GROOVED CMP POLISHING PAD

FIELD OF THE INVENTION

[0001] The present invention relates generally to chemical mechanical polishing of substrates, and more particularly to a polishing pad having a grooved pattern for a chemical mechanical polishing system.

BACKGROUND OF THE INVENTION

[0002] Compositions and methods for chemical-mechanical polishing of the surface of a substrate are well known in the art. Polishing compositions (also known as polishing slurries, CMP slurries, and CMP compositions) for CMP of surfaces of semiconductor substrates (e.g., integrated circuits) typically contain an abrasive, various additive compounds, and the like.

[0003] Chemical-mechanical polishing (CMP) involves the concurrent chemical and mechanical abrasion of surface, e.g., abrasion of an overlying first layer to expose the surface of a non-planar second layer on which the first layer is formed. One such process is described in U.S. Patent No. 4,789,648 to Beyer *et al.* Briefly, Beyer *et al.*, discloses a CMP process using a polishing pad and a slurry to remove a first layer at a faster rate than a second layer until the surface of the overlying first layer of material becomes coplanar with the upper surface of the covered second layer. More detailed explanations of chemical mechanical polishing are found in U.S. Patents No. 4,671,851, No. 4,910,155 and No. 4,944,836.

[0004] In conventional CMP techniques, a substrate carrier or polishing head is mounted on a carrier assembly and positioned in contact with a polishing pad in a CMP apparatus. The carrier assembly provides a controllable pressure to the substrate, urging the substrate against the polishing pad. The pad and carrier, with its attached substrate, are moved relative to one another. The relative movement of the pad and substrate serves to abrade the surface of the substrate to remove a portion of the material from the substrate surface, thereby polishing the substrate. The polishing of the substrate surface typically is further aided by the chemical activity of the polishing composition (e.g., by oxidizing agents, acids, bases, or other additives present in the CMP composition) and/or the mechanical activity of an abrasive suspended in the polishing composition. Typical abrasive materials include silicon dioxide, cerium oxide, aluminum oxide, zirconium oxide, and tin oxide.

[0005] One problem in CMP relates to polishing slurry distribution over the polishing pad. The CMP process requires the interaction of the polishing pad, abrasive particles and any reactive agent or chemical in the polishing composition with the substrate to obtain the desired polishing results. Ineffective distribution of the slurry across the surface of the polishing pad can lead to diminished polishing efficiency. Polishing pads generally include some feature such as perforations or textures (e.g., grooves, surface depressions, and the like) to aid in distributing the abrasive polishing slurry relatively uniformly across the pad. Grooves are often a preferred texturing feature, because they can be designed to directly channel the excess slurry to where it is needed. Grooved polishing pads are often characterized by the dimensions (e.g., width and depth) of the grooves and the spacing between the grooves (known as "pitch"). Examples of grooved pads include those disclosed in U.S. Patent No. 5,921,855 to Osterheld *et al.*, U.S. Patent No. 6,520,847 to Osterheld *et al.*, and U.S. Patent No. 6,736,847 to James *et al.*

[0006] While conventional grooved CMP pads have certain preferred performance characteristics over, for example, perforated pads, there is still a need in the art for improved pad performance features, such as improved pad lifetime (e.g., due to reduced wear rates). The present invention addresses this need.

BRIEF SUMMARY OF THE INVENTION

[0007] The present invention provides polishing pads for use in CMP processes. In one embodiment, a pad comprises a surface defining a plurality of grooves with landing surfaces separating the grooves, the landing surfaces together defining a substantially planar polishing surface, each groove having a depth of at least 10 mil and a width, W_G, with any two adjacent grooves being separated from each other by a landing surface having a width, W_L, wherein the quotient W_L/W_G is less than or equal to 3. In a preferred embodiment, the surface of the pad defines a series of concentric, substantially circular grooves. Preferably, each groove has the same W_G, and each landing surface has the same W_L.

[0008] In an alternative embodiment, the surface of the pad defines a spiral groove having a depth of at least 10 mil and a width W_G, and a spiral landing surface outlining the spiral groove. The spiral landing surface has a width, W_L, and defines a

substantially planar polishing surface. As in the previously described embodiment, the quotient W_L/W_G is less than or equal to 3.

[0009] The polishing surface of the polishing pads of the present invention can be formed from any substance suitable for use in CMP pad construction. In some preferred embodiments the polishing surface of the pad is formed from a thermoplastic polyurethane material. The pads can be constructed from a single layer of pad material or from multiple layers (e.g., a base layer and a surface layer).

[0010] The polishing pads of the present invention provide an unexpected improvement in polishing removal rate uniformity over extended use (e.g., polishing of up to 650 semiconductor wafers) compared to a conventional grooved pad of similar construction, but with W_L/W_G equal to 7.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 illustrates a top plan view of an embodiment of a polishing pad of the present invention including a plurality of circular, concentric grooves.

[0012] FIG. 2 provides a partial cross-sectional view of the pad of FIG. 1.

[0013] FIG. 3 illustrates an embodiment of a polishing pad of the present invention including a single spiral groove in the polishing surface.

[0014] FIG. 4 shows a graph of copper removal rate versus number of wafers polished for a pad of the invention compared to a conventional reference pad.

[0015] FIG. 5 shows a graph of copper removal rate uniformity stability versus number of wafers polished for a pad of the invention compared to a conventional reference pad.

[0016] FIG. 6 shows a graph of pad wear rate for pads of the invention compared to a conventional reference pad.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In one embodiment, a polishing pad of the present invention comprises a surface defining a plurality of grooves, preferably concentric and substantially circular grooves, with landing surfaces separating the grooves. The landing surfaces together define a substantially coplanar polishing surface. Each groove has a depth of at least 10 mil and a width, W_G, with any two adjacent grooves being separated by a landing surface having a width, W_L, wherein the quotient W_L/W_G is less than or equal to 3. Preferably, each of the plurality grooves has substantially the same depth, and/or

substantially the same W_G. Each of the landing surfaces preferably has substantially the same W_L, as well. The width of each groove preferably is substantially uniform throughout the majority of the groove depth, although the bottom of the groove may be rounded, resulting in a decreasing width near the bottom of the groove.

[0018] FIG. 1 illustrates a top plan view of a polishing pad of the present invention. Pad 10 includes a surface layer 12 defining concentric circular grooves 14 separated by landing surfaces 16, with peripheral surface 18 framing the pad surface. Landing surfaces 16 are substantially coplanar with each other, as are peripheral surface 18 and central surface 20. Collectively, landing surfaces 16 define a substantially coplanar polishing surface.

[0019] FIG. 2 shows a partial cross-sectional view of surface 12 along plane 2-2 of FIG. 1. Surface layer 12 is affixed to base layer 22. Grooves 14 have a depth, D_G, and a width W_G, while the landing surfaces 16 have a width, W_L. The distance from the beginning of one groove to the beginning of the next groove is defined as the pitch, P, which is equal to the sum of W_L and W_G. In the pads of the invention W_L/W_G is less than or equal to 3. Landing surfaces 16 are substantially coplanar, thereby forming a coplanar polishing surface for contacting the surface of a substrate to be polished, while grooves 14 provide a reservoir for an abrasive polishing slurry, and aid in channeling and distributing the polishing slurry over the entire surface of pad 10.

[0020] In an alternative embodiment, a polishing pad of the present invention comprises a surface defining a spiral groove having a depth of at least 10 mil with a spiral landing surface outlining the spiral groove. The spiral landing surface defines a substantially planar polishing surface. The groove has a width, W_G, and the landing surface has a width, W_L, wherein the quotient W_L/W_G is less than or equal to 3. FIG. 3 provides a top plan view of such an alternative embodiment. Pad 30 includes a substantially planar surface layer 32 having a single spiral groove 34 formed therein, which is outlined by a nested spiral landing surface 36. The pitch, P, which is equal to the sum of the widths of groove 34 and landing surface 36, is also indicated in FIG. 3.

[0021] In each of the embodiments of the present invention, each groove in the surface of the polishing pad preferably has a depth of not more than 50 mil. In some

preferred embodiments, the depth of each groove is in the range of 10 to 50 mil, more preferably 15 to 40 mil.

[0022] If desired, the quotient W_L/W_G in any given embodiment of the polishing pad of the present invention can less than or equal to 2, or less than or equal to 1.

[0023] In certain preferred embodiments, W_L for each landing surface is not more than 80 mil. In other preferred embodiments, W_L for each landing surface is in the range of 30 to 60 mil. W_G for each groove preferably is not more than 50 mil. In some preferred embodiments, W_G for each groove is in the range of 20 mil to 40 mil.

[0024] Table 1 illustrates some specific examples of different grooving dimensions suitable for polishing pads of the present invention.

Table 1.

Pitch (mil)	W_G (mil)	W_L (mil)	W_G/W_L	W_L/W_G
80	20	60	0.33	3.00
80	30	50	0.60	1.67
80	40	40	1.00	1.00
80	50	30	1.67	0.60
70	20	50	0.40	2.50
70	30	40	0.75	1.33
70	40	30	1.33	0.75
60	20	40	0.50	2.00
60	30	30	1.00	1.00
50	20	30	0.67	1.50
50	30	20	1.50	0.67
40	20	20	1.00	1.00
30	10	20	0.50	2.00
30	20	10	2.00	0.50

[0025] The polishing pads of the present invention are particularly suited for use in conjunction with a chemical-mechanical polishing apparatus. Typically, the CMP apparatus comprises a platen, which, when in use, is in motion and has a velocity that results from orbital, linear, and/or circular motion, a polishing pad in contact with the platen and moving relative to the platen when in motion, and a carrier that holds a substrate to be polished by contacting and moving relative to the surface of the polishing pad. The polishing of the substrate takes place by the substrate being placed in contact with the polishing pad of the invention and then moving the polishing pad relative to the substrate, so as to abrade at least a portion of the substrate to polish the substrate.

[0026] Suitable materials for forming at least a portion of a polishing pad of the invention polishing pads include, for example, polymers of varying density, hardness, thickness, compressibility, ability to rebound upon compression, and compression modulus. Non-limiting examples of such polymers include polyvinylchloride, polyvinylfluoride, nylon, fluorocarbon, polycarbonate, polyester, polyacrylate, polyether, polyethylene, polyamide, polyurethane, polystyrene, polypropylene, coformed products thereof, and mixtures thereof. The surface of the polishing pad defining the plurality of grooves can comprise any such material. In a preferred embodiment, the surface defining the plurality of grooves or spiral groove comprises a thermoplastic polyurethane. If desired the pads of the present invention can be composed of a single layer of material or can include two or more layers of material, e.g., a base layer and a surface layer.

[0027] Desirably, the CMP pads of the invention can further comprise at least one light-or other radiation-transmitting window region for *in situ* inspecting and monitoring a polishing process by analyzing the light or other radiation reflected from a surface of a workpiece being polished with the pad. Many *in situ* polishing endpoint detection systems and techniques for inspecting and monitoring the polishing process by analyzing light or other radiation reflected from a surface of the workpiece are known in the art. Such methods are described, for example, in U.S. Patent No. 5,196,353 to Sandhu *et al.*, U.S. Patent No. 5,433,651 to Lustig *et al.*, U.S. Patent No. 5,949,927 to Tang, and U.S. Patent No. 5,964,643 to Birang *et al.* Desirably, the inspection or monitoring of the progress of the polishing process with respect to a workpiece being polished enables the determination of the polishing end-point, i.e., the determination of when to terminate the polishing process with respect to a particular workpiece.

[0028] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE 1

[0029] This example illustrates the superior removal rate stability and removal uniformity stability obtainable in copper CMP utilizing a polishing pad of the present invention.

[0030] A polishing pad comprising a thermoplastic polyurethane surface layer including a series of concentric circular grooves each having a width, W_G, of 30 mil, separated by concentric landing surfaces having a width, W_L, of 30 mil (pitch of 60 mil), with W_L/W_G equal to 1. The polishing was repeatedly performed with the same pad on copper blanket wafers using the commercial polishing slurry C8800 (Cabot Microelectronics Corporation, Aurora, IL) on Mirra polisher under the following polishing conditions: down-force of 1 pounds-per-square inch (psi), platen speed of 93 revolutions-per-minute (rpm), carrier speed of 87 rpm, and a slurry feed rate of 100 milliliters-per-minute (mL/min). For comparison, copper blanket wafers were also polished under the same conditions with a similar polyurethane polishing pad having concentric annular grooves separated by concentric annular landing surfaces, but having W_L of 70 mil and W_G of 10 mil (pitch of 80 mil), with W_L/W_G of 7.

[0031] FIG. 4 illustrates the change in copper removal rate versus number of wafers polished for each of the pads, showing the removal rates obtained at wafer 150 and wafer 650. As is evident from FIG. 4, the pad having a convention W_L/W_G of greater than 7 exhibited a decrease in Cu removal rate, while the pad of the present invention, having W_L/W_G of 1, exhibited an unexpected increase in Cu removal rate.

[0032] The observed removal uniformity stability percentage, defined as WIWNU or with-in-wafer non-uniformity (i.e., relative standard deviation of Cu removal across 49 point diameter scan of entire wafer with 5 mm edge exclusion), obtained with each pad is graphed in FIG. 5 for the same wafers. As can be seen in FIG. 5, the pad of the present invention exhibited an unexpectedly consistent removal uniformity stability compared to the conventional pad.

EXAMPLE 2

[0033] This example illustrates the effect of the grooving configuration on pad wear rate.

[0034] Three polishing pads of the invention comprising a thermoplastic polyurethane surface layer including a series of concentric circular grooves were used for relative pad wear test. The test was performed on an IPEC polisher with 7 ft-lb conditioning down force, 105 rpm platen speed, and 100 rpm conditioner rotational speed. Conditioner was from 3M Co (Model A188). D.I. water was used and the test last for 40 minutes. Wear rate was calculated using data from minute 10 to minute 40, and normalized to mil-per-hour by times 2. The pads had the following dimensions: Pad 60/20 - W_G = 20 mil, W_L = 40 mil, pitch = 60 mil, W_L/W_G = 2; Pad 60/30 - W_G = 30 mil, W_L = 30 mil, pitch = 60 mil, W_L/W_G = 1; and Pad 40/20 - W_G = 20 mil, W_L = 20 mil, pitch = 40 mil, W_L/W_G = 1. For comparison, a similar polyurethane polishing pad having concentric annular grooves separated by concentric annular landing surfaces, but having W_L of 70 mil and W_G of 10 mil (pitch of 80 mil), with W_L/W_G of 7 (Pad 80/10) was tested.

[0035] FIG. 6 provides a graph of pad wear rate in mil/hour for each of the pads examined. As the data in FIG. 6 shows, the pad wear rate increases for a given groove width (e.g., 20 mil) as W_L/W_G decreases from 2 to 1 (Pads 60/20 and 40/20, respectively). In addition, the wear rate also increases for a given pitch (e.g., 60 mil) as the groove width increases from 20 to 30 mil (Pads 60/20 and 60/30, respectively).

[0036] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIMS

1. A polishing pad suitable for use in chemical-mechanical polishing of a substrate, the pad comprising a surface defining a plurality of grooves with landing surfaces separating the grooves, the landing surfaces together defining a substantially coplanar polishing surface, each groove having a depth of at least 10 mil and a width, W_G, with any two adjacent grooves being separated by a landing surface having a width, W_L, wherein the quotient W_L/W_G is less than or equal to 3.

2. The polishing pad of claim 1 wherein the plurality of grooves comprises concentric, substantially circular grooves.

3. The polishing pad of claim 1 wherein the grooves have a depth of not more than 50 mil.

4. The polishing pad of claim 1 wherein the depth of each groove is in the range of 10 to 50 mil.

5. The polishing pad of claim 1 wherein W_L for each landing surface is not more than 80 mil.

6. The polishing pad of claim 1 wherein W_L for each landing surface is in the range of 30 mil to 60 mil.

7. The polishing pad of claim 1 wherein W_G for each groove is in the range of 20 mil to 40 mil.

8. The polishing pad of claim 1 wherein each groove has substantially the same depth.

9. The polishing pad of claim 1 wherein each groove has substantially the same W_G.

10. The polishing pad of claim 1 wherein each landing surface has substantially the same W_L.

11. A polishing pad suitable for use in chemical-mechanical polishing of a substrate, the pad comprising a surface defining a spiral groove with a spiral landing surface separating the turns of the spiral groove, the spiral landing surface defining a substantially coplanar polishing surface, the groove having a depth of at least 10 mil and a width, W_G, and the landing surface having a width, W_L, wherein the quotient W_L/W_G is less than or equal to 3.

12. The polishing pad of claim 11 wherein the spiral groove has a depth of not more than 50 mil.

13. The polishing pad of claim 11 wherein the depth of the groove is in the range of 10 to 50 mil.

14. The polishing pad of claim 11 wherein W_L is not more than 80 mil.

15. The polishing pad of claim 11 wherein W_L is in the range of 30 mil to 60 mil.

16. The polishing pad of claim 11 wherein W_G is in the range of 20 mil to 40 mil.

17. The polishing pad of claim 11 wherein the quotient W_L/W_G is less than or equal to 2.

18. The polishing pad of claim 11 wherein the quotient W_L/W_G is less than or equal to 1.

19. The polishing pad of claim 1 wherein the quotient W_L/W_G is less than or equal to 2.

20. The polishing pad of claim 1 wherein the quotient W_L/W_G is less than or equal to 1.