

HYBRID CMP CONDITIONING HEAD

FIELD OF THE INVENTION

The present invention relates generally to a conditioning head comprising a shaving edge. More specifically, the present invention relates to conditioning heads comprising a substrate of various non-planar configurations and methods for manufacturing thereof.

BACKGROUND TO THE INVENTION

The products of the present invention have utility in a wide variety of applications, including heads or disks for the conditioning of polishing pads, including pads used in Chemical-Mechanical-Planarization (CMP). CMP is an important process in the fabrication of integrated circuits, disk drive heads, nano-fabricated components, and the like. For example, in patterning semiconductor wafers, advanced small dimension patterning techniques require an absolutely flat surface. After the wafer has been sawed from a crystal ingot, and irregularities and saw damage have been removed by rough polishing, CMP is used as a final polishing step to remove high points on the wafer surface and provide an absolutely flat surface. During the CMP process, the wafer will be mounted in a rotating holder or chuck and lowered onto a pad surface rotating in the same direction. When a slurry abrasive process is used, the pad is generally a cast and sliced polyurethane material or a urethane-coated felt. A slurry of abrasive particles suspended in a mild etchant is placed on the polishing pad. The process removes material from high points, both by mechanical abrasion and by chemical conversion of material to, e.g., an oxide, which is then removed by mechanical abrasion. The result is an extremely flat surface.

In addition, CMP can be used later in the processing of semiconductor wafers when deposition of additional layers has resulted in an uneven surface. CMP is desirable in that it provides global planarization across the entire wafer, is applicable to all materials on the wafer surface, can be used with multi-material surfaces, and avoids use of hazardous gases. As an example, CMP can be used to remove metal overfill in damascene inlay processes.

CMP represents a major portion of the production cost for semiconductor wafers. These CMP costs include those associated with polishing pads, polishing slurries, pad conditioning disks and a variety of CMP parts that become worn during the planarizing and polishing operations. The total cost for the polishing pad, the downtime to replace the pad and the cost of the test wafers to recalibrate the pad for a single wafer polishing run can be quite high. In many complex integrated circuit devices, up to thirty or more CMP runs are required for each finished wafer, which further increases the total manufacturing costs for such wafers.

With polishing pads designed for use with abrasive slurries, the greatest amount of wear on the polishing pads is the result of polishing pad conditioning necessary to place the pad into a suitable condition for wafer planarization and polishing operations. A typical polishing pad comprises closed-cell polyurethane foam approximately 1/16 inch thick.

Pad conditioning determines the asperity structure (peaks and valleys) of the pad and acts to maintain the surface stability. During pad conditioning, the pads are subjected to mechanical abrasion to physically cut through the cellular layers of the surface of the pad. The exposed surface of the pad contains open cells, which trap abrasive slurry consisting of the spent polishing slurry and material removed from the wafer. In each subsequent pad-conditioning step, the ideal conditioning head removes only the outer layer of cells containing the embedded materials without removing any of the layers below the outer layer.

Conditioning also addresses the loss of polish rates caused by glazing of the pad's surface. Glazing is known to be caused by plastic deformation, which flattens the asperity peaks. Conditioning is used to break up the glazed area and restore the asperity structure to the pad.

An ideal conditioning head would:

- achieve a rapid and complete removal of the top-most layer of cells of the polishing pad with the least possible removal of underlying cell layers of the polishing pad that do not contain embedded materials to maximize the useful life of the pad;
- rejuvenate the asperity structure of the pad to maintain the polishing rate and performance of the pad; and
- remove the spent slurry and debris from the conditioning pad's pores without cutting out the pores, resulting in less aggressive conditioning and a longer pad life.

Over-texturing of the pad results in a shortening of pad life; under-texturing results in an insufficient material removal rate during the CMP step and a lack of wafer uniformity.

Using the conventional conditioning heads that achieve satisfactory removal rates, numbers of wafer polishing runs as few as 200 to 300 and as many as several thousand (depending on the specific run conditions) can be made before the pad becomes ineffective and must be replaced. Replacement typically occurs after the pad is reduced approximately to half of its original thickness.

As a result, there is a great need for a conditioning head that achieves close to an ideal balance between high wafer removal rates and low pad wear rate, so that the effective life of the polishing pad can be significantly increased without sacrificing the quality of the conditioning.

US20090224370 addresses this need by providing a conditioning head which utilises a non-planar edge shaving region. The use of a non-planar edge shaving region was born from the discovery that damage to fixed abrasive pads (and other sensitive CMP pads) resulting from contact with conditioning heads can be considerably reduced by avoiding the presence of large diamond crystals in the conditioning head surface due to the "point cutting" aspect of the larger individual diamond crystals ordinarily grown. Whilst this conditioning head reduces pad wear rates, there are still opportunities to improve the rate at which debris shaved from the wafer is removed, as well as increasing slurry retention on the pad during the CMP process.

SUMMARY OF THE INVENTION

In a first aspect of the present invention, there is provided a conditioning head comprising:

- (a) a substrate comprising a substrate surface;
- (b) at least one raised non-planar abrasive region relative to the substrate surface,

wherein the non-planar abrasive region comprises an edge shaving region (R_{es}) comprising a surface roughness R_{p1} and a point cutting region (R_{cp}) comprising one or more protrusions resulting in a surface roughness R_{p2} , the ratio of the surface area of the edge shaving region to the point cutting region is at least 2:1 and the ratio of R_{p2} to R_{p1} is at least 2:1.

In a second aspect of the present invention, there is provided a conditioning head comprising:

- (a) a substrate comprising a substrate surface;
- (b) at least one raised non-planar abrasive region relative to the substrate surface,

wherein the non-planar abrasive region comprises an edge shaving region and a point cutting region, the ratio of the surface area of the edge shaving region to the point cutting region is at least 2:1; and wherein the point cutting region comprises one or more protrusions extending no more 1mm, or no more than 500 μm , or no more than 250 μm from mean height of the edge shaving region.

In a third aspect of the present invention, there is provided a conditioning head comprising:

- (a) a substrate comprising a substrate surface;
- (b) at least one raised non-planar abrasive region relative to the substrate surface, said at least one raised abrasive region comprising a shaving edge, and at least one cutting point to form an abrasive cutting/shaving front

wherein the at least one cutting point comprises at least one protrusion extending no more than 1 mm or no more than 500 μm , or no more 250 μm from a shaving edge plane, and at least one protrusion makes up no more than 10% of the abrasive cutting/shaving front.

For example, two protrusions having a base dimension of 100 μm position along the leading edge of each spiral with a length of 100 mm (100,000 μm) would make up 0.1% of the cutting/shaving front.

Preferably, the one or more protrusions make up no more than 5% or 1% or 0.5% or 0.3% or 0.2% or 0.1% of the cutting/shaving front. (i.e. if vane has a leading edge (i.e. in the direction of rotation) length of 50,000 μm and the protrusion has a leading edge of 50 μm (e.g. circular protrusion of 50 μm diameter), then the protrusion would make up 0.1% of the cutting/shaving front).

The non-planar edge shaving region preferably comprises more than 2 or 4 or 6 or 8 or 10 or 12 linear or spiral vanes radiating from a central axis region of the conditioning head.

The surface of the conditioning head is preferably coated with CVD diamond. The CVD diamond coating provides a highly abrasive and durable surface, which also seals the conditioning head to prevent the transfer of contaminating material from the substrate layer on to the polishing pad and slurry. However, it would be appreciated that use of a CVD diamond layer is not essential in many embodiments for the working of the present invention. For example, the cutting point region may comprise diamond grit or diamond grit composite protrusions adhered to the substrate, with no CVD coating layer. It will be understood that diamond grit may be substitutable for other abrasive particles such as carbides and nitrides.

In a fourth aspect of the present invention, there is provided a conditioning head comprising:

- (a) a substrate comprising a substrate surface;
- (b) at least one non-planar raised edge shaving region (R_{es}) relative to the substrate surface; and
- (c) at least one non-planar raised cutting point region (R_{cp}) relative to the substrate surface,

wherein at least one non-planar raised edge shaving region comprises a roughness R_a of less than 10 μm and at least one non-planar raised cutting point region comprises a roughness R_p in the range of 5 μm and 250 μm relative to the mean height of at least one non-planar raised edge shaving region; and wherein the ratio of the surface area of R_{es} to the surface area to R_{cp} is greater than 2:1.

The at least one raised edge shaving region is preferably coated with a CVD diamond layer.

In a fifth aspect of the present invention, there is provided a conditioning head comprising:

(a) a substrate comprising a substrate surface;

(b) at least one raised abrasive region relative to the substrate surface,

wherein the non-planar abrasive region comprises an edge shaving region comprising a mean CVD diamond coating thickness S_a and a cutting point region comprising one or more protrusions and having a mean CVD diamond coating thickness S_b , the ratio of said surface area of the edge shaving region to the surface area of the cutting point region is at least 2:1.

The ratio of S_b to S_a is preferably at least 2:1.5 or at least 1½:1 and more preferably at least 2:1 or 3:1.

The surface roughness resulting from growing CVD diamond on a substrate typically ranges from about 2 to 5 microns from peak-to-valley on a substrate having a thickness of about 10 microns of CVD diamond. In general, the peak-to-valley surface roughness for a typical CVD diamond layer ranges from about 1/4 to about 1/2 the thickness of the CVD diamond that is grown on the substrate. The thickness of the diamond film layer is preferably in the range of about 1 to about 50 microns, more preferably in the range of about 5 to about 30 microns, and most preferably in the range of about 10 to about 18 or 20 microns.

Correspondingly for CVD diamond coating embodiments, R_{p1} is preferably in the range of 0.25 μm to 25 μm , while S_a is preferably in the range of 1 to 50 μm .

The conditioning head of the present invention provides a combination of edge shaving and point cutting to provide a desirable combination of low pad wear rate, excellent wafer material removal rates and slurry retention to provide a long pad life and a low rate of wafer imperfections. In contrast to conventional conditioner heads, the portion of the conditioner head of the present invention having a point cutting function is very low on an absolute level. As a result, the conditioned polishing pads have fewer and preferably shallower asperities.

Edge Shaving Region

The edge shaving region is substantially parallel with the conditioning head plane. The edge shaving region may be raised approximately between 0.1mm to 5 mm or approximately between 0.5mm to 2mm from the substrate surface of the conditioning head.

The edge shaving region (R_{es}) preferably has a surface roughness R_a of less than 10 μm , more preferably less than 6 μm , even more preferably less than 3 μm and yet even more preferably less than 1 μm . A low surface roughness results in shallow asperities in the polishing pad and low pad wear rates. A shaving edge surface typically has a roughness R_a of at least 0.1 μm and more preferably at least 0.2 μm .

The shaving edge is the leading edge of the raised, non-planar, edge shaving region, which comes into first contact with the polishing pad during conditioning. This can result in the

edge shaving region “shaving” the surface of the pad rather than “scratching” and cutting the pad.

The area of the edge shaving region may be less than 80%, less than 50%, less than 25%, less than 10%, less than 5%, or less than 2% of the area of the area of the substrate surface of the conditioning head. Additionally or alternatively, the area of edge shaving region may be more than 0.5%, more than 1%, more than 2%, more than 5%, or more than 10% of the area of the substrate surface of the conditioning head.

Cutting Point Region

The cutting point region (or R_{cp}) provides a source of cutting points that rejuvenate the polishing pad's surface by forming asperities, thereby eliminating glazed areas on the pad. The quantity and height of the protrusions forming the cutting points dictate the asperity structure provided to the polishing pad. In applications in which a low pad wear rate is required, lower and fewer protrusions are preferred.

It has been found that the combination of a shaving edge combined with a small amount of cutting points enables the conditioner to most effectively perform its function. It is considered that the use of a shaving edge alone is unable to effectively break up glazed areas of the polishing pad and remove embedded contaminants; the use of cutting points alone is unable to effectively break up glazed areas and remove contaminants without high pad wear rates. The present invention has been able to combine the benefits of both conditioning techniques.

Preferably there are no more than 50 protrusions, more preferably no more than 30 protrusions, even more preferably no more than 20 protrusions, and yet even more preferably no more than 10 protrusions. Preferably, there is at least one protrusion, more preferably at least two protrusions, even more preferably at least 4 protrusions, and yet even more preferably at least 8 protrusions.

Each protrusion has a height above the mean height of the edge shaving region – preferably in the range of 5 μm to 250 μm , more preferably in the range of 10 μm to 150 μm , even more preferably in the range of 15 μm to 100 μm , and yet even more preferably in the range of 20 μm to 60 μm or 70 μm . In embodiments requiring low polishing pad wear rates, each protrusion has a height above the mean height of the edge shaving region – preferably less than 55 μm or less than 50 μm or less than 45 μm or less than 40 μm .

Each protrusion has a cross-sectional length parallel to the shaving edge, preferably in the range of 10 μm to 250 μm , more preferably in the range of 10 μm to 150 μm , even more

preferably in the range of 15 μm to 100 μm , and yet even more preferably in the range of 20 μm to 60 μm or 70 μm .

Each protrusion is preferably rounded, convex, and/or has a flat top surface. In some embodiments, the protrusions are geometric in shape and configuration with other protrusions. In other embodiments, the protrusions are non-geometric in shape and configuration with other protrusions. Due to the relatively small number of protrusions compared to conventional conditioning heads, consistent conditioner head performance may be achieved by obtaining protrusions within specified dimensional ranges rather than exact geometric shapes. In particular, conditioner heads are monitored to screen out over-sized protrusions that may detrimentally impact upon the balance between pad wear rate, wafer material removal from the polishing pad, rejuvenation of asperity structure of the polishing pad, and slurry retention of the polishing pad. The conditioning heads of the present invention are able to provide conditioned polishing pads with an asperity structure which results in a higher density of smaller contact interfaces with the wafer. These smaller contact interfaces enables improved wafer material removal and lower defects, as the smaller contact interfaces can more readily maintain a lubricated state.

The cutting point region may comprise or consist of one or more protrusions. In embodiments, in which the cutting point regions consist of one or more protrusions, the one or more protrusions preferably protrude from the edge shaving region. In embodiments in which the point cutting region comprises one or more protrusions, the one or more protrusions may protrude from a mean height which is above the mean height of the edge shaving region. For example, the point cutting region may comprise a raised plateau with protrusions thereon.

The protrusions of the point cutting region are preferably less than 10%, more preferably less than 5%, even more preferably less than 1%, yet even more preferably less than 0.5% or 0.4% or 0.3% or 0.2%, and more preferably less than 0.1% of the area of the shaving edge(s) of the conditioner head. If the point cutting region is too large or contains protrusions that are too high or acute, the hybrid nature of the conditioning head is lost, with the cutting points more aggressively removing pad material, such that the low material removal rates achieved by the shaving edge region are nullified. As a result, the conditioning head functions as a cutting point conditioning head.

R_{cp} and R_{es} are preferably contiguous with protrusions of the R_{cp} rising from the R_{es} . However, it will be understood that the point cutting region may be non-contiguous to the edge shaving region.

The ratio of the surface area of said edge shaving region to said point cutting region is preferably at least 5:1, even more preferably at least 10:1, yet even more preferably at least 50:1, yet even more preferably at least 100:1, and most preferably at least 200:1. The conditioning head of the present invention is still based upon a shaving edge to remove the majority of pad material, whilst the cutting point portion of the conditioning head is focused upon conditioning the pad's surface (i.e. providing the asperity structure), rather than on material removal. As such, the portion of the conditioning head which functions as a cutting points is relatively small compared to the portion that functions as a shaving edge.

The point cutting region is preferably positioned greater than 50%, more preferably greater than 60%, even more preferably greater than 80%, and yet even more preferably greater than 90% along a straight radial line between a central axis and a peripheral edge of the conditioning head. The outermost protrusion is preferably positioned within 5mm, more preferably within 3mm, and even more preferably within 2mm of the peripheral edge of the conditioning head. By positioning the protrusions in close proximity to the peripheral edge of the conditioning edge, the point cutting protrusions of the conditioning head will more readily cover the entire polishing pad surface during the conditioning process. This enables a smaller proportion of cutting points to be used, thereby reducing pad wear rates.

In embodiments where more than one protrusion is clustered together, the protrusions are preferably aligned along the cutting edge.

Preferably the ratio of the surface area of the base of the protrusion to the surface area of the top of the protrusion is less than 5:1 and more preferably less than 2:1. This combination of features results in relatively shallow asperities in the polishing pad. These shallow asperities are thought to be conducive to wafer material removal from the pad and slurry retention thereon, whilst minimising increases in the pad wear rate. It will be appreciated that the characteristics of the protrusions may vary depending upon the nature of the polishing pad, slurry and wafer.

It will be also appreciated that the protrusion(s) may be formed via a number of methods. In one embodiment, the protrusion comprises CVD diamond coated diamond grit. In another embodiment, the protrusion comprises a diamond layer of greater thickness on a substantially flat substrate. In a further embodiment, the protrusion comprises a CVD diamond coating on a protrusion in the adjacent substrate.

In one embodiment, the cutting point region and the edge shaving region comprise a polycrystalline diamond layer, the average grain size of the polycrystalline diamond on the point cutting region being larger than the average grain size of the polycrystalline diamond

on the edge shaving region. The larger grain size preferably results in the formation of one or more protrusions on the cutting point region.

The raised non-planar abrasive region preferably comprises one or more discrete raised non-planar edge shaving segments. The raised non-planar abrasive region preferably comprises one or more discrete raised non-planar abrasive segments. The one or more segments preferably have a shape selected from the group consisting of concentric circles, broken concentric circles, spirals, broken spiral segments, linear segments, broken linear segments, curved segments, broken curved segments and combinations thereof.

The area of the non-planar abrasive region may be less than 80%, less than 50%, less than 25%, less than 10%, less than 5%, or less than 2% of the area of the area of the substrate surface of the conditioning head. Additionally or alternatively, the area of the non-planar abrasive region may be more than 0.5%, more than 1%, more than 2%, more than 5%, or more than 10% of the area of the area of the substrate surface of the conditioning head. The non-planar abrasive region may be raised approximately between 0.1mm to 5mm or approximately between 0.5mm to 2mm from the substrate surface of the conditioning head.

In embodiments where the raised segment comprises concentric circles, the outermost concentric ring comprises the cutting point region.

The cross section of the raised non-planar cutting edge region is preferably in the shape of a truncated triangle, with two inclining sides framed by a substantially level top surface. The width of the top surface is preferably between 0.5 mm and 10mm wide, and more preferably between 1.0 mm and 6mm wide.

In one embodiment, the point cutting region is distributed across one or more of the segments, and more preferably distributed across less than 60% of the segments.

In some embodiments, the point cutting region comprises one or more isolated or clusters of protrusions.

In one embodiment, the conditioning head as previously described in the first to fifth aspects of the present invention wherein the raised non-planar abrasive region or R_{es} comprises at least four radially extending vanes and between one and fifty protrusions, wherein each vane comprises between zero and five protrusions and said protrusion(s) are positioned greater than 70% along a radial line starting from the central axis and ending at the peripheral edge of the conditioning head.

Preferably at least 50% of the vanes comprises at least one protrusion, more preferably at least 75% of the vanes comprises at least one protrusion, and even more preferably every vane comprises at least one protrusion.

In one embodiment, the number of protrusions per vane is preferably between one and three. In another embodiment, alternative vanes comprise between one and three protrusions.

Average roughness (R_a) is a measure of the relative degree of coarse, ragged, pointed or bristle-like projections on a surface, and is defined as the average of the absolute values of the differences between the peaks and their mean line.

R_p is the height of the highest peak above the mean line in the sample length.

The point cutting region is defined as a surface area comprising or consisting of one or more protrusions. The point cutting region has a surface area defined as the surface area of the base of the protrusion for isolated protrusions. For clusters of protrusions, the surface area of the protrusions is deemed to be the area encompassing the protrusions, which are spaced not more than 100 μm apart and preferably no more than 50 μm apart.

As used herein, the term "ceramic" is to be interpreted in its widest sense as including not only oxides but also non-oxide materials, for example silicon carbide or silicon nitride.

As used herein, the meaning of the term "conditioning" encompasses the removal of the outer layers of the polishing pad and the embedded wafer material embedded therein and/or the rejuvenation of the polishing pad's asperity structure. As used herein, the term "conditioning head" and the term "conditioner head" are terms which may be used interchangeably.

As used herein, the term "wear rate" (unless context dictates otherwise) means the rate of removal of the outer layers of the polishing pad, which is a measure of the durability of the polishing pad.

As used herein, the term "cutting point region" refers to an area of the conditioning head that conditions the polishing pad through the action of protrusions, which form a cutting point.

As used herein, the terms "shaving edge region" and "edge shaving region" refer to an area of the conditioning head that conditions the polishing pad through the action of a non-planar edge based feature(s). The shaving edge preferably comprises an elongated edge of a constant height.

As used herein, the term "carbide-forming material" means a material that is capable, under appropriate conditions, of formation of a covalently bonded compound with carbon in a carbide. It is believed that regions of the carbide-forming material react with the depositing CVD diamond material to form regions of bonded carbide structures at the interface between the substrate and the CVD diamond layer, resulting in strong adhesion of the diamond layer to the substrate.

The term "non-planar" refers to the existence of edge-based shaving or cutting point features raised out of the natural plane of the otherwise substantially level conditioning head. In this way, the raised features are said to be out of plane, or non-planar, relative to the conditioning head plane.

Surface area measurements referred herein relate to the planar surface area (i.e. measurement of the plane rather than the surface topology).

"Cutting point" and "point cutting" are terms which may be used interchangeably.

BRIEF DESCRIPTION OF THE FIGURES

Figures 1a and 1b are schematic diagrams of a cross section of a portion of the conditioner head, in accordance with one embodiment of the present invention.

Figures 2a to 2f are magnified optical images of a spiral vane surface on the conditioner head represented in Figures 1a and 1b.

Figure 3a is an image of a diamond particle adhered to the substrate prior to diamond CVD. Figure 3b is an image of Figure 3a after diamond CVD.

Figure 4 is a schematic diagram of the conditioner head of Figures 1a and 1b.

Figure 5 is a topographic profile of a protrusion (cutting point region) and an adjacent edge shaving region.

Figures 6 to 10 are images and associated topography profiles of the surface of a portion of the conditioner head of Figure 1a.

Figure 11a to 11f are images of alternative raised non-planar edge shaving regions of conditioner head of the present invention.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE PRESENT INVENTION

Figure 1a illustrates a cross-sectional portion of a conditioning head 10 through a longitudinal portion of a spiral vane, with the left side positioned proximal to the central axis of the conditioning head and the right side forming the peripheral edge. The conditioning head comprises a backing plate 20, such as a stainless steel plate. The substrate 30 may comprise a variety of materials including ceramic material, such as Si or Si₃N₄, or from at least one ceramic material selected from the group consisting of Al₂O₃, AlN, TiO₂, ZrO_x, SiO₂, SiC, SiO_xN_y, WN_x, Wo_x, DLC (diamond-like coating), BN and Cr₂O₃. Preferably, the substrate is a carbide.

The substrate 30 can be made from a cemented carbide material such as tungsten carbides (WC) selected from the group consisting of tungsten carbonite-cobalt (WC--Co), tungsten carbonite-carbon titanium-cobalt (WC--TiC--Co) and tungsten carbonite-carbon titanium-

carbon tantalum-cobalt (WC--TiC--TaC--Co). The substrate 30 can also be made from other cemented carbide materials such as TiCN, B₄C or TiB₂. In a preferred embodiment, the substrate comprises Reaction-Bonded Silicon Carbide (RBSiC) comprising silica carbide and unreacted silica carbide forming material, e.g. Si. Further details on RBSiC are disclosed in US7,367,875, which is incorporated into the current specification to the extent allowable under national law.

The substrate is usually in the form of a disk ranging in diameter from about two (2) to four (4) inches (about 50 to 100mm). However, other geometries have been used as the substrate for conditioning heads. The base substrate thickness ranges from about 0.5mm to about 6.5mm, preferably 1.0mm to 2.0mm for a silicon substrate. Thicknesses for other substrates may vary from these ranges. For instance, the silicon carbide-silicon composite substrate may have a thickness ranging from about 1.0mm to about 7.5mm, although thicknesses outside this range are also feasible. Larger diameter substrates will be correspondingly thicker.

The substrate 30 comprises a raised non-planar abrasive region in the form of a spiral vane. The top of the spiral vane 40 is raised approximately between 0.5mm to 2mm from the natural plane of the conditioning head.

Details of the variations in configuration and methods of producing the non-planar abrasive region are further detailed in US20090224370 in the name of the applicant. US20090224370 is incorporated into the current specification to the extent allowable under national law.

The polycrystalline CVD diamond layer 40 typically covers the whole of the conditioning head, although in some embodiments the vanes may be separately attached to a backing plate. The diamond layer 40 forms the edge shaving region, which covers the majority (e.g. > 80%) of the top of the spiral vane and preferably the vane side. The edge shaving region of the substrate 40 is preferably first uniformly distributed with about 100 to 5000 grains per mm² of diamond grit having an average particle diameter preferably less than 10 µm and even more preferably between 0.5 to 2 µm. However, seedless formation of the CVD diamond layer is also possible. The concentration and size of the grain as well as the CVD diamond processing conditions, may be adjusted to achieve the required surface roughness. Further details of the CVD diamond process are provided in paragraphs 73 to 76 of US20090224370, which are incorporated by reference. Other seeding methods are disclosed in US6054183.

The lateral cross-section view of the vane is the shape of a truncated triangle with the top about 1.1mm wide. A protrusion 50 (cutting point region) is positioned towards the peripheral edge of the spiral vane at the outer diameter of the conditioning head 10. The protrusion is

an enlarged diamond grain adhered to the substrate prior to the CVD diamond layer being applied. The protrusion 50 has a height of 40 μm (R_{p2}) above the edge shaving region 40 of AB, corresponding to the difference between the peak height of the protrusion to the peak height of the edge shaving region 40. The mean thickness of the protrusion (relative to the substrate) is about 30 μm . In Figure 1a, the mean CVD diamond layer thickness is about 10 μm for the edge shaving region, with a roughness R_{p1} of about 4 μm .

Figure 1b illustrates an embodiment in which the point cutting region is defined between enlarged diamond grains 50 and 52. The diamond height AB is 42 μm (R_{p2}), whilst roughness R_{p1} remains at about 4 μm .

Figures 2a to 2f illustrate protrusions positioned towards the peripheral edge of the spiral vanes, such as those illustrated in Figure 4. The protrusions were formed by adhering single diamond grains (or three diamond grains in Figure 2e) to the required location prior to applying the CVD diamond layer. Through selection of appropriately sized diamond grains, protrusions may be formed within a height tolerance of $\pm 5 \mu\text{m}$ (and preferably $\pm 3 \mu\text{m}$). Figure 3a illustrates a substrate with the diamond grain adhered thereto, whilst Figure 3b illustrates the protrusion formed therefrom after application of the CVD diamond layer. In a variation to the conditioning head of Figure 4, the spiral vanes form the surface edge shaving region; raised cutting point protrusions are positioned preferably within 3mm of the peripheral edge between one or more of the spiral vanes and preferably between alternatively spiral vanes. The spiral vanes comprise a shaving edge which is able to efficiently remove the top layers of the polishing pad without an excessive pad wear rate. The small portion of raised cutting points is able to rejuvenate the polishing pad surface by breaking up glazed areas and restoring the asperity structure.

When compared to the 3M Trizact B5 pad conditioner, the conditioning head of Figure 4 created about the same contact area (contact area is the area of the polishing pad that will contact the wafer during CMP under 2 psi load). However, the conditioning head of the present invention had a mean contact density (at 2 psi pressure) of 220 counts/ mm^2 compared to 129 counts/ mm^2 when the polishing pad was conditioned with the 3M pad conditioner. These results indicate that the conditioning heads of the present invention are able to produce a polishing pad asperity structure defined by a higher frequency of smaller asperity peaks. This enables improved wafer material removal and lower wafer defects as the contact areas can stay more lubricated. Larger contact areas can become non-lubricated, causing friction and increased defects.

Figure 5 illustrates a portion of a surface profile of a raised spiral vane of Figure 4. The roughness of the edge shaving region R_{p1} is determined by performing a line scan across

the full length of the spiral vane (excluding the cutting point region). In Figure 4, this involved two separate line scans either side of the protrusion. The largest Rp_1 between the separate line scans was 8 μm , whilst Rp_2 was 41 μm .

Figures 6 to 8 illustrate the shape and dimensions of protrusions formed from the adhering diamond grains to the top surface of the non-planar raised substrate. As illustrated, the protrusions have substantially level top surfaces. Figures 9 and 10 illustrate protrusions with rounded tops formed from catalytic seeds, which promoted accelerated diamond growth and resulted in a thicker diamond layer immediately adjacent the catalytic seeds.

The cross-sectional portion of the grains ranged from about 30 μm to 50 μm . The spiral shaving edge vane has a shaving edge length of about 50 mm. Therefore, the portion of the cutting point/shaving edge functioning as cutting points is about 0.06% to 0.10%. For embodiments in which only half of the vanes comprised these protrusions, the portion of the cutting/shaving edge functioning as cutting points would also be halved.

Figures 11a to 11f provide a number of possible configurations of the raised non-planar edge shaving region. The Rp_1 in all samples was less than 5 μm , whilst the protrusion heights were all greater than 30 μm and less than 50 μm . In embodiments where the region comprises concentric circular vanes (such as those illustrated in Figures 11e and 11f), the protrusions of the point cutting region are preferably on the outermost concentric circular vane. The embodiments shown in Figures 11a, 11b, 11c, and 11d each have a series of spiral raised edge shaving regions.

It will be appreciated that the cutting points may be generated by a variety of means. In one embodiment, the substrate adjacent the cutting point region is distributed with catalytic seeds. Accordingly, the cutting point region is preferably adjacent catalytic seed(s) disposed upon the substrate. The catalytic seeds preferably comprise diamond, silicon, iron, cobalt, nickel and/or alumina. A CVD diamond layer is then deposited, resulting in the cutting point region comprising larger and higher diamond grains relative to the diamond grains forming the edge shaving region.

In another embodiment, the substrate comprises one or more protrusions which form the cutting point region once coated with CVD diamonds.

In yet another embodiment, the cutting point region may be obtained through etching protrusions from a diamond layer, as described in US89796183.

Within the scope of this application, it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features

thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. For the avoidance of doubt, the terms “may”, “and/or”, “e.g.”, “for example” and any similar term as used herein should be interpreted as non-limiting such that any feature so-described need not be present. Indeed, any combination of optional features is expressly envisaged without departing from the scope of the invention, whether or not these are expressly claimed. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim, although not originally claimed in that manner.

CLAIMS

1. A conditioning head comprising:
 - (a) a substrate comprising a substrate surface;
 - (b) at least one raised non-planar abrasive region relative to the substrate surface, wherein the raised non-planar abrasive region comprises between one and fifty protrusions arranged in at least four radially extending vanes, wherein each vane comprises:
 - an edge shaving region; and
 - a point cutting region, wherein the point cutting region comprises between zero and five protrusions extending no more than 250 microns from the mean height of the edge shaving region, wherein each protrusion is positioned greater than 70% along a radial line starting at the central axis and ending at the peripheral edge of the conditioning head;wherein the ratio of the surface area of the edge shaving region to the point cutting region is at least 2:1.
2. The conditioning head according to any one of the preceding claims, wherein the edge shaving region is coated with a CVD diamond layer.
3. The conditioning head according to any one of the preceding claims, wherein the point cutting region is positioned greater than 50% along a straight radial line starting from a central axis and ending at a peripheral edge of the conditioning head.
4. The conditioning head according to any one of the preceding claims, wherein the point cutting region is positioned greater than 90% along a radial line starting from a central axis and ending at a peripheral edge of the conditioning head.
5. The conditioning head according to any one of the preceding claims, wherein the point cutting region comprises one or more protrusions comprising CVD diamond coated diamond grit.
6. The conditioning head according to any one of claim 1 to 5, wherein the point cutting region and the edge shaving region comprises a polycrystalline diamond layer, the average grain size of the polycrystalline diamond on the point cutting region being greater than the average grain size of the polycrystalline diamond layer on the edge shaving region.

7. The conditioning head according to claim 6, wherein the cutting point region is adjacent catalytic seeds disposed upon the substrate.
8. The conditioning head according to claim 7, wherein the catalytic seeds comprise diamond, silicon, iron, cobalt, nickel and/or alumina.
9. The conditioning head according to any one of the preceding claims, wherein the one or more protrusions extend between 5 and 250 micron from the mean height of the edge shaving region.
10. The conditioning head according to any one of the preceding claims, wherein the one or more protrusions extend between 10 and 50 micron from the mean height of the edge shaving region.
11. The conditioning head according to any one of the preceding claims, wherein the one or more protrusions are rounded or convex.
12. The conditioning head according to any one of the preceding claims, wherein the one or more protrusions are non-geometric with other protrusions.
13. The conditioning head according to any one of the preceding claims, wherein the raised non-planar abrasive region comprises one or more discrete raised non-planar abrasive segments.
14. The conditioning head according to any one of the preceding claims, wherein the one or more segments have a shape selected from the group consisting of concentric circles, broken concentric circles, spirals, broken spirals segments, linear segments, broken linear segments, curved segments, broken curved segments and combinations thereof.
15. The conditioning head according to claims 13 or 14, wherein the point cutting region is distributed across one or more of the segments.
16. The conditioning head according to claim 15, wherein the point cutting region is distributed across less than 60% of the segments.
17. The conditioning head according to any one of the preceding claims, wherein the point cutting region comprising one or more isolated or clusters of protrusions.

18. The conditioning head according to any one of the preceding claims, wherein the ratio of the surface area of the edge shaving region to the point cutting region is at least 100:1.
19. The conditioning head according to any one of the preceding claims, wherein the ratio of the surface area of the edge shaving region to the point cutting region is at least 200:1.