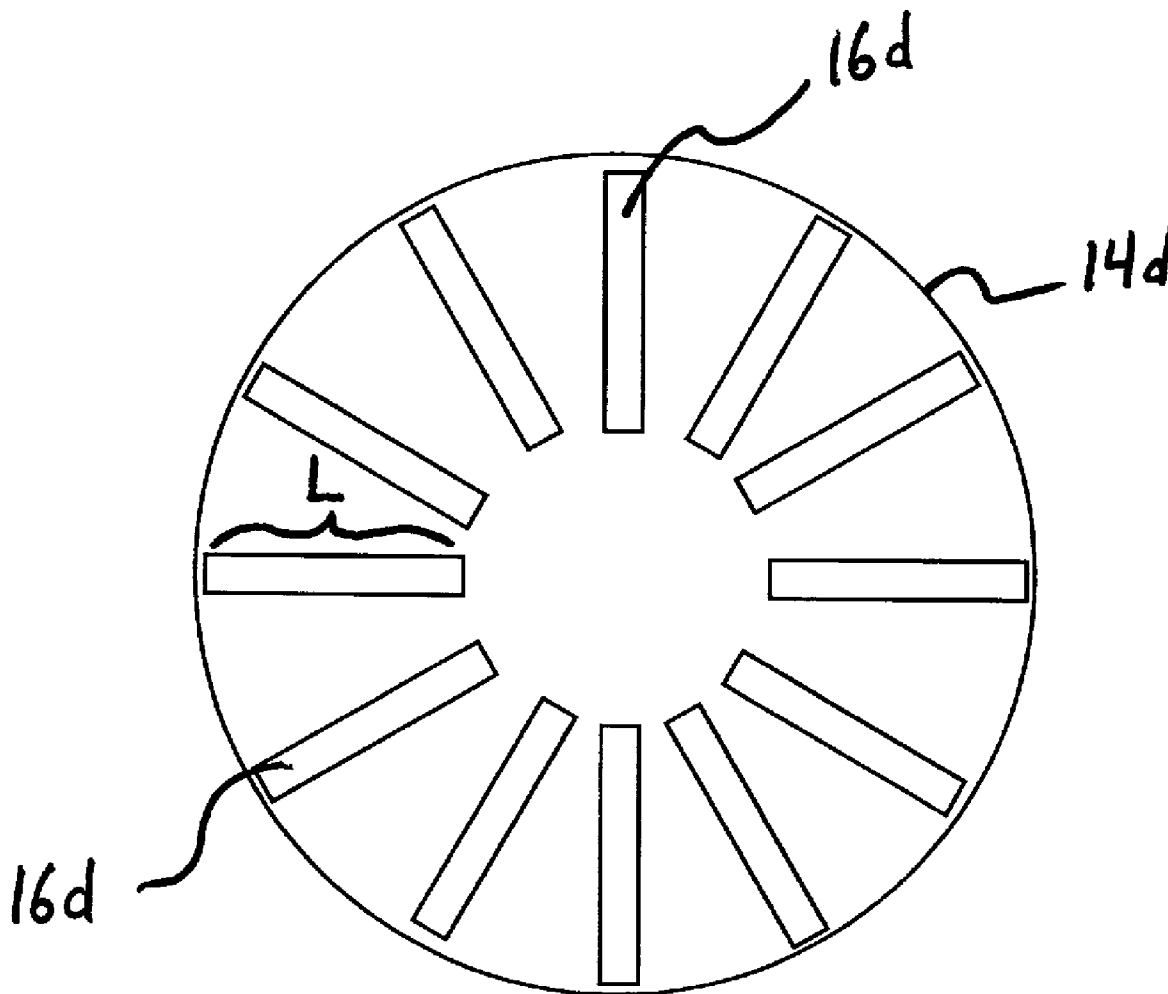
(57) **ABSTRACT**

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A method of reducing a degree of compression of a CMP pad during conditioning of the CMP pad comprises engaging the CMP pad with at least one superhard cutting element, the cutting element including a cutting face, the cutting face being angled at 90 degrees or less relative to a finished surface of the CMP pad; and moving the CMP pad and the cutting element relative to one another in a direction resulting in removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

Related U.S. Application Data

(60) Provisional application No. 60/866,202, filed on Nov. 16, 2006.



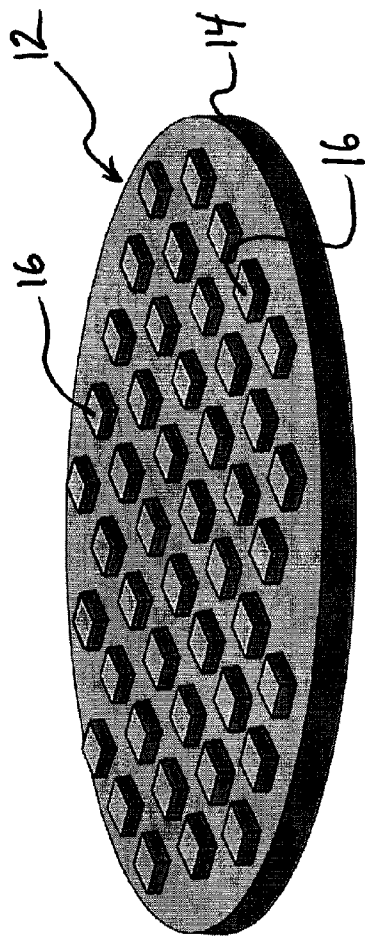


FIG. 1

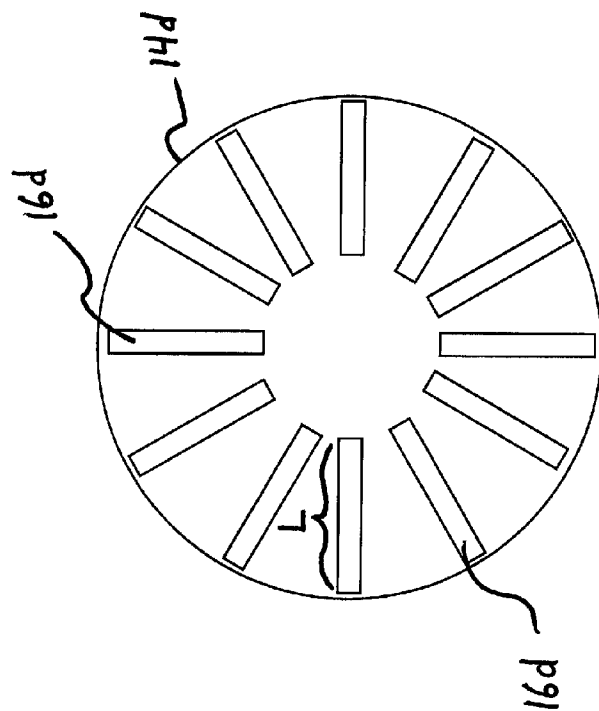


FIG. 2

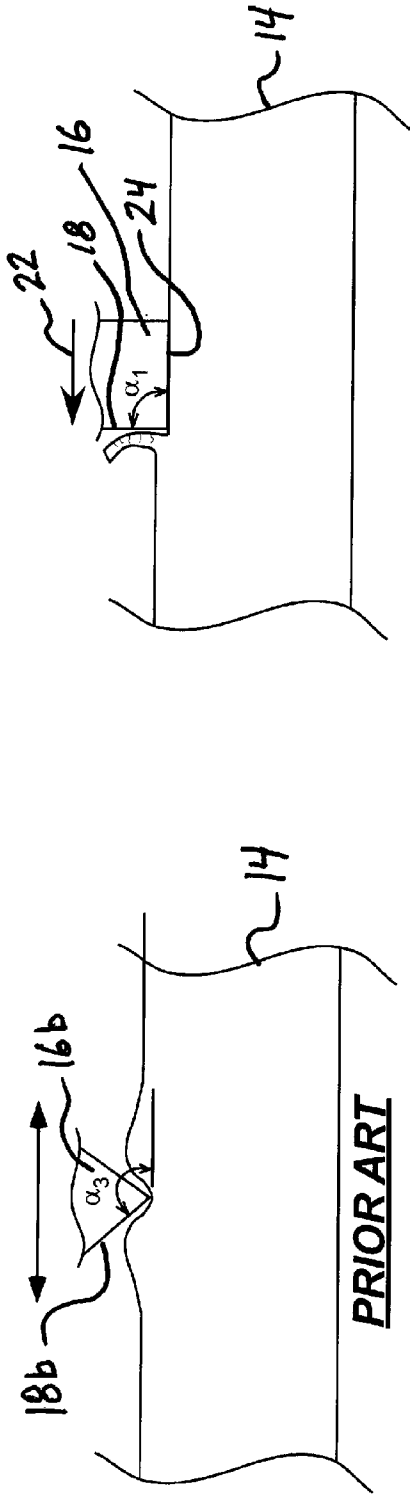
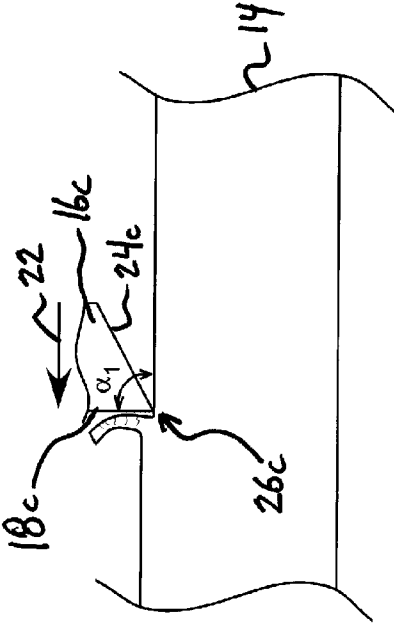


FIG. 3A



FIG. 3D



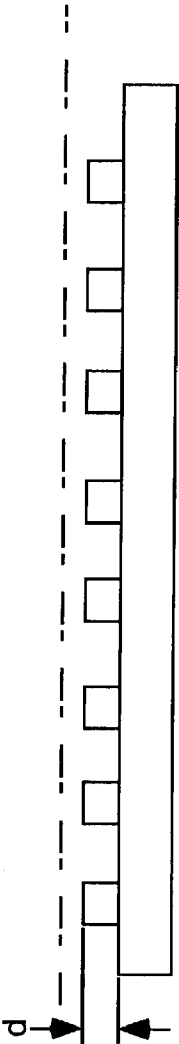
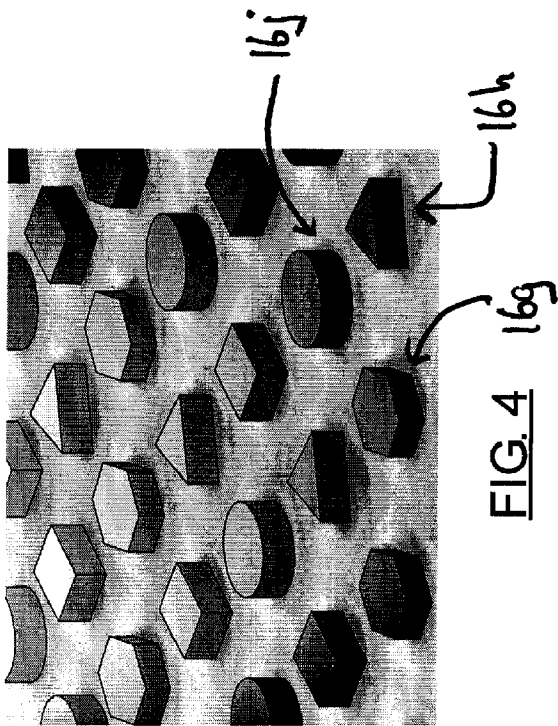


FIG. 5

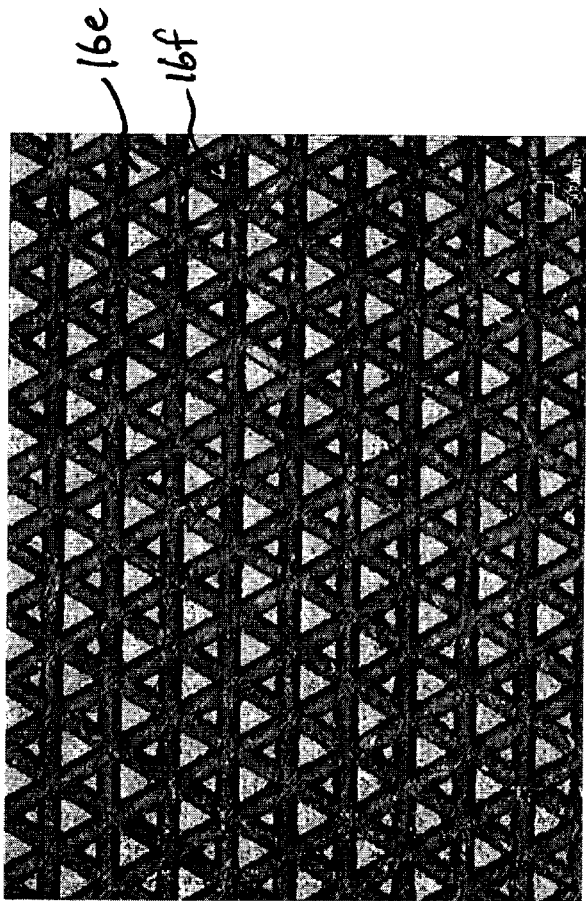


FIG. 6A

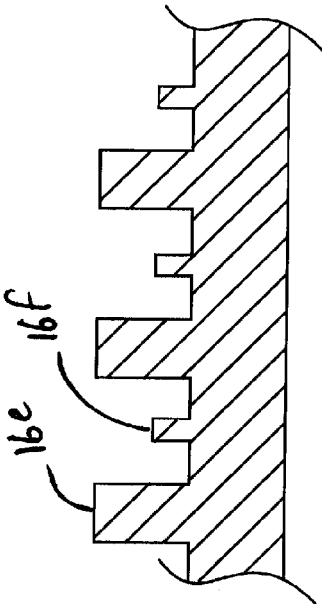


FIG. 6B



FIG. 7

CMP PAD CONDITIONERS AND ASSOCIATED METHODS

[0001] Priority is claimed of copending U.S. Provisional Patent Application No. 60/866,202, filed Nov. 16, 2006, which is hereby incorporated herein in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to CMP pad conditioners used to remove material from (e.g., smooth, polish, dress, etc.) CMP pads. Accordingly, the present invention involves the fields of chemistry, physics, and materials science.

BACKGROUND OF THE INVENTION

[0003] Abrasive materials are used in wide range of polishing, planing, dressing, or conditioning processes. As one example, the semiconductor industry currently spends in excess of one billion U.S. Dollars each year manufacturing silicon wafers that must exhibit very flat and smooth surfaces. Known techniques to manufacture smooth and even-surfaced silicon wafers are plentiful. The most common of these involves the process known as Chemical Mechanical Polishing (CMP) which includes the use of a polishing pad in combination with an abrasive slurry. Dressing of these CMP pads can be done with a variety of tools.

SUMMARY OF THE INVENTION

[0004] In accordance with one embodiment, the present invention provides a method of reducing a degree of compression of a CMP pad during conditioning of the CMP pad, comprising: engaging the CMP pad with at least one superhard cutting element, the cutting element including a cutting face, the cutting face being angled at 90 degrees or less relative to a finished surface of the CMP pad; and moving the CMP pad and the cutting element relative to one another in a direction resulting in removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

[0005] In accordance with another aspect, the present invention provides a pad conditioner for removing material from a CMP pad while minimizing compression of the CMP pad, including a base and a plurality of cutting elements, extending from the base. The cutting elements can each having a cutting face angled at 90 degrees or less relative to a finished surface of the CMP pad. The faces of the cutting elements can be oriented such that relative movement of the pad conditioner and the CMP pad results in removal of material from the CMP pad with the cutting faces to thereby condition the CMP pad.

[0006] In accordance with another aspect of the invention, a method of reducing a degree of compression of a CMP pad during conditioning of the CMP pad is provided, including: engaging the CMP pad with a plurality of superhard cutting elements formed from a polycrystalline diamond compact, each of the cutting elements including a cutting face, the cutting faces being angled at 90 degrees or less relative to a finished surface of the CMP pad; and moving the CMP pad and the cutting element relative to one another in a direction resulting in removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

[0007] There has thus been outlined, rather broadly, various features of the invention so that the detailed description

thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying exemplary claims, or may be learned by the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a perspective view of a pad conditioner in accordance with an embodiment of the invention;

[0009] FIG. 2 is a top view of a pad conditioner in accordance with an embodiment of the invention;

[0010] FIG. 3A is a partial view of a pad being conditioned in accordance with a PRIOR ART method;

[0011] FIG. 3B is a partial view of a pad being conditioned in accordance with an embodiment of the invention;

[0012] FIG. 3C is a partial view of a pad being conditioned in accordance with another embodiment of the invention;

[0013] FIG. 3D is a partial view of a pad being conditioned in accordance with another embodiment of the invention;

[0014] FIG. 4 is a perspective view of a portion of a pad conditioner having cutting elements of varying geometry associated therewith;

[0015] FIG. 5 is a side, sectional view of a pad conditioner in accordance with an embodiment of the invention;

[0016] FIG. 6A is a photographic, top view of a pad conditioner in accordance with an embodiment of the invention;

[0017] FIG. 6B is a sectional view of the pad conditioner of FIG. 6A;

[0018] FIG. 7 is a photograph of a portion of a pad conditioner in accordance with an embodiment of the invention.

[0019] It will be understood that the attached figures are merely for illustrative purposes in furthering an understanding of the invention. The figures may not be drawn or shown to scale, thus dimensions, particle sizes, and other aspects may, and generally are, exaggerated to make illustrations thereof clearer. Therefore, departure can be made from the specific dimensions and aspects shown in the figures in order to produce the pad conditioners of the present invention.

DETAILED DESCRIPTION

[0020] Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

[0021] It must be noted that, as used in this specification and any appended or following claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a cutting element" can include one or more of such elements.

DEFINITIONS

[0022] In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

[0023] All mesh sizes that may be referred to herein are U.S. mesh sizes unless otherwise indicated. Further, mesh sizes are generally understood to indicate an average mesh

size of a given collection of particles since each particle within a particular “mesh size” may actually vary over a small distribution of sizes.

[0024] As used herein, the term “substantially” refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. As an arbitrary example, when two or more objects are referred to as being spaced a “substantially” constant distance from one another, it is understood that the two or more objects are spaced a completely unchanging distance from one another, or so nearly an unchanging distance from one another that a typical person would be unable to appreciate the difference. The exact allowable degree of deviation from absolute completeness may in some cases depend upon the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained.

[0025] The use of “substantially” is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result. As an arbitrary example, a cavity that is “substantially free of” foreign matter would either completely lack any foreign matter, or so nearly completely lack foreign matter that the effect would be the same as if it completely lacked foreign matter. In other words, a cavity that is “substantially free of” foreign matter may still actually contain minute portions of foreign matter so long as there is no measurable effect upon the cavity as a result thereof.

[0026] As used herein, “base” or “substrate” means a portion of a pad conditioner that supports abrasive materials, and to which abrasive materials may be affixed, or may extend from. Substrates useful in the present invention may be any shape, thickness, or material, that is capable of supporting abrasive materials in a manner that is sufficient provide a pad conditioner useful for its intended purpose. Substrates may be of a solid material, a powdered material that becomes solid when processed, or a flexible material. Examples of typical substrate materials include without limitation, metals, metal alloys, ceramics, relatively hard polymers or other organic materials, glasses, and mixtures thereof. Further the substrate may include material that aids in attaching abrasive materials to the substrate, including, without limitation, brazing alloy material, sintering aids and the like. The substrate and the abrasive cutting elements can, in some embodiments, be formed from the same material and can be formed from an integral, single piece of material.

[0027] As used herein, “abrasive profile” is to be understood to refer to a shape or a space defined by abrasive materials that can be used to remove material from a CMP pad. Examples of abrasive profiles include, without limitation, rectangular shapes, tapering rectangular shapes, truncated wedge shapes, wedge shapes, and the like. In some embodiments, the abrasive profile exhibited by abrasive segments of the present invention will apparent when viewed through a plane in which the CMP pad will be oriented during removal of material from the CMP pad.

[0028] As used herein, “superhard” may be used to refer to any crystalline, or polycrystalline material, or mixture of such materials which has a Mohr’s hardness of about 8 or greater. In some aspects, the Mohr’s hardness may be about 9.5 or greater. Such materials include but are not limited to diamond, polycrystalline diamond (PCD), cubic boron nitride (cBN), polycrystalline cubic boron nitride (PcBN), corun-

dum and sapphire, as well as other superhard materials known to those skilled in the art. Superhard materials may be incorporated into the present invention in a variety of forms including particles, grits, films, layers, pieces, segments, etc. In some cases, the superhard materials of the present invention are in the form of polycrystalline superhard materials, such as PCD and PcBN materials.

[0029] As used herein, “organic material” refers to a semi-solid or solid complex amorphous mix of organic compounds. As such, “organic material layer” and “organic material matrix” may be used interchangeably, refer to a layer or mass of a semisolid or solid complex amorphous mix of organic compounds. Preferably the organic material will be a polymer or copolymer formed from the polymerization of one or more monomers.

[0030] As used herein, “particle” and “grit” may be used interchangeably.

[0031] As used herein, the term “abrasive” can describe a variety of structures capable of removing (e.g., cutting, polishing, scraping) material from a CMP pad. An abrasive can include a mass having several cutting points, ridges or mesas formed thereon or therein. It is notable that such cutting points, ridges or mesas may be from a multiplicity of protrusions or asperities included in the mass. Furthermore, an abrasive can include a plurality of individual abrasive particles that may have only one cutting point, ridge or mesa formed thereon or therein. An abrasive can also include composite masses, such as PCD pieces, segment or blanks, either individually comprising the abrasive layer or collectively comprising the abrasive layer.

[0032] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

[0033] Concentrations, amounts, particle sizes, volumes, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited.

[0034] As an illustration, a numerical range of “about 1 micrometer to about 5 micrometers” should be interpreted to include not only the explicitly recited values of about 1 micrometer to about 5 micrometers, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

THE INVENTION

[0035] The present invention provides systems and methods for use in conditioning CMP pads in manners that greatly improve the quality of the CMP pad conditioning process, as

well as decrease the costs and waste rates associated therewith. Generally speaking, the systems and methods of the present invention provide superior cutting interfaces between the pad conditioners and the CMP pads to thereby reduce the amount of pressure or force required to maintain cutting (e.g., conditioning) of the CMP pad. During conventional, prior art CMP pad dressing or conditioning processes, a large degree of downward is applied to the pad conditioner while dressing the pad.

[0036] This downward force results in compression of the pad material. As the pad material is generally a relatively pliable material (such as polyurethane), the downward force often results in the pad material becoming much more stiff and resistant to cutting than when in a non-compressed state. The compressed pad material is correspondingly more difficult to cut smoothly and evenly, with often large pieces being torn resulting in asperities being formed in the CMP pad. These asperities can damage the silicone wafer to be conditioned by the pad.

[0037] Conventional diamond pad conditioners usually include “dull” diamond tips that cut the soft CMP pad with a negative angle (conventionally used to refer to an angle greater than 90 degrees relative to a finished surface applied to the pad, as the tips move away from the finished surface). As such, the relatively soft pad must be compressed, resulting in significant deformation (elastic and plastic) before it is penetrated by the diamond tips. Due to the resulting dragging and tearing, the cutting path remaining on the pad is jagged with varying width and depth.

[0038] The present invention can apply multiple cutting tips that can penetrate the soft pad with minimal disruption. This aspect of the invention becomes even more critical as CMP pads become softer and gentler in order to avoid damaging (e.g. dishing, erosion, scratching) the delicate IC during polishing. Some new pads (e.g. Room Haas’ Eco Vision) have a full order of magnitude in contact area with the IC wafer so the cutting during pad dressing must be clean and effective.

[0039] This concept is illustrated in FIG. 3, where a conventional cutting element **16b** is shown engaging a CMP pad **14**. As with most conventional, prior art cutting elements, the cutting element **16b** includes cutting faces **18b** that form an angle α_3 relative to a finished surface to be applied to the pad that is greater than 90 degrees (relative to the finished surface to be applied to the pad, as the cutting element moves away from the finished surface—sometimes referred to as a negative cutting angle). As the cutting element **16b** is pressed downward into the pad, the pad material experiences plastic deformation, resulting in a more stiff response to force applied to the pad material. As such, cutting the pad material is more difficult, and the resulting cut produces a rough and uneven surface on the pad.

[0040] The present invention addresses this issue by reducing the downward force required between the pad conditioner and the CMP pad. As a result, the CMP pad is left with a conditioned surface that is much more smooth and level than that obtained using conventional methods.

[0041] As shown in the attached figures, in one embodiment of the invention, a pad conditioner **12** is provided for removing material from a CMP pad (**14** in FIGS. 3B through 3D) while minimizing compression of the CMP pad. The conditioner can include a base **14** and a plurality of superhard cutting elements **16** extending from the base. As best appreciated from FIG. 3B, the cutting elements can each have a cutting face **18** angled at 90 degrees or less relative to a

finished surface to be applied to the CMP pad (e.g., relative to movement of the cutting face away from the finished surface—sometimes referred to as a positive cutting angle). The face **18** of the cutting element **16** can be oriented such that relative movement of the pad conditioner (in the direction indicated at **22** in FIG. 3B) and the CMP pad results in clean removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

[0042] By angling the cutting face **18** at 90 degrees or less, relative to a finished surface to be applied to the pad **14**, the dressing process can cleanly shave a layer of pad material from the pad. The resultant surface applied to the pad can be safely used in the CMP process without damaging expensive silicon wafers. The present pad conditioners can be used to shave even a very shallow, thin layer of material from the pad and leave behind a clean, smooth and even finished surface on the pad. This technique can be used to remove thin layers of glaze that can be formed on the surface of the CMP pad.

[0043] Cutting faces **18** are shown in the figures oriented at angle α_1 of about 90 degrees relative to the finished surface to be applied to the CMP pad. Cutting face **18a** of FIG. 3D is oriented at angle α_2 that is less than 90 degrees relative to the finished surface to be applied to the CMP pad, on the order of about 60 degrees. The cutting faces can be oriented at a variety of angles, and in one embodiment vary from about 45 degrees to about 90 degrees relative to the finished surface of the CMP pad. It has been found that reducing the angle creates an even sharper cutting interface between the cutting element and the pad.

[0044] As will be appreciated from the cutting element **16a** of FIG. 3D, and the cutting element shown in the microphotograph of FIG. 7, the cutting elements can include a distal portion (e.g., a portion furthest from a base of the pad conditioner) and a proximal portion (e.g., a portion closest to the base). A cross section of the distal portion can be wider than a cross section of the proximal portion. In other words, in some embodiments of the invention, the cutting element can flare outward (in one or more directions) at a lowermost portion (e.g., a portion to be engaged with the pad). In this manner, the angle of the cutting face can be decreased below 90 degrees.

[0045] The angles of the cutting faces can vary from one embodiment to another. In one aspect, the cutting angle is on the order of about 90 degrees. In another aspect, the cutting angle can be slightly larger than 90 degrees, on the order of 95 degrees, 100 degrees, and ranges inclusive of each of these values (e.g., 90-92 degrees, 93-97 degrees, etc.), and increments falling between these values. In other aspects, the cutting angle can be on the order of less than about 90 degrees, less than about 80 degrees, less than about 75 degrees, less than about 70 degrees, less than about 65 degrees, less than about 60 degrees, and ranges inclusive of each of these values (e.g., 60 degrees to 90 degrees), and increments falling between these values.

[0046] While the cutting element **16a** shown in FIG. 3D includes a cutting face **18a** that continually tapers outward, it is to be understood that the cutting element can extend downwardly (relative to the orientation shown in the figures) for some distance until flaring outward. Also, a curved or arcuate slope can be provided to the cutting face, as shown by example in FIG. 7.

[0047] In the aspect of the invention illustrated in FIGS. 3B and 3D, the cutting elements include a trailing edge **24**, **24a** that is substantially parallel to the finished surface of the CMP

pad. In other embodiments, however, such as that shown by example in FIG. 3C, the cutting element 16c can include a trailing edge 24c that provides a relief area between the finished surface of the CMP pad and the cutting element. In this manner, the sharpness of the cutting edge 26c of the blade can be increased without requiring a sloped or tapering cutting face 18c.

[0048] In addition, while cutting elements 16 shown in FIG. 1 are generally tooth-like, individual projections, in some embodiments of the invention, the cutting elements can include cutting blades. This embodiment is shown by example in FIG. 2, in which cutting elements or blades 16d are arranged across the face of base 14d. While not so required, the cutting blades can have a cutting length "L" at least twice as great as a cutting height ("d" in FIG. 5). The cutting blades can advantageously be used to remove a larger percentage of pad material per pass. The cutting blades can also include varying cutting angles along the length of the cutting blades, and can include individual teeth formed thereon, or therewith. Serrations, protrusions, and the like can also be formed on or in the cutting blades, or attached thereto, to enhance the cutting ability of the teeth or blades.

[0049] The cutting elements of the present invention can be associated with the base 14 in a variety of manners. In one embodiment, the cutting elements and the base are formed from an integral piece of material, such as a polycrystalline diamond compact, a polycrystalline cubic boron nitride compact, and the like. In other aspects, the cutting elements can be bonded, welded or otherwise attached to the base.

[0050] Also, various reverse casting methods may be utilized to associate the cutting elements with the base. For example, a spacer layer may be applied to a working surface of a temporary substrate. The cutting elements can be arranged so that at least a portion of each the cutting elements is at least partially embedded in the spacer layer. In one aspect, the cutting elements can be pressed by a variety of mechanisms or means such that tips of the cutting elements come into contact with the temporary substrate. In this manner, the temporary substrate can define the final leveling configuration (e.g., contour) of the finished pad conditioner/cutting tool. As such, the temporary substrate can include varying degrees and combinations of contour, levelness, slope, steps, etc., according to the desired contours of the pad conditioner/cutting tool.

[0051] An adhesive may be optionally applied to the temporary substrate and/or the spacer layer and/or the cutting elements to facilitate proper arrangement and temporary attachment. The adhesive used on any noted surface may be any adhesive known to one skilled in the art, such as, without limitation, a polyvinyl alcohol (PVA), a polyvinyl butyral (PVB), a polyethylene glycol (PEG), a paraffin, a phenolic resin, a wax emulsion, an acrylic resin, or combinations thereof. In one aspect, the fixative is a sprayed acrylic glue.

[0052] The spacer layer may be made from any soft, deformable material with a relatively uniform thickness, and may be selected according to particular needs of manufacturing, future use, compositional considerations of tool precursors, etc. Examples of useful materials include, but are not limited to, rubbers, plastics, waxes, graphites, clays, tapes, grafoils, metals, powders, and combinations thereof. In one aspect, the spacer layer may be a rolled sheet comprising a metal or other powder and a binder. For example, the metal may be a stainless steel powder and a polyethylene glycol binder. Various binders can be utilized, which are well known

to those skilled in the art, such as, but not limited to, a polyvinyl alcohol (PVA), a polyvinyl butyral (PVB), a polyethylene glycol (PEG), a paraffin, a phenolic resin, a wax emulsions, an acrylic resin, and combinations thereof.

[0053] An at least partially uncured resin material can be applied to the spacer layer opposite of the temporary substrate. A mold, e.g. of stainless steel or otherwise, may be utilized to contain the uncured resin material during manufacture. Upon curing the resin material, a resin layer is formed, cementing at least a portion of a cutting element. Optionally, a permanent tool substrate may be coupled to the resin layer to facilitate its use in dressing a CMP pad or in other uses. In one aspect, the permanent substrate may be coupled to the resin layer by means of an appropriate adhesive. The coupling may be facilitated by roughing the contact surfaces between the permanent substrate and the resin layer. In another aspect, the permanent substrate may be associated with the resin material, and thus become coupled to the resin layer as a result of curing.

[0054] The mold and the temporary substrate can subsequently be removed from the CMP pad dresser once the resin is cured. Additionally, the spacer layer can be removed from the resin layer. This may be accomplished by any means known in the art including peeling, grinding, sandblasting, scraping, rubbing, abrasion, etc.

[0055] Therefore, the protrusion of the cutting elements from the resin is dependent on the amount covered or concealed by the spacer layer. Additionally, the arrangement of the cutting elements can be relatively fixed by the resin. As such, the cutting elements can be placed in a variety of configurations, thus creating a variety of configurations of a surface of an assembled tool.

[0056] The cutting elements can be formed in a variety of manners. As mentioned above, one embodiment includes forming the cutting elements from a polycrystalline diamond compact or a polycrystalline cubic boron nitride compact (individual cutting elements can be formed from the compacts and attached to the base, or the base and the cutting elements can be formed from an integral piece of the compact).

[0057] In another aspect, the cutting elements can be formed by creating a sintered alumina plate having the basic shape of the cutting elements extending therefrom. A layer of DLC can be coated over this resulting patterned surface. Also, CVD can be coated over a patterned surface of ceramic. In addition, a sintered SiC plate (with molten silicon used to infiltrate the pores) can be used. In another embodiment, sintered silicon nitride (Si₃N₄) can be used.

[0058] In addition, other materials can be used as the cutting element, either alone or in combination with other materials, and are to be included in the scope of the disclosure herein. For example, the cutting element can comprise or consist essentially of ceramics, or other diamond or cBN films, including those deposited via chemical vapor deposition (CVD). Non-limiting examples of ceramics that can be used as a cutting element include alumina, aluminum carbide, silica, silicon carbide, silicon nitride, zirconia, zirconium carbide, and mixtures thereof. Cutting elements can be, in one embodiment, sintered masses, partially sintered masses, and/or layers of material attached to the substrate of the tool precursor according to any method known in the art. The cutting element can, in one aspect, include a mixture, homogeneous or otherwise, of a plurality of materials, optionally including abrasive particles. In another aspect, the cutting

element can include a plurality of layers of material. As a non-limiting example, the cutting element can include a ceramic overcoated with CVD diamond.

[0059] As shown in FIG. 5, each of the cutting elements 16 can include one or a plurality of cutting edges 26 aligned in a common plane 21. Thus, each of the cutting elements can include four cutting edges, which can each serve to cut or plane material from a workpiece. By including a plurality of cutting elements, each with a plurality of cutting edges, a total length of cutting edges per cutting element can be advantageously increased. In addition, since each cutting element is of substantially the same height, relative to the working surface of the base, all of the cutting edges from all of the cutting elements can be aligned in the same common plane. By aligning each of the cutting edges in a common plane, the cutting device is substantially self-aligned to shave higher regions of the workpiece first, then continue cutting until all "high" points on the workpiece have been reduced, leaving a smooth and flat workpiece surface.

[0060] In addition to finding great utility in dressing CMP pads, the cutting devices of the present invention can be utilized in a number of other applications, including use in planing substantially brittle materials, such as silicon wafers, glass sheets, metals, used silicon wafers to be reclaimed by planarization, LCD glass, LED substrates, SiC wafers, quartz wafers, silicon nitride, zirconia, etc. In conventional silicon wafer processing techniques, a wafer to be polished is generally held by a carrier positioned on a polishing pad attached above a rotating platen. As slurry is applied to the pad and pressure is applied to the carrier, the wafer is polished by relative movements of the platen and the carrier. Thus, the silicon wafer is essentially ground or polished, by very fine abrasives, to a relatively smooth surface.

[0061] While grinding of silicon wafers has been used with some success, the process of grinding materials such as silicon wafers often results in pieces of the material being torn or gouged from the body of the material, resulting in a less than desirable finish. This is due, at least in part, to the fact that grinding or abrasive processes utilize very sharp points of abrasive materials (which are often not level relative to one another) to localize pressure to allow the abrasives to remove material from a workpiece.

[0062] In contrast to conventional polishing or grinding processes, the present invention can utilize one or more sharply angled cutting edges of cutting elements to cut material from a workpiece to finish or plane a surface of the workpiece. In general, when a cut is made in a material, the region of the cut will either deform plastically or will crack in a brittle manner. If the plastic deformation is slower than the crack propagation, then the material is known as brittle. The reverse is true for ductile deformation. However, under a high pressure, the rate of crack propagation is suppressed. In this case, a brittle material (e.g. silicon) may exhibit more ductile characteristics, similar to soft metals. When a sharp cutting edge of the present invention is pressed against the surface of brittle silicon, the area of the first contact is extremely small (e.g. a few nanometers across). Consequently, the pressure can be very high (e.g. several GPa). Because the cracks are suppressed, the sharp diamond edge can penetrate silicon plastically. As a result, the external energy can be transferred to the very small volume of silicon continually to sustain the ductile cutting. In other words, the sharp cutting edges can shave or plane silicon in a manner not previously achieved.

[0063] When PCD or PcBN compacts are utilized in the present invention, the resulting cutting elements are generally superhard, resulting in little yielding by the cutting elements when pressed against a wafer. As hardness is generally a measure of energy concentration, e.g., energy per unit volume, the PCD or PcBN compacts of the present invention are capable of concentrating energy to a very small volume without breaking. These materials can also be maintained with a very sharp cutting edge due to their ability to maintain an edge within a few atoms.

[0064] As the ductility of the silicon is maintained by applying pressure to a very small volume, the penetrating radius is generally kept relatively small. This is shown by example in FIG. 5, where the depth (or height) of the cutting elements 16 is shown generally by the letter "d" and is on the order of about 0.1 mm. In addition, the shape of the cutting edge must be kept relatively sharp; in some cases with a radius on the order of 2 nm. In order to accommodate these dual traits, the material of the cutting edge of the present invention is hard enough to withstand deformation during the cutting or planing process. In this manner, both sharpness and hardness of the cutter is realized to ensure the ductility of the workpiece.

[0065] Each of the cutting elements 16 can include a substantially planar trailing face 24 that can define a workpiece contact area. A combined workpiece contact area of all of the cutting elements can comprise from between about 5% of a total area of the base to about 20% of a total area of the base. Thus, in one aspect of the invention, if a pad dresser has a diameter of about 100 mm, and the combined contact areas of the cutting element will be about 10% of that total, then the total contact area of all cutting elements can be about 7850 mm². An edge-to-area ratio of each cutting element can be about 4/mm, resulting in a total edge length being about 31400 mm.

[0066] The cutting devices of the present invention can be utilized in either a wet system or a dry system. In a dry application, the cutting elements can be used to cut or plane chips from a workpiece without the presence of a liquid slurry. In a typical application, the cutting device can be mounted to a holder cushion that can be coupled to a rotatable chuck. The workpiece, for example, a silicon wafer or a CMP pad, can be coupled to a vacuum chuck that provides for rotation of the workpiece. Both the rotatable chuck and the vacuum chuck can be rotated in either a clockwise or a counterclockwise direction to remove material from the workpiece. By changing the rotation of one element relative to another, more or less material can be removed in a single rotation of the workpiece. For example, if the workpiece and cutting elements are rotated in the same direction (but at different speeds), less material will be removed than if they are rotated counter to one another.

[0067] In this typical application, a slurry can be applied that can aid in planing the workpiece surface. The slurry can be either a water slurry or a chemical slurry. In the case where a chemical slurry is used, the chemical can be selected to provide cooling or to react with the surface of the workpiece to soften the workpiece to provide a more efficient cutting process. It has been found that the wear rate of a silicon wafer can be dramatically increased by softening its surface. For example, a chemical slurry that contains an oxidizing agent (e.g. H₂O₂) may be used to form a relatively highly viscous oxide that will tend to "cling" on the wafer surface. In this case, the PCD cutting devices of the present invention need

not necessarily cut the wafer, but rather can scrape the oxide off the surface of the wafer. Consequently, the sharpness of the cutting edge becomes less critical. In addition, the service life of the cutting device can be greatly extended by utilizing a slurry. For example, a PCD scraper used with a slurry may last 1000 times longer than a PCD cutter.

[0068] FIG. 4 illustrates a variety of cutting elements **16g**, **16h**, **16j** in accordance with an embodiment of the invention. In this aspect of the invention, the cutting elements can be sized and shaped with rectangular cross sections, oval cross sections, circular cross sections, triangular, polygonal, pyramidal cross sections, etc. The various sized and shaped cutting elements can be formed by varying locations, and widths, of grooves cut on the surface of the PCD or PcBN compacts. While not shown in the figures, the cutting elements can also be formed below the surface of a PCD or a PcBN compact, such that the cutting elements comprise inset cavities that include, for example, circular or polygonal shapes.

[0069] FIGS. 6A and 6B illustrate another embodiment of the invention in which a plurality of cutting elements **16e** and **16f** are formed in a PCD base. As can be appreciated from FIG. 6A, the present invention can provide for the integral formation from a superhard polycrystalline material of cutting elements having differing sizes and configurations. For example, in the embodiment shown, the larger cutting elements **16e** can be used as cutting, planing or dressing elements while the smaller cutting elements **16f** can be used primarily as “stopping” elements. In other words, the larger cutting elements can extend further from the base of the PCD to cut further, or deeper, into the pad (not shown in this figure) on which the cutting elements are being used.

[0070] When the larger cutting elements **16e** extend sufficiently far, or deep, into the workpiece, the smaller cutting elements can “bottom out” on the surface of the workpiece to limit further traveling of the larger elements **16e** into the workpiece. To facilitate this concept, the larger cutting elements can be made sharper than the smaller cutting elements: for example, they can terminate in an apex point (similar to the cutting elements shown in FIG. 3C), while the smaller cutting elements can terminate in a flat, planar face (similar to the cutting elements shown in FIG. 3B). In this manner, the larger cutting elements can more easily cut the workpiece than can the smaller cutting elements, causing the smaller elements to serve as depth “stopping” elements. In this manner, the present invention can provide very accurate control of the depth that the cutting elements cut into a workpiece (e.g., a CMP pad that is being dressed).

[0071] In addition, as the cutting elements of the present invention can be formed from an integral piece of polycrystalline superhard material, there can remain a useful excess portion of polycrystalline superhard material below the cutting elements on the base of the cutting device (or that forms the base of the cutting device). Thus, in one aspect of the invention, once the cutting elements have become dull or damaged during use, the cutting device can be sharpened by removing a thin layer of the superhard material across the entire face of the cutting device in the same pattern that was originally created on the face of the device. Cutting devices of the present invention can thus be relatively easily sharpened or repaired, so long as sufficient polycrystalline material

remains beneath the cutting elements to allow for further sharpening of the cutting elements.

EXAMPLES

[0072] The following examples illustrate embodiments of the invention that are presently known. Thus, these examples should not be considered as limitations of the present invention, but are merely in place to teach how to make the best-known systems and methods of the present invention based upon current experimental data. As such, a representative number of systems and methods are disclosed herein.

Example 1

[0073] A PCD compact with sintered polycrystalline diamond coupled with cemented tungsten carbide substrate is used as a blank for EDM machining. The compact disk has a diameter of 34 mm (e.g. Adico), 52 mm (e.g. Adico), 60 mm (e.g. Diamond Innovations), 74 mm (e.g. Element Six), or 100 mm (e.g. Tomei Dia). The typical PCD layer is 400-600 microns thick. The total thickness (including the WC substrate) can be 1.6 mm or 3.2 mm as standard materials.

[0074] The PCD surface is fine polished to have an Ra less than about 1 micron. The blank is wire-EDM cut to form zigzag pattern with tip-to-tip distance of about 400 microns and tip-to-valley depth of about 100 microns. The tip angle can be 60, 70, 80, 90 or 100 degrees (relative to a finished surface applied to a pad), which can be varied by the computer setting for traversing the PCD blank. The zigzag pattern produces symmetrical profiles on the vertically sliced blades. The blade (e.g., cutting element) thickness can be less than about 1 mm. If the wire used is thin (e.g. 150 microns) the kerf loss can be minimized so the number of blades per compact disk is maximized.

[0075] The blades can then be cleaned in an ultrasonic bath with micron diamond suspension to remove all dangling debris, as well as the thermally degraded surface layer with micro cracks and back converted diamond.

[0076] The blade (e.g., cutting element) can then be anchored to a groove mold that allows the leveling of all cutting tips to within 20 microns. Subsequently, the mold is over cast with epoxy resin to consolidate the blades that are set in a radial pattern on a disk of about 100 mm in diameter by 7 mm thick. The blades can be set with cutting edges vertical to the mold surface or with a controlled tilt.

[0077] As a result, the cutting angle can be adjusted to achieve the optimal grooving result on the polishing pad. The protrusion of the cutting tips above the epoxy matrix is also controlled (e.g. 100 microns). This protrusion can be offset to allow gradual increases of cutting tips. Due to such a controlled spread of cutting amount, the pad can be cleaned and with terraces of asperities that may achieve optimized polishing effects.

[0078] For example, the high asperities can sweep quickly the protrusion points of the copper deposition on the wafer. They will be flattened soon so the next terrace of asperities can begin polish to make the copper thinner. Finally, the asperities can becoming relatively level to allow buffing of the already thinned copper layer to remove the barrier layer (e.g. TaN). Current CMP processes would require fast polishing, slow polishing, and buffing with three consecutive stages. The present pad conditioners may, as an option, do all in one stage with significant saving of manufacturing cost and the boost of production throughput.

[0079] Once the above tips become dull, as indicated by the decline of removal rate during the polishing of wafers, the used tips can be recovered simply by dissolving in solvent or burning away epoxy matrix. The blade can then be reset with the other zigzag side for making a new pad conditioner. This can significantly reduce the cost of manufacture. Conventional pad conditioners are rarely if ever reused due to the inability to sort out the worn tips from sharp tips.

Example 2

[0080] A process similar to that described in Example 1 is used, except that a WC blank is used instead of PCD. The WC blank contains a low amount of cobalt (e.g. 6 wt %). The straight blades are set in a fixture and placed in a CVD reactor with methane (1%) hydrogen mixture that is thermally decomposed and dissociated to form carbon and atomic hydrogen. The CVDD coated WC will deposit diamond grains with sharp cutting tips that can be spaced by controlling the nucleation density, sparse nuclei distribution, larger grains, and higher protrusion and further separation. The diamond grains can range from nano crystalline (i.e. the edge is straight) to grains with larger than 10 microns. The low cobalt amount in WC can help diamond retaining by avoiding the back conversion due to its catalytic ability.

Example 3

[0081] A process similar to that described in Example 2 is used, except that the blade is sliced from a silicon infiltrated SiC blank.

Example 4

[0082] A process similar to that described in Example 3 is used, except that the blade is sliced from a sintered micron grained Si₃N₄.

Example 5

[0083] A process similar to that described in Example 2 is used, except that the blank is made from yttrium toughened zirconia. (ZrO₂) with Ti can also be used as the interface coating buffer for diamond film deposition.

[0084] It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and any appended or following claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

1. A method of reducing a degree of compression of a CMP pad during conditioning of the CMP pad, comprising:
engaging the CMP pad with at least one superhard cutting element, the cutting element including a cutting face, the cutting face being angled at 90 degrees or less relative to a finished surface of the CMP pad; and

moving the CMP pad and the cutting element relative to one another in a direction resulting in removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

2. The method of claim 1, wherein the cutting face is oriented at about 90 degrees relative to the finished surface of the CMP pad.

3. The method of claim 1, wherein the cutting face is oriented at an angle less than 90 degrees relative to the finished surface of the CMP pad.

4. The method of claim 1, wherein the cutting face is oriented at an angle greater than 45 degrees and less than 90 degrees.

5. The method of claim 1, wherein the cutting element includes a distal portion and a proximal portion, the proximal portion being closer to a base from which the cutting element extends than is the distal portion, and wherein the distal portion includes a wider cross section than does the proximal portion.

6. The method of claim 1, wherein the cutting element includes a cross section and extends from a base, and wherein the cross section of the cutting element includes a narrowed portion intermediate ends of the cutting element.

7. The method of claim 1, wherein engaging the CMP pad comprises engaging the CMP pad with a plurality of superhard cutting elements.

8. The method of claim 7, wherein the superhard cutting elements are formed from a polycrystalline diamond compact.

9. The method of claim 7, wherein the plurality of cutting elements are formed from a polycrystalline cubic boron nitride compact.

10. The method of claim 1, wherein the cutting element includes a trailing edge angled to provide a relief area between the finished surface of the CMP pad and the cutting element.

11. The method of claim 1, wherein the cutting element includes a trailing edge that is substantially parallel to the finished surface of the CMP pad.

12. The method claim 1, wherein the cutting element comprises a cutting blade having a cutting length at least twice as great as a cutting height.

13. A pad conditioner for removing material from a CMP pad while minimizing compression of the CMP pad, comprising:

a base; and

a plurality of superhard cutting elements, extending from the base, the cutting elements each having a cutting face angled at 90 degrees or less relative to a finished surface of the CMP pad;

the faces of the cutting elements being oriented such that relative movement of the pad conditioner and the CMP pad results in removal of material from the CMP pad with the cutting faces to thereby condition the CMP pad.

14. The pad conditioner of claim 13, wherein each of the cutting faces is oriented at about 90 degrees relative to the finished surface of the CMP pad.

15. The pad conditioner of claim 13, wherein each of the cutting faces is oriented at an angle less than 90 degrees relative to the finished surface of the CMP pad.

16. The pad conditioner of claim 13, wherein each of the cutting faces is oriented at an angle greater than 45 degrees

and less than 90 degrees relative to the finished surface of the CMP pad.

17. The pad conditioner of claim **13**, wherein each of the cutting elements includes a distal portion and a proximal portion, the proximal portion being closer to a base from which the cutting elements extend than is the distal portion, and wherein a cross section of the distal portion is wider than a cross section of the proximal portion.

18. The pad conditioner of claim **13**, wherein each of the cutting elements includes a cross section and extends from a base, and wherein the cross section of the cutting element includes a narrowed portion intermediate ends of the cutting element.

19. The pad conditioner of claim **13**, wherein the superhard cutting elements are formed from an integral piece of a polycrystalline diamond compact.

20. The pad conditioner of claim **13**, wherein the plurality of cutting elements are formed from a polycrystalline cubic boron nitride compact.

21. The pad conditioner of claim **13**, wherein each of the cutting elements includes a trailing edge angled to provide a relief area between the finished surface of the CMP pad and the cutting element.

22. The pad conditioner of claim **13**, wherein the cutting element includes a trailing edge that is substantially parallel to the finished surface of the CMP pad.

23. The pad conditioner of claim **13**, wherein the cutting element comprises a cutting blade having a cutting length at least twice as great as a cutting height.

24. A method of reducing a degree of compression of a CMP pad during conditioning of the CMP pad, comprising: engaging the CMP pad with a plurality of superhard cutting elements formed from a polycrystalline diamond compact, each of the cutting elements including a cutting face, the cutting faces being angled at 90 degrees or less relative to a finished surface of the CMP pad; and moving the CMP pad and the cutting element relative to one another in a direction resulting in removal of material from the CMP pad with the cutting face to thereby condition the CMP pad.

25. The method of claim **24**, wherein the cutting elements extend from a base, and wherein the base and the cutting elements are formed from an integral piece of a polycrystalline diamond compact.

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