

WIDE LIPSEAL FOR ELECTROPLATING

TECHNICAL FIELD

[0001] This invention relates to the formation of damascene interconnects for integrated circuits, and electroplating apparatuses which are used during integrated circuit fabrication.

BACKGROUND

[0002] Electroplating is a common technique used in integrated circuit (IC) fabrication to deposit one or more layers of conductive metal. In some fabrication processes it is used to deposit single or multiple levels of copper interconnects between various substrate features. An apparatus for electroplating typically includes an electroplating cell having a pool/bath of electrolyte and a clamshell designed to hold a semiconductor substrate during electroplating.

[0003] During operation of the electroplating apparatus, a semiconductor substrate is submerged into the electrolyte pool such that one surface of the substrate is exposed to electrolyte. One or more electrical contacts established with the substrate surface are employed to drive an electrical current through the electroplating cell and deposit metal onto the substrate surface from metal ions available in the electrolyte. Typically, the electrical contact elements are used to form an electrical connection between the substrate and a bus bar acting as a current source. However, in some configurations, a conductive seed layer on the substrate contacted by the electrical connections may become thinner towards the edge of the substrate, making it more difficult to establish an optimal electrical connection with the substrate.

[0004] Another issue arising in electroplating is the potentially corrosive properties of the electroplating solution. Therefore, in many electroplating apparatus a lipseal is used at the interface of the clamshell and substrate for the purpose of preventing leakage of electrolyte and its contact with elements of the electroplating apparatus other than the inside of the electroplating cell and the side of the substrate designated for electroplating.

SUMMARY

[0005] Disclosed herein is a lipseal for use in a lipseal assembly of an electroplating clamshell which engages and supplies electrical current to a semiconductor substrate during electroplating. The lipseal comprises an elastomeric body having an outer portion configured to engage a cup of the lipseal assembly and an inner portion configured to engage a peripheral region of the semiconductor substrate. The inner portion includes a protrusion having a width in a radial direction sufficient to inhibit diffusion of acid in an electroplating

solution used during the electroplating. The protrusion comprises an annular rim which extends completely around an inner periphery of the lipseal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 shows an electroplating apparatus in which a lipseal as described herein may be used to prevent acid from reaching contact elements.

[0007] FIG. 2 shows details of a lipseal assembly which can be used in the apparatus shown in FIG. 1.

[0008] FIG. 3 shows details of the lipseal assembly shown in FIG. 2.

[0009] FIG. 4 shows details of the lipseal assembly shown in FIG. 3.

[0010] FIG. 5 is a graph of acid concentration in lipseal area versus lipseal width.

[0011] FIGS. 6a-c are photos of the copper seed layer after electroplating with FIG. 6a showing the copper seed layer after electroplating a dry wafer, FIG. 6b showing severe corrosion after electroplating a wet wafer using a 0.028 inch wide lipseal, and FIG. 6c showing minor corrosion of the copper seed layer after electroplating a wet wafer using a 0.034 inch wide lipseal.

DETAILED DESCRIPTION

[0012] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the presented concepts. The presented concepts may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail so as to not unnecessarily obscure the described concepts. While some concepts will be described in conjunction with specific embodiments, it will be understood that these embodiments are not intended to be limiting.

[0013] An exemplary electroplating apparatus is presented in FIG. 1 in order to provide some context for the various lipseal and contact element embodiments disclosed herein. Specifically, FIG. 1 presents a perspective view of a wafer holding and positioning apparatus 100 for electrochemically treating semiconductor wafers. The apparatus 100 includes wafer-engaging components, which are sometimes referred to as "clamshell components," or a "clamshell assembly," or just as a "clamshell." The clamshell assembly comprises a cup 101 and a cone 103. As will be shown in subsequent figures, the cup 101 holds a wafer and the cone 103 clamps the wafer securely in the cup. Other cup and cone designs beyond those specifically depicted here can be used. A common feature is that a cup that has an interior region in which the wafer resides and a cone that presses the wafer against the cup to hold it in place.

[0014] In the depicted embodiment, the clamshell assembly (which includes the cup 101 and the cone 103) is supported by struts 104, which are connected to a top plate 105. This

assembly (101, 103, 104, and 105) is driven by a motor 107 via a spindle 106 connected to the top plate 105. The motor 107 is attached to a mounting bracket (not shown). The spindle 106 transmits torque (from the motor 107) to the clamshell assembly causing rotation of a wafer (not shown in this figure) held therein during plating. An air cylinder (not shown) within the spindle 106 also provides a vertical force for engaging the cup 101 with the cone 103. When the clamshell is disengaged (not shown), a robot with an end effector arm can insert a wafer in between the cup 101 and the cone 103. After a wafer is inserted, the cone 103 is engaged with the cup 101, which immobilizes the wafer within apparatus 100 leaving a working surface on one side of the wafer (but not the other) exposed for contact with the electrolyte solution.

[0015] In certain embodiments, the clamshell assembly includes a spray skirt 109 that protects the cone 103 from splashing electrolyte. In the depicted embodiment, the spray skirt 109 includes a vertical circumferential sleeve and a circular cap portion. A spacing member 110 maintains separation between the spray skirt 109 and the cone 103.

[0016] For the purposes of this discussion, the assembly including components 101-110 is collectively referred to as a "wafer holder" (or "substrate holder") 111. Note however, that the concept of a "wafer holder"/"substrate holder" extends generally to various combinations and sub-combinations of components that engage a wafer/substrate and allow its movement and positioning.

[0017] A tilting assembly (not shown) may be connected to the wafer holder to permit angled immersion (as opposed to flat horizontal immersion) of the wafer into a plating solution. A drive mechanism and arrangement of plates and pivot joints are used in some embodiments to move wafer the holder 111 along an arced path (not shown) and, as a result, tilt the proximal end of wafer holder 111 (i.e., the cup and cone assembly).

[0018] Further, the entire wafer holder 111 is lifted vertically either up or down to immerse the proximal end of wafer holder into a plating solution via an actuator (not shown). Thus, a two-component positioning mechanism provides both vertical movement along a trajectory perpendicular to an electrolyte surface and a tilting movement allowing deviation from a horizontal orientation (i.e., parallel to the electrolyte surface) for the wafer (angled-wafer immersion capability).

[0019] Note that the wafer holder 111 is used with a plating cell 115 having a plating chamber 117 which houses an anode chamber 157 and a plating solution. The chamber 157 holds an anode 119 (e.g., a copper anode) and may include membranes or other separators designed to maintain different electrolyte chemistries in the anode compartment and a cathode compartment. In the depicted embodiment, a diffuser 153 is employed for directing electrolyte upward toward the rotating wafer in a uniform front. In certain embodiments, the flow diffuser is a high resistance virtual anode (HRVA) plate, which is made of a solid piece

of insulating material (e.g. plastic), having a large number (e.g. 4,000-15,000) of one dimensional small holes (0.01 to 0.050 inches in diameter) and connected to the cathode chamber above the plate. The total cross-section area of the holes is less than about 5 percent of the total projected area, and, therefore, introduces substantial flow resistance in the plating cell helping to improve the plating uniformity of the system. Additional description of a high resistance virtual anode plate and a corresponding apparatus for electrochemically treating semiconductor wafers is provided in U.S. Published Patent Application No. 2010/0032310, which is hereby incorporated by reference herein in its entirety for all purposes. The plating cell may also include a separate membrane for controlling and creating separate electrolyte flow patterns. In another embodiment, a membrane is employed to define an anode chamber, which contains electrolyte that is substantially free of suppressors, accelerators, or other organic plating additives.

[0020] The plating cell 115 may also include plumbing or plumbing contacts for circulating electrolyte through the plating cell--and against the work piece being plated. For example, the plating cell 115 includes an electrolyte inlet tube 131 that extends vertically into the center of anode chamber 157 through a hole in the center of anode 119. In other embodiments, the cell includes an electrolyte inlet manifold that introduces fluid into the cathode chamber below the diffuser/HRVA plate at the peripheral wall of the chamber (not shown). In some cases, the inlet tube 131 includes outlet nozzles on both sides (the anode side and the cathode side) of the membrane 153. This arrangement delivers electrolyte to both the anode chamber and the cathode chamber. In other embodiments, the anode and cathode chamber are separated by a flow resistant membrane 153, and each chamber has a separate flow cycle of separated electrolyte. As shown in the embodiment of FIG. 1, an inlet nozzle 155 provides electrolyte to the anode-side of membrane 153.

[0021] In addition, plating cell 115 includes a rinse drain line 159 and a plating solution return line 161, each connected directly to the plating chamber 117. Also, a rinse nozzle 163 delivers deionized rinse water to clean the wafer and/or cup during normal operation. Plating solution normally fills much of the chamber 117. To mitigate splashing and generation of bubbles, the chamber 117 includes an inner weir 165 for plating solution return and an outer weir 167 for rinse water return. In the depicted embodiment, these weirs are circumferential vertical slots in the wall of the plating chamber 117.

[0022] As stated above, an electroplating clamshell typically includes a lipseal and one or more contact elements to provide sealing and electrical connection functions. A lipseal may be made from an elastomeric material. The lipseal forms a seal with the surface of the semiconductor substrate and excludes the electrolyte from a peripheral region of the substrate. No deposition occurs in this peripheral region and it is not used for forming IC devices, i.e., the peripheral region is not a part of the working surface. Sometimes, this

region is also referred to as an edge exclusion area because the electrolyte is excluded from the area. The peripheral region is used for supporting and sealing the substrate during processing, as well as for making electrical connection with the contact elements. Since it is generally desirable to increase the working surface, the peripheral region needs to be as small as possible while maintaining the functions described above. In certain embodiments, the peripheral region is between about 0.5 millimeters and 3 millimeters from the edge of the substrate.

[0023] During installation, the lipseal and contact elements are assembled together with other components of the clamshell. One having ordinary skill in the art would appreciate the difficulty of this operation, particularly, when the peripheral region is small. An overall opening provided by this clamshell is comparable to the size of the substrate (e.g., an opening for accommodating 200 mm wafers, 300 mm wafers, 450 mm wafers, etc.). Furthermore, substrates have their own size tolerances (e.g., ± 0.2 millimeters for a typical 300 mm wafer according to the SEMI specification). A particularly difficult task is alignment of the elastomeric lipseal and contact elements, since both are made from relatively flexible materials. These two components need to have very precise relative locations. When a sealing edge of the lipseal and contact elements are positioned too far away from each other, insufficient or no electrical connection may be formed between the contacts and substrate during operation of the clamshell. At the same time, when the sealing edge is positioned too close to the contacts, the contacts may interfere with the seal and cause leakage into the peripheral region. For example, conventional contact rings are often made with multiple flexible "fingers" that are pressed in a spring-like action onto the substrate to establish an electrical connection as shown in the clamshell assembly of FIG. 2 (note cup 201, cone 203, and lipseal 212). Not only are these flexible fingers 208 very difficult to align with respect to the lipseal 212, they are also easily damaged during installation and difficult to clean if and when electrolyte gets into the periphery region.

[0024] As explained above, in an electroplating cell, electrical contact is made to the wafer around the wafer edge, and electroplating is carried out on the rest of the wafer. However, if the plating solution reaches the contacts, acid in the plating solution can corrode the metal seed layer on the wafer in the contact area, resulting in increased resistance irregularly distributed around the wafer and correspondingly lowering plating performance and increasing within wafer non-uniformity. Metal ions in solution can also plate out onto the contacts, reducing plating efficiency. In order to prevent seed corrosion and plating on the contacts, the area where contact is made is separated from the plating solution by a lipseal. Previously, it was thought that, unless there was gross damage to the lipseal (cracking, tearing, etc.), this was sufficient to completely isolate the contacts from the plating solution. However, recent investigation has shown that, when a wet wafer is placed onto the lipseal

(for example, as in a Sabre 3D advanced pretreatment process), a thin water layer remains between the lipseal and the wafer that acid in the plating solution can diffuse through to reach the contact area. At high temperatures and/or long plating times, this diffusion can occur to the extent that enough acid reaches the contact area to cause corrosion of the metal seed layer (seed corrosion). To address this problem, a wider lipseal has been designed to increase the distance the acid must diffuse over and correspondingly slow the rate of acid reaching the contact area. In this way, seed corrosion at the edge of the wafer is reduced, and plating uniformity is improved.

[0025] In the electroplating cell, the wafer to be plated is held in a cup, which makes electrical contact with the edge of the wafer in an area enclosed by a lipseal while exposing the rest of the wafer to the plating solution. The cup is partially immersed in the plating solution in the plating cell during plating. However, as explained above, acid can diffuse across a liquid film between the wafer and the lipseal fast enough to damage the metal seed layer on the wafer in the contact area.

[0026] According to an embodiment, a hardware design change has been implemented to increase the width of the lipseal (the width of a protrusion on the lipseal which seals against a wafer) to reduce the rate of acid diffusion through a liquid layer between the wafer and the lipseal. The increased width of the lipseal increases the diffusion distance and results in less acid reaching the contact area and thus less etching of the metal seed layer.

[0027] Lipseal width can be increased by either increasing the outer diameter of the protrusion of the lipseal, or by decreasing the inner diameter of the protrusion. The preferred implementation is to increase the outer diameter of the protrusion, as this does not reduce the area available for plating.

[0028] The shape of the protrusion on the lipseal can be extended to form a lipseal with a similarly-shaped cross section as previous designs, wherein the protrusion is simply elongated in the radial dimension. This is the preferred implementation. The lipseal can include a single contact surface in the form of an annular rim with cylindrical walls and a flat or angled surface which contacts a wafer.

[0029] Previously, the lipseal design for the Sabre 3D did not prevent appreciable acid diffusion into the contact area at higher temperatures or higher plating solution acid concentrations than present during past standard operating conditions (less than or equal to 35 °C, less than or equal to 140 grams per liter acid). An advantage of the wider lipseal is that adequate sealing can be provided in more demanding operating conditions such as above 35°C and/or at higher acid concentrations than 140 grams per liter acid.

[0030] In processing a wafer, when a wet wafer is placed on a lipseal, a thin water layer remains and acid can diffuse through this layer and reach the contact area and attack the metal seed layer on the wafer. To avoid this problem, the lipseal is configured to provide a

longer diffusion path for the acid and thus substantially increase the amount of time needed for etching to occur in the contact area. A longer diffusion path can be achieved through a wider lipseal (longer linear length).

[0031] Diffusion past the lipseal can be modeled as 1D diffusion with a constant source, which has the formula: $C/C_s = \text{erfc}(z/2\sqrt{Dt})$, wherein z is the width of the lipseal, D is the diffusion constant of the acid, t is time, C_s is the concentration of the acid at the source, C is the concentration of the acid at z , and erfc is the complementary error function. Thus, $2\sqrt{Dt}$, the diffusion length, can be estimated by knowing C , C_s , and z for a given condition, and can be used to find C as a function of z and C_s and $2\sqrt{Dt}$ can be expected to remain approximately constant as long as time, temperature, and the diffusing species remains the same.

[0032] For example, consider the case with $z = 0.020$ " and $C_s = 180$ g/L sulfuric acid: Under these conditions, C is estimated to be approx. 8-9 g/L after a 1.5h plating time, yielding $2\sqrt{Dt} \approx 0.014$ " and $2\sqrt{Dt}$ can be used to estimate post-plating sulfuric acid concentration at other lipseal widths, as shown in the graph depicted in FIG. 5. C reaches 1 g/L (approximate level at which negligible corrosion occurs over 1.5h) at approximately 0.028 inch lipseal width, and falls rapidly after that. A preferred lipseal width is at least 0.032 inch and more preferably at least about 0.034 inch.

[0033] FIG. 3 shows an embodiment of the lipseal 212 mounted on a cup 201 with electrical contacts 208 engaging an underside of a semiconductor substrate such as a wafer W. As shown in FIG. 4, the lipseal 212 includes an inner portion 218 having a protrusion 220 having an upper surface 220a in contact with an underside of the wafer W and an outer portion 230 having a rim 232 which engages a recess 201a in the cup 201. The protrusion 220 extends axially upward and has a width (measured radially between inner and outer cylindrical walls of the protrusion) sufficient to inhibit diffusion of acid in the plating solution from reaching the point of contact between the electrical contacts 208 and the wafer W. For processing a 300 mm diameter wafer, the width of the protrusion 220 can be at least about 0.032 inch, preferably at least about 0.034 inch. The lipseal 212 is preferably an integral piece made entirely of elastomeric material which is configured to mate with the cup 201. Thus, the lipseal 212 is a separate consumable part which can be easily replaced when desired.

[0034] FIGS. 6a-c are photos of the outer edges of wafers which were processed under different conditions. FIG. 6a shows a wafer which was plated without pre-wetting and because the lipseal provided an adequate seal which prevented acid from diffusion past it, the copper seed layer at the wafer's edge is not corroded. A scratch is visible on the copper seed layer which resulted from the electrical contact used during electroplating. FIG. 6b

shows a wafer which was plated with pre-wetting and a 0.028 inch wide lipseal which did not provide an adequate seal. The pre-wetting formed a water film between the wafer and lipseal which allowed acid to diffuse past it and corrode the copper seed layer at the wafer's edge. In FIG. 6b, the copper seed layer was severely corroded and only thick copper oxide (black) and tantalum barrier layer (silver) are visible. FIG. 6c shows a wafer which was plated with pre-wetting and a 0.034 inch wide lipseal which provided an adequate seal. Due to the wider lipseal which created a longer diffusion path, the copper seed layer suffered only minor corrosion as the copper seed layer is visible and a very thin layer of copper oxide on the surface of the copper seed layer creates a minor discoloration in the image.

[0035] In this specification, the word "about" is often used in connection with numerical values to indicate that mathematical precision of such values is not intended. Accordingly, it is intended that where "about" is used with a numerical value, a tolerance of $\pm 10\%$ is contemplated for that numerical value.

[0036] Although illustrative embodiments and applications of this invention are shown and described herein, many variations and modifications are possible which remain within the concept, scope, and spirit of the invention, and these variations would become clear to those of ordinary skill in the art after perusal of this application. Accordingly, the present embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

WHAT IS CLAIMED IS:

1. A lipseal for use in a lipseal assembly of an electroplating clamshell which engages and supplies electrical current to a semiconductor substrate during electroplating, the lipseal comprising an elastomeric body having an outer portion configured to engage a cup of the lipseal assembly and an inner portion configured to engage a peripheral region of the semiconductor substrate, the inner portion including a protrusion having a width in a radial direction sufficient to inhibit diffusion of acid in an electroplating solution used during the electroplating, the protrusion comprising an annular rim which extends completely around an inner periphery of the lipseal.
2. The lipseal of claim 1, wherein the width is between inner and outer walls of the protrusion and the width is at least about 0.032 inch.
3. The lipseal of claim 2, wherein the width is about 0.034 inch.
4. The lipseal of claim 1, wherein the outer portion includes a downwardly extending rim configured to be received in a recess of the cup.
5. The lipseal of claim 1, wherein an inner surface of the projection defines an inner diameter of the lipseal.
6. A method of electroplating a semiconductor substrate using the lipseal of claim 1, comprising supporting a pre-wet semiconductor substrate in an electroplating clamshell such that the protrusion of the lipseal contacts an outer periphery of the semiconductor substrate, and contacting an exposed surface of the semiconductor substrate inwardly of the protrusion with an electroplating solution.
7. The method of claim 6, wherein the projection has a width of about 0.034 inch.