CMP CONDITIONER PADS WITH SUPERABRASIVE GRIT ENHANCEMENT

This application claims priority to U.S. Provisional Application No. 61/642,874 filed May 4, 2012. Said application is incorporated herein by reference including the Appendix thereto.

FIELD OF THE INVENTION

The disclosure is directed generally to semiconductor manufacturing equipment. More specifically, the disclosure is directed to conditioning devices for the cleaning of polishing pads used in the manufacture of semiconductors.

BACKGROUND

Chemical mechanical planarization (CMP) is used extensively in the manufacture of semiconductor chips and memory devices. During a CMP process, material is removed from a wafer substrate by the action of a polishing pad, a polishing slurry, and optionally chemical reagents. Over time, the polishing pad becomes matted and filled with debris from the CMP process. Periodically the polishing pad is reconditioned using a pad conditioner that abrades the polishing pad surface and opens pores and creates asperities on the surfaces of the polishing pad. The function of the pad conditioner is to maintain the removal rate in the CMP process.

CMP represents a major production cost in the manufacture of semiconductor and memory devices. 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. Additional cost for the CMP process includes tool downtime in order to replace the polishing pad and the cost of the test wafers to recalibrate the CMP polishing pad.

A typical polishing pad comprises closed-cell polyurethane foam with a thickness in the range of approximately 0.15 to .20 centimeters thick. During pad conditioning, the pads are subjected to mechanical abrasion in order to physically cut through the cellular layers of the pad surface. The exposed surface of the pad contains open cells, which can be used during the CMP process to trap abrasive slurry consisting of the spent polishing

slurry and material removed from the wafer. The pad conditioner removes the outer layer of cells containing the embedded materials and minimizes removal of layers below the outer layer. Over-texturing of the polishing pad results in a shortened life, while under-texturing results in insufficient material removal rate and lack of wafer uniformity during the CMP step.

Certain pad conditioners utilize superabrasive particles such as diamond that are adhered to a substrate. See, e.g., U.S. Patent No. 7,201,645 to Sung (Sung) (disclosing a contoured CMP pad dresser that has a plurality of superabrasive particles attached to the substrate); U.S. Patent Application Publication No. 2006/0128288 to An et al. (An) (disclosing a layer of metal binder fixing the abrasive particles to a metal substrate, with a diameter difference between smaller and bigger abrasive particles ranging from 10% to 40%). A problem with prior art pad conditioners is that the forces generated on the proudest features of the pad conditioners can result in the particles that experience the higher forces to become dislodged from the pad conditioner. Dislodged particles can be captured by the polishing pad which can lead to scratching of the wafers during the polishing operation.

There is a continuing need for CMP pad dressers that reduce or eliminate abrasive particles becoming dislodged and CMP pad dressers that have varying surface heights for dressing CMP polishing pads.

SUMMARY OF THE INVENTION

In various embodiments of the invention, a pad conditioner machined from a substrate to have a desired distribution of feature heights and roughness characteristics is provided. The protrusions on the shaped substrate act as geometric features that provide force concentrations on the pad surface. In embodimeents first a substrate is produced having roughened or textured repeating protrusions, diamond grains are dispersed over the surface area and a layer of a polycrystalline CVD diamond coating that is grown over the surface protrusions and diamond grains. The roughness of the substrate facilitating securement of the diamond seed grains within the diamond coating to minimize or prevent dislodging.

In embodiments, the diamond grains being of a size that is less than the average thickness of the CVD coating measured in a direction extending away from the pad.

Features and advantages of embodiments of the invention are enhanced performance of the pad conditioner. In embodiments conditioner to conditioner cut rate repeatability is provided and consistent cut rate over the life of the conditioner, and reduced defects followed by the addition of diamond grit crystals onto the roughened surfaces and the addition of a CVD diamond layer wherein the diamond grit seed crystals are part of the matrix and the thickness of the CVD

In embodiments, silicon carbide segments having a roughened substrate with roughened protrusions formed thereon are first provided with small diamond seed grains (for example, diamond grit in the 1 nm to 30 nm diameter size range). Larger diamond grit seed crystals (for example, in the range from about 1 micormeter (μm) to about 12 μm range) can then be applied to the substrate and protrusions. A few milligrams of the large diamond grit can be applied to each segment. The large diamond grit adheres to the silicon carbide substrate and protrusions, with the roughened surface (for example, about 2 μm to about 5 μm RMS roughness) helps retain the larger diamond particles.

The addition of the larger diamond grit seed also allows the cut rate of the pad conditioner to be "tailored" over a wide range depending upon the size of the larger diamond grit seed crystals. “Larger” grit crystal sizes that are typically much less than the prior art utilization of grit that actually provided the cutting features. In embodiments, the grit is generally within the average thickness in the z-direction of the CVD coating. The textured surface helps retain the seed crystals, thereby abating the problem of particle dislodgement experienced with prior art pad conditioners. The seeded surfaces can then be coated with, for example, polycrystalline diamond.

DESCRIPTION OF THE FIGURES

Figure 1 is a pictorial view of a wafer polishing apparatus with a pad conditioner.

Figure 2 is a perspective view of a pad conditioner assembly in accord with the inventions.

Figure 3 is a perspective view of a pad conditioner assembly in accord with the inventions.

Figure 4 is a photo image of a conditioner pad in accord with the inventions.

Figure 5 is a perspective image showing projections on a surface in accord with the inventions.

Figure 6a is a plan view of a projection array on a pad in accord with the inventions herein.

Figure 6b is a plan view of a projection array on a pad in accord with the inventions herein Figure 7 is a plan view of a projection array on a pad in accord with the inventions herein.

Figure 8 is a cross sectional view of a protrusion on a substrate with coatings in accord with the inventions herein.

Figure 9 is a chart showing experimental cut rates utilizing the inventions herein.

Figure 10 is a micrograph.

Figure 11 is a micrograph.

Figure 12 is a micrograph.

Figure 13 is a micrograph.

Figure 14 is a cross sectional view of a protrusion on a substrate with coatings in accord with the inventions herein.

Figure 15 is a cross sectional view of a protrusion on a substrate with coatings in accord with the inventions herein.

DETAILED DESCRIPTION

Referring now to FIG. 1, a wafer polishing apparatus 30 with a pad conditioner 32 in a chemical mechanical planarization (CMP) process is depicted in an embodiment of

the invention. The depicted wafer polishing apparatus 30 includes a rotation table 34 having an upper face 36 with a CMP pad 38 (such as a polymeric pad) mounted thereon. A wafer head 42 having a wafer substrate 44 mounted thereon is arranged so that the wafer substrate 44 is in contact with the CMP pad 38. In one embodiment, a slurry feed device 46 provides an abrasive slurry 48 to the CMP pad 38.

In operation, the rotation table 34 is rotated so that the CMP pad 38 is rotated beneath the wafer head 42, pad conditioner 32 and slurry feed device 46. The wafer head 42 contacts the CMP pad 38 with a downward force F. The wafer head 42 can also be rotated and/or oscillated in a linear back-and-forth action to augment the polishing of the wafer substrate 44 mounted thereon. The pad conditioner 32 is also in contact with the CMP pad 38, and is translated back and forth across the surface of the CMP pad 38. The pad conditioner 32 can also be rotated.

Functionally, the CMP pad 38 removes material from the wafer substrate 44 in a controlled manner to give the wafer substrate 44 a polished finish. The function of the pad conditioner 32 is to remove debris from the polishing operation that fills the debris from the CMP process and to open the pores of the CMP pad 38, thereby maintaining the removal rate in the CMP process.

Referring to FIGS. 2 and 3, pad conditioner assemblies 50A, and 50b are depicted in embodiments of the invention. The pad assemblies (collectively referred to as pad assemblies 50) include conditioning segments 52a, 52b respectively (collectively referred to as conditioning segments 52), affixed to an underlying substrate or backing plate 54. The conditioning segments 52 can have protrusions of two or more different average heights, as discussed for various embodiments as discussed in WO 2012/1221186 A2, also PCT Patent Application No. PCT/US2012/027916 (“Smith”), assigned to the owner of the instant invention and applicaiotn , is incorporated herein by reference. In one embodiment, the segments are bonded to the backing plate 54 using an adhesive such as an epoxy. FIG. 4 illustrates an individual segments. FIG. 5 illustrates an enlarged perspective view of a substrate surface 64 with protrusions 66 in a spaced pattern thereon formed by suitable machining in accord with the invention herein. FIGS. 6A, 6B, and 7 illustrate various densities of matrixical patterns 70A, 70B, and 70C suitable for the

invention herein. “Matrix” when used herein may refer to a matrix with rows and columns or a circular matrix with circular rows expanding outwardly or portions thereof.

Referring to FIG. 8, a substrate 80, such as from one of the segments above, comprises a protrusion 80 having large diamond seed crystals 82 and small diamond seed crystals 84 seeded thereon and a polycrystalline diamond coating 86 thereover is depicted in an embodiment of the invention. The sectional view depicts the height h of the protrusions, the thickness t of the polycrystalline layer, and the roughness R of the substrate/protrusion material. The protrusion is characterized as having a height referenced from a floor level F of the substrate. To the exent the floor f is not uniform, the floor level may be considered the average of the lowest level between each adjacent protursion, the height of the protrusions may be measured from this average datum level.

In various embodiments, the thickness of the polycrystalline diamond layer can be about the diameter of the large diamond grit particles, as depicted in FIG. 8, or it can be larger in embodiments and in embodiment smaller. In various embodiments, the thickness of the polycrystalline diamond overlying the diamond grit seed and the surfaces ranges from about 50% to about 100% of the diameter of the large diamond grit size, the latter case of 100% of the grit size being depicted.

Functionally, the large diamond grit seed crystals add another dimension of roughness to the substrate and protrusion surfaces. The cut rate of the pad conditioner can advantageously be varied by choosing narrow size ranges for the large diamond grit seed crystals; narrow size ranges can be 1 μm, 2 μm, 4 μm, and up to about 6 μm.

Referring to FIG. 9, performance metrics for a pad conditioner for varying large sized grit diameters is depicted in an embodiment of the invention. The data presented in FIG. 2 was for a conditioning pad having a 4 inch diameter with 5 segments coupled thereto. The features on the segments have a base dimension of 125 μm at a density of 10 features per square millimeter. The height of the features was nominally 20 μm. The pad cut rate using this conditioner was determined using a Buehler Ecomet 4 Benchtop Polisher. The pad used was an IC 1000 (TM) pad (Rohm and Haas) rotated at 50 rpm. The IC 1000 pad was contacted with the prototype pad conditioner with 7 lbs force and the rotation of the prototype pad conditioner was 35 rpm. Deionized water at a flow of 80 milliliters per minute was dispensed onto the pad during the cut rate experiment. The

experiment was repeated with a new polishing pad having the large seed crystals, with diameters corresponding to the seeding process on the x-axis for FIG. 2.

The cut rate for a pad with large seed crystals in the range of 1 μm to 2 μm, (x-axis label 1) is about 23 μm per hour; for the 2 μm to 4 μm seed crystals (x-axis label 2) the cut rate is about 28 μm per hour; for the 4 μm to 8 μm seed crystals (x-axis label 3), the cut rate is about 32 μm per hour; and for 6-12 μm seed crystals the cut rate is about 50 μm per hour. The cut rate can also vary depending upon the type of pad conditioner. The point at "0 seeding" process in the graph corresponds to the case where only nanometer sized small diamond grit seed crystals are used (about 10 μm per hour cut rate).

FIG. 10 is a photograph of a protrusion without polycrystalline diamond (not the roughness). FIG. 11 is a photograph of a protrusion coated with polycrystalline diamond (with small nanometer sized seed crystals). FIG. 12 is a photograph of large diamond grit seed crystals on a protrusion and surfaces of a silicon carbide substrate having roughened surfaces. FIG. 13 is a photograph of polycrystalline diamond coating with larger diamond grit seed crystals, 6 to 12 microns, on a protrusion.

Example an non-limiting dimensions for the various aspects of FIG. 1 include: protrusion heights in the range of 10 to 150 μm; the polycrystalline diamond layer of about 7 to 15 μm average thickness with approximately 2 μm variation; the RMS roughness of the polycrystalline diamond coating can be from about 0.1 μm to about 2 μm; the roughness of the substrate, which can be silicon carbide, can be about 2 μm to about 5 μm. The protrusion features and their fabrication can be as described in Smith.

Referring to FIG. 14, a protrusion 90 having roughened or textured surfaces 91 on a rough base material 92 of a pad conditioner is depicted in an embodiment of the invention. The large diamond grit seed crystals 94 are interspersed on the roughened surface and in some cases the large diamond grit seed crystal in are substantially captured by the indentations or depressions that characterize the roughened surface. The large diamond seed crystals are shown on the "top" surface 95 of the protrusions, on the sides 96 of the protrusion, and in the channel 97 between protrusions. Advantageously the roughened surfaces of the protrusions helps to secure the large diamond grit seed crystals to part or all of the side surfaces, at least prior to the coating process. The roughness of the protrusions and substrate and the polycrystalline diamond coating atop the larger

diamond grit seed also help to secure the diamond to the pad surface and reduces or eliminates loosening and loss of diamond crystals from the pad. The sides are typically form an obtuse angle measured between the channel region and incline. In embodiments the protrusion is rounded as illustrated. In embodiments the protrusion has a mesa or plateau, a flattened region rather than a rounded apex or peak.

Referring to FIG. 15, a portion of a pad conditioner, a substrate 100, having post shaped protrusions 104, 106 of differing heights, larger diamond grit seed crystals 110 on the surfaces of the substrate and protrusions of the pad conditioner, and a layer 114 of polycrystalline diamond that has a thickness that covers the large diameter sized diamond grit and surfaces of the conditioner. In one embodiment, the diameters of the larger grit seed crystals is in a range of diameters that is less than 6 μm. The polycrystalline diamond can be between 50% and 100% of the diameter of the larger diamond grit seed crystals. In embodiments, greater than 100%.

Smith, assigned to the assignee of the present application, discloses the use of pad conditioners having protrusions with surfaces that are roughened or textured and coated with CVD diamond material. The application of small diamond grit to surfaces for nucleating polycrystalline diamond films is disclosed by Malshe et al., Electrochemical Society Proceedings, Vol. 97-32 (1998), pp. 399-421 (ISBN 1-56677-185-4), disclosing the use of 4 nm sized diamond crystals as seeds. See also in U.S. Patent No. 4,925,701 to Jansen et al. (disclosing the implementation of 100 nm diamond seed) and U.S. Patent No. 5,474,808 to Aslam (disclosing the use of 25 nm seed). The above-referenced publications are hereby incorporated by reference herein in their entirety except for express definitions contained therein.

As provided in the illustration, the pad cut rate and pad surface roughness are relatively steady for the pad conditioner of an embodiment of the invention compared to the commercial pad conditioners. The surface finish of an embodiment of the invention was also typically smoother than with the commercially available pad conditioner. As used herein and in the appended claims, the singular forms "a", "an", and "the" include plural reference unless the context clearly dictates otherwise. Thus, for example, reference to a "protrusion" is a reference to one or more protrusions and equivalents thereof known to those skilled in the art, and so forth. Unless defined otherwise, all technical and scientific

terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. Methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the present invention. All publications mentioned herein are incorporated by reference in their entirety, except for express definitions contained therein. Nothing herein is to be construed as an admission that the invention is not entitled to antedate such disclosure by virtue of prior invention. "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where the event occurs and instances where it does not. All numeric values herein can be modified by the term "about," whether or not explicitly indicated. The term "about" generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e., having the same function or result). In some embodiments the term "about" refers to ±10% of the stated value, in other embodiments the term "about" refers to ±2% of the stated value. While compositions and methods are described in terms of "comprising" various components or steps (interpreted as meaning "including, but not limited to"), the compositions and methods can also "consist essentially of or "consist of the various components and steps, such terminology should be interpreted as defining essentially closed-member groups. Although the invention has been shown and described with respect to one or more implementations, equivalent alterations and modifications will occur to others skilled in the art based upon a reading and understanding of this specification and the drawings. The invention includes all such modifications and alterations and is limited only by the scope of the following claims. In addition, while a particular feature or aspect of the invention may have been disclosed with respect to only one of several implementations, such feature or aspect may be combined with one or more other features or aspects of the other implementations as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "includes", "having", "has", "with", or variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprising." Also, the term "exemplary" is merely meant to mean an example, rather than the best. It is also to be appreciated that features, layers and/or elements depicted herein are illustrated with particular dimensions and/or orientations relative to one another for purposes of simplicity and ease of understanding, and that the actual dimensions and/or orientations may differ substantially from that illustrated herein.

Although the invention has been described in considerable detail with reference to certain embodiments thereof, other versions are possible. Therefore the spirit and scope of the appended claims should not be limited to the description and the versions contain within this specification. While various compositions and methods are described, it is to be understood that this invention is not limited to the particular molecules, compositions, designs, methodologies or protocols described, as these may vary. It is also to be understood that the terminology used in the description is for the purpose of describing the particular versions or embodiments only, and is not intended to limit the scope of the present invention which will be limited only by the appended claims.

Claims:

1. A chemical mechanical polishing pad conditioner, comprising: a substrate including a front surface having a plurality of protrusions integral therewith, said plurality of protrusions extending in a frontal direction that is substantially normal to said front surface, each of said plurality of protrusions including a distal extremity, and a dispersion of superabrasive grit seeds disposed on said protrusions, the chemical mechanical polishing pad conditioner being characterized by:

each of said plurality of protrusions having a root-mean-square surface roughness that is greater than 3 μm;

a dispersion of superabrasive grit seeds disposed on said substrate; and

a diamond coating that covers said substrate, said protrusions and said dispersion of superabrasive grit seeds.

2. The chemical mechanical polishing pad conditioner of claim 1, wherein the protrusions of the substrate have a matrixical arrangement, the projections each having a highest most peak, and each highest most peak positioned on its respective projection in a non repeating fashion with respect to the other projections.

3. The chemical mechanical polishing pad conditioner of claim 1 wherein the protrusions of the substrate have repeating spacing pattern providing a density, the density being .5 to 5 projections per square mm.

4. The chemical mechanical polishing pad conditioner of claim 1, wherein the protrusions of the substrate have a matrixical arrangement of projections of a first height and a matrixical arrangement of projections of a different height.

5. The chemical mechanical polishing pad conditioner of claim 1, wherein said plurality of superabrasive diamond grit seeds have diameters that range from about 1 μm to about 15 μm.

6. The chemical mechanical polishing pad conditioner of claim 1, wherein said plurality of superabrasive diamond grit seeds have diameters that range from about 1 μm to about

15 μm and said coating has a thickness that is in the range of 50% to 100% of an average diameter of said superabrasive grit seeds.

7. The chemical mechanical polishing pad conditioner of claim 5, further comprising a second plurality of superabrasive grit seeds disposed on said surfaces of said substrate and said protrusions, said second plurality of superabrasive grit seeds having diameters that range from about 1 nm to about 30 nm.

8. The chemical mechanical polishing pad conditioner of claim 3, wherein said substrate and said protrusions are of a silicon carbide material.

9. The chemical mechanical polishing pad conditioner of any of the above claims wherein the substrate is mounted on a backing plate and there are at least 4 additional like substrates.

10. A method of manufacturing a chemical mechanical polishing pad conditioner according to claim 1, comprising providing a ceramic substrate, the method characterized by:

removing material from the silicon carbide substrate by machining to provide a repeating pattern of projections each having a height of 10 to 150 microns, and having a root-mean-square surface roughness that is greater than 3 μm;

dispersing a quantity of diamond grains across on the substrate;

coating the surface of the substrate by chemical vapor deposition with diamond thereby covering the projections and the quantity of diamond grains.

11. The method of claim 10 further comprising selecting the quantity of diamond grains to be substantially sized to be less than 12 microns.

12. The method of claim 10 further comprising selecting the quantity of diamond grains to be substantially sized with a maximum diameter from 1 nm to 30 nm, and further selecting an additional quantity of diamond seed grains to be sized to be greater than 2 microns and less than 12 microns, and further dispersing the additional quantity across the substrate.

13. The method of claim 10 further comprising selecting a silicon substrate with a porosity of at least 10 per cent.

14. The method of any one of claims 10 through 13 further comprising providing a roughness to the silicon carbide of about 2 microns to about 5 microns before coating the surface with diamond.

15. The method of any of claims 10 through 13 further comprising providing a plurality of the ceramic substrates and attaching them evenly spaced about a circular disk.