ORBITAL POLISHING APPARATUS

Technical Field

The present invention relates generally to semiconductor manufacturing, and more specifically to the field of chemical-mechanical polishing methods and apparatus for the planarization and removal of thin films used in semiconductor manufacturing.

Background of the Invention

A flat disk or "wafer" of single crystal silicon is the basic substrate material in the semiconductor industry for the manufacture of integrated circuits. Semiconductor wafers are typically created by growing an elongated cylinder or boule of single crystal silicon and then slicing individual wafers from the cylinder. The slicing causes both faces of the wafer to be extremely rough. The front face of the wafer on which integrated circuitry is to be constructed must be extremely flat in order to facilitate reliable semiconductor junctions with subsequent layers of material applied to the wafer. Also, the material layers (deposited thin film layers usually made of metals for conductors or oxides for insulators) applied to the wafer while building interconnects for the integrated circuitry must also be made a uniform thickness.

Integrated circuits manufactured today are made up of literally millions of active devices such as transistors and capacitors formed in a semiconductor substrate. Integrated circuits rely upon an elaborate system of metalization in order to connect the active devices into functional circuits. A typical multilevel interconnect 100 is shown in Fig. 1. Active devices such as MOS transistors 107 are formed in and on a silicon substrate or well 102. An interlayer dielectric (ILD) 104, such as SiO_2, is formed over silicon substrate 102. ILD 104 is used to electrically isolate a first level of metalization which is typically aluminum from the active devices formed in substrate 102. Metalized contacts 106 electrically couple active devices formed in substrate 102 to interconnections 108 of the first level of metalization. In a similar manner metal vias 112 electrically couple interconnections 114 of a second level of metalization to interconnections 108 of the first level of metalization. Contacts and vias 106 and 112 typically comprise a metal 116 such as tungsten (W) surrounded by a barrier metal 118 such as titanium-nitride (TiN). Additional ILD/contact and metalization layers can be stacked one upon the other to achieve the desired interconnections.

Planarization is the process of removing projections and other imperfections to create a flat planar surface, both locally and globally, and/or the removal of material to create a uniform

thickness for a deposited thin film layer on a wafer. Semiconductor wafers are planarized or polished to achieve a smooth, flat finish before performing process steps that create integrated circuitry or interconnects on the wafer. A considerable amount of effort in the manufacturing of modern complex, high density multilevel interconnects is devoted to the planarization of the individual layers of the interconnect structure. Nonplanar surfaces create poor optical resolution of subsequent photolithographic processing steps. Poor optical resolution prohibits the printing of high density lines. Another problem with nonplanar surface topography is the step coverage of subsequent metalization layers. If a step height is too large there is a serious danger that open circuits will be created. Planar interconnect surface layers are required in the fabrication of modern high density integrated circuits. To this end, CMP tools have been developed to provide controlled planarization of both structured and unstructured wafers.

In a conventional CMP tool for planarizing a wafer, a wafer is secured in a carrier connected to a shaft. The shaft is typically connected to mechanical means for transporting the wafer between a load or unload station and a position adjacent a polishing pad mounted on a platen. A pressure is exerted on the back surface of the wafer via the carrier in order to press the wafer against the polishing pad, usually in the presence of slurry. The wafer and/or polishing pad are then moved in relation to each other via motor(s) connected to the shaft and/or platen in order to remove material in a planar manner from the front surface of the wafer.

The motion of the carrier and polishing pad in relation to each other is an important factor in the planarization process. The search for improved motions for the carrier and the polishing pad continues as new requirements and materials are used in the manufacturing process of semiconductors. One of the goals of the planarization process is to remove material at a uniform rate across the front surface of the wafer. One method for trying to remove material at a uniform rate is to have every point on the front surface of the wafer experience the same relative motion against the polishing pad as every other point. An orbital tool, which orbits the polishing pad around an axis offset from the center of the polishing pad while continually maintaining the rotational orientation of the polishing pad throughout the orbit, is one possible way to achieve this goal. Orbital tools are desirable since they allow every point on the front surface of the wafer to experience the same circular motion against the polishing pad as every other point.

Conventional orbital tools use a polishing pad that is supported by a diaphragm. Front-reference carriers are known in the art for supporting a wafer with a fluid or flexible diaphragm/membrane. Front-reference carriers are able to uniformly press on the back surface

of a wafer regardless of the back surface's contour. Applicant has discovered that when a front-reference carrier is used with a conventional orbital tool, i.e. one with a polishing pad supported by a diaphragm, the resulting planarization process lacks stability. The reasons for the lack of stability are not entirely understood, but Applicant believes they may be caused by the lack of a fixed reference plane.

Another problem with conventional orbital tools is that they tend to leave a band on the periphery of the front surface of the wafer where material is removed at an accelerated rate. Applicant noticed that the width of the band is typically the same as the diameter of the orbit of the polishing platen. Applicant believes the band may be due to the loading of the center of the polishing pad with residue from the planarization process while the periphery of the polishing pad is slightly conditioned by the retaining ring. This results in the center of the wafer polishing slower against the loaded polishing pad while the periphery of the wafer polishes faster against the conditioned periphery of the polishing pad.

What is needed is a system for planarizing the front surface of a wafer to a very fine degree that provides a stable process while minimizing the band of nonuniform material removal at the periphery of the wafer.

Summary of the Invention

The present invention is an apparatus and method for planarizing a front surface of a wafer. The present invention includes a rigid platen, i.e. does not use a membrane or diaphragm as in the prior art, for supporting a polishing pad. The platen is connected to a supporting base that has means, or is connected to means, for orbiting the platen. A carrier, preferably a front-reference carrier, holds and presses the wafer against the polishing pad while the supporting base orbits the platen.

Optionally, the carrier may be connected to a motor via a shaft for rotating or otherwise moving the wafer during the planarization process. Additional flexibility for the planarization process may be obtained by using a carrier that is able to apply a plurality of different pressure zones to the back surface of the wafer. The planarization process may be optimized for various wafers and thin films deposited on the wafer by adjusting the orbital radius and/or orbital speed. Applicant has discovered that improved planarization results may be obtained by orbiting the polishing pad in a radius smaller than conventional orbital radii, orbiting the polishing pad at a rate faster than conventional orbital rates and, preferably, both in combination.

The present invention may be practiced by loading a wafer in a carrier, preferably a

front-reference carrier, and positioning the wafer adjacent a polishing pad mounted to a substantially rigid platen. The wafer is planarized by pressing the wafer against the polishing pad as the polishing pad is orbited, preferably with a radius smaller than a four mm and at a speed faster than 400 orbits per minute. Optionally, the carrier may be rotated to smooth out patterns that tend to form on the front surface of the wafer. As a further option, the carrier may be alternately rotated clockwise and counterclockwise, preferably with each rotation less than 360 degrees, to simplify the communication of fluids to the carrier.

If a front-reference carrier with a plurality of individually controllable pressure zones is used, further improvements to the planarization process may be obtained. Higher or lower pressures may be applied adjacent the back surface of the wafer corresponding to areas on the front surface of the wafer with greater or lesser amounts of material to remove. The wafer planarization process may be terminated by removing the wafer from the polishing pad or stopping relative motion between the wafer and the polishing pad.

Brief Description of the Drawings

The present invention will hereinafter be described in conjunction with the appended drawing figures, wherein like numerals denote like elements, and:

Figure 1 is a cross sectional illustration of a standard multilayer interconnect structure used in semiconductor integrated circuits;

Figure 2 is a cross section view of a front-reference carrier holding a wafer against a polishing pad mounted on a solid platen;

Figure 3 is a plan view of a wafer adjacent an orbiting polishing pad;

Figure 4a is a plan view of a stationary wafer with an orbiting polishing pad shown at four different times during the orbit of the polishing pad;

Figure 4b is a view of the front face of the wafer illustrating the motion experienced by every point on the front face of the wafer due solely to an orbital motion;

Figure 5 is a cross section view of one possible mechanism for producing an orbital motion for a polishing pad; and

Figure 6 is a flow chart illustrating one possible method of practicing the present invention.

Detailed Description of Exemplary Embodiments

An improved polishing apparatus and method utilized in the polishing of semiconductor

substrates and thin films formed thereon will now be described. In the following description, numerous specific details are set forth illustrating Applicants' best mode for practicing the present invention and enabling one of ordinary skill in the art to make and use the present invention. It will be obvious, however, to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known machines and process steps have not been described in particular detail in order to avoid unnecessarily obscuring the present invention.

Referring to Fig. 2, an apparatus for practicing the present invention will now be discussed. A front-reference carrier 215 may be used to hold and press the wafer 216 against the polishing pad 207 during a planarization process. Front-reference carriers provide a substantially uniform pressure on the back surface of the wafer 216 despite protrusions on the back surface of the wafer 216. Thus, problems associated with protrusions for back-reference carriers are avoided, i.e. creating localized high pressure spots on the front surface of the wafer opposite the protrusions. Front-reference carriers typically use a pressurized fluid, e.g. filtered air, deionized water, etc., and/or a flexible membrane/diaphragm 203 to press uniformly against the back surface of the wafer 216. A few examples of front-reference carriers that may be used to practice the present invention are disclosed in U.S. Patent No. 5,423,716 Strasbaugh, U.S. Patent No. 5,449,316 Strasbaugh, U.S. Patent No. 5,635,083 Breivogel et al., U.S. Patent No. 5,851,140 Barns et al., U.S. Patent No. 6,012,964 Arai et al. and U.S. Patent No. 6,024,630 Shendon et al. and are hereby incorporated by reference.

The carrier 215 may have a plurality of areas 204, 228 or zones, typically concentric to each other, that may be individually pressurized to create a plurality of uniform pressure areas. In other words, while each area may have a pressure different from every other area, the pressure is substantially uniform within each area. These multizone carriers 215 may be advantageously used for removing excess material faster from the front face of the wafers 216 at concentric areas having bulges. Specifically, the multizone carrier 215 may exert a higher uniform pressure against the back surface of the wafer 216 opposite a bulge. At the same time, other areas on the back surface of the wafer, for example areas between bulges, may have a lower uniform pressure applied to them. Examples of multizone front-reference carriers that may be used to practice the present invention are disclosed in U.S. Patent No. 5,941,758 Mack, U.S. Patent Application No. 09/540,476 and U.S. Patent Application No. 08/504,686 and are all hereby incorporated by reference.

Fig. 2 illustrates one possible embodiment of a front-reference carrier 215 having two

individually controllable uniform pressure areas 204, 228 with equipment for practicing the present invention. A pressure source 227 may be used to feed two pressure regulators 223, 224 via a manifold 229. The pressure regulators 223, 224 are preferably computer controlled and may be connected to a control system 230. The pressure regulators 223, 224 may communicate pressurized fluids to corresponding rotary couplers (not shown) in the carrier shaft 201. The rotary couplers may then communicate the pressurized fluids through tubes or channels 225, 226 in the shaft 201 to corresponding tubes or channels in the carrier 215. The tubes or channels in the carrier 215 may then direct the pressurized fluid to plenums 204, 228 in the carrier 215 for controlling the pressure exerted on a corresponding area on the back surface of the wafer 216. The plenums 204, 228 may be separated by one or more ring shaped barriers 205 so that each plenum may have a separate internal pressure. Thus, the control system 230 is able to individually control the pressure exerted by two areas 204, 228 on the back surface of the wafer 216 with this particular embodiment of the present invention. It is to be appreciated that a variety of other carriers may be employed to facilitate a desired application of pressure on the back surface of the wafer. While a particular front-reference carrier 215 has been described in detail and the invention is preferably practiced with a front-reference carrier, the invention may be practiced using a variety of front and back-reference carriers.

The carrier 215 may be held stationary or moved in a variety of motion, e.g. moved linearly, orbited, vibrated or rotated on the polishing pad. For example, the carrier 215 may be rotated by motor 222 via shaft 201. If the carrier 215 is rotated, it is preferably rotated at about 10-20 rpm. Rotating the carrier 215 has been shown to smooth-out or eliminate patterns that tend to develop on the front face of the wafer due to the periodic nature of the orbital motion of the polishing pad 207. As an alternative, the carrier 215 may be alternately rotated clock-wise and counterclock-wise. This is particularly beneficial if a front-reference carrier with multiple chambers is being used. Every chamber requires additional fluid communication paths to operate. If the carrier 215 rotates only in one direction, complicated fluid communication means, such as rotary couples, will be needed. However, if the carrier 215 alternately rotates clock-wise and counterclock-wise, preferably less than 360 degrees, then less complicated fluid communication means, such as conventional tubing, may be used.

During the planarization process, the front face of the wafer 216 is pressed against a polishing pad 207 fixed to a rigid platen 221, typically in the presence of a slurry. The polishing pad 207 may be, for example, an IC1000 or an IC1000 supported by a Suba IV polishing pad, both manufactured and made commercially available by Rodel Inc.

headquartered in Phoenix, Arizona. The particular polishing pad 207 used may be varied depending on the characteristics of the wafer 216, but typically comprises a urethane based material. As shown in Fig. 3, the polishing pad 207 may have holes 322 for delivering slurry to the surface of the polishing pad 207. Slurries are generally silica-based solutions that have different additives depending upon the type of material being polished. In addition, the polishing pad 207 may have grooves (not shown) for assisting in the distribution of slurry over the face of the polishing pad 207.

Referring back to Fig. 2, the platen 221 may be made from a rigid material with a substantially planar surface for mounting a polishing pad 207 thereto. The platen 221 for the present invention should be stiffer than conventional platens in prior art orbital tools that use pressurized diaphragms or membranes to support the polishing pad. For example, the platen 221 may comprise aluminum, stainless steel, ceramic, titanium, polymer or other such materials that are rigid and preferably noncorrosive.

During the planarization process, the platen 221 may be orbited by a supporting base 220. Referring to Fig. 4a, the orbital motion of the polishing pad will be further described. The polishing pad moves through positions 207a, 207b, 207c and 207d at time 1, time 2, time 3 and time 4 respectively resulting in the "X" on the polishing pad traveling in a circle 400a. It should be observed that the polishing pad does not rotate when orbited. The radius of the orbit is the same as the radius of the circle 400a or any other circle generated by an orbited point on the polishing pad. The size of the orbital motion shown by circle 400a is larger than typically desired to aid in the description of the orbital motion.

Referring to Fig. 4b, a wafer 216 is shown with multiple circular motions 400b. The circular motions 400b represent the motion each point on the front surface of the wafer 216 experiences during an orbit. The radius of the orbit creating the circular motion 400b is much smaller than the radius of the orbit creating the circular motion 400a. The radius of the orbit may be controlled by the mechanisms used to create the orbital motion, several examples of which will now be discussed.

U.S. Patent No. 5,582,534 Shendon et al. and U.S. Patent No. 5,938,884 Hoshizaki et al. disclose several mechanisms for creating an orbital motion for a carrier. The principles for the mechanisms disclosed for creating an orbital motion may be applied by one of ordinary skill in the art to create a supporting base 220 capable of orbiting the platen 221 and are hereby incorporated by reference.

Fig. 5 is a cross-sectional view of an exemplary supporting base 220 that may be used to

generate an orbital motion for the platen 211. The supporting base is generally disclosed in U.S. Patent No. 5,554,064 Breivogel et al. and is hereby incorporated by reference. Supporting base 220 may have a rigid frame 502 that can be securely fixed to the ground. Stationary frame 502 is used to support and balance motion generator 500. The outside ring 504 of a lower bearing 506 is rigidly fixed by clamps to stationary frame 502. Stationary frame 502 prevents outside ring 504 of lower bearing 506 from rotating. Wave generator 508 formed of a circular, hollow rigid stainless steel body is clamped to the inside ring 510 of lower bearing 506. Wave generator 508 is also clamped to outside ring 512 of an upper bearing 514. Wave generator 508 positions upper bearing 514 parallel to lower bearing 506. Wave generator 508 offsets the center axis 515 of upper bearing 514 from the center axis 517 of lower bearing 506. A circular aluminum platen 211 is symmetrically positioned and securely fastened to the inner ring 519 of upper bearing 514. A polishing pad or pad assembly can be securely fastened to ridge 525 formed around the outside edge of the upper surface of platen 211. A universal joint 518 having two pivot points 520a and 520b is securely fastened to stationary frame 502 and to the bottom surface of platen 211. The lower portion of wave generator 508 is rigidly connected to a hollow and cylindrical drive spool 522 that in turn is connected to a hollow and cylindrical drive pulley 523. Drive pulley 523 is coupled by a belt 524 to a motor 526. Motor 526 may be a variable speed, three phase, two horsepower AC motor.

The orbital motion of platen 211 is generated by spinning wave generator 508. Wave generator 508 is rotated by variable speed motor 526. As wave generator 508 rotates, the center axis 515 of upper bearing 514 orbits about the center axis 517 of lower bearing 506. The radius of the orbit of the upper bearing 517 is equal to the offset (R) 526 between the center axis 515 of upper bearing 514 and the center axis 517 of the lower bearing 506. Upper bearing 514 orbits about the center axis 517 of lower bearing 506 at a rate equal to the rotation of wave generator 508. It is to be noted that the outer ring 512 of upper bearing 514 not only orbits but also rotates (spins) as wave generator 508 rotates. The function of universal joint 518 is to prevent torque from rotating or spinning platen 211. The dual pivot points 520a and 520b of universal joint 518 allow the platen 211 to move in all directions except a rotational direction. By connecting platen 211 to the inner ring 519 of upper bearing 514 and by connecting universal joint 518 to platen 211 and stationary frame 502 the rotational movement of inner ring 519 and platen 211 is prevented and platen 211 only orbits as desired. The orbit rate of platen 211 is equal to the rotation rate of wave generator 508 and the orbit radius of platen 211 is equal to the offset of the center 515 of upper bearing 514 from the center 517 of lower bearing

506. It is to be appreciated that a variety of other well-known means may be employed to facilitate the orbital motion of the polishing pad. While a particular method for producing an orbital motion has been given in detail, the present invention may be practiced using a variety of techniques for orbiting the polishing pad on the platen 211.

With reference to Figs. 2 and Fig. 6, an exemplary method of operation for the present invention will now be disclosed. The first step is to load a wafer 216 into a carrier 215 (step 600). While a back-reference carrier 215 may be used, exceptional results have been obtained using a front-reference carrier 215 with the invention. If the wafer 216 has one or more concentric bulges of excess material on its front surface, a front-reference carrier 215 with a plurality of individually controllable pressure areas may be advantageously used. The individually controllable pressure areas may apply a higher pressure on the back surface of the wafer adjacent bulges as compared to the pressure applied adjacent troughs or low points on the wafer. The number and placement of bulges may be determined, for example, by taking in situ measurements or by knowing the typical wafer contour created by the previous processing step.

The wafer 216 may then be positioned adjacent a polishing pad 207 fixed to a rigid platen 221 (step 601). Mechanical means for moving the wafer 216 adjacent the polishing pad 207 are well known in the art and will not be discussed to avoid unnecessarily obscuring the invention. The pressure applied to the back surface of the wafer 216 urges the wafer against the polishing pad 207 (step 604). The optimum pressure or pressures applied to the back surface of the wafer 216 will vary depending on the characteristics of the wafer 216, polishing pad 207, slurry, desired removal rate and other factors. However, pressures between about three (3) and about seven (7) psi have yielded excellent results. However, the present invention may easily be used with lower or higher pressures.

At about the same time as the wafer 216 is being pressed against the polishing pad 207 (step 604), the polishing pad 207 may start to orbit (step 602) and the carrier may start to rotate (step 603). The polishing pad 207 is preferably orbited faster than 400 orbits per minute and the Applicant has obtained excellent planarization results at about 600 orbits per minute with a 16 mm orbit radius. In addition, the orbital radius of the polishing pad may be less than six mm and Applicant has obtained excellent planarization results with an orbital radius of about 1.5 mm with an orbital frequency of about 6400 orbits per minute. A smaller orbit radius will generally require a higher orbital frequency to maintain a given removal rate of material from the front surface of the wafer. The carrier may be rotated slower than 30 rpm and is preferably rotated between about 10 and about 20 rpm. The fluid communication paths 225, 226 may be

simplified if the carrier 215 is alternately rotated clockwise and counterclockwise less than 360 degrees.

The wafer 216 may be removed from the polishing pad 207 thereby terminating the planarization process based on input from an end-point detection system or based on an empirically found time required by the particular planarization process.

While the invention has been described with regard to specific embodiments, those skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and scope of the invention.

We claim:

1. An apparatus for planarizing a wafer comprising:

a rigid platen;

a supporting base coupled to the platen and configured to move the platen in an orbital motion during a polishing operation;

a polishing pad affixed to the platen; and

a front-reference carrier comprising:

a rotationally mounted carrier having an upper and a lower surface;

a flexible membrane comprising a first surface for pressing the wafer against the polishing pad while the platen moves in an orbital motion and a second surface facing the lower surface of the carrier and defining a pressurizable plenum between the carrier and the second surface.

2. The apparatus of claim 1 wherein the supporting base is configured to move the platen in orbital motion having an orbital radius of less than about 4 mm.

3. The apparatus of claim 1 wherein the supporting base is configured to move the platen in orbital motion at an orbital rate of greater than about 400 orbits per minute.

4. The apparatus of claim 1 wherein the polishing pad comprises a single layer.

5. The apparatus of claim 1 wherein the polishing pad comprises two or more layers.

6. The apparatus of claim 1 wherein the polishing pad comprises a urethane based material.

7. A method of planarizing a wafer comprising the steps of:

loading a wafer into a carrier, the carrier comprising a flexible membrane on a lower surface thereof, the flexible membrane defining at least one plenum;

positioning the wafer adjacent a polishing pad mounted to a solid platen;

pumping fluid into the at least one plenum to press the wafer against the polishing pad;

orbiting the polishing pad while pumping the fluid into the at least one plenum;

alternately rotating the carrier in a clock-wise direction and a counterclockwise direction; and

removing the wafer from the carrier.

8. The method of claim 7 wherein the step of pumping comprises the step of:

pumping a fluid into a plurality of plenums to create different pressures in each of the plurality of plenums.

9. The method of claim 7 wherein the step of orbiting the polishing pad comprises the step of orbiting the polishing pad at an orbital speed of greater than about 400 orbits per minute.

10. The method of claim 7 wherein the step of orbiting the polishing pad comprises the step of orbiting the polishing pad in an orbit having a radius smaller than about 4 mm.

11. The method of claim 7 wherein the polishing pad is orbited faster than about 400 orbits per minute in an orbital radius smaller than about 4 mm.

12. The method of claim 7 wherein the carrier is a front-reference carrier.