

A WORKPIECE CARRIER WITH ADJUSTABLE PRESSURE ZONES AND BARRIERS

Technical Field

5 The present invention relates generally to the art of planarizing a workpiece against an abrasive surface. For example, the present invention may be used to planarizing a wafer, or thin films deposited thereon, in an improved wafer carrier with adjustable pressure zones and adjustable pressure barriers against a polishing pad in a chemical-mechanical planarization (CMP) tool.

Background of the Invention

10 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
15 extremely rough. In addition, applicant has noticed other semiconductor wafer processing steps, e.g. shallow trench isolation (STI) and copper deposition, produce predictable concentric bulges of excess material on the wafer. For example, applicant has noticed that conventional STI processes usually produce a wide peripheral ring shaped bulge and a small central disk shaped bulge with a narrow trough between bulges. Applicant has also noticed that
20 conventional copper deposition processes usually produce a narrow peripheral ring shaped bulge and a small central disk shaped bulge with a wide trough between bulges.

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
25 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. 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
30 achieve a smooth, flat finish before performing process steps that create integrated circuitry or interconnects on the wafer. To this end, machines have been developed to provide controlled planarization of both structured and unstructured wafers.

A conventional method of planarizing a wafer will now be discussed. The wafer is secured in a carrier that is connected to a shaft in a CMP tool. The shaft transports the carrier,

and thus the wafer, to and from a load or unload station and a position adjacent a polishing pad mounted to a platen. A pressure is exerted on the back surface of the wafer by the carrier in order to press the wafer against the polishing pad, usually in the presence of slurry. The wafer and/or polishing pad may be rotated, orbited, linearly oscillated or moved in a variety of geometric or random patterns via motors connected to the shaft and/or platen.

Numerous carrier designs are known in the art for holding and distributing a pressure on the back surface of the wafer during the planarization process. Conventional carriers commonly have a hard flat pressure plate that is used to press against the back surface of the wafer that does not conform to the back surface of the wafer. As a consequence, the pressure plate is not capable of applying a uniform polish pressure across the entire area of the wafer, especially at the edge of the wafer. In an attempt to overcome this problem, the pressure plate is often covered by a soft carrier film. The purpose of the film is to transmit uniform pressure to the back surface of the wafer to aid in uniform polishing. In addition to compensating for surface irregularities between the carrier plate and the back surface of the wafer, the film deforms around and smoothes over minor contamination on the wafer surface. Such contamination could produce high pressure points in the absence of such a carrier film. Unfortunately, the films are only partially effective with limited flexibility and no capability for globally adjusting once they have been applied to the pressure plate.

A common problem for conventional carriers having a hard flat plate is that they cannot compensate for incoming wafers that have one or more bulges. The hard flat plate is limited by the fact that it cannot adjust the pressure applied to different zones on the back surface of the wafer. It is common for some wafer processing steps to leave bulges on the wafer. Conventional carriers typically remove approximately the same amount of material across the entire front face of the wafer, thereby leaving the bulges on the wafer. Only sufficiently smooth, flat portions of the wafer surface may be effectively used for circuit deposition. Thus, the depressions limit the useful area of the semiconductor wafer.

Other conventional carriers implement means for applying more than one pressure region across the back surface of the wafer. Specifically, some conventional carriers provide a carrier housing with a plurality of concentric internal chambers that may be independently pressurized separated by barriers. By pressurizing the individual chambers in the top plate to different magnitudes, a different pressure distribution can be established across the back surface of the wafer.

However, Applicants have discovered that the pressure distribution across the back surface of the wafer for conventional carriers is not sufficiently controllable. This is due to the

lack of control of the pressure caused by the barriers on the back surface of the wafer. The barriers are important in controlling the pressure on the back surface of the wafer between internal chambers. Therefore, the ability to control the applied pressure across the entire back surface of the wafer is limited, thereby restricting the ability to compensate for anticipated removal problems.

What is needed is a system for controlling the application of multiple pressure zones and the pressure from the barriers between zones across the entire back surface of a wafer during planarization.

Summary of the Invention

Thus, it is an object of the present invention to provide an apparatus and method for controlling the pressure distribution on the back surface of a wafer through independently controllable concentric zones and barriers while planarizing the wafer.

In one embodiment of the present invention, a carrier is disclosed for planarizing a surface of a wafer. The carrier includes a central disk shaped plenum, a plurality of concentric ring shaped plenums surrounding the central plenum and a plurality of concentric barriers between neighboring plenums. The pressure distribution on the back surface of the wafer may thus be controlled by adjusting the pressure in the plenums and the pressure exerted on the barriers.

In another embodiment, a carrier is disclosed that includes a carrier housing that advantageously comprises a rigid non-corrosive material. The carrier housing is preferably cylindrically shaped with a first major surface being used to couple the carrier to a CMP tool and a second major surface with a plurality of concentric ring-shaped plenums.

An elastic web diaphragm is placed over the second major surface thereby covering the carrier plenums. A plurality of elastic ring shaped ribs extends orthogonally from the web diaphragm opposite the ring shaped carrier plenums. The web diaphragm and ribs may be made from a single mold, but are preferably separate pieces. The plurality of ring shaped ribs extending from the web diaphragm thereby defines a central disk shaped web plenum surrounded by one or more concentric ring shaped web plenums. The web diaphragm and ribs may be held in place by clamping rings that are tightened against the carrier housing thereby trapping the web diaphragm and ribs placed between the clamping rings and carrier housing.

The carrier plenums may be pressurized by corresponding carrier fluid communication paths in fluid communication with each of the carrier plenums. The carrier plenums are used to control an urging force on the ribs to assist the ribs in sealing against the wafer or to assist in

the distribution of force on the back surface of the wafer between neighboring web plenums.

The web plenums may be pressurized by corresponding web fluid communication paths in fluid communication with the central web plenum and each of the plurality of ring shaped web plenums. The web plenums are used to control an urging force on concentric zones to assist in controlling the distribution of pressure on the back surface of the wafer. The wafer may then be supported by the ribs and the central and ring shaped web plenums during the planarization process.

The ribs are supported by the web diaphragm on one end while the other end (rib foot) supports the wafer. The rib foot may be flat, round or have other shapes that improve the pivoting of the foot on the wafer or the sealing of the foot against the wafer. A vacuum path may be routed through the rib to further assist in sealing the rib to the wafer. While using ribs as the barrier between neighboring web plenums is the preferred method, other barriers such as o-rings, bellows or shields may be used to prevent fluid exchange between neighboring web plenums.

The carrier preferably has a floating retaining ring connected to the carrier housing. The retaining ring surrounds the wafer during the planarization process to prevent the wafer from escaping laterally beneath the carrier when relative motion is generated between the wafer and the abrasive surface. The floating retaining ring may be attached to the carrier housing with a retaining ring diaphragm held taut over a ring shaped recess in the periphery of the carrier housing. A retaining ring plenum is thus created between the ring shaped recess in the carrier housing and the retaining ring diaphragm. A retaining ring fluid communication path may be placed in either the carrier housing and/or retaining ring to communicate a desired pressure onto the retaining ring. The retaining ring preloads and shapes a portion of the polishing pad prior to the wafer moving over that portion of the polishing pad. The pressure on the retaining ring may thus be used to enhance, particularly near the wafer's edge, the planarization process for the wafer.

In another embodiment, a disk shaped wafer diaphragm is placed adjacent the feet of the ribs, thereby enclosing the web plenums. The wafer diaphragm is placed over, and is supported partially by, the ribs. To prevent leakage between the web plenums, the rib feet may be bonded to the wafer diaphragm or they may be made from a single mold. Alternatively, the rib feet may be sealed to the wafer diaphragm using the same methods as described above for sealing the rib feet to the wafer. A wafer may then be placed against the wafer diaphragm during the planarization process while the carrier plenums and/or web plenums are adjusted to control the distribution of force on the back surface of the wafer. As a further alternative, the outermost rib

may be a bellows molded as a single piece with the wafer diaphragm or may be bonded to the wafer diaphragm. As a further alternative, a spring ring may be placed inside the outermost web plenum against the juncture of the outermost rib and the wafer diaphragm. The compressed spring ring will try to uniformly expand radially outward and assist in maintaining a taut wafer diaphragm.

The present invention may be practiced by analyzing incoming wafers for repeating geometric patterns. Some semiconductor wafer processing steps leave predictable concentric bulges on the wafer. The number, position, width and height of the bulges from these processing steps are often substantially the same from wafer to wafer. By using a carrier with adjustable concentric pressure zones and adjustable barrier pressures between zones, the carrier may optimize a pressure distribution across the entire back surface of the wafer. The pressure distribution on the back surface of the wafer is optimized by pressing harder on zones with larger bulges during the planarization process to produce a wafer with a substantially uniform thickness.

These and other aspects of the present invention are described in full detail in the following description, claims and appended drawings.

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 section view of a simplified carrier having adjustable concentric ribs defining adjustable pressure zones there between;

Figure 2 is a bottom view of a web diaphragm with orthogonally attached concentric ribs defining a central disk shaped web plenum surrounded by concentric ring shaped web plenums;

Figure 3 is a cross section view of a simplified carrier having adjustable concentric ribs defining adjustable pressure zones there between wherein the zones are enclosed by a wafer diaphragm;

Figure 4 is a graph relating pressure to corresponding zones on the back surface of a wafer;

Figure 5 is a cross section view of a rib with a square foot;

Figure 6 is a cross section view of a rib with a round foot;

Figure 7 is a cross section view of a rib with an "elephant" or self-sealing foot;

Figure 8 is a cross section view of a rib with a self-sealing foot with a vacuum assist

system;

Figure 9 is a cross section view of another embodiment of the invention;

Figure 10 is a flow chart of an exemplary process to practice the invention;

Figure 11 is a more detailed drawing of a carrier similar to the carrier in Fig. 1; and

5 Figure 12 is a cross section view of a carrier having adjustable concentric ribs defining adjustable pressure zones wherein the zones are enclosed by a wafer diaphragm and the outermost rib is configured as a bellows.

Detailed Description of Exemplary Embodiments

10 The preferred embodiment of the present invention is as an improved wafer carrier for planarizing a wafer in a CMP tool. The present invention may be used with a variety of CMP tools, such as the AvantGaard 676, 776 or 876 or Auriga C or CE made commercially available by SpeedFam-IPEC headquartered in Chandler, Arizona. CMP tools that may be used to practice the present invention are well known in the art and will not be discussed in detail to avoid obscuring the nature of the present invention.

15 A wafer carrier in a CMP tool must retain the wafer and assist in the distribution of a pressing force on the back of the wafer while the front of the wafer is planarized against an abrasive surface. The abrasive surface typically comprises a polishing pad wetted by chemically active slurry with suspended abrasive particles. The preferred polishing pad and slurry are highly dependant on the particular process and workpiece being used. Conventional
20 CMP polishing pads and slurries are made commercially available by Rodel Inc. from Newark, Delaware for typical applications.

Referring to Fig. 1 and Fig. 11, an exemplary embodiment of the present invention will be discussed in detail. The carrier 156 has a rigid cylindrical carrier housing 154 providing a rigid superstructure. The carrier housing 154 may comprise, for example, stainless steel to give
25 the carrier housing 154 the necessary rigidity and resistance to corrosion needed in a CMP environment. The top major surface of the cylindrical carrier housing 154 may be adapted to be connected to almost any conventional CMP tool. Most conventional CMP tools have a movable shaft used for transporting the carrier 156 and wafer 150. The movable shaft typically allows the carrier 156 to move between a wafer loading and/or unloading station and a position
30 in proximity and parallel to an abrasive surface in a CMP tool.

The bottom major surface of the carrier housing 154 has a plurality of concentric ring shaped recesses (hereinafter called carrier plenums) 131-134. For maximum control of the pressure distribution on the back surface of a wafer, at least one carrier fluid communication

path 141-144 is in fluid communication with each carrier plenum 131-134. The carrier fluid communication paths 141-144 are routed through the carrier housing 154 to an apparatus for delivering an independently pressurized fluid to each carrier plenum 131-134, the purpose for which will be explained below.

5 A web diaphragm 100 is coupled to the carrier housing 154 across the carrier housing's bottom major surface thereby sealing the carrier plenums 131-134. The web diaphragm 100 may be coupled to the carrier housing 154 with adhesives, screws or other known techniques. However, the web diaphragm 100 is preferably kept in place by tightening a plurality of bolts 158 that pull clamp rings 157 against the carrier housing 154 thereby trapping the web
10 diaphragm 100 placed between the carrier housing 154 and the clamp rings 157.

A plurality of concentric barriers 101-104 extends orthogonally from a major surface of the web diaphragm 100 opposite the carrier plenums 131-134. The barriers 101-104 may take the form of o-rings, bellows or other known configurations capable of separating neighboring pressure zones having a pressure differential. However, the preferred barrier is a short elastic
15 piece of material hereafter referred to as a "rib". The head of each rib 101-104 is connected to the web diaphragm 100 while the foot of each rib 101-104 is used to support either a wafer 150 or a wafer diaphragm 300 (the wafer diaphragm 300 is discussed below with reference to Fig. 3 and Fig. 12). The ribs 101-104 are made as short as possible, preferably less than 15 mm and about 2.5 mm wide, to maximize the load capabilities and minimize deflections during the
20 planarization process. While the web diaphragm 100 and ribs 101-104 may be manufactured as a single piece of elastic material, they are preferably separate pieces held together against the carrier housing 154 by clamping rings 157. The web diaphragm 100 and ribs 101-104 may comprise an elastic material such as EPDM.

The number of concentric barriers or ribs the web 155 has will directly correspond to the
25 number of independently controllable pressure zones that may be created. Using Fig. 2 as an example (which is a bottom view of the web 155 in Fig. 1 and Fig. 11), four concentric ribs 101-104 are used to create a central disk shaped web plenum 111 surrounded by three concentric ring shaped web plenums 112-114. The central disk shaped web plenum 111 is defined by the inner diameter of the innermost rib 101, while the surrounding web plenums
30 112-114 are defined by the outer diameter and inner diameter of the ribs 101-104. The spacing between the ribs 101-104 (and carrier plenums 131-134) may be adjusted to control the width of the web plenums 111-114. The position of the ribs 101-104 (in combination with the carrier plenums 131-134) may be adjusted to alter the position of the web plenums 111-114. For optimum control of the pressure distribution on the back surface of the wafer, at least one

independently controllable web fluid communication path 121-124 is in fluid communication with each web plenum 111-114. The web fluid communication paths 121-124 may be routed through the carrier housing and out the center of the carrier.

With reference to Fig. 1, an example of one possible method for routing a pressurized fluid to the carrier plenums 131-134, web plenums 111-114 and retaining ring plenum 115 will now be given for a typical CMP tool design. A compressor may be used to generate a pressurized fluid that may be fed through a manifold to one or more regulators. The pressure generated by the compressor should be higher than the pressure actually needed by any of the plenums. One independently controllable regulator is preferably used for each carrier plenum 131-134, web plenum 111-114 and retaining ring plenum 115 on the carrier 156. The regulators are in fluid communication with their corresponding carrier fluid communication paths 141-144, web fluid communication paths 121-124 and retaining ring fluid communication path 125. The fluid communication paths may be routed through a rotary union on a hollow shaft, commonly found in CMP tools, connected to the carrier 156. The fluid communication paths may then be routed through the hollow shaft and carrier 156 to their respective plenums. The present invention may be practiced using a variety of compressors, manifolds, regulators, fluid communication paths, rotary unions and hollow shafts that are well known in the art.

The central disk shaped web plenum 111 and surrounding ring shaped web plenums 112-114 may be individually pressurized to produce a plurality of concentric constant pressure zones on the back surface of a wafer 150. The web plenums 111-114 may be made smaller, and are thus easier and quicker to pressurize, by increasing the size of the clamp rings 157. The particular pressure chosen for each pressure zone depends on the surface geometry and materials comprising the incoming wafers in combination with the other process parameters of the CMP tool. For STI or copper deposition semiconductor wafers, pressures from 1 to 10 psi, and preferably 3 to 7 psi, on conventional CMP tools may be used.

Carriers 156 with additional controllable pressure zones have zones with a smaller average width, thereby giving the carrier 156 finer control of the pressure distribution on the backside of the wafer 150. However, additional zones increase the cost of manufacturing, the cost of additional plumbing and the complexity of the carrier 156. The preferred carrier 156 therefore uses the minimum number of web plenums 111-114 necessary for a given wafer surface geometry.

Additional structural support may be used to increase the ribs' hoop strength and minimize the deflection of the ribs 101-104. Additional structural support for the ribs 101-104 may be added with external or internal hoops being attached on the side of the ribs 101-104,

external or internal structural threads attached to the ribs 101-104 or by using materials for the ribs 101-104 having a higher modulus of elasticity.

5 An individually controllable pressing force may be placed on the head of each rib 101-104 by pressurizing the rib's corresponding carrier plenum 131-134. The down forces generated by the carrier plenums 131-134 may be transmitted through the ribs 101-104 to the rib feet. The force on each rib 101-104 presses the rib's feet against either a wafer 150 or a wafer diaphragm 300 (discussed below with reference to Fig. 3 and Fig. 12) to create a superior seal for each web plenum 111-114. The pressure on each rib 101-104 is advantageously made equal to or greater than the pressure in the neighboring web plenums 111-114 to help prevent
10 fluid from leaking between the neighboring web plenums 111-114. The pressurized fluid for the carrier plenums 131-134, web plenums 111-114 and retaining ring plenum 115 may be a liquid or gas and is preferably filtered air.

The rib feet may be enhanced to prevent pressurized fluid from leaking between neighboring web plenums 111-114. The shape of the rib feet will affect how well the feet seal,
15 the pressure transmission through the rib 101-104 to the wafer 150 and how well the feet "gimbal" on the wafer 150.

Referring to Fig. 5, a cross section of a square foot 101a is shown connected to a web diaphragm 100a prior to being sealed to surface 501. The square foot 101a is easy to manufacture and provides a medium size contact area with the surface 501 to be sealed against,
20 but has limited gimbaling characteristics.

Referring to Fig. 6, a cross section of a rounded foot 101b is shown connected to a web diaphragm 100b to be sealed to surface 601. The rounded foot 101b is harder to manufacture than the square foot, has minimal contact area with the surface 601 to be sealed against, but has excellent gimbaling characteristics.

25 Referring to Fig. 7, a cross section of an "elephant" foot 101c is shown connected to a web diaphragm 100c prior to being sealed to surface to surface 701. The elephant foot 101c is the most difficult to manufacture and has poor gimbaling characteristics, but provides a large contact area with the surface 701 to be sealed against. In addition, pressure in the neighboring web plenums 702 and 703 may be used to press on the "elephant" foot 101c as graphically
30 illustrated by arrows A702 and A703 to assist the "elephant" foot 101c in sealing against surface 701.

Referring to Fig. 8, a cross section of an "elephant" foot 101d is shown connected to a web diaphragm 100d prior to being sealed to a surface 801. For this rib foot 101d configuration, a vacuum line 802 is passed through to the rib foot 101d to assist in the rib foot

101d sealing against a surface 801. While the vacuum line 802 is shown in combination with the "elephant" foot design, it may also be used with other rib foot designs to improve their sealing capability.

Referring to Fig. 1 and Fig. 11, a floating retaining ring 151 is suspended from the carrier housing 154 by a retaining ring membrane 153. The retaining ring membrane 153 preferably comprises an elastic material such as fairprene. The upper portion of the retaining ring 151 is enclosed in a retaining ring plenum 115 defined by the carrier housing 154 and retaining ring membrane 153. The lower portion of the retaining ring 151 extends below the retaining ring membrane 153 and makes contact with a polishing pad. A pressurized fluid may be introduced to the retaining ring plenum 115 through a retaining ring fluid communication path 125 to control the pressure the retaining ring 151 exerts on the polishing pad. The optimum pressure of the retaining ring 151 on the polishing pad will vary depending on the particular application, but for most conventional wafer process applications will typically be less than 10 psi and usually between 4 and 8 psi. The optimum pressure for the retaining ring 151 will usually be about the same pressure as that for the wafer 150 against the polishing pad.

Adjusting the pressure of the retaining ring 151 in relation to the pressure of the wafer 150 against a polishing pad may be used to control the rate of removal of material, particularly at the periphery, of the wafer 150. Specifically, a higher retaining ring 151 pressure will usually slow the rate of material removal, while a lower retaining ring 151 pressure will usually increase the rate of material removal, at the periphery of the wafer 150.

The retaining ring 151 surrounds the wafer 150 during the planarization process and prevents the wafer 150 from laterally escaping from beneath the carrier 156. The retaining ring membrane 153 allows the retaining ring 151 to adjust to variations in the polishing pad's thickness, without undesirably tilting the carrier housing 154. Because the retaining ring 151 rubs against the abrasive polishing pad, it preferably comprises a wear resistant material such as a ceramic. However, the inner diameter of the retaining ring 151 makes repeated contact with the wafer 150 and may undesirably chip the wafer 150. To prevent the wafer 150 from being chipped, a material softer than the wafer, such as delrin, may be used to create a barrier 152 between the wafer 150 and the retaining ring 151.

With reference to Fig. 3, another embodiment of the present invention will be discussed. The illustrated carrier 305 has a similar carrier housing 154, carrier plenums 131-134, carrier fluid communication paths 141-144, web diaphragm 100, ribs 101-104, rib plenums 111-114, web fluid communication paths 121-124 and floating retaining ring 151 as previously discussed. However, a wafer diaphragm 300 is positioned between the wafer 150 and the ribs

101-104 and is supported on the feet of the ribs 101-104. The ribs 101-104 may be sealed against the wafer diaphragm 300 in a manner similar to the ribs' feet sealing against the wafer 150 in the previous embodiment of the carrier 158. However, the ribs 101-104 are preferably bonded to the wafer diaphragm 300 to assist in preventing leakage between neighboring web plenums 111-114.

A compressed spring ring 301 may be inserted in the outermost web plenum 114 near the junction between the outermost rib 114 and the wafer diaphragm 300. The spring ring 301 is advantageously designed to expand uniformly in a radial direction to assist in maintaining a taut wafer diaphragm 300.

With reference to Fig. 12, another embodiment of a carrier 156 is shown. This embodiment has ribs 101-103, web plenums 111-114, carrier plenums 131-133, carrier fluid communication paths 141-143 and web plenum fluid communication paths 121-124 as shown in the prior embodiments. However, the outermost rib 104 shown in Fig. 3 is replaced with a bellows 304. The bellows 304 does not need a carrier plenum 134 or carrier fluid communication path 144 (both shown in Fig. 3), thereby simplifying the design and construction of the carrier 1200.

Fig. 9 illustrates another embodiment where the wafer diaphragm 300a is actually attached to the rib 901 thereby sealing web plenum 904. Web plenum 904 may be pressurized by web fluid communication path 903 in a manner similar to the other embodiments already discussed. This embodiment has the additional feature of a vacuum or discharge path 900 for either assisting in picking-up the wafer 150 with a vacuum or removing the wafer 150 from the carrier with a rapid discharge of fluids at point 905a.

The carriers in Fig. 3 and Fig. 12 have the advantage of the wafer diaphragm 300 preventing the backside of the wafer 150 from being exposed to a fluid, such as air, that might dry or adhere the slurry onto the back surface of the wafer. Once slurry has dried or adhered to the wafer 150, it is extremely difficult to remove, thereby introducing contaminants that may be harmful to the wafer 150.

The carrier 156 in Fig. 1 and Fig. 11, the carrier 305 in Fig. 3 and the carrier 1200 in Fig. 12 may be used to pick-up a wafer 150 by creating one or more vacuum zones on the back surface of the wafer 150. A vacuum zone may be created by one or more of the web fluid communication paths 121-124 communicating a vacuum to one of the web plenums 111-114. The vacuum for carrier 156 in Fig. 1 and Fig. 11 is communicated directly to the back surface of the wafer 150. The vacuum for the carrier 305 in Fig. 3 or the carrier 1200 in Fig. 12 lifts the wafer diaphragm 300 from the backside of the wafer 150 creating a vacuum between the wafer

diaphragm 300 and the wafer 150.

The carrier 156 in Fig. 1 and Fig. 11, the carrier 305 in Fig. 3 and the carrier 1200 in Fig. 12 may be used to discharge a wafer 150 from the carrier. A rapid discharge of fluids through one or more of the web fluid communication paths for the carrier 156 in Fig. 1 and Fig. 11 will directly impact the wafer 150 and blow the wafer 150 out of the carrier 156. A wafer 150 in carrier 305 in Fig. 3 or carrier 1200 in Fig. 12 may be removed from the carrier by pressurizing the web plenums 111-114 which will cause the wafer diaphragm 300 to extend outwards thereby dislodging the wafer 150 from the carrier 305.

An exemplary process for using the present invention will now be discussed with reference to Fig. 4 and Fig. 10. The first step is to determine the number, location, height and/or width of concentric bulges on incoming wafers (step 1000). This may be done by reviewing incoming wafers prior to planarization with various known metrology instruments, such as a UV1050 manufactured by KLA-Tencor located in San Jose, California.

A carrier with adjustable concentric pressure zones that correspond to the surface geometry of the incoming wafers may be advantageously selected for use (step 1001). The carrier should have adjustable pressure zones that correspond to the ridges and adjustable pressure zones that correspond to the troughs between ridges on the wafer.

A wafer may then be loaded into the selected carrier and the carrier and wafer moved so that the wafer is parallel to and adjacent (near or just touching) an abrasive surface such as a polishing pad (step 1002). The wafer may then be pressed against the abrasive surface by pressurizing the independently controlled pressure zones (web plenums). The pressure in each zone may be independently controlled by adjusting the pressure communicated through the zone's corresponding web fluid communication path to provide an optimum planarization process for the surface geometry of that wafer (step 1003).

Fig. 4 illustrates one possible pressure distribution on the back surface of a wafer with a central zone 1 and three surrounding zones 2-4. The central zone 1 (web plenum 111 in Fig. 3) is pressurized to 4 psi, zones 2 and 3 (web plenums 112 and 113 respectively in Fig. 3) are pressurized to 5 psi and zone 4 (web plenum 114 in Fig. 3) is pressurized to 6 psi. This distribution of pressure on the back surface of a wafer may be used for wafers with a thin bulge around the periphery and a small depression near the center of the wafer. The variation of pressures allows the carrier to press harder on zones with bulges and softer on zones with troughs or depressions during the planarization process to produce a wafer with a substantially uniform thickness. Additional zones, smaller zones or zones of varying sizes may be used to give finer control over the distribution of pressure on the back surface of the wafer, but increase

the complexity and manufacturing cost of the carrier.

Applicant has noticed certain semiconductor wafer processing steps leave predictable concentric bulges on the wafer. The bulges from these processing steps are substantially the same from wafer to wafer in that the wafers typically have the same surface geometry. For example, applicant has noticed current copper deposition processes typically have a narrow bulge near the periphery and another bulge in the shape of a small disk near the center of the wafer. Additionally, applicant has noticed current STI processes typically have a wide bulge near the periphery and another bulge in the shape of a small disk near the center of the wafer. A single carrier design with four roughly equal zones, as illustrated in Fig. 1 and Fig. 3, may be advantageously used for both copper deposition and STI wafers in this situation. For a specific example, zones 1 and 4 that correspond to bulges on a copper deposition wafer may have a higher pressure, e.g. 6 psi, while the zones 2 and 3 that correspond to the trough may have a lower pressure, e.g. 5 psi. Likewise, zones 1, 3 and 4 that correspond to bulges on an STI wafer may have a higher pressure, e.g. 6 psi, while zone 2 that corresponds to a trough may have a lower pressure, e.g. 5 psi. This strategy allows one carrier design to be used to planarize wafers after two different processes.

The carrier preferably also has carrier plenums that may be individually pressurized by corresponding carrier fluid communication paths. Each pressurized carrier plenum exerts a force against the head of each rib that is transmitted through the rib to assist in pressing the feet of the rib against the back surface of the wafer (or wafer diaphragm if one is used). This pressing force assists the feet of the ribs in making a good seal with the back surface of the wafer. The pressure in the carrier plenums may be made equal to or slightly greater (about .1 to .3 psi) than the pressure in the neighboring web plenums to assist in preventing leakage between neighboring web plenums (step 1004). Alternatively, the pressure in each carrier plenum may be set between the pressure in its neighboring web plenums to create a smoother distribution of pressure on the back surface of the wafer.

Relative motion is necessary between the wafer and the abrasive surface to remove material from the front face of the wafer thereby planarizing the front face of the wafer. The abrasive surface and/or carrier of the present invention may be rotated, orbited, linearly oscillated, moved in particular geometric patterns, dithered, moved randomly or moved in any other motion that removes material from the front face of the wafer. In addition, the abrasive surface and/or carrier may be moving relative to each other prior to, or after, the front face of the wafer contacts the abrasive surface (step 1005). However, the preferred relative motion is generated by the carrier rotating and the polishing pad orbiting. The carrier and polishing pad

motion may be ramped up to their desired speeds simultaneously with the pressure on the back surface of the wafer being ramped to its desired level.

5 Although the foregoing description sets forth preferred exemplary embodiments and methods of operation of the invention, the scope of the invention is not limited to these specific embodiments or described methods of operation. Many details have been disclosed that are not necessary to practice the invention, but have been included to sufficiently disclose the best mode of operation and manner and process of making and using the invention. Modification may be made to the specific form and design of the invention without departing from its spirit and scope as expressed in the following claims.

Claims

We claim:

- 5 1. A carrier for planarizing a surface of a wafer comprising:
 - a) a central disk shaped plenum;
 - b) a plurality of concentric ring shaped plenums surrounding the
10 central plenum; and
 - c) a plurality of concentric barriers with one barrier placed between
every pair of neighboring plenums, wherein at least one of the barriers is
pressure adjustable.
2. A carrier for planarizing a surface of a wafer comprising:
 - a) a pressure adjustable central disk shaped plenum;
 - b) a pressure adjustable plurality of concentric ring shaped plenums
15 surrounding the central plenum; and
 - c) a plurality of pressure adjustable concentric barriers, wherein one
barrier is placed between every pair of neighboring plenums;
3. A carrier for planarizing a surface of a wafer comprising:

20 a carrier housing;

 a web diaphragm having a first and a second major surface supported by the
carrier housing;

 a plurality of ring shaped ribs each having a head and a foot, wherein the head of
each rib is connected orthogonally to the first major surface of the web diaphragm
thereby defining a plurality of concentric web plenums;

25 a plurality of individually controllable web fluid communication paths, each in
fluid communication with one of the corresponding plurality of web plenums;

 a plurality of recesses adjacent the second major surface of the web diaphragm,
each of the plurality of recesses opposite one of the plurality of ring shaped ribs thereby
defining a plurality of ring shaped carrier plenums; and

30 a plurality of individually controlled carrier fluid communication paths in fluid
communication with the corresponding plurality of carrier plenums for controlling the
pressure in the plurality of carrier plenums exerted on the plurality of spaced apart ring
shaped ribs.
4. A carrier as in claim 3 wherein the web diaphragm and the plurality of ring
35 shaped ribs are both made from a single piece of elastic material.
5. A carrier as in claim 3 further comprising:

a) a plurality of clamping rings for connecting the web diaphragm or ribs to the carrier housing.

6. A carrier as in claim 3 wherein the web diaphragm comprises a separate independent ring shaped diaphragm associated with each rib.

5 7. A carrier as in claim 3 wherein at least one of the rib feet is rounded.

8. A carrier as in claim 3 wherein at least one of the rib feet is adapted to be self-sealing.

9. A carrier as in claim 8 further comprising:

10 a) a rib vacuum line routed through a rib for communicating a vacuum near the rib foot.

10. A carrier as in claim 3 further comprising:

a retaining ring recess in the carrier housing;

a retaining ring diaphragm connected to the periphery of the carrier housing and covering the retaining ring recess to form a retaining ring plenum; and

15 a retaining ring coupled to the retaining ring diaphragm.

11. A carrier as in claim 10 further comprising:

a) a retaining ring fluid communication path in fluid communication with the retaining ring plenum for controlling the pressure on the retaining ring.

20 12. A carrier as in claim 10, wherein an inner diameter of the retaining ring is coated with a resilient material.

13. A carrier for planarizing a surface of a wafer comprising:

a) a carrier housing;

b) a web diaphragm having a first and a second major surface supported by the carrier housing;

25 c) a plurality of ring shaped ribs each having a head and a foot, wherein the head of each rib is connected to the first major surface of the web diaphragm thereby defining a plurality of concentric web plenums;

d) a bellows having a head and a foot, wherein the bellows surrounds the outermost rib and the head of the bellows is connected to the carrier housing;

30 e) a wafer diaphragm connected to the bellows foot and adjacent the plurality of rib feet; and

f) a plurality of individually controllable web fluid communication paths in fluid communication with a corresponding plurality of web plenums.

35 14. A carrier as in claim 13 wherein the bellows and the wafer diaphragm are both

made from a single piece of elastic material.

15. A carrier as in claim 13 further comprising:

a) a plurality of clamping rings for connecting the web diaphragm and ribs to the carrier housing.

5 16. A carrier as in claim 13 wherein the wafer diaphragm is bonded to the plurality of rib feet.

17. A carrier as in claim 13 wherein the web diaphragm and the plurality of concentric ribs are both made from a single piece of elastic material.

10 18. A carrier as in claim 13 wherein the carrier housing has a plurality of recesses adjacent the second major surface of the web diaphragm and opposite the plurality of concentric ribs thereby defining a plurality of concentric ring shaped carrier plenums.

19. A carrier as in claim 18 further comprising:

a) a plurality of individually controllable carrier fluid communication paths in fluid communication with a corresponding plurality of carrier plenums.

20. A carrier as in claim 13 further comprising:

a) a retaining ring diaphragm connected to the periphery of the carrier housing;

b) a retaining ring connected to the retaining ring diaphragm; and
20 wherein the carrier housing has a retaining ring recess apposite the retaining ring diaphragm thereby defining a retaining ring plenum.

21. A carrier as in claim 20 further comprising:

a) a retaining ring fluid communication path in fluid communication with the retaining ring plenum for controlling the pressure on the retaining ring.

22. A carrier as in claim 21, wherein the inner diameter of the floating retaining ring is coated with a material softer than the wafer.

23. A carrier for planarizing a surface of a wafer comprising:

a) a carrier housing with a bottom surface having a central disk shaped recess and a plurality of surrounding concentric recesses;

b) a web diaphragm, having a first and a second major surface, supported by the bottom surface of the carrier housing, wherein the second major surface of the web diaphragm covers the recesses in the carrier thereby defining a plurality of carrier plenums;

c) a plurality of concentric ring shaped barriers, each having a head

and a foot, wherein the head of each barrier is connected orthogonally to the first major surface of the web diaphragm, opposite the carrier plenums, thereby defining a plurality of concentric web plenums;

d) at least one controllable web fluid communication paths in fluid communication with a corresponding web plenum; and

e) at least one controllable carrier fluid communication paths in fluid communication with a corresponding carrier plenum.

24. A carrier as in claim 23 further comprising:

a) a wafer diaphragm connected to the outermost barrier.

25. A carrier as in claim 24 further comprising:

a) a spring ring inserted in the outermost concentric web plenum adapted to stretch the wafer diaphragm uniformly in a radial direction.

26. A carrier for planarizing a surface of a wafer comprising:

a) a carrier housing;

b) a web diaphragm having a first and a second major surface supported by the carrier housing;

c) a plurality of ring shaped ribs each having a head and a foot, wherein the head of each rib is connected to the first major surface of the web diaphragm thereby defining a plurality of concentric web plenums;

d) a bellows having a head and a foot, wherein the bellows surrounds the outermost rib and the head of the bellows is connected to the carrier housing;

e) a wafer diaphragm connected to the bellows foot and is adjacent to the plurality of rib feet;

f) a plurality of individually controllable web fluid communication paths in fluid communication with a corresponding plurality of web plenums; and

g) a rib vacuum line routed through the wafer diaphragm and rib for communication a vacuum near the foot of the rib.

27. A carrier as in claim 26 wherein the web diaphragm and the plurality of ribs are both made from a single piece of elastic material.

28. A carrier as in claim 26 further comprising:

a) a plurality of clamping rings for connecting the web diaphragm and the ribs to the carrier housing.

29. A carrier as in claim 27 wherein the carrier housing has a plurality of recesses

adjacent the second major surface of the web diaphragm and opposite the plurality of ribs thereby defining a plurality of concentric ring shaped carrier plenums.

30. A carrier as in claim 29 further comprising:

a) a plurality of individually controllable carrier fluid communication paths in fluid communication a corresponding plurality of carrier plenums.

31. A carrier as in claim 26 further comprising:

a) a retaining ring diaphragm connected to the periphery of the carrier housing;

b) a retaining ring connected to the retaining ring diaphragm; and ring diaphragm wherein the carrier housing has a retaining ring recess apposite the retaining thereby defining a retaining ring plenum.

32. A carrier as in claim 31 further comprising:

a) a retaining ring fluid communication path in fluid communication with the retaining ring plenum for controlling the pressure on the retaining ring.

33. A carrier as in claim 31, wherein a material softer than the wafer is fixed to the inner diameter of the floating retaining ring.

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

a) loading an incoming wafer into a carrier having a plurality of pressure adjustable concentric plenums and a pressure adjustable concentric barrier between every pair of neighboring plenums;

b) moving the carrier until the wafer is near or touches an abrasive surface;

c) determining a desired removal rate for a plurality of concentric zones on the wafer that correspond to the plurality of concentric plenums of the carrier;

d) pressing the wafer against the abrasive surface by pressurizing each concentric plenum of the carrier with a pressure intended to achieve the desired removal rate on each respective concentric zone on the wafer;

e) adjusting the pressure on each of the plurality of barriers between concentric plenums; and

f) causing relative motion between the wafer and the abrasive surface.

35. A method as in claim 34, wherein step (a) comprises the step of loading an

incoming wafer into a carrier having a plurality of pressure adjustable concentric plenums and a pressure adjustable concentric barrier between every pair of neighboring plenums, the barriers between neighboring plenums comprising elastic ribs.

36. A method as in claim 34, wherein the pressure on each of the plurality of barriers is equal to or greater than each of the pressures in the neighboring concentric plenums to prevent leakage between the neighboring plenums.

37. A method as in claim 34, wherein the step of adjusting the pressure comprises adjusting the pressure on each of the plurality of barriers between concentric plenums to a pressure equal to or between the pressure in the neighboring concentric plenums.

38. A method of planarizing a copper thin film deposited on a wafer or an STI wafer comprising the steps of:

- a) loading an incoming wafer into a carrier comprising:
 - a pressure adjustable peripheral ring plenum,
 - a pressure adjustable intermediate ring plenum;
 - a pressure adjustable central disk plenum;
 - a pressure adjustable concentric barrier between the peripheral and intermediate plenum; and
 - a pressure adjustable concentric barrier between the intermediate and central disk plenum;
- b) moving the carrier until the wafer is near or touches an abrasive surface;
- c) pressing the wafer against the abrasive surface by pressurizing the peripheral, intermediate and central plenum, wherein the pressure in each of the peripheral and central plenums is at a higher pressure than the pressure in the intermediate plenum;
- d) adjusting the pressure on each of the plurality of barriers between plenums; and
- e) causing relative motion between the wafer and the abrasive surface to planarize the wafer.

39. A method as in claim 38, wherein the barriers between neighboring plenums comprise elastic ribs.

40. A method as in claim 38, wherein the pressure on each of the plurality of barriers is equal to or greater than each of the pressures in the neighboring plenums to prevent leakage between the neighboring plenums.

41. A method as in claim 38, wherein the pressure on each of the plurality of barriers

is equal to or between the pressures in the neighboring plenums to assist in a smooth transition of pressure on the backside of the wafer between neighboring plenums.

42. A method of planarizing a copper thin film deposited on a wafer comprising the steps of:

- 5 a) loading an incoming wafer into a carrier comprising:
 - a pressure adjustable central ring plenum,
 - a pressure adjustable second ring plenum;
 - a pressure adjustable third ring plenum;
 - a pressure adjustable peripheral ring plenum;
 - 10 a pressure adjustable first barrier between the central and second plenum;
 - a pressure adjustable second barrier between the second and third plenum; and
 - a pressure adjustable third barrier between the third and peripheral ring plenum;
 - 15 b) moving the carrier until the wafer is near or touches an abrasive surface;
 - c) pressing the wafer against the abrasive surface by pressurizing the central, second, third and peripheral plenums, wherein the pressure in each of the central and peripheral plenums is at a higher pressure than the pressure in each of the second and third plenums;
 - 20 d) adjusting the pressure on each of the plurality of barriers between plenums; and
 - e) causing relative motion between the wafer and the abrasive surface to planarize the wafer.
 - 25

43. A method as in claim 42, wherein the barriers between neighboring plenums comprise elastic ribs.

44. A method as in claim 42, wherein the pressure on each of the plurality of barriers is equal to or greater than each of the pressures in the neighboring plenums to prevent leakage between the neighboring plenums.

45. A method as in claim 42, wherein the pressure on each of the plurality of barriers is equal to or between the pressures in the neighboring plenums to assist in a smooth transition of pressure on the backside of the wafer between neighboring plenums.

46. A method of planarizing an STI wafer comprising the steps of:

- 35 a) loading an incoming wafer into a carrier comprising:

a pressure adjustable central ring plenum,
 a pressure adjustable second ring plenum;
 a pressure adjustable third ring plenum;
 a pressure adjustable peripheral ring plenum;

5 a pressure adjustable first barrier between the central and second plenum;

a pressure adjustable second barrier between the second and third plenum; and

10 a pressure adjustable third barrier between the third and peripheral ring plenum;

b) moving the carrier until the wafer is near or touches an abrasive surface;

15 c) pressing the wafer against the abrasive surface by pressurizing the central, second, third and peripheral plenums, wherein the pressure in each of the central, second and peripheral plenums is at a higher pressure than the pressure in the third plenum;

d) adjusting the pressure on each of the plurality of barriers between plenums; and

20 e) causing relative motion between the wafer and the abrasive surface to planarize the wafer.

47. A method as in claim 46, wherein the barriers between neighboring plenums comprise elastic ribs.

25 48. A method as in claim 46, wherein the pressure on each of the plurality of barriers is equal to or greater than each of the pressures in the neighboring plenums to prevent leakage between the neighboring plenums.

49. A method as in claim 46, wherein the pressure on each of the plurality of barriers is equal to or between the pressures in the neighboring plenums to assist in a smooth transition of pressure on the backside of the wafer between neighboring plenums.

30 50. A carrier for planarizing a surface of a wafer comprising:
 a carrier housing;
 a wafer diaphragm having a first and a second major surface, the first major surface adapted for contacting a wafer;

a plurality of spaced apart ring shaped ribs, each coupled at one end to the second major surface of the wafer diaphragm and at the opposite end to the carrier housing

thereby defining, in combination with the carrier housing and the wafer diaphragm, a plurality of concentric web plenums;

5 a plurality of individually controllable web fluid communication paths in fluid communication with the corresponding plurality of web plenums for controlling the pressure in each of the plurality of concentric web plenums;

a plurality of concentric ring shaped carrier plenums formed in the carrier housing and aligned with the plurality of spaced apart ring shaped ribs; and

10 a plurality of individually controlled carrier fluid communication paths in fluid communication with the corresponding plurality of carrier plenums for controlling the pressure in the plurality of carrier plenums exerted on the plurality of spaced apart ring shaped ribs.

51. A carrier as in claim 50 further comprising:

a plurality of clamping rings for connecting the ribs to the carrier housing.

52. A carrier as in claim 50 further comprising:

a retaining ring recess in the carrier housing;

15 a retaining ring diaphragm connected to the periphery of the carrier housing and covering the retaining ring recess to form a retaining ring plenum; and

a retaining ring coupled to the retaining ring diaphragm.

53. A method as in claim 34, wherein step (d) comprises the step of pressing the wafer against the abrasive surface by pressurizing each concentric plenum of the carrier with a
20 pressure intended to achieve the desired removal rate on each respective concentric zone on the wafer, said pressure applied to the wafer through a wafer diaphragm having a first major surface adapted for contacting a wafer, and a second major surface coupled to the concentric barriers.

54. A method as in claim 34, wherein the step of adjusting the pressure comprises
25 the step of adjusting the pressure applied to a pressure operable web diaphragm associated with each of the plurality of concentric plenums.

55. A method as in claim 34, further comprising the steps of:

g) providing a retaining ring attached to the carrier and positioned to surround the wafer; and

30 h) independently applying a pressure exerted by the retaining ring against the abrasive surface.

56. A method as in claim 55, wherein the step of independently applying comprises adjusting the pressure exerted on the abrasive surface by the retaining ring to affect in a predetermined manner the rate of removal of material from a perimeter portion of the wafer.

57. A carrier as in claim 50, wherein each of said ring shaped ribs is connected to the carrier housing by a flexible ring shaped rib diaphragm coupled to said opposite end of each rib.

58. A carrier of a CMP apparatus, comprising:

a carrier body; and

5 a diaphragm having a first surface adapted for pressing against a surface of a work piece and a plurality of concentric ribs extending substantially orthogonally from a second surface of the work piece diaphragm, each of the plurality of concentric ribs terminating in an expanded portion substantially parallel to the work piece diaphragm, the expanded portion adapted for clamping to the carrier body.

10 59. A method for planarizing a first surface of a work piece utilizing a CMP apparatus comprising: a polishing pad, a work piece diaphragm supported by a plurality of ribs, each of the ribs having a pressure adjustable carrier plenum associated therewith, the work piece diaphragm having a first surface for pressing against a second surface of the work piece, a plurality of pressure adjustable web plenums positioned adjacent a second surface of the work
15 piece diaphragm, and a wear ring surrounding the work piece diaphragm and configured to press against the polishing pad, the pressure with which the wear ring presses against the polishing pad being adjustable, the method comprising the steps of:

positioning a second surface of a work piece adjacent the first surface of the work piece diaphragm;

20 positioning the first surface of the work piece in contact with the polishing pad; establishing a predetermined pressure in each of the pressure adjustable web plenums;

establishing a predetermined pressure in each of the carrier plenums;

25 adjusting, independent of the predetermined web plenum and carrier plenum pressures, the pressure with which the wear ring presses against the polishing pad; and initiating relative motion between the work piece diaphragm and the polishing pad.