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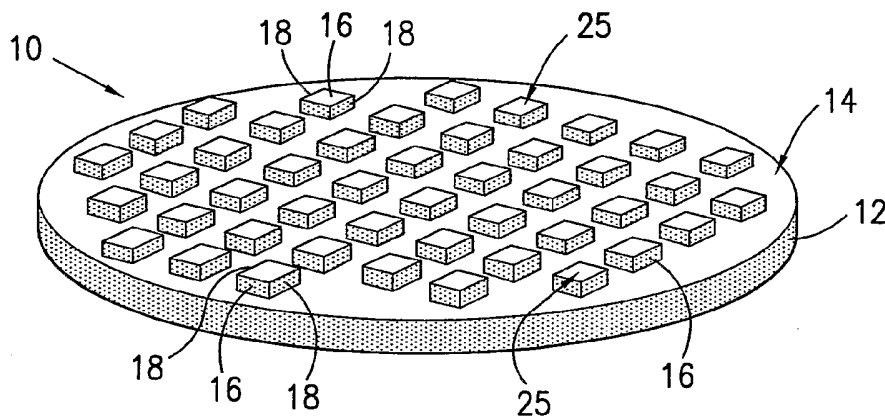
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(54) Title: SUPERHARD CUTTERS AND ASSOCIATED METHODS



(57) Abstract: A cutting device (10) comprises a base (12) having a working side (14) that is oriented to face a workpiece (19) from which material is to be removed. A plurality of individual cutting elements (16) are arranged on the working side of the base, with each cutting element having a peak that comprises at least one cutting edge (18) that is formed from a polycrystalline superhard material. The peaks of the cutting elements are aligned in a common plane (20).

SUPERHARD CUTTERS AND ASSOCIATED METHODS

FIELD OF THE INVENTION

The present invention relates generally to cutting devices used to plane workpieces
5 formed of various materials. Accordingly, the present invention involves the fields of chemistry, physics, and materials science.

BACKGROUND OF THE INVENTION

It is estimated that the semiconductor industry currently spends more than one
10 billion U.S. Dollars each year manufacturing silicon wafers that exhibit very flat and smooth surfaces. Typically, chemical mechanical polishing ("CMP") is used in the manufacturing process of semiconductor devices to obtain smooth and even surfaced wafers. In a conventional process, 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
15 pad and pressure is applied to the carrier, the wafer is polished by relative movement of the platen and the carrier.

While this well-known process has been used successfully for many years, it suffers from a number of problems. For example, this conventional process is relatively expensive and is not always effective, as the silicon wafers may not be uniform in
20 thickness, nor may they be sufficiently smooth, after completion of the process. In addition to becoming overly "wavy" when etched by a solvent, the surface of the silicon wafers may become chipped by individual abrasive grits used in the process. Moreover, if the removal rate is to be accelerated to achieve a higher productivity, the grit size used on the polishing pad must be increased, resulting in a corresponding increase in the risk of
25 scratching or gouging expensive wafers. Furthermore, because surface chipping can be discontinuous, the process throughput can be very low. Consequently, the wafer surface preparation of current state-of-the-art processes is generally expensive and slow.

In addition to these considerations, the line wide (e.g., nodes) of the circuitry on semiconductors is now approaching the virus domain (e.g., 10-100 nm). In addition, more
30 layers of circuitry are now being laid down to meet the increasing demands of advanced logic designs. In order to deposit layers for making nanometer sized features, each layer must be extremely flat and smooth during the semiconductor fabrication. While diamond grid pad conditioners have been effectively used in dressing CMP pads for polishing

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previous designs of integrated circuitry, they have not been found suitable for making cutting-edge devices with nodes smaller than 65 nm. This is because, with the decreasing size of the copper wires, non-uniform thickness due to rough- or over-polishing will change the electrical conductivity dramatically. Moreover, due to the use of coral-like dielectric layers, the fragile structure must be polished very gently to avoid disintegration. Hence, the pressure used in CMP processes must be reduced significantly.

In response, new CMP processes, such as those utilizing electrolysis (e.g. Applied Materials ECMP) of copper or those utilizing air film cushion support of wafer (e.g. Tokyo Semitsu), are being pursued to reduce the polishing pressure on the contact points between wafer and pad. However, as a consequence of gentler polishing action, the polishing rate of the wafer will decrease. To compensate for the loss of productivity, polishing must occur simultaneously over the entire surface of the wafer. In order to do so, the contact points between the wafer and the pad must be smaller in area, but more numerous in quantity. This is in contrast to current CMP practice in which the contacted areas are relatively large but relatively few in number.

Thus, in order to polish fragile wafers more and more gently, the CMP pad asperities must be reduced. However, to prevent the polishing rate from declining, more contact points must be created. Consequently, the pad asperities need to be finer in size but more in number. However, the more delicate the polishing process becomes, the higher the risk of scratching the surface of the wafer becomes. In order to avoid this risk, the highest tips of all asperities must be fully leveled. Otherwise, the protrusion of a few "killer asperities" can ruin the polished wafer.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a cutting device, including a base having a working side that can be oriented to face a workpiece from which material is to be removed. A plurality of individual cutting elements can be arranged on the working side of the base. Each cutting element can have a peak that comprises at least one cutting edge that is formed from a polycrystalline superhard material. The peaks of the cutting elements can be aligned in a common plane. The base and each of the cutting elements can be formed from an integral piece of polycrystalline superhard material.

In accordance with another aspect of the invention, a cutting device is provided, including a base having a working side that can be oriented to face a workpiece from

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which material is to be removed. The base can be formed from an integral piece of a polycrystalline superhard material. A plurality of individual cutting elements can be integrally formed with the working side of the base. Each cutting element can have a peak that comprises at least a tip. The peaks of the cutting elements can be aligned in a
5 common plane.

In accordance with another aspect of the invention, a method of forming the cutting device above is provided, including the steps of: providing a polycrystalline superhard material compact; and removing material from a working side of a base of the polycrystalline superhard material compact to form the plurality of individual cutting
10 elements from the polycrystalline superhard material compact.

In accordance with another aspect of the invention, a product is provided that can be formed by the process comprising: engaging a surface of a workpiece with a plurality of individual cutting elements of a cutting device, the individual cutting elements being integrally formed from a working side of an integral piece of a polycrystalline superhard
15 material and each cutting element having a peak that is aligned in a common plane; and moving the workpiece and the cutting device relative to one another to thereby remove material from the workpiece with the cutting elements.

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
20 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.

25 **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a schematic, perspective view of a cutting device in accordance with an embodiment of the invention;

FIG. 2 is a side, plan view of the cutting device of FIG. 1;

FIG. 3 is a schematic, partial side view of a cutting element cutting a workpiece in
30 accordance with an embodiment of the invention;

FIG. 4A is a perspective, more detailed view of a series of cutting elements in accordance with an embodiment of the invention;

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FIG. 4B is a perspective view of a cutting device having arcuate cutting elements in accordance with an embodiment of the invention;

FIG. 5 is a sectional view of a pair of cutting elements of the cutting device of FIG. 1;

5 FIG. 6 is a sectional view of a cathode and an anode of an electrical discharge machining process;

FIG. 7A is a top view of a cutting device in accordance with an embodiment of the invention;

10 FIG. 7B is a sectional view of a series of cutting elements of the cutting device of FIG. 7A;

FIG. 8 is an image of a cutting device with a magnified image of a cutting element in accordance with an aspect of the invention; and

FIG. 9 is an image of a cutting device with a magnified image of a cutting element in accordance with an aspect of the invention.

15 It will be understood that the above figures are merely for illustrative purposes in furthering an understanding of the invention. Further, the figures may not be drawn 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 cutting
20 devices of the present invention.

DETAILED DESCRIPTION

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
25 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.

It must be noted that, as used in this specification and the appended claims, the
30 singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a cutting element” includes one or more of such elements and reference to “a brittle material” includes reference to one or more of such a material.

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Definitions

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

As used herein, "particle" and "grit" may be used interchangeably, and when used
5 in connection with a carbonaceous material, refer to a particulate form of such material. Such particles or grits may take a variety of shapes, including round, oblong, square, euahedral, etc., as well as a number of specific mesh sizes. As is known in the art, "mesh" refers to the number of holes per unit area as in the case of U.S. meshes. All mesh sizes referred to herein are U.S. mesh unless otherwise indicated. Further, mesh sizes are
10 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.

As used herein, "substantial," or "substantially," refers to the functional achievement of a desired purpose, operation, or configuration, as though such purpose or
15 configuration had actually been attained. Therefore, cutting edges that are substantially aligned in a common plane function as though, or nearly as though, they were precisely aligned in such a plane.

Furthermore, when used in an exclusionary context, such as a material "substantially lacking" or being "substantially devoid of, or free of" an element, the terms
20 "substantial" and "substantially" refer to a functional deficiency of the element to which reference is being made. Therefore, it may be possible that reference is made to a material in which an element is "substantially lacking," when in fact the element may be present in the material, but only in an amount that is insufficient to significantly affect the material, or the purpose served by the material in the invention.

25 As used herein, "working side" refers to the side of a tool which contacts or is configured to contact material of a workpiece during a planing or dressing procedure. In some aspects, the working side may merely face a workpiece to be worked, but may not actually contact the workpiece.

As used herein, a "common plane" refers to a profile, including planar or contoured
30 profiles, above a base surface with which the peaks of the cutting elements are to be aligned. Examples of such profiles may include, without limitation, wavy profiles, convex profiles, concave profiles, multi-tiered profiles, and the like.

As used herein, cutting "edge" refers to a portion of a cutting element that includes

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some measurable width across a portion that contacts and removes material from a workpiece. As an exemplary illustration, a typical knife blade has a cutting edge that extends longitudinally along the knife blade, and the knife blade would have to be oriented transversely to a workpiece to scrape or plane material from the workpiece in order for the cutting “edge” of the knife blade to remove material from the workpiece.

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) 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, etc.

As used herein, “vapor deposition” refers to a process of depositing materials on a substrate through the vapor phase. Vapor deposition processes can include any process such as, but not limited to, chemical vapor deposition (CVD) and physical vapor deposition (PVD). A wide variety of variations of each vapor deposition method can be performed by those skilled in the art. Examples of vapor deposition methods include hot filament CVD, rf-CVD, laser CVD (LCVD), metal-organic CVD (MOCVD), sputtering, thermal evaporation PVD, ionized metal PVD (IMPVD), electron beam PVD (EBPVD), reactive PVD, and the like.

As used herein, “sintering” refers to the joining of two or more individual particles to form a continuous solid mass. The process of sintering involves the consolidation of particles to at least partially eliminate voids between particles. Sintering may occur in either metal or carbonaceous particles, such as diamond. Sintering of metal particles occurs at various temperatures depending on the composition of the material. Sintering of diamond particles generally requires ultrahigh pressures and the presence of a carbon solvent as a diamond sintering aid, and is discussed in more detail below. Sintering aids are often present to aid in the sintering process and a portion of such may remain in the final product.

As used herein, the term “cutting element” refers to a protrusion or an indentation formed in a cutting device that includes one or more cutting edges or tips that are configured to cut or plane material from a surface of a workpiece. While not so limited,

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cutting elements described herein can include a frontal surface and an upper surface that meet at substantially a 90° angle to form the cutting edge. In some cases, cutting elements of the present invention have a three-dimensional configuration with relatively substantial width, depth and height. Each cutting element can include one or more cutting edges that have a cutting width coinciding with one of the width or depth of the cutting element.

As used herein, the term “peak” refers to a relative portion of a cutting element that extends the greatest distance from a base of a cutting element. Thus, when oriented to contact a workpiece, the peaks of cutting elements of a cutting device would contact the surface of the workpiece prior to any other portion of the cutting device contacting the workpiece.

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.

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.

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

The present invention provides a cutting device and associated methods that can be utilized in cutting or otherwise affecting a workpiece to remove material from the

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workpiece and provide a finished, smooth and/or flat surface to the workpiece. Cutting devices of the present invention can be advantageously utilized, for example, as planing devices that plane material from a workpiece, as dressing devices that dress various workpieces, and as polishing devices that polish various workpieces.

5 In the embodiment of the invention illustrated in FIG. 1, the cutting device 10 can include a base 12 that can have a working side 14 that faces a workpiece (19 in FIG. 3) to be cut or planed. A plurality of individual cutting elements 16 can be arranged on the working side of the base. Each of the cutting elements can include at least one cutting edge or tip 18, each of which can be aligned in a common plane 20, shown schematically
10 in FIG. 2. As discussed in more detail below, the cutting edges can be engaged with the workpiece 19, and the workpiece and the cutting edges can be moved relative to one another, to cut, slice, plane or otherwise remove small pieces or chips from the workpiece to create a surface on the workpiece that is both very flat and very smooth.

In one aspect of the invention, each of the cutting elements 16 can include one or a
15 plurality of cutting edges 18 aligned in the common plane 20. Thus, in the embodiment illustrated in FIG. 1, each of the cutting elements includes 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
20 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
25 surface.

The cutting edges 18 of the cutting elements 16 can be formed from a variety of materials including, in one embodiment, a polycrystalline superhard material. While not so limited, the polycrystalline superhard material can be a polycrystalline diamond compact (“PCD”) or a polycrystalline cubic boron nitride compact (“PcBN”). The PCD or
30 PcBN compact can be formed in a variety of manners, as discussed in more detail below. In the aspect of the invention shown in FIG. 1, the base 12 and each of the cutting elements 16 and cutting edges 18 are integrally formed from an integral piece of polycrystalline superhard material.

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The cutting device of the present invention can be utilized in a number of applications, and in one embodiment is particularly well adapted for 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.

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.

In contrast to conventional polishing or grinding processes, the present invention can utilize one or more 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.

The PCD or PcBN compacts of the present invention 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

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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.

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. 2, where the depth 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. The ductile process of cutting and removing material from a workpiece is shown schematically in FIG. 3, where cutting edge 18 of cutting element 16 is shown shaving chip 24 from the workpiece 19.

Each of the cutting elements 16 can include a substantially planar face 25 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 PCD cutter 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.

The life of the PCD or PcBN cutting devices can often be limited by the radius of the cutting edge. When the edge becomes worn such that the radius is increased to about 10 nm, the contact area may increase up to 100 times. This will reduce the contact pressure significantly. As a result, the edge will not "bite" into the silicon but will rather slide against its surface. In this case, heat will be generated, and the wafer surface might become thermally damaged. Thus, it can be important that a sharp edge be maintained on the cutting edges, less than about 10 nm in radius for many applications.

The contact area of a cutting device in accordance with the present invention will generally determine the pressure applied to the workpiece. Generally, the larger the area ratio is between the cutting element contact area and the groove, the smaller the contact pressure between the cutting element and the workpiece will be. The contact pressure (P)

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will determine the penetration depth (d) as the following expression:

$$d = Pt/B,$$

where t is the thickness of the wafer; and B is the bulk modulus of the workpiece.

In general, bulk modulus measures the incompressibility of a material. Its value generally correlates to the pressure to compress a material completely (zero thickness) at the initial rate of volume reduction. Bulk modulus of a PCD compact is about 4 Mb (megabars); the bulk modulus of silicon is about 1 Mb. Thus, silicon is about four times more compressible than a PCD compact. When a PCD cutting device or planer is pressed against a silicon wafer, the relative displacement of the wafer is due primarily to the sink of silicon wafer surface relative to the PCD surface. A typical silicon wafer is about 1 mm in thickness, so the shaving depth may be approximated by:

$$d = 10^{-6} P \text{ mm, where } P \text{ is expressed in bar or atmospheric pressure.}$$

If $P = 1$ bar, then the shaving thickness is about 1 nm. This is about five atomic layers. At this penetration depth, if the cutting edge is sharp (e.g. radius < 1 nm), then the shaving or cutting is ductile, resulting in a finished, planed surface that is very smooth, in some cases smoother than a mirror finish. For this reason, it is important to shave, cut or plane a silicon wafer with very sharp edge of the PCD planer. If the edge becomes overly dull, the ductility of silicon can be lost and the resulting brittle fracturing may destroy the wafer surface.

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, 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 planer are rotated in the same direction (but at different speeds), less material will be removed than if they are rotated counter to one another.

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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. H_2O_2) 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.

Another way to expedite the removal of silicon wafer is by applying a DC current across the wafer surface. Although diamond is an insulator, PCD is often electrically conducting due to its inclusions of metallic cobalt. In this case, the silicon wafer can be connected to an anode (not shown) and the PCD can be connected to a cathode (not shown). An electrolytically conducting slurry may be used to bridge the two electrodes. In this case, the surface of the silicon may be oxidized by anodation. Furthermore, silicon or its surface circuitry can be dissolved by electrolysis that will further accelerate the material removal process.

Thus, if the cutting device is used to shave or plane in a dry system, it may last for a few passes on a 12 inch wafer. However, chemical slurry may increase the scraped surface area by a thousand times, and if electrical current is applied to assist the material removal, the cutting device may last an even longer time.

FIG. 4A illustrates a variety of cutting elements 16a, 16b, 16c 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

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shapes.

As shown in FIG. 4B, the cutting elements 16d can be formed in elongate, arcuate fashion, with grooves cut or formed between the cutting elements. The grooves or depressed regions of the PCD or PcBN compacts can serve as the reservoirs for slurry used to cut wafer, as well as for cut debris. The pattern of the network and the depth of the grooves or recessions can affect the flow for both slurry and debris. Each PCD cutting element design can be optimized for the individual process of planarization of a particular workpiece.

FIG. 5A illustrates two additional embodiments of the invention in which cutting element 16 of the cutting device 10 of FIG. 1 includes a series of secondary cutting elements 40a and 40b formed on an upper surface or face of the cutting element. In this aspect of the invention, the secondary cutting elements can be configured to maintain a sharpness of each of the cutting edges during use of the cutting device. As shown, the secondary cutting elements can vary in shape, and can include pyramidal-shaped cutting elements. The secondary cutting elements can also be formed in a truncated pyramidal shape (not shown). By utilizing secondary cutting elements on the primary cutting elements, the total cutting edge length of the cutting element can be extended by as much as 10,000 times.

FIGs. 7A and 7B illustrate another embodiment of the invention in which a plurality of cutting elements 16e and 16f are formed in a PCD base 12a. As can be appreciated from FIG. 7A, 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 12a of the PCD to cut further, or deeper, into the workpiece (not shown in this figure) on which the PCD is being used.

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, while the smaller cutting elements can terminate in a flat, planar face. 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 PCD pad that is being dressed).

5 FIGs. 8 and 9 present images taken of cutting elements 16g and 16h, respectively, formed from an integral piece of PCD. As will be appreciated, the present invention provides a great deal of flexibility in the shape and size of the cutting elements that can be formed, with some cutting elements formed in an upright “mesa” configuration, and others formed in a pyramidal configuration.

10 In addition, as the cutting elements of the present invention can be formed from an integral piece of polycrystalline superhard material, there generally remains 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
15 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.

20 The PCD or PcBN compacts utilized in the present can be formed in a variety of manners. In one embodiment of the invention, the PCD compact can contain micron (e.g. 1 to 10 μm) diamond, and can be polished before use. In another aspect, the diamond grains can be large (e.g. 50 μm) and the surface can be ground without polishing. In one aspect of the invention, SiC grains can be mixed with diamond grains as the feed stock for
25 a PCD compact. The PCD can include a diamond content of about 80% to about 98% by volume.

 The cutting elements of the present invention can be formed on or in the polycrystalline superhard material in a variety of manners. In one aspect, the grooves between the individual cutting elements can be formed on a PCD surface with electro-
30 chemical machining, by laser ablation, by plasma etching, by oxidation (to form carbon dioxide or monoxide gas), hydrogenation (to form methane gas), etc. Laser beams with relatively longer wavelengths (e.g. ND:YAG) have been shown to form grooves on PCD effectively. Laser beams with relatively short wavelengths (e.g. excimers) may be used to

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carve out the secondary cutting elements on top of the primary cutting elements (as shown in FIG. 5). While the latter may be slower in cutting speed, it is generally more precise due to the shorter wavelength used. Moreover, the surface damage can be less with more concentrated energy in higher frequencies. This has been found suitable for shaving or
5 planing a silicon wafer in accordance with the present invention.

In another aspect of the invention, material can be removed from a polycrystalline superhard material compact to integrally form the individual cutting elements from the polycrystalline superhard material compact. In other words, the cutting elements can be formed by removing the polycrystalline material from around and about the cutting
10 elements, leaving the cutting elements as the only remaining material above the base of the cutting device.

In one aspect of the invention, the material is removed from the PCD or PcBN compact by electrical discharge machining ("EDM"). In this aspect, the EDM process can utilize one or more electrodes that include diamond. For example, the cathode used in the
15 EDM process can be a boron doped diamond material and the anode used in the EDM process can be the PCD (in this case, the PCD would generally need to be at least partially electrically conductive). As current is applied through the boron doped diamond material, the material of the PCD can be carefully and controllably removed to form various patterns on the PCD.

As shown for example in FIG. 6, in one aspect of the invention, the anode 30 of the EDM process can comprise a portion of a boron doped diamond ("BDD") material through which current is applied. The BDD anode can include a series of "V"-shaped protrusions
20 31 that, during the EDM process, form a series of corresponding channels 32 in the PCD compact 34 (which, in turn, define a plurality of cutting elements in the PCD compact). While the protrusions are shown as being generally V-shaped, it is of course contemplated that they can be formed in a variety of shapes that can be selected to form channels having desired shapes in the PCD compact. As is known to those having ordinary skill in the art, the EDM process will generally utilize an insulating liquid such as oil or deionized water, the details of which are not illustrated in the drawings.
25

It has been found that, while the configuration illustrated in FIG. 6 (in which the PCD compact serves as the cathode of the EDM process and the BDD material serves as the anode) performs well, the reverse configuration can also be used. For example, in this aspect of the invention, the BDD material is used as the anode and the PCD is used as the
30

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cathode, resulting in the PCD material removal rate being relatively fast (note that both the BDD material and the PCD material will be consumed, at varying rates, during the EDM process). However, by reversing the polarity (e.g., by using the BDD as the cathode and the PCD as the anode), the PCD material removal rate will be slower than in the first configuration but the surface finish of the PCD will better.

It is contemplated that the use of an electrically conducting diamond containing material as an electrode to remove material from another electrically conducting diamond containing material (as the other electrode) can be extended to a variety of applications in addition to those explicitly discussed herein. For example the diamond-diamond EDM process can be utilized to remove material from an electrically conductive diamond material that is used in: abrasive applications, load bearing applications, protective covering applications, heat spreading applications, material molding applications, acoustic applications, semiconductor applications, etc.

In accordance with another aspect, the present invention provides a product formed by a process comprising: engaging a surface of a workpiece with a plurality of individual cutting elements of a cutting device, the individual cutting elements being integrally formed from a working side of an integral piece of a polycrystalline superhard material and each cutting element having a peak that is aligned in a common plane; and moving the workpiece and the cutting device relative to one another to thereby remove material from the workpiece with the cutting elements.

Examples

The following examples present various methods for making the cutting tools of the present invention. Such examples are illustrative only, and no limitation on present invention is meant thereby.

Example 1:

A boron doped diamond film ("BDD") having a resistivity of about 0.001 ohm-cm and a thickness of about 500 μm has a "zigzag" pattern formed on one edge via a wire EDM process. The resulting blade is mounted on an EDM machine as a cathode. The anode is a flat PCD about 100 mm in diameter and about 2 mm in thickness. The diamond table used is about 500 μm in thickness. An electrically conducting fluid is used to carry the electricity between the two electrodes. During the EDM process, the PCD is gradually traversed across the stationary BDD blade. This process is repeated while the BDD is

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gradually descending into the PCD compact. The portion of the PCD that is brought in close proximity to the edge of the BDD is selectively eroded away by electrical discharging, electrolysis, and dissolution.

In this manner, a corresponding "zigzag" pattern of ridges is gradually formed on the flat PCD top. When the grooves reach a predetermined height (e.g., 80 μm), the serrated ridges so formed are cleaned for measurements of geometry. Subsequently, the PCD is rotated 90 degrees and the process is repeated such that pyramid shapes are formed. The angle of the pyramids produced generally matches the angle of the zigzag pattern on the BDD. The tips of these pyramids also duplicate the pattern of recesses of the zigzag pattern on the BDD.

The PCD planer so formed has improved dimension tolerances compared to PCD planers formed by metallic electrodes used in an EDM process. In addition, the consumption rate of BDD blade is much lower. Also, the voltage (90 V) and current (30A) utilized are much lower than metallic electrode processes (e.g. 120 V and 80A). During the process of EDM, the pulsation period for EDD (20 micro seconds on by 20 micro seconds off) can be 10 times longer due to diamond's exceptional thermal stability, thermal conductivity, and chemical inertness. It was estimated that the maximum electrode temperature (about 400° C, compared to oxidation threshold temperature of 750° C) during the BDD EDM process was about 200° C lower than that of the metallic process. The wear rate of the BDD (0.3%) was also fractional compared to the wear rate of copper tungsten (30%). The EDM speed (20 microns per minutes) was twice as fast.

Example 2

The above example was repeated with the reverse polarity: e.g., the BDD was positively biased. In this case, the EDM process was still viable except that the wear rate of the BDD was more than doubled. However, the surface finish of the ADD improved due to a slower erosion rate on the surface.

Example 3

The process of Example 1 was repeated except that the cathode was replaced by a PCD blank of 1.6 mm in thickness (PCD table 0.5 mm thick, cemented tungsten carbide 1.5 mm thick). The PCD used had a 25 μm diamond grain size, it contained 10 wt% of cobalt and had an electrical resistivity of 0.001 ohm-cm.

Example 4

BDD grits of 100/120 mesh were used to make a bronzed bonded grinding wheel. The outside diameter was shaped by a BDD EDM process to form a zigzag pattern thereon. The BDD wheel was then used as a cathode for an EDM process performed on a PCD blank. During the traversing of the PCD surface, the BDD wheel was slowly turned to uniformly expose the contact edge from which electrical current was emitted. After the ridges were formed, the PCD was rotated to traverse in a perpendicular direction until a series of pyramidal cutting elements were formed on the PCD.

Example 5

A BDD was formed to an "A" point and used as an anode in an EDM process. A PCD compact was rotated about the "A" point to gradually form a V notch in the PCD compact. The V notch was formed at several radius positions in order to produce concentric ridges on the PCD surface. The resulting tool can be used as a PCD planer for truing workpieces.

Example 6

The process of Example 5 was repeated followed by traversing the "zigzag"-patterned BDD in three equally spaced directions. The resulting triangular pyramid formed concentric island chains. The resulting tool included excellent radial slurry/debris passages as well as very sharp cutting points.

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 the appended 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.

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CLAIMS

What is claimed is:

1. A cutting device, comprising:

a base having a working side that can be oriented to face a workpiece from which
5 material is to be removed; and

a plurality of individual cutting elements arranged on the working side of the base,
each cutting element having a peak that comprises at least one cutting edge that is formed
from a polycrystalline superhard material, the peaks of the cutting elements being aligned in a
common plane.

2. The device of claim 1, wherein the base and each of the cutting elements are formed
from an integral piece of polycrystalline superhard material.

3. A cutting device, comprising:

a base having a working side that can be oriented to face a workpiece from which
15 material is to be removed, the base being formed from an integral piece of a polycrystalline
superhard material; and

a plurality of individual cutting elements integrally formed with the working side of
the base, each cutting element having a peak that comprises at least a tip, the peaks of the
20 cutting elements being aligned in a common plane.

4. The device of either of claim 2 or claim 3, wherein the polycrystalline superhard
material comprises a polycrystalline diamond compact.

5. The device of claim 4, wherein the polycrystalline diamond compact has a diamond
25 grain size of about 50 μm or smaller.

6. The device of claim 5, wherein the polycrystalline diamond compact has a diamond
grain size of about 1 μm to about 10 μm .

7. The device of claim 4, wherein the polycrystalline diamond compact has a diamond
30 content of about 80% to about 98% by volume.

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8. The device of either of claim 2 or claim 3, wherein the polycrystalline superhard material comprises a polycrystalline cubic boron nitride compact.

9. The device of claim 1, wherein the cutting device comprises a planing device.

5

10. The device of claim 3, wherein the cutting device comprises a dressing device.

11. The device of claim 1, further comprising a series of secondary cutting elements formed on a face of each of the cutting elements, the secondary cutting elements being
10 configured to maintain a sharpness of each of the cutting edges during use of the cutting device.

12. The device of either of claim 1 or claim 3, wherein the peaks of the cutting element are operable to cut a substantially brittle material.

15

13. The device of claim 12, wherein the brittle material is a member selected from the group consisting of: a metal, a silicon wafer, a used silicon wafer to be reclaimed by planarization, LCD glass, an LED substrate, a SiC wafer, a quartz wafer, silicon nitride, zirconia, sapphire, lithium niobate, lithium titantate, PZT, gallium arsenide, gallium nitride,
20 indium nitride, boron phosphate, aluminum nitride and boron nitride.

14. The device of either of claim 1 or claim 3, wherein the peak of each of the cutting elements includes a plurality of cutting edges aligned in the common plane.

25 15. The device of either of claim 1 or claim 3, wherein the peak of each of the cutting elements includes a shape selected from the group consisting of: a square, a rectangle, a triangle, a hexagon, a circle and an oval.

16. The device of either of claim 1 or claim 3, further comprising a series of secondary
30 cutting elements having at least a tip aligned in a second common plane, the second common plane being disposed closer to an opposing side of the base than is the common plane, the secondary cutting elements being configured to limit a depth to which the cutting elements can cut into the workpiece.

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17. The device of claim 16, wherein the secondary cutting elements terminate in a planar face.

5 18. The device of either of claim 1 or claim 3, wherein the peaks of the cutting elements are leveled relative to the common plane within about 0.5 μm to about 50 μm .

19. The device of claim 18, wherein the peaks of the cutting elements are leveled relative to the common plane within about 25 μm .

10

20. The device of either of claim 1 or claim 3, wherein the common plane is pitched from about 200 μm to about 2000 μm across the working side of the cutting device.

21. A method of forming the cutting device as recited in either claim 2 or claim 3,
15 comprising the step of:

providing a polycrystalline superhard material compact; and

removing material from a working side of a base of the polycrystalline superhard material compact to form the plurality of individual cutting elements from the polycrystalline superhard material compact.

20

22. The method of claim 21, wherein the polycrystalline superhard material compact comprises a polycrystalline diamond compact.

23. The method of claim 22, wherein the polycrystalline diamond compact has a diamond
25 grain size of about 50 μm or smaller.

24. The method of claim 23, wherein the polycrystalline diamond compact has a diamond grain size of about 1 μm to about 10 μm .

30 25. The method of claim 22, wherein the polycrystalline diamond compact has a diamond content of about 80% to about 98% by volume.

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26. The method of claim 21, wherein the polycrystalline superhard material compact comprises a polycrystalline cubic boron nitride compact.

27. The method of claim 21, further comprising forming a series of secondary cutting
5 elements on an upper surface of each of the cutting elements, the secondary cutting elements being configured to maintain a sharpness of each of the cutting elements during use of the cutting device.

28. The method of claim 21, wherein cutting edges of the cutting elements are operable to
10 cut a substantially brittle material.

29. The method of claim 28, wherein the brittle material is a member selected from the group consisting of: a metal, a silicon wafer, a used silicon wafer to be reclaimed by planarization, LCD glass, an LED substrate, a SiC wafer, a quartz wafer, silicon nitride,
15 zirconia, sapphire, lithium niobate, lithium titanate, PZT, gallium arsenide, gallium nitride, indium nitride, boron phosphate, aluminum nitride and boron nitride.

30. The method of claim 21, wherein forming the cutting elements includes aligning a plurality of cutting edges of each cutting element in the common plane.

20

31. The method of claim 21, wherein the peak of each of the cutting elements includes a shape selected from the group consisting of: a square, a rectangle, a triangle, a circle and an oval.

25 32. The method of claim 21, wherein removing material from the working side of the base includes removing material by a process selected from the group consisting of: laser ablation, electro-chemical machining, plasma etching, oxidation and hydrogenation.

33. The method of claim 21, wherein removing material from the working side of the base
30 includes removing material by electrical discharge machining.

34. The method of claim 33, wherein the electrical discharge machining process utilizes an electrode that includes diamond.

35. The method of claim 34, wherein the electrode is an anode that includes boron doped diamond.

5 36. The method of claim 35, wherein the boron doped diamond anode includes a series of shaped protrusions extending therefrom, the shaped protrusions being configured to remove material from the face of the compact in a grooved pattern.

10 37. The method of claim 34, wherein the electrode is a cathode that includes boron doped diamond.

15 38. The method of claim 35, wherein the boron doped diamond cathode includes a series of shaped protrusions extending therefrom, the shaped protrusions being configured to remove material from the face of the compact in a grooved pattern.

15 39. The method of claim 21, wherein removing material from the face of the compact further comprises forming a series of secondary cutting elements having at least a tip aligned in a second common plane, the second common plane being disposed closer to an opposing side of the compact than is the common plane, the secondary cutting elements being
20 configured to limit a depth to which the cutting elements can cut into the workpiece.

40. The method of claim 39, wherein each of the secondary cutting elements terminates in a planar face.

25 41. The method of claim 21, wherein the peaks of the cutting elements are leveled relative to the common plane within about 0.5 μm to about 50 μm .

42. The method of claim 41, wherein the peaks of the cutting elements are leveled relative to the common plane within about 25 μm .

30 43. The method of claim 21, wherein the common plane is pitched from about 200 μm to about 2000 μm across the face of the cutting device.

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44. A product formed by a process comprising:

engaging a surface of a workpiece with a plurality of individual cutting elements of a cutting device, the individual cutting elements being integrally formed from a working side of an integral piece of a polycrystalline superhard material and each cutting element having a peak that is aligned in a common plane; and

moving the workpiece and the cutting device relative to one another to thereby remove material from the workpiece with the cutting elements.

45. The product of claim 44, wherein the polycrystalline superhard material comprises a polycrystalline diamond compact.

46. The product of claim 45, wherein the polycrystalline diamond compact has a diamond grain size of about 50 μm or smaller.

47. The product of claim 46, wherein the polycrystalline diamond compact has a diamond grain size of about 1 μm to about 10 μm .

48. The product of claim 45, wherein the polycrystalline diamond compact has a diamond content of about 80% to about 98% by volume.

49. The product of claim 44, wherein the polycrystalline superhard material comprises a polycrystalline cubic boron nitride compact.

50. The product of claim 44, wherein each of the plurality of cutting elements includes a cutting edge aligned in the common plane.

51. The product of claim 44, wherein the process further comprises engaging the surface of the workpiece with a series of secondary cutting elements having at least a tip aligned in a second common plane, the second common plane being disposed closer to an opposing side of the polycrystalline superhard material than is the common plane, to thereby limit a depth to which the cutting elements cut into the workpiece.

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52. The product of claim 51, wherein the secondary cutting elements terminate in a planar face.

53. The product of claim 44, wherein the peaks of the cutting elements are leveled relative
5 to the common plane within about 0.5 μm to about 50 μm .

54. The product of claim 44, wherein the peaks of the cutting elements are leveled within about 15 μm .

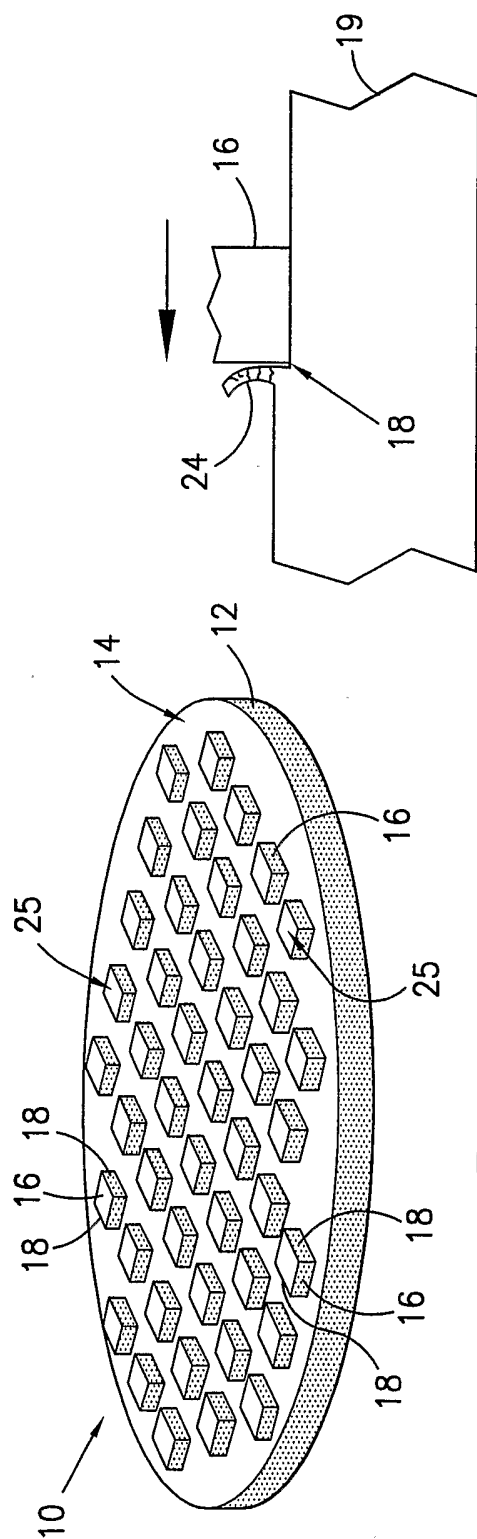


FIG. 1

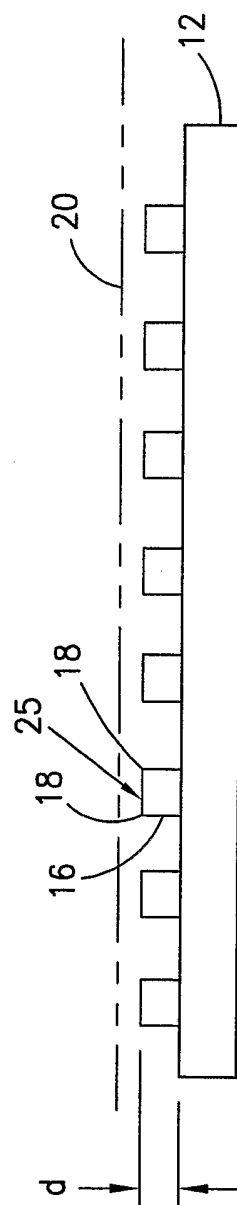
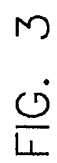


FIG. 2

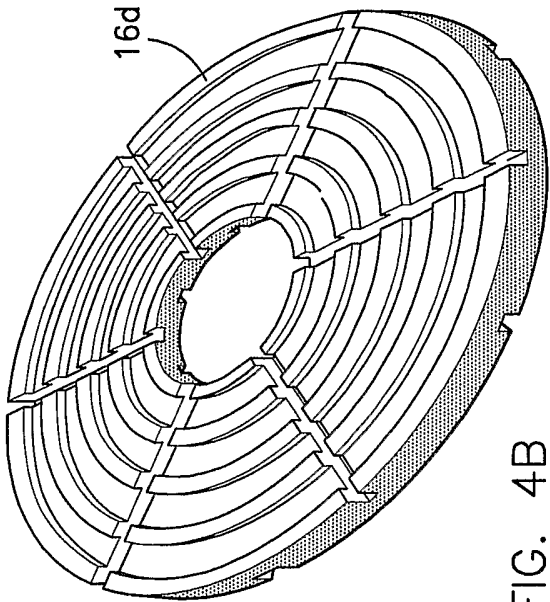


FIG. 4B

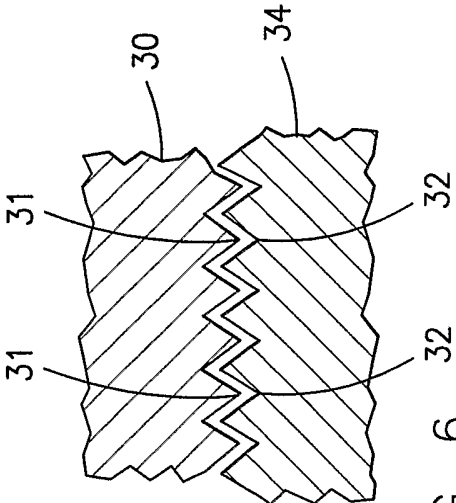


FIG. 6

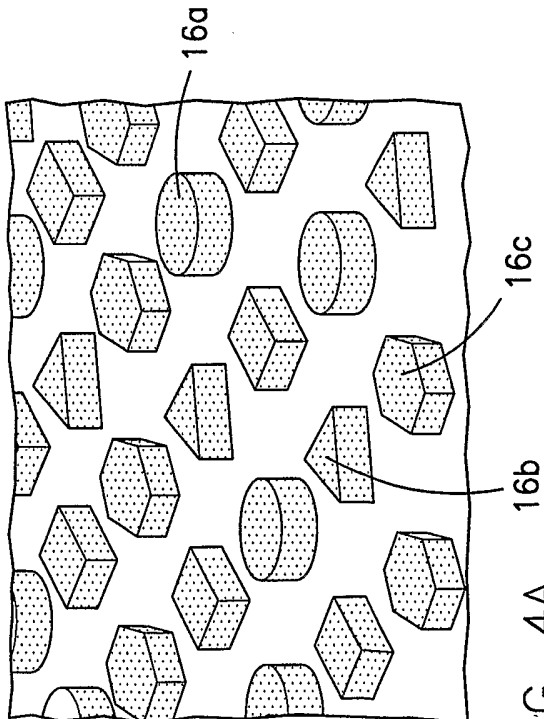


FIG. 4A

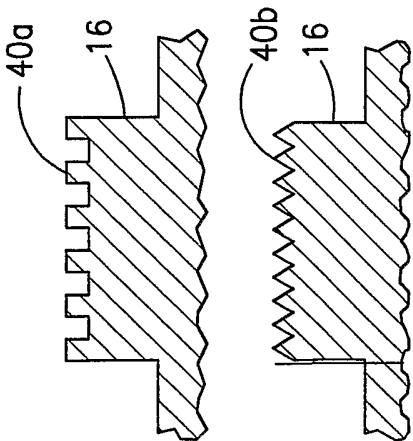


FIG. 5

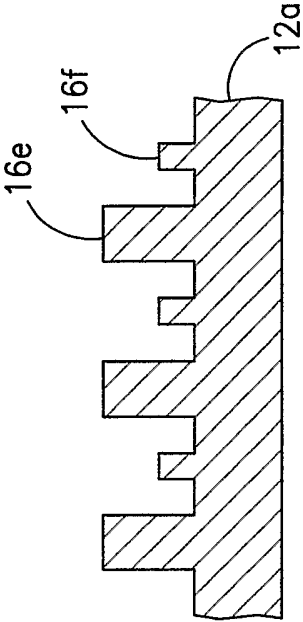
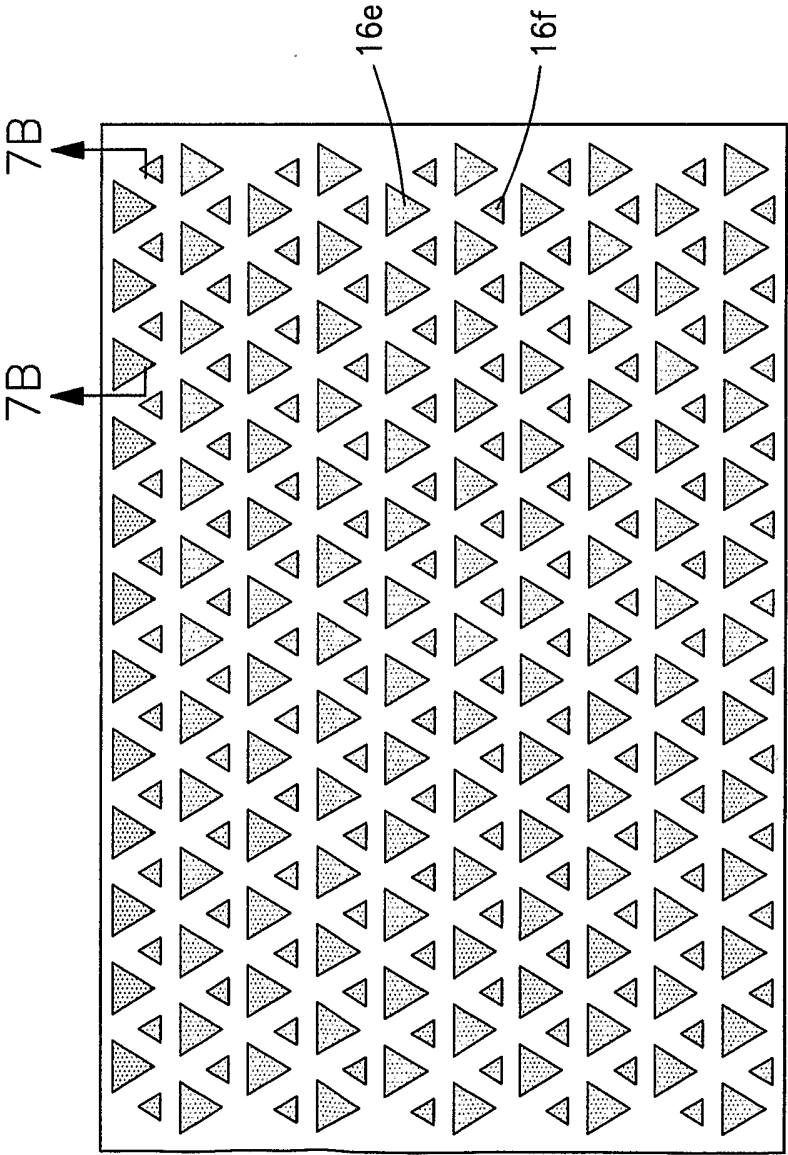


FIG. 7A

FIG. 7B

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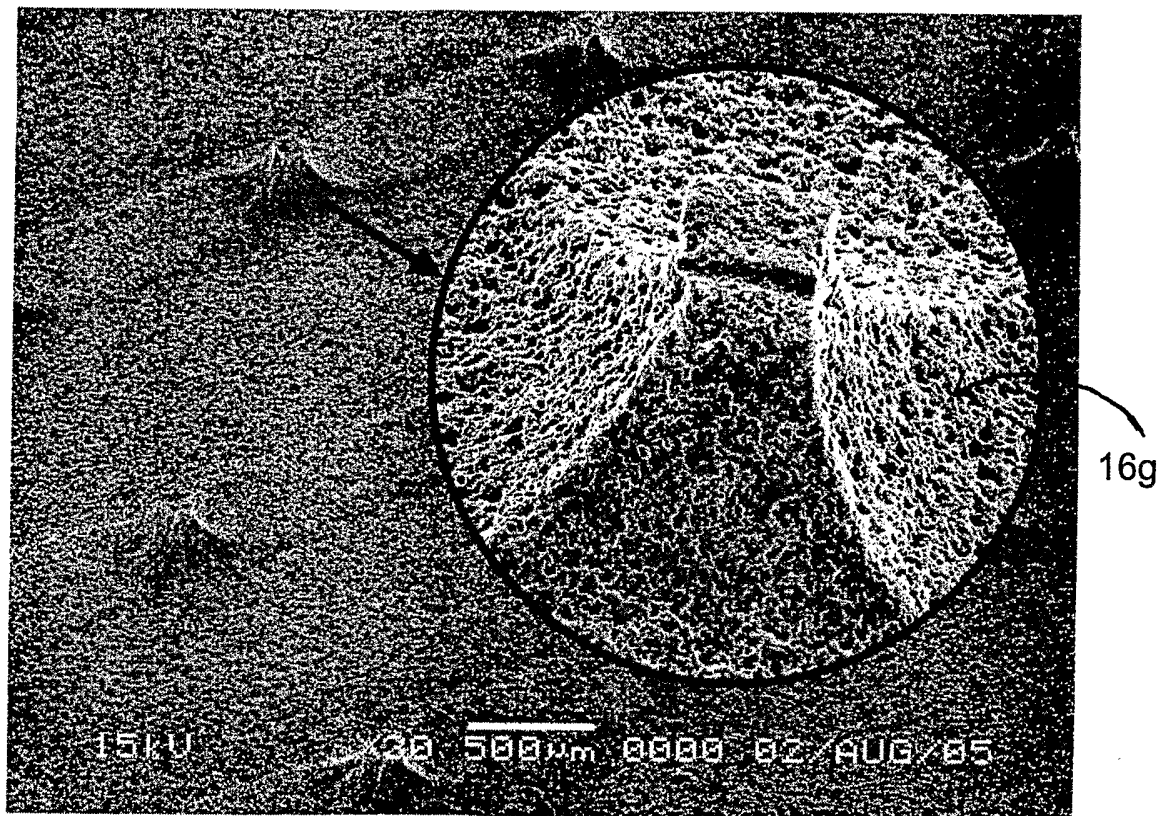


FIG. 8

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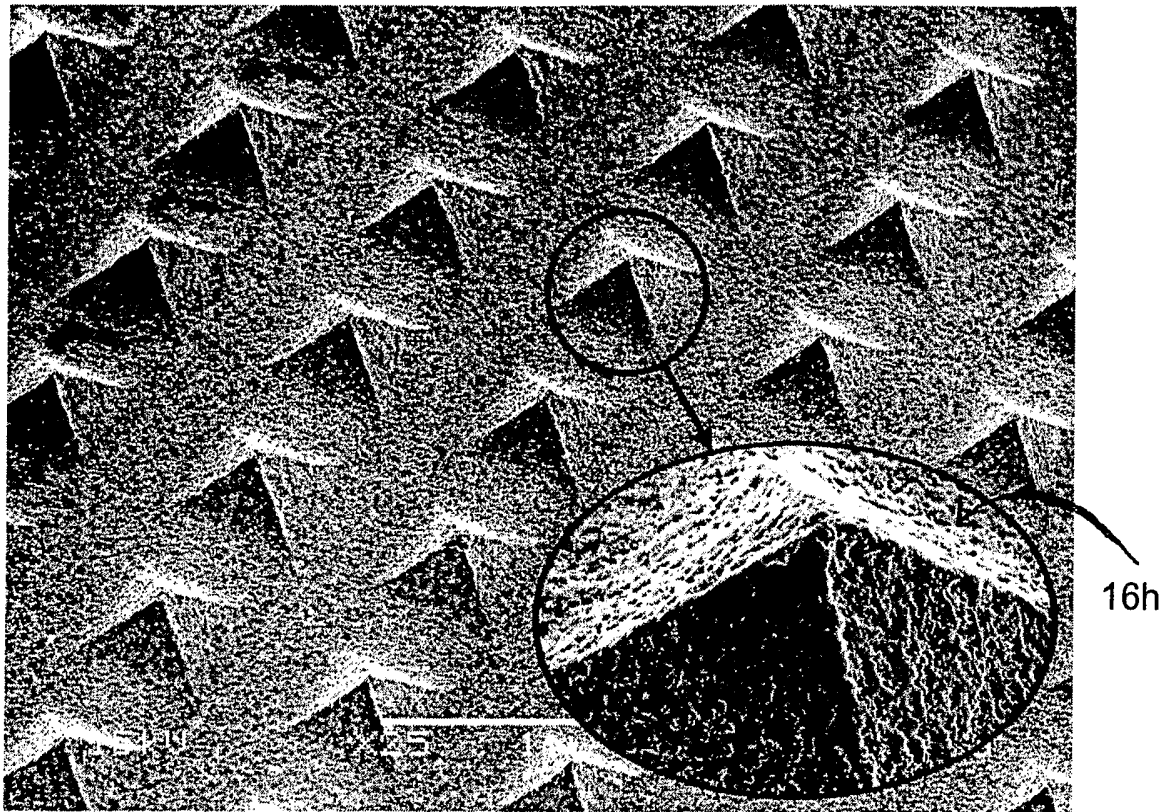


FIG. 9