(19) INTELLECTUAL PROPERTY OFFICE OF SINGAPORE

(11) Publication number: **SG 190811 A1**

(43) Publication date: **31.07.2013**

(51) Int. Cl: **B24D 18/00, B24B 53/017, B24D 3/34, B24D 3/06, B24D 7/02;**

(12) Patent Application

(21) Application number: **2013037270**

(22) Date of filing: **20.12.2011**

(30) Priority: **US 61/424,870 20.12.2010**

(71) Applicant: **DIAMOND INNOVATIONS, INC. 6325 HUNTLEY ROAD WORTHINGTON, OH 43229 OH US**

(72) Inventor: **RULAND, GARY, E. 220 FALCON CREST WARNER ROBINS, GA 31088 US**
RAREY, CHARLES 2625 ABBEY KNOLL DRIVE LEWIS CENTER, OH 43035 US
EASLEY, THOMAS, CHARLES 2603 BRENTWOOD ROAD BEXLEY, OH 43209 US
GRAHAM, JAMES 703 TIM TAM AVENUE GAHANNA, OH 43230 US
SCHWEIZER, MARK 7570 INDIAN SPRINGS DRIVE POWELL, OH 43065 US

(54) **Title:**
CMP PAD CONDITIONING TOOL

(57) **Abstract:**
The present disclosure provides a CMP pad conditioning tool with at least one integral abrasive protrusion. The present disclosure further provides a method for preparing this CMP pad conditioning tool, along with a method for using said tool to condition a CMP pad.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 June 2012 (28.06.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/088004 A2

(51) International Patent Classification:
E21B 33/12 (2006.01) *B32B 38/00* (2006.01)

(21) International Application Number:
PCT/US2011/065970

(22) International Filing Date:
20 December 2011 (20.12.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/424,870 20 December 2010 (20.12.2010) US

(71) Applicant *(for all designated States except US)*: **DIAMOND INNOVATIONS, INC.** [US/US]; 6325 Huntley Road, Worthington, OH 43229 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **RULAND, Gary, E.** [US/US]; 220 Falcon Crest, Warner Robins, GA 31088 (US). **RAREY, Charles** [US/US]; 2625 Abbey Knoll Drive, Lewis Center, OH 43035 (US). **EASLEY, Thomas, Charles** [US/US]; 2603 Brentwood Road, Bexley, OH 43209 (US). **GRAHAM, James** [US/US]; 703 Tim Tam Avenue, Gahanna, OH 43230 (US). **SCHWEIZER, Mark** [US/US]; 7570 Indian Springs Drive, Powell, OH 43065 (US).

(74) Agent: **GASAWAY, Maria, C.**; Diamond Innovations, Inc., 6325 Huntley Road, Worthington, OH 43229 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on next page]

(54) Title: CMP PAD CONDITIONING TOOL

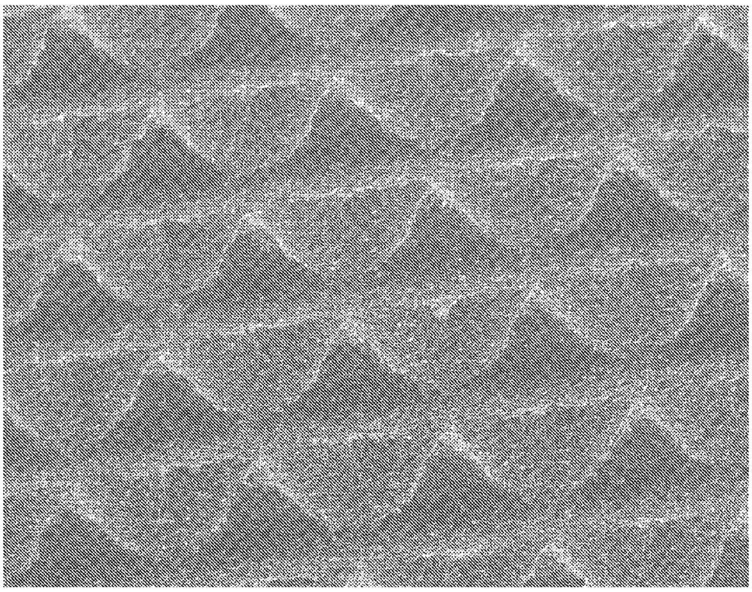

Fig. 6

(57) **Abstract**: The present disclosure provides a CMP pad conditioning tool with at least one integral abrasive protrusion. The present disclosure further provides a method for preparing this CMP pad conditioning tool, along with a method for using said tool to condition a CMP pad.

WO 2012/088004 A2

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

CMP Pad Conditioning Tool

Inventors: Gary Ruland, Charles Rarey, Thomas Easley, James Graham, and Mark Schweizer

TECHNICAL FIELD AND INDUSTRIAL APPLICABILITY

[0001] The present disclosure provides a novel tool and method for reconditioning chemical mechanical polishing ("CMP") pads. The present disclosure further includes methods for preparing the novel tool described herein as well as methods for using it.

BACKGROUND OF THE INVENTION

[0002] CMP methods are well known in the art and are regularly used to polish integrated circuit wafers. In a CMP process, polishing reactants, abrasives, and carrier fluids are applied to the wafer surface by a porous pad. Through a combination of chemical and mechanical action, the pad resurfaces the wafer being polished, such that a smooth wafer surface is obtained. In order to maintain the utility of the CMP pad, it must be periodically reconditioned to maintain uniform, repeatable polishing performance. This reconditioning may use a pad conditioning tool to remove spent reactants, abrasives, and polishing swarf.

[0003] Various CMP pad conditioning tools are known in the art as well. Typically, these conditioning tools comprise abrasives held randomly on a substrate by a bonding agent. U.S. Patent Publication 2009/0275274, for example, describes a conditioning tool comprising abrasive grains fixed to the surface of a metal support with a brazing metal. Similarly, U.S. 7,641,538 describes a CMP pad conditioning tool comprising abrasive particles fixed to a substrate using a brazing alloy and a sintered corrosion resistant powder.

[0004] U.S. Patent publication 2010/0139174 describes a CMP conditioning pad wherein abrasive particles are fixed to the surface of a substrate using organic materials such as amino resins, acrylate resins, polyester resins, polyurethane resins, phenolic resins, etc. U.S. Patent publication 2009/0224370 describes growing CVD diamond on the surface of a substrate for the preparation of a CMP conditioning tool and PCT/US2008/073823 discloses a CMP pad conditioning tool comprising abrasive grains bound to a substrate using a brazing alloy prepared from a brazing film.

[0005] Although the above described CMP pad conditioning tools have been used extensively in reconditioning processes, the above-described abrasives frequently present a non-planar surface that abrades and deforms the polishing pad in an irregular manner, limiting control over the conditioning process. Moreover, many of the above described CMP pad conditioning tools can release abrasive particles or other contaminants onto the CMP pad as the result of a failure in the bonding agent holding the abrasive particles to the substrate. If the CMP pad containing the contaminants is then used to polish an integrated circuit wafer, the wafer can be damaged.

[0006] Therefore, what is needed is a CMP pad conditioner that does not suffer from the above described defects.

SUMMARY OF THE INVENTION

[0007] The present disclosure provides a CMP pad conditioning tool comprising a fully integral array of abrasive protrusions that provide more complete control of the CMP pad reconditioning process. These abrasive protrusions are integrally attached to a substrate by high strength bonds that preclude abrasive particle loss. The present disclosure further provides a method of producing controlled single protrusions or arrays of controlled protrusions in the CMP pad conditioning tool.

[0008] The present invention includes a chemical mechanical polishing ("CMP") pad conditioning tool for conditioning a surface of a CMP pad. The tool comprises a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof. The tool face has at least one integral abrasive protrusion extending from said tool face and the at least one integral abrasive protrusion has at least one side angled at greater than 90 degrees relative to the surface of the CMP pad to be conditioned.

[0009] In certain embodiments, the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions. In particular embodiments, the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that the pyramids, tetrahedral, cones, or other polygons have at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad to be conditioned.

[0010] In certain embodiments, the material is selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof. In certain embodiments the material is a SiC-diamond composite.

[0011] The present invention further provides a method for conditioning a surface of a CMP pad. This process comprises steps a) and b). Step a) comprises contacting the surface of a CMP pad with a CMP pad conditioning tool comprising a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof; the tool face having at least one integral abrasive protrusion extending from said tool face; and said at least one integral abrasive protrusion having at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad contacted by said CMP pad conditioning tool. Step b) comprises conditioning the surface of said CMP pad, optionally, in the presence of one or more conditioning fluids.

[0012] In certain embodiments, the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions. In particular embodiments, the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that the pyramids, tetrahedra, cones, or other polygons have at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad contacted by the CMP pad conditioning tool.

[0013] In certain embodiments, the material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof is a SiC-diamond composite.

[0014] The present invention further provides a system for conditioning a surface of a CMP pad. The system comprises at least one CMP pad conditioning system adapted to receive at least one CMP pad; and at least one CMP pad conditioning tool comprising a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof; said tool face having at least one integral abrasive protrusion extending from said tool face; and said at least one integral abrasive protrusion having at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad to be conditioned.

[0015] In certain embodiments, the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions. In particular embodiments, the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that the pyramids, tetrahedra, cones, or other polygons have at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad contacted by said CMP pad conditioning tool.

[0016] In certain embodiments, the material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof is a SiC-diamond composite.

[0017] The present invention further provides a method for preparing a CMP pad conditioning tool for conditioning a surface of a CMP pad. This method comprises machining a surface of a blank comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof to produce a CMP pad conditioning tool according to claim 1.

[0018] In certain embodiments, the machining results in a plurality of integral abrasive protrusions.

[0019] In certain embodiments, the plurality of protrusions are a regular array of integral abrasive protrusions.

[0020] In some embodiments, the machining method is wire EDM. In other embodiments, the machining method is plunge EDM.

[0021] The present invention further includes another method for preparing the CMP pad conditioning tool described herein. This method comprises pressing a powder mixture comprising about 90% diamond powder by weight, about 9.5% silicon powder by weight, and about 0.5% Si_3N_4 by weight, into a negative form, said negative form comprising a silicon mass, and heating said powder and said mass under pressure, to produce the CMP pad conditioning tool described herein.

[0022] The present invention further includes another method for preparing the CMP pad conditioning tool described herein. This method comprises mixing a powder comprising about 90% diamond powder by weight, about 9.5% silicon powder by weight, and about 0.5% Si_3N_4 by weight, with a binder to form a powder/binder mixture. The method further includes pressing said powder/binder mixture to form a preform, said preform having a preform face, said preform face comprising at least one integral abrasive protrusion extending from said preform face; heating said preform to a temperature and in an atmosphere suitable for removing all of the binder from the preform by incineration; and firing said preform at a temperature of at least about 1000 ºC for at least about 5 minutes to partially react the powder particles and form a porous rigid preform.

[0023] In certain embodiments, the binder is polyethyleneglycol or polyvinylalcohol.

[0024] In some embodiments, the preform is fired at a temperature of at least about 1450 ºC for at least about 5 minutes. In other embodiments, the preform is fired at a temperature of about 1300 ºC for about 5 minutes.

[0025] In certain embodiments, the method further includes heating the porous rigid preform in an inert gas or under vacuum at a second temperature; and contacting the rigid porous preform heated to said second temperature with liquid silicon so that the liquid silicon infiltrates the preform and reacts with the diamond in the preform to form SiC.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The foregoing summary, as well as the following detailed description of the embodiments, will be better understood when read in conjunction with the appended drawings. For the purpose of illustration, there are shown in the drawings some embodiments which may be preferable. It should be understood, however, that the embodiments depicted are not limited to the precise arrangements and instrumentalities shown.

[0027] Figure 1 depicts the surface of an SiC-diamond composite CMP pad conditioning tool wherein the surface of the tool is populated with an array of evenly distributed square pyramids that are integral with the surface of the tool.

[0028] Figure 2 is a schematic representation of the pattern shown on the surface of the tool depicted in Figure 1.

[0029] Figure 3 is a schematic representation of a generalized wire EDM cutting pattern that can be used to create a variety of arrays of protrusions.

[0030] Figure 4 is a schematic representation of a wire EDM cutting pattern used to arrive at a substrate having the square-pyramid pattern observed in Figure 1.

[0031] Figure 5 is a schematic representation of the angle formed between an abrasive protrusion of a CMP pad conditioning tool described herein and a CMP pad being conditioned.

[0032] Figure 6 is a schematic representation of the pattern as described in Example 3.

DETAILED DESCRIPTION

[0033] The present disclosure provides a CMP pad conditioning tool comprising at least one, and in certain embodiments, an array of fully integral abrasive protrusions that provides more complete control of the CMP pad reconditioning process. The integral abrasive protrusions and substrate on which they reside are formed from a single piece of material, using one of the various processes described herein. Fashioning the substrate and its protrusions from a single piece of material negates the need to glue or otherwise indirectly bond the abrasive protrusions to the substrate on which they reside. The fully integral protrusions are substantially less susceptible to abrasive particle loss.

[0034] Without wishing to be bound by any particular theory, it is believed that the lack of susceptibility to abrasive particle loss derives at least in part from the inherent strength of the material used to prepare the substrate and abrasive protrusions, as well as the resistance of this material to corrosive attack by chemicals in polishing slurries typically used during the CMP process. Therefore, when compared to known CMP pad conditioning tools, such as those described in U.S. Patent 7,641,538, the CMP pad conditioning tool described herein provides higher abrasive retention rates and longer tool life. The processes and materials described herein also allow the aggressiveness of the integral abrasive protrusions' cutting action to be optimized and controlled.

[0035] The present disclosure further provides a method of producing a CMP pad conditioning tool having at least one abrasive protrusion or an array thereof. For example, the process for preparing the CMP pad conditioning tool described herein provides full control over the geometry of the integral abrasive protrusion(s). The ability to control the height, width, spacing, and shape of the integral abrasive protrusion(s) eliminates irregularities common in current conditioning tools and precludes the need to correct or remove one or more overly aggressive protrusions common in known random arrays. See, for example, U.S. Publication 2010/0186479. The tools and methods described herein also improve the repeatability of the conditioning process.

[0036] In certain embodiments, the CMP pad conditioning tool can be fabricated from known materials such as polycrystalline diamond (including Co-bonded polycrystalline diamond and SiC-bonded diamond), polycrystalline cubic boron nitride, boron carbide, silicon carbide, combinations thereof, or other extremely hard and corrosion resistant materials. These hard, corrosion resistant materials may be presented as single crystal material, as polycrystalline material, or as a composite.

[0037] For example, in certain embodiments, the CMP pad conditioning tool can be prepared from an SiC-diamond composite such as the material described in U.S. 5,106,393, the entire contents of which are incorporated herein by reference. In particular embodiments, the SiC-diamond composite can comprise about 78 weight % to about 82 weight % diamond, about 18 weight % to about 20 weight % SiC, and, optionally, about 1 weight % to about 2 weight % un-reacted Si as measured by x-ray diffraction.

[0038] When Si_3N_4 is included in the mixture of materials used to prepare the SiC/diamond composite, trace amounts of nitrogen can infiltrate the molten mixture during processing and replace carbon. The trace quantities of nitrogen impart electrical conductivity to the resulting material. The quantity of nitrogen in the SiC-diamond composite is typically less than about 0.2 weight % of the total composition. The diamond used in the composite can include a single grain size, or optionally any combination of grain sizes, ranging from sub-micron sizes up to about 200 microns.

[0039] In particular embodiments, the SiC-diamond composite can include a mixture of diamonds of two different grain sizes. In certain embodiments, the primary diamond grain size can be about 20 microns and the secondary diamond grain size can be about 5 microns. These diamonds can be mixed in a weight ratio of from about 1:10 to about 10:1. In particular embodiments, the weight ratio of primary to secondary diamond grain size is about 4:1.

[0040] In certain embodiments, the materials described herein as suitable for use in the CMP conditioning pad can be produced by CVD methods. Polycrystalline diamond and cubic boron nitride can be produced by known HPHT methods. Reaction sintered diamond and cubic boron nitride composites can be produced by HPHT sintering, capillary infiltration, reaction sintering, or conventional sintering. Single crystal conventional abrasives, such as SiC, or sintered assemblages of abrasive crystals may also be produced by these methods.

[0041] Any of the materials described herein as suitable for use in the CMP conditioning pad can be intrinsically conductive, doped to be made conductive or semiconductive, or comprise a mixture of materials, one or more of which may be electrically conductive. Electrical conductivity facilitates plasma machining methods such arc wire EDM, plunge EDM, formed electrode discharge grinding, discharge grinding, and similar methods known to those of skill in the art.

[0042] For non-electrically conductive materials, machining methods include, but are not limited to, conventional grinding, lithography, laser ablation, and other conventional methods. These conventional methods can also be used in conjunction with, or as an alternative to, plasma machining in samples suitable for plasma machining.

[0043] A CMP pad conditioning tool prepared using the materials described herein can include at least one abrasive protrusion but may include a plurality of protrusions. The protrusions can have straight, curved, or serrated edges. The protrusions can take the form any known geometrical shapes, including, but not limited to, pyramids (including, but not limited to, square pyramids, triangular pyramids, octagonal, and other polygonal pyramids), truncated pyramids, tetrahedra, cones (full or truncated), cylinders, prisms (including, but not limited to, triangular, rectangular, pentagonal, hexagonal, and any other regular or irregular prisms), and other polygons.

[0044] Protrusions such as, but not limited to, pyramids, cones, and tetrahedra may come to a point according to their natural geometry, or may be truncated or otherwise blunted. In preferred embodiments, the geometry of the protrusions are such that an angle between the surface of the CMP pad being conditioned and a surface of the protrusion is greater than about 90°, greater than about 95°, greater than 100°, or even greater than 105° or 110°. The angle, α_3, can be measured as shown in Figure 5.

[0045] In certain embodiments, the CMP pad conditioning tool can include an array of abrasive protrusions. The size of the arrayed protrusions can be varied in plan dimensions and height within a single tool or from tool to tool. The array can have a periodic Cartesian nature, rotational symmetry, repeatable semi-random character, or fully random character. The conditioning tool may also include penetrations that permit fluids, reactants, and polishing swarf to be more effectively removed from the tool.

[0046] The protrusions on the CMP pad conditioning tool can be produced by a number of methods. For example, in certain embodiments, an SiC-diamond composite having the composition described previously herein, can be formed with abrasive protrusions during the material manufacturing process, without the need for secondary machining. Such a process involves placing the requisite diamond and silicon powders in contact with a silicon mass having a negative form of the desired protrusion or array of protrusions in its surface. The negative form in the silicon surface can be prepared using known methods including etching, drilling, laser ablation, and electro discharge machining.

[0047] During the manufacturing process, the diamond and silicon powder mixture is pressed into the negative form, taking its shape. At the completion of the manufacturing process, i.e. heating the powder mixture at temperature under pressure, the resulting SiC-diamond composite has a surface with protrusions having the size, shape, and spacing of the corresponding negative form in the silicon mass.

[0048] CMP pad conditioning tools prepared according to the above described method can be prepared individually, or in groups, both according to known processes.

[0049] In other embodiments, an Si-C diamond composite CMP pad conditioning tool can be prepared by blending the appropriate silicon and diamond powder mixture with a binder such as PEG (polyethyleneglycol) or PVA (polyvinylalcohol) so that when pressed in a die or punch, the powder mixture is consolidated to produce a "preform." By making a punch or die having an array of depressions corresponding to the desired protrusion or array of protrusions, a preform containing the desired surface geometry can be produced. Optionally, before being compressed into a preform, the powders may be granulated using a process such as spray drying, freeze granulation, or other granulation method.

[0050] The preform, still presenting the desired surface geometry, can then be fired in a furnace having a controlled atmosphere and temperature in order to remove the binder. In certain embodiments, the preform is subsequently fired at about 1000 ºC so that some silicon in the preform will react with some diamond in the preform to produce microscopic amounts of SiC. In some embodiments, the perform is fired at about 1300 ºC for at least about 5 minutes. The microscopic SiC bonds the particles together, facilitating further processing. The thus fired preform also contains a matrix of porosity where the binder used to be.

[0051] The fired preform can then be placed in another furnace wherein it is heated in an inert gas and placed into contact with liquid silicon so that the silicon infiltrates and fills the pores within the preform. During the infiltration process, silicon reacts with diamond in the perform to form SiC to produce a dense body composed of diamond, SiC, and silicon. In certain embodiments, and as an alterative to heating under an inert gas, the fired preform can be heated in a vacuum. Either process results in the formation of a nearly fully dense body.

[0052] In an alternative embodiment, the preform containing binder can be fired at a temperature of at least about 1450ºC for at least about 5 minutes. In a process of this nature, the conversion of Si to SiC is substantially complete, resulting in a SiC-diamond composite containing about 20% to about 50% porosity by volume. The amount of porosity can be controlled by adjusting the powder composition, powder processing, and preform pressing parameters.

[0053] Regardless of the process employed, the resulting product retains the desired surface geometry and is suitable, after any necessary post processing, for use as a CMP pad conditioning tool.

[0054] In other embodiments, a CMP pad conditioning tool can be prepared by preparing the substrate first, and subsequently machining the substrate to present the desired protrusion or array of protrusion. For example, an electrically conductive SiC-diamond composite can be subjected to a plasma machining technique such as wire EDM to prepare protrusions of varying sizes and geometries.

[0055] According to the general wire EDM procedure, an electrically conductive material, such as an SiC-diamond composite described previously herein, is prepared in a convenient shape or size, such as a bar with circular, square, hexagonal, or other desired cross section and appropriate diameter. In certain embodiments, the blank is mounted in a wire EDM such that it's axis is horizontal. Subsequently, and in certain embodiments, a first cut can made so that fresh surface is exposed for further processing.

[0056] In certain embodiments, a series of cuts can be made into and across the surface of the blank. An exemplary series of cuts is illustrated schematically in Figure 3. This series of cuts traverses across the surface of the blank in one direction and includes at least one first cut into the surface of the blank at a first angle α_1 between about 0 and about -90 degrees with respect to the normal of the blank surface. In particular embodiments, α_1 can be between about -45 and about 0 degrees. The cut can progress into the blank to an appropriate depth such as measured on a line perpendicular to the surface of the blank. This distance is shown in Figure 3 as $-y2$.

[0057] The cut can then proceed parallel to the surface, and at depth $-y2$, for a desired distance, $x5$, wherein $x5$ can be greater than or equal to 0. The cut can then proceed out of the blank at a second angle α_2 with respect to the surface normal. In certain embodiments, α_2 can have the same absolute value as α_1, but have a different sign (i.e. about -30° and about 30°). In other embodiments, α_1 and α_2 can be identical. In still other embodiments, α_1 and α_2 can have different absolute values and different signs. This series of cuts results in the formation of a trough in the surface of the blank.

[0058] In certain embodiments, the wire can then be positioned for a subsequent cut by moving the wire a distance x6, in either the positive or negative direction, relative to the first series of cuts, depending upon the type of protrusion that is desired. Subsequently, in certain embodiments, a second series of cuts can be made such that a subsequent trough, or series of troughs, are cut into the surface of the blank. This process can be repeated as desired, until there is no additional surface area to cut.

[0059] After cutting a desired number of appropriately shaped troughs in the surface of the blank, the blank can be rotated about its axis by an angle β, and the above described cutting process can be repeated, such that a second series of troughs are created at an angle β relative to the first series of troughs. Depending on the shape, size, and spacing of the protrusions desired, the rotation β and trough cutting may be repeated additional times.

[0060] The CMP pad conditioning tool can be incorporated into an assembly of one or more tools in an equipment module that moves the tool across the CMP pad surface.

[0061] Examples

[0062] The CMP pad conditioning tool and method for making it disclosed herein are now further detailed with reference to the following examples. These examples are provided for the purpose of illustration only, and the CMP pad conditioning tool and method for making it should in no way be construed as being limited to these examples but rather should be construed to encompass any and all variations which become evident as a result of the teaching provided herein.

[0063] Example 1

[0064] An approximately cylindrical SiC-diamond composite was prepared according to the following procedure. A mixture comprising about 90% diamond by weight, about 9.5% Si powder by weight, and about 0.5% Si_3N_4 by weight was prepared. The diamond powder included 4 parts of a diamond powder with a particle size of about 20 microns and 1 part of a diamond powder with an average particle size of about 5 microns. The Si powder had an average particle size of less than about 10 microns, and the Si_3N_4 powder had a particle size of about 1 micron.

[0065] The powder mixture was subsequently loaded into a pressure cell and placed in contact with a body of silicon. This material was then subject to HPHT at a pressure of up to about 30 kBar at about 1600ºC. After 30 minutes, the temperature and pressure were gradually reduced to ambient conditions and an approximately cylindrical SiC-diamond composite sample was recovered from the pressure cell.

[0066] The resulting diamond composite comprised approximately about 78 weight % to about 82 weight % diamond, about 18 weight % to about 20 weight % of a continuous SiC matrix, about 1 weight % to 2 weight % un-reacted Si, as determined by x-ray diffraction.

[0067] Example 2

[0068] A CMP pad conditioner having the surface pattern shown in Figure 2 was prepared by the following process. All machining was performed on a Fanuc Robocut alpha-oc wire EDM machine. In the wire EDM machine, a 0.008" diameter wire was held in a vertical orientation, and a cylinder of SiC-diamond composite prepared according to Example 1 was mounted with the cylinder's axis in a horizontal orientation. A first cut was made perpendicular to the cylinder's axis, to expose a fresh surface of SiC-diamond composite.

[0069] A series of second cuts was then made into and across this fresh surface. This series of cuts consisted of a cut angled at 30 degrees, 0.5mm into the surface of the sample; a cut 0.2mm in length parallel to the surface of the sample at the 0.5mm depth; and a subsequent cut at an angle of -30 degrees out of the surface. This series of cuts resulted in a trough in the surface of the SiC-diamond composite. A graphical representation of this cutting pattern is shown in Figure 4.

[0070] This series of cuts was repeated across the surface of the cylinder such that a series of parallel troughs were formed. Next, the cylinder was rotated by 90 degrees about its axis and a series of third cuts, identical to the series of second cuts, was made leaving a matrix of square-pyramid shaped protrusions on the cylinder surface. A final cut, parallel to the first cut and perpendicular to the cylinder's axis was then made at an appropriate distance behind the freshly cut surface to remove a circular CMP pad conditioning tool from the cylinder of SiC-diamond composite.

[0071] Example 3

[0072] A CMP pad conditioner having the surface pattern shown in Figure 6 was prepared by the same process as in Example 2, except for the following differences.

[0073] A series of second cuts was then made into and across this fresh surface. This series of cuts consisted of a cut angled at -15 degrees, 0.5mm into the surface of the sample; a cut 0.18mm in length parallel to the surface of the sample at the 0.5mm depth; and a subsequent cut at an angle of 15 degrees out of the surface. This series of cuts resulted in a trough in the surface of the SiC-diamond composite.

[0074] This series of cuts was repeated across the surface of the cylinder such that a series of parallel troughs were formed. Next, the cylinder was rotated by 120 degrees about its axis and a series of third cuts, identical to the series of second cuts, was made. Next, the cylinder was rotated again by 120 degrees and a series of fourth cuts, identical to the series of second and third cuts, leaving a matrix of triangular-pyramid shaped protrusions on the cylinder surface. A final cut, parallel to the first cut and perpendicular to the cylinder's axis was then made at an appropriate distance behind the freshly cut surface to remove a circular CMP pad conditioning tool from the cylinder of SiC-diamond composite.

[0075] While reference has been made to specific embodiments, it is apparent that other embodiments and variations can be devised by others skilled in the art without departing from their spirit and scope. The appended claims are intended to be construed to include all such embodiments and equivalent variations.

CLAIMS

What is claimed is:

1. A chemical mechanical polishing ("CMP") pad conditioning tool for conditioning a surface of a CMP pad, said tool comprising

a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof;

said tool face having at least one integral abrasive protrusion extending from said tool face

said at least one integral abrasive protrusion having at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad to be conditioned.

2. The CMP pad conditioning tool of claim 1, wherein the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions.

3. The CMP pad conditioning tool of claim 2, wherein the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that said pyramids, tetrahedral, cones, or other polygons have at least one side angled at greater than 90 degrees relative to the surface of the CMP pad to be conditioned.

4. The CMP pad conditioning tool of claim 1, wherein the material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof is a SiC-diamond composite.

5. A method for conditioning a surface of a CMP pad, said process comprising

a) contacting the surface of said CMP pad with a CMP pad conditioning tool comprising:

a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof;

said tool face having at least one integral abrasive protrusion extending from said tool face;

said at least one integral abrasive protrusion having at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad contacted by said CMP pad conditioning tool; and

b) conditioning the surface of said CMP pad, optionally in the presence of one or more conditioning fluids.

6. The method according to claim 5, wherein the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions.

7. The method according to claim 6, wherein the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that said pyramids, tetrahedra, cones, or other polygons have at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad contacted by said CMP pad conditioning tool.

8. The method according to claim 5, wherein the material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof is a SiC-diamond composite.

9. A system for conditioning a surface of a CMP pad, said system comprising

at least one CMP pad conditioning system, adapted to receive at least one CMP pad; and

at least one CMP pad conditioning tool, said tool comprising

a tool body having a tool face, said tool body and tool face comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof;

said tool face having at least one integral abrasive protrusion extending from said tool face; and

said at least one integral abrasive protrusion having at least one side angled at greater than about 90 degrees relative to the surface of the CMP pad to be conditioned.

10. The system according to claim 9, wherein the at least one integral abrasive protrusion comprises an array of integral abrasive protrusions.

11. The system according to claim 10, wherein the array of integral abrasive protrusions comprises an array of pyramids, tetrahedra, cones, or other polygons, provided that said pyramids, tetrahedra, cones, or other polygons have at least one side angled at greater than 90 degrees relative to the surface of the CMP pad contacted by said CMP pad conditioning tool.

12. The system according to claim 9, wherein the material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof is a SiC-diamond composite.

13. A method for preparing a CMP pad conditioning tool for conditioning a surface of a CMP pad, said method comprising

machining a surface of a blank comprising a material selected from the group of polycrystalline diamond, polycrystalline cubic boron nitride, boron carbide, silicon carbide, and combinations thereof to produce a CMP pad conditioning tool according to claim 1.

14. The method according to claim 13, wherein said machining results in a plurality of integral abrasive protrusions.

15. The method according to claim 14, wherein said plurality of protrusions are a regular array of integral abrasive protrusions.

16. The method of claim 13, wherein the machining method is wire EDM.

17. The method of claim 13, wherein the machining method is plunge EDM.

18. A method for preparing a CMP pad conditioning tool according to claim 1, said method comprising:

pressing a powder mixture comprising about 90% diamond powder by weight, about 9.5% silicon powder by weight, and about 0.5% Si_3N_4 by weight, into a negative form, said negative form comprising a silicon mass, and

heating said powder and said mass under pressure, to produce the CMP pad conditioning tool according to claim 1.

19. A method for preparing the CMP pad conditioning tool according to claim 1, said method comprising:

mixing a powder comprising about 90% diamond powder by weight, about 9.5% silicon powder by weight, and about 0.5% Si_3N_4 by weight, with a binder to form a powder/binder mixture;

pressing said powder/binder mixture to form a preform, said preform having a preform face, said preform face comprising at least one integral abrasive protrusion extending from said preform face;

heating said preform to a temperature and in an atmosphere suitable for removing all of the binder from the preform by incineration; and

firing said preform at a temperature of at least about 1000 ºC for at least about 5 minutes to partially react the powder particles and form a porous rigid preform.

20. The method according to claim 19, wherein the binder is polyethyleneglycol or polyvinylalcohol.

21. The method according to claim 20, wherein the preform is fired at a temperature of at least about 1450 ºC for at least about 5 minutes.

22. The method according to claim 20, wherein said preform is fired at a temperature of about 1300 ºC for about 5 minutes.

23. The method according to claim 19, further comprising

heating said porous rigid preform in an inert gas or under vacuum at a second temperature; and

contacting the rigid porous preform heated to said second temperature with liquid silicon, so that said liquid silicon infiltrates the preform and reacts with the diamond in the preform to form SiC.