Description

Retaining ring for chemical-mechanical polishing head, polishing apparatus, slurry cycle system, and method

The present invention relates to an apparatus and to a method for fabricating semiconductor wafers and, more particularly, to chemical-mechanical polishing (CMP).

Chemical-mechanical polishing (CMP) removes material from the top layer of a wafer in the production of ultra-high density integrated circuits (instead of "polishing", "planarization" is also used). Often, the top layer is an oxide film (e.g., silicon dioxide), but other materials can also be removed. In a typical CMP process, the top layer of the wafer is exposed to an abrasive medium under controlled chemical, pressure, velocity, and temperature conditions. Conventional abrasive media include slurry solutions and polishing pads.

The slurry solutions generally contain small, abrasive particles (e.g., silicon dioxide for oxide polishing) and chemically-reactive substances (e.g., potassium hydroxide for Oxide polishing).

The polishing pads are generally planar pads made from a relatively porous material such as blown polyurethane, and the polishing pads may also contain abrasive particles.

Thus, when the pad and/or the wafer moves with respect to each other, material is removed from the top layer mechanically by the abrasive particles in the pad and/or slurry, and chemically by the chemicals in the slurry.

In the competitive semiconductor industry, it is desirable to minimize the number of defective or impaired circuits on each wafer.

Therefore, CMP must consistently and accurately produce a uniform, planar surface of the top layer because it is, for example, important to accurately focus the image of circuit patterns in further fabrication steps. As the density of integrated circuits increases, it is often necessary to accurately focus the critical dimensions of the circuit pattern to better than a tolerance of approximately 0.01 micro meter (μm).

Focusing the circuit patterns to such small tolerances, however, is very difficult when the distance between the lithography equipment and the surface of the wafer varies because the top layer surface is not uniformly planar.

For the application of CMP and for prior art designs, the following references are useful: Unites States Patents 5,205,082 (Shendon et al.), 5,533,924 (Stroupe et al.), 5,571,044 (Bolandi et al.), 5,624,299 (Shendon), 5,635,083 (Breivogel et al.), 5,643,061 (Jackson et al.), 5,664,988 (Stroupe et al.), 5,664,990 (Adams et al.), 5,700,180 (Sandhu et al.), 5,707,492 (Stager et al.), 5,755,614 (Adams et al.), 5,762,539 (Nakashiba et al.), 5,762,544 (Zuniga et al.), 5,795,215 (Gutbrie), 5,803,799 (Volodarsky et al.), 5,857,899 (Volodarsky et al.), 5,868,896 (Robinson et al.), 5,879,226 (Robinson), 5,882,243 (Das et al.), 5,948,204 (Maveety et al.), 5,993,302 (Chen et al.), 6,004,193 (Nagahara et al.), 6,012,964 (Arai et al.); as well as European and PCT documents EP 0 548 846 B1 (Shendon et al.), EP 0 589 433 B1 (Hirose et al.), EP 0 599 299 B1 (Okumura et al.), EP 0 786 310 A1 (Volodarsky et al.) and WO 99/58297 (Perlov et al.).

It is therefore a primary objective of the present invention to improve the uniformity of the planarization process during chemical-mechanical polishing of ,e.g., semiconductor wafers.

The object is solved by a retaining ring for encircling a wafer in a chemical-mechanical polishing apparatus being cha-

racterized by a U-shaped cross-section, said ring having an outer wall and an inner wall that enclose a partially open chamber adapted to apply a pressurized fluid to a polishing pad of said apparatus.

In other words, the retaining ring (for carrier head that polishes wafer) comprises generally an annular body with substantially U-shaped cross-section, an inner surface, an outer surface and a groove between the surfaces to distribute the pressurized slurry along the wafer periphery, i.e. the wafer edge.

A chemical-mechanical polishing apparatus with polishing pad and polishing head, (to receive wafer and to hold wafer against pad) has retaining ring to engage with head and to surround wafer. Ring has an open chamber to distribute pressurized slurry to pad and to periphery of wafer.

A polishing head comprises a wafer supporting surface and a retaining ring engaged with the supporting surface to retain the wafer in place. The retaining ring is shaped such as to carry slurry and has an inner surface facing the wafer but spaced to the pad to distribute slurry into a clearance between the wafer and the inner surface.

A method for operating chemical polishing apparatus comprises the following steps: placing wafer on pad, thereby surrounding wafer by the retaining ring; and applying slurry through a chamber within retaining ring to pad and to space between inner diameter surface of ring and periphery of wafer.

Further advantages and aspects are evident from the dependent claims.

The invention will be better understood by reference to embodiments taken in conjunction with accompanying drawings, wherein

FIG. 1AB illustrates a simplified side view of a chemical-mechanical polishing (CMP) machine according to the present Invention, the machine having a platen, a polishing head with a retaining ring and a resilient member, as well as a polishing pad with slurry;

FIG. 2AB illustrates simplified top and side views of a wafer having a top layer to be polished;

FIG. 3 illustrates a simplified plot of top layer thickness versus coordinate X - after polishing;

FIG. 4 illustrates - during polishing - an unwanted edge effect by a simplified and partial Cross-sectional view of the wafer, the pad and a conventional retaining ring;

FIG. 5 illustrates - during polishing - an improvement by a simplified and partial Cross-sectional view of the wafer, the pad, the resilient member and a retaining ring according to the present invention;

FIG. 6 illustrates a simplified top view of the retaining ring according to the present Invention;

FIG. 7 illustrates a simplified block diagram of a slurry cycle system using the retaining ring according to the present Invention;

FIG. 8 illustrates a partial cross-sectional view of the retaining ring having a chamber with an alternative shape;

FIG. 9 illustrates a partial cross-sectional view of the retaining ring having a chamber with a further alternative shape; and

FIG. 10 illustrates a view from below of the retaining ring with an alternative lower surface.

Side views use Cartesian coordinate system XYZ. Unless specified otherwise, the X-axis goes right, the Y-axis goes into the page, and the Z-axis goes up (right-handrule). The terms "up" and "down" are convenient synonyms to indicate positive and negative direction senses along the Z-axis, respectively.

Where convenient, some views also use polar coordinate system QV with radius Q and angle V. For purposes of explanation, the origin of both systems is defined as the center of the wafer at the top layer. A system transformation can be accomplished using well-known relations (e.g., Pythagoras' theorem, sine or cosine functions).

The term "wafer" stands collectively for any planar work - piece having a top layer to be polished.

Preferably, the work-piece is a semiconductor wafer. However, it is recognized that the polishing technique according to the present invention can be applied to a work-piece not limited to a semiconductor wafer, such as to a compact disk, a liquid crystal display etc.

Subscript indices are "W" for "wafer" and "R" for "ring". A glossary of Symbols is provided at the end of the specification.

FIG. 1AB illustrates a simplified diagram of CMP machine 101 according to the present invention comprising platen 120 (or "turn table"), polishing head 100 (or "wafer carrier", right-going hatching) with retaining ring 200/300 (left-going hatching), as well as polishing pad 140 with slurry 144.

In the following, reference numerals 300, 301 ... etc. are used when referring to a retaining ring according to the pre-

sent invention. Details are explained in connection with FIGS. 5-7. According to the present invention, ring 300 has an U-shape profile (preferably, it is asymmetric). Ring 300 has outer and inner walls (cf. FIG. 5 for details) that enclose partially open chamber 350 adapted to apply pressurized fluid (preferably slurry) to pad 140.

Reference numerals 200, 201 etc. are used when referring to a conventional retaining ring (cf. FIG. 4). FIG. 1 illustrates ring 200 only by an auxiliary view on the left side of FIG. 1B that would replace the illustration of ring 300 in FIG. 1A.

Usually, drive assembly 191 rotates platen 120 as indicated by arrow 1, or reciprocates platen 120 back and forth as indicated by arrow 2.

Head 100 may be a weighted, free-floating carrier, or actuator assembly 192 may be attached to wafer carrier 100 to impart axial and rotational motion, as indicated by arrows 3 (Z-axis) and 4, respectively.

Wafer 150 is attached to resilient member 134 (e.g., a bakking film) positioned between wafer 150 and lower surface 132 of head 100. Means to hold wafer 150 at head 100, especially during changing wafers, for example, that temporarily apply vacuum to the wafer, are well known in the art and are therefore not shown for simplicity. Member 134 prevents that head 100 directly touches backside 152 of wafer 150.

By surrounding wafer 150, retaining ring 200/300 keeps wafer 150 below head 100. Ring 200/300 has an overall width B defined as the distance between inner annular surface 201/301 and outer annular surface 202/302. Ring 200 touches pad 140 by lower surface 205.

According to one aspect of the invention details below, ring 300 touches pad 140 by a lower surface 304 (cf. FIG. 5) that is, as compared to surface 205, (a) smaller and (b) located more distant from wafer 150.

In the operation of CMP machine 101, wafer 150 is positioned face-downward with top layer 154 against polishing pad 140. As wafer 150 moves, polishing pad 140 and slurry 144 remove material from layer 154.

Since the inner diameter in surface 201/301 of ring 200/300 is slightly larger (e.g., by 0.2...20 milli meters (mm) or even less) than the wafer diameter (e.g., 300 mm), gap 136 ("clearance" C) between ring 200/300 and wafer periphery 153 occurs. An unwanted edge effect related to gap 136 is further discussed below.

Ring 300 is pressed to pad 140 by an adjustable down-force; the pressure applied by ring 300 to pad 140 is thereby distributed substantially equally across. An estimation about the value of the down-force is given in connection with the explanation of FIG. 5. Persons of skill in the art can adjust the down-force without the need of further explanation herein.

FIG. 2AB illustrates, in relation to both coordinate systems, simplified top (2A) and side (2B) views of wafer 150. Wafer 150 is shown with periphery 153 in both views and top layer 154 (to be polished) and backside 152 in the side view only. Wafer 150 has a diameter D_W (e.g., 300 mm). T stands for the thickness of top layer 154; and G stands for the thickness of wafer 150 (between the surface of top layer 154 and backside 152). T is a function of Q and V. Measuring T (alongside Z-axis) is well known in the art. Variations of G are not relevant here.

FIG. 3 illustrates a simplified plot of top layer thickness T (in nano meters (nm)) versus coordinate X (in mm) obtained for a D_W = 300 mm wafer after polishing with conventional retaining ring 200 (cf. auxiliary view in FIG. 1). In the example of FIG. 3, angle V is zero; similar results can be obtained for other V and for averaging V over the whole circle. The sharp increase in layer thickness T towards the wafer periphery is unwanted.

FIG. 4 illustrates - during polishing - the unwanted edge effect ("edge exclusion") by a simplified and partial view of wafer 150 (periphery 153, layer 154), pad 140, and conventional retaining ring 200 (surfaces 201, 202). FIG. 4 is intended to be an example, the edge effect can express itself otherwise too. As illustrated, the edge effect causes ripples 149 on pad 140; in other words, the pad surface locally shifts by displacement S with respect to the XY plane. For example, as indicated in FIG. 4, within gap 136, pad 140 moves upwards (positive S); below wafer 150 at the wafer periphery zone (e.g., the outermost 5 to 10 mm), pad 140 moves downwards (negative S); and near the center zone, pad 140 uniformly presses to top layer 154 (zero S).

The edge effect can be caused, for example, (i) by forces (in the XY plane) resulting from the relative movement between head 100 and platen 120 (cf. FIG. 1) and (ii) by the different pressures that ring 200 and wafer 150 apply to pad 140 (Z direction).

With the non-uniform displacement S, the pressure between pad 140 and layer 154 is also non-uniform. Hence, the material abrasion becomes non-uniform too; material is better removed from the periphery zone than from center zone (cf. FIG. 3; or vice versa). The edge effect might make the wafer periphery zone unsuitable for integrated circuits.

Quantities of the edge effect (e.g., displacement S, pressure, abrasion rate, periphery zone, etc.) depend, for example, on the hardness of pad 140, the clearance C of gap 136, and the relative speed between wafer 150 and pad 140.

FIG. 5 illustrates - during polishing - an improvement by a simplified and partial cross-sectional view of wafer 150, pad 140, resilient member 134 and retaining ring 300 according to the present invention. The XZ plane is the section plane.

Similar as in the prior art, ring 300 has outer annular surface 302 and, arranged orthogonally thereto, lower surface 304. Surface 304 is ring-shaped and substantially flat. Surface 304 touches pad 140. In contrast to the prior art, ring 300 has inner annular surface 301 that, preferably, does not extend to pad 140. Lower surface 303 (substantially orthogonal to 301) is located above pad 140 at channel height H and does not touch pad 140. Channel 360 is formed between surface 303 and pad 140.

While lower surfaces 304 and 303 do not touch to each other, ring 300 has chamber 350 ("groove") for carrying a pressurized fluid. Preferably, this fluid is slurry 144, but fluid that is substantially not being abrasive can also be used.

Conveniently, FIG. 5 also illustrates slurry inlet 371 for supplying slurry into chamber 350. A slurry outlet (similar to inlet 371) is illustrated in FIG. 6. Pressurized slurry can be accomplished by a person of skill in the art. For example, the pressure in chamber 350 is regulated by a pump at supply line 371 (cf. FIG. 7) and by a valve. Providing inlet 371 and outlet 372 at surface 302 (substantially in parallel to pad 140) is also possible.

Viewing the cross-section, ring 300 appears as an asymmetric U-shaped profile having base 353, outer wall 352 and inner wall 351 (short wall). Walls 351 and 352 are partly limited

by surfaces 301 and 302, respectively. The shape of chamber 350 is not important; its illustration to be rectangular is provided only for convenience.

By having slurry 144 pressed within charmber 350, slurry 144 propagates through channel 360 into gap 136. Resilient member 134 prevents further propagation of slurry 144. Thereby, the pressure in chamber 350 is substantially equally distributed also to gap 136. Forces that would cause pad bending (cf. FIG. 4) are reduced. The pressure across the wafer is made more uniform by minimizing ripples (cf. FIG. 4) on polishing pad 140.

In other words, in comparison to the prior art (cf. ring 200), (i) the pad touching lower surface (cf. surface 205 in FIG. 1 vs. surface 304 in FIG. 5) is located more distant from the wafer; and (ii) gap 136 is pressurized with fluid (i.e. slurry). Thereby, head 100 using ring 300 according to the present invention alleviates the edge effect. Using ring 300 leads to better uniformity of material removal throughout radius coordinate Q because local pressure from wafer 150 to pad 140 becomes substantially independent from radius coordinate Q.

Preferably, ring 300 is made of plastic or ceramic. Convenient values for B are in the range between 10 and 15 mm. Height H is preferably, larger than wafer thickness G (cf. FIG. 2, from top layer to backside). Preferably, H and G are related by a H-to-G ratio in the range between 1.05 to 2.0. Other values can also be used.

As mentioned above, an estimation for the adjustable down-force F_R (ring 300 to pad 140) is given. F_R is one of other forces: up-force F applied by slurry 144 counteracts on F_R; down-force F_W applied through resilient member 134 acts from wafer 150 an pad 140. Considering the surface areas through that each force acts (e.g., surface 304, inside area of cham-

ber 350, wafer surface), pressures P_R, P and P_W, respectively, can be defined. The pressures are conveniently considered by absolute values (symbol ||). Preferably, the ring pressure P_R is larger than or equal to the sum of the slurry pressure P and the wafer pressure P_W, that is

$$|P_R| \geq |P| + |P_W|.$$

Further, it is convenient when wafer 150 is changed to suck back slurry 144 or to keep slurry 144 in chamber 350 by below atmospheric pressure.

FIG. 6 illustrates a simplified top view of retaining ring 300. Corresponding to sectional view of FIG. 5, ring 300 is illustrated with inner annular surface 301, outer annular surface 302, and chamber 350 (dashed, because hidden). As illustrated for a preferred embodiment, slurry inlet 371 and slurry outlet 372 arranged in a angle V = 180°. However, multiple inlets and multiple outlets can also be provided, conveniently, alternating in the order in/out/in/out, and spaced with V being the fraction of 360° over the total number of inlets/outlets.

Having used the terms "annular" and "ring" is convenient for explanation; however, it is not required that the geometry of ring 300 always has to keep equal distance to the center. As indicated by dashed lines 359, ring portions can optionally be sized and shaped to match with the particular orientation edge discontinuity shape of a wafer.

FIG. 7 illustrates a simplified block diagram of slurry cycle system 375 using retaining ring 300 according to the present invention. Slurry cycle system 375 comprises slurry pump 374 and slurry recycle unit 380 that are coupled to slurry inlet 371 and slurry outlet 372 (cf. FIG. 6) by pipe arrangement 377 as illustrated. A preferred slurry flow direction is in-

dicated by arrows. System 375 allows to reduce the consumption of slurry.

In other words, system 375 for cycling slurry from inlet 371 to outlet 372 has slurry distribution channel 350 that is part of retaining ring 300 of polishing head 100. Recycle unit 380 recycles the slurry by techniques well known in the art such as filtering, blending (e.g., with fresh slurry 378, rejuvenating chemicals, or water), monitoring (e.g., temperature, pH, conductivity), heating or cooling, etc.

Monitoring can optionally be extended to endpointing the polishing process, for example, by measuring ion concentration in the slurry.

Having the invention implemented as illustrated and described in connection with the exemplary embodiment of FIGS. 1-7 is convenient, but not necessary. The following presents alternative embodiments.

FIG. 8 illustrates a partial cross-sectional view of retaining ring 300 having chamber 350 with an alternative shape (half-circle).

FIG. 9 illustrates a partial cross-sectional view of retaining ring 300 having chamber 350 with a further alternative shape (full-circle).

FIG. 10 illustrates a view from below of retaining ring 300 with an alternative lower surface 30. For convenience, ring 300 is shown magnified in a circle segment. Surface 303 has a plurality of ring portions 307 that, preferably, touch pad 140 (i.e., H is around zero). Between the portions, a plurality of slurry delivery channels 308. As indicated by arrows, channels 308 carry slurry from chamber 350 to wafer periphery 153 (shown dashed). The number N of channels 308 is between

150 and 500, a preferred value is N = 200. The resulting intra-channel angle is calculated as 360°/N. Preferably, channels 308 are (a) arranged radially towards the center of ring 300, i.e. along the dashed lines towards the coordinate origin; or (b) as in FIG. 10 with angle A.

In other words, ring 300 of the embodiment of FIG. 5 has chamber 350 that applies slurry 144 (to pad 140) through channel 360 that is provided by a plurality ofring portions 307 for touching pad 140 and forming a plurality of slurry delivery channels 308.

Having described the invention in detail above, the invention is summarized as follows:

While the invention has been described in terms of particular structures, those of skill in the art will understand based on the description herein that it is not limited merely to such examples and that the full scope of the invention is properly determined by the claims.

List of symbols used in the text:

A	angle
B	width
C	clearance distance
D	diameter
F	force
H	height
G	wafer thickness
N	number of delivery channels
P	pressure
Q	polar radius coordinate
R	index for "ring"
S	pad displacement
T	layer thickness

	V	polar angle coordinate
	W	index for "wafer"
	X	Cartesian coordinate
	Y	Cartesian coordinate
5	Z	Cartesian coordinate
	mm	milli meter
	µm	micro meter
	nm	nano meter
	°	degree
10	||	absolute value

Claims:

1. A retaining ring (300) for encircling a wafer (150) in a chemical-mechanical polishing apparatus (101), said retaining ring (300) characterized by a U-shaped cross-section, said retaining ring (300) having an outer wall (352) and an inner wall (351), wherein said walls enclose a partially open chamber (350) adapted to apply pressurized fluid (144) to a polishing pad (140) of said apparatus (101).

2. The retaining ring (300) according to claim 1 wherein said U-shaped cross-section is asymmetric.

3. The retaining ring (300) according to claim 1 wherein said fluid is pressurized slurry (144).

4. The retaining ring (300) according to claim 3, wherein when said retaining ring (300) is used in said apparatus (101), said outer wall (352) touches said polishing pad and said inner wall (351) allows said pressurized slurry (144) to propagate.

5. The retaining ring (300) according to claim 3, wherein when said retaining ring (300) is used in said apparatus (101), said chamber (350) applies said slurry through a channel (360) that is limited between a lower surface (303) of said inner wall (351) and said polishing pad (140).

6. The retaining ring (300) according to claim 5, wherein the wafer (150) has a thickness, wherein said channel (360) has a height defined as a distance between said lower surface (303) of said inner wall (351) and said polishing pad (140), and wherein said height is smaller than the thickness of said wafer (150).

7. The retaining ring (300) according to claim 3, wherein when said retaining ring (300) is used in said apparatus

(101), said chamber (350) applies said slurry (144) through a channel (360) that is provided by a plurality of ring portions (307) touching said polishing pad (140) and forming a plurality of slurry delivery channels (308).

8. The retaining ring (300) according to claim 1, wherein said retaining ring (300) comprises a generally annular body having said U-shaped cross-section, an inner surface (301), an outer surface (302) and a groove (350) between said surfaces to distribute pressurized slurry (144) along the periphery (153) of the wafer (150).

9. A chemical-mechanical polishing apparatus (101), comprising:

- a polishing pad (140);
- a polishing head (100) to receive a wafer (150) and to hold the wafer (150) against the polishing pad (140); and
- the retaining ring (300) according to claim 1 to engage with said head (100) and to surround the wafer (150), said retaining ring (300) having said open chamber (350) to distribute the pressurized fluid (144) to said pad (140) and to a periphery (153) of said wafer (150).

10. The apparatus (101) according to claim 9, wherein said ring (300) has an outer wall (302) substantially touching said pad (140) and an inner wall (301) being substantially spaced from said pad (140).

11. The apparatus (101) according to claim 10, wherein said wafer has an overall thickness, and wherein said inner wall is spaced from said pad by a channel having a height smaller than the overall thickness of said wafer.

12. The apparatus (101) according to claim 10, further comprising a slurry recycle unit (380) to cycle slurry (144)

from an outlet (372) of said ring (300) to an inlet (371) of said ring (300).

13. The apparatus (101) acoording to claim 12 that endpoints the polishing process by monitoring said slurry (144).

14. A polishing head (100) for polishing a semiconductor wafer (150) by moving said wafer (150) across a pad (140), said polishing head (100) comprising:

- a surface (132) supporting said wafer (150); and
- the retaining ring (300) according to claim 1 being engaged with the supporting surface (132) to retain the wafer (150) in place, said retaining ring (300) being shaped to carry said pressurized fluid (144) and having an inner surface (301) facing the wafer but being spaced to said pad (140) to distribute said pressurized fluid (144) into a clearance gap (136) between said wafer (150) and said inner surface (301).

15. A slurry cycle system (375) for a chemical-mechanical polishing machine (101) having a polishing head (100), said system (375) for cycling slurry (144) from an inlet (371) to an outlet (372), said system (375) characterized in that said inlet (371) and said outlet (372) are connected to a slurry distribution channel (360) that is part of the retaining ring (300) according to claim 1 of said polishing head (100).

16. A method for operating the chemical polishing apparatus (101) according to claim 9, said method comprising the following steps:

- placing the wafer (150) having a periphery (153) on a pad (140), thereby surrounding said wafer (150) by said retaining ring (300) having an inner surface (301), the periphery (153) of said wafer (150) and the inner diameter surface (301) of said ring (300) defining a space (136) therebetween; and

- applying slurry (144) through a chamber (350) within said retaining ring (300) to said pad (140) and to the space (136) between the inner diameter surface (301) of said ring (300) and the periphery (153) of said wafer (150).