

ELECTRO-DEPOSITING METAL LAYERS OF UNIFORM THICKNESS ON SEMICONDUCTING WAFERS

FIELD OF THE INVENTION

The invention is in the field of electroplating in general, and more particularly in the field of semiconductor wafer electroplating, as well as in other applications in which uniform layers of the plated metal or metal alloy are required.

BACKGROUND OF THE INVENTION

Electrodeposition is a well-known and widely used technique. It entails deposition of a metal or metal alloy from a solution onto a surface of an article by electrochemical action driven by an electric current. Electrodeposition is carried out by contacting an electrically-conductive surface, termed the substrate, with a solution of one or more metal salts and passing an electric current through the solution to the surface. The substrate surface is thus a cathode of an electrochemical cell. Metal cations from the solution are reduced at the substrate surface by electrons from the electric current so that a reduced metal or metal alloy deposits on the surface.

Electroplating of semiconductor wafers has become a routine procedure in semiconductor manufacturing. Plating procedures include backside metallization, in which the entire surface of the wafer is plated, and pattern plating, in which photo resist is applied to the surface of the wafer and only select, open areas of the resist are plated. Pattern plating is typically used to create bumps or pillars, electrical interconnections, or for flip chip interconnect applications. Commonly deposited metals include copper, gold and tin. The metal layers are required to be highly uniform over the surface of the wafer. Highly uniform layers are those that have a thickness coefficient of variation of less than 10%, preferably less than 5%. This requires plating equipment and procedures that provide very uniform current densities and very uniform solution agitation over the wafer surface.

SUMMARY OF THE INVENTION

An apparatus for the electrodeposition of metals or metal alloys on semiconductor wafers is provided. The apparatus includes a plating cell with an anode disposed within it. A cathode comprising a semiconductor wafer is positioned with the surface to be electroplated facing and in spaced-apart relation to the anode. A power supply provides electrical contact between the anode and the cathode. Electrical contact with the wafer is made via

a conducting ring formed to provide continuous contact with the edge of the wafer or via an electrically insulated conducting ring having uninsulated, conducting fingers that extend inwardly to make contact with the edge of the wafer, which is slightly smaller in diameter than the conducting ring.

The apparatus includes solution spraying means for delivering plating solution to the surface of the semiconductor wafer to be electroplated. The solution spraying means is disposed between the anode and the cathode. The solution spraying means includes at least one hollow cross bar but it could include 2, 3, 4, 5 or more hollow cross bars. The cross bar or cross bars are formed with a series of spaced-apart holes arranged in a line extending from one end or near one end of the cross bar to the other end or near the other end of the cross bar. The solution spraying means also includes a hollow support bar attached at one of its ends to the middle of the hollow cross bar to form a "T-bar" with the support bar being the vertical portion of the T and the hollow cross bar positioned at and on top of the top of the support bar such that the line of spaced-apart holes in the cross bar are directed at the cathode. Alternatively, the cross bar may be attached at one of its ends to the support bar forming an "L-bar" in the same manner and with the line of spaced-apart hole in the cross bar directed at the cathode. If there are more than two cross bars, the support bar is attached such that the cross bars radiate and extend at a right angle from the centrally positioned support bar toward the inner sides of the plating cell.

In this embodiment, the assembly includes means for propelling the solution delivery assembly about its axis. In a preferred embodiment, the means for propelling includes at least one pair of side holes in the hollow cross bar, one of the side hole pair being formed and positioned near the end of one side of the cross bar and the other one of the side hole pair being formed and positioned near the end of the opposite side of the cross bar. In alternative embodiments, the means for propelling the solution delivery assembly about its axis includes a separate motor that is functionally connected with the support bar and rotates the support bar about its axis, thereby causing the cross bars to rotate, spraying the surface of the semiconducting wafer to be plated with electroplating solution.

The apparatus may also include an electroplating solution holding tank for holding and circulating the electroplating solution into and out of the plating cell and the solution spraying means may also include a pump for pumping electroplating solution from the electroplating solution holding tank into the solution spraying means.

In a preferred embodiment, the solution spraying means rotates about a central axis to spray the surface of the semiconducting wafer to be plated with electroplating solution in

a repeated and continuous manner. In an alternate embodiment, the semiconducting wafer to be plated rotates about a central axis such that the electroplating solution is sprayed on the wafer by the stationary solution spraying means in a repeated and continuous manner. Electrical contact with the wafer is made via a conducting ring or conducting fingers which rotate with the wafer. In another embodiment both the wafer and the solution spraying means may rotate about a central axis.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional side view of the plating cell portion of the apparatus of the invention.

Figure 2 is a cross-sectional side view of the apparatus illustrated in Fig 1, positioned in an external tank and connected to a plating power supply and circulation pump.

Figure 3 is an expanded cross-sectional side view of the cathode mount portion of the apparatus of the invention.

Figure 4A is a top plan view of the apparatus of the invention including the optional cathode shield described infra.

Figure 4B is a cross-sectional side view of the apparatus shown in Figure 4A.

Figs. 5A-D are top plan views of various embodiments of the cross bar portion of the solution delivery assembly of the apparatus of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is an apparatus and method for forming uniform layers of a metal or metal alloy on a semiconductor wafer substrate by electro-deposition. A uniform layer, as defined herein, has a thickness coefficient of variation CV of less than 10%, and preferably less than 5%.

In one embodiment of the invention, a plating cell, 6, fabricated of an electrically insulating material, is provided. The plating cell is cylindrical in shape with an open top and a bottom having a central opening 9. An anode, 4, is positioned at the bottom of the plating cell. The anode is circular and has a diameter somewhat smaller than the inside diameter of the plating cell. The anode may be a dimensionally stable, insoluble electrode composed of platinized niobium, platinized titanium, or iridium oxide, or it may be a soluble electrode, copper for example. Choosing the proper anode for the electroplating of semiconducting wafers is within the skill in the art. Anode 4 is formed with a hole in its center. It is electrically

connected to the positive terminal of the power supply 14 via wire 18 insulated anode conducting ring 40 and titanium screws 42 as shown in Fig. 1.

In the embodiment illustrated herein, the plating cell is vertically positioned. The plating cell could also be positioned horizontally or even upside down, as one of skill in the art would appreciate, but this would complicate the loading and unloading of the cell.

The plating cell should have a diameter slightly smaller than the diameter of the semiconducting wafer. Flange 8 is mounted to the top of the plating cell. It provides a circumferential ledge on which the wafer is disposed. Cathode conducting ring 10 is electrically connected to the negative terminal of the power supply. A series of conductive spring fingers, 7, are mounted to cathode conducting ring 10 by screw 9, and make electrical contact with the edge exclusion area of the wafer, 2. Any number of conductive fingers 7 can be used, however, 4-8 fingers are typical. Alternatively, a continuous contacting ring could be used to make contact with the edge exclusion area of the wafer. It is advantageous that the conducting ring 10 is electrically insulated except where it makes contact with the conducting fingers.

As illustrated herein, cathode 2, i.e., the semiconducting wafer to be plated, is positioned with its face to be plated facing the anode. In one embodiment, the cathode may be held in a stationary position by a cathode mount, 8, that is positioned on the rim of plating cell 6. The cathode mount could also be mounted on the side of the cell near the top or in any other position as long as it is able to hold the cathode in its proper stationary position at the top of the plating cell. The cathode mount is shown in detail in Fig. 3. It comprises the mount itself, 8, which is fabricated of a non-electrically conductive material, most typically a polymer. Mount 8 is affixed to the top edge of the plating cell side wall and houses cathode conducting ring 10, which is fabricated from a metal, typically stainless steel, and to which conductive spring fingers 7 are attached via screws 9 as can best be seen in Fig. 4A. Rubber gasket 11 seals the inner portion of the cell from the cathode conducting ring, 10, and prevents solution from contacting it. Wafer 2 is held in place by disk 34, which is detachably affixed to mount 8 via retention clip 36, which is rotated to either retain or release disk 34 to allow loading and unloading of the wafer to the plating cell.

The power supply can be a DC power supply, or pulsed power supply, or a periodic pulsed reverse power supply. It is connected to the anode via wire 18 and to the cathode via wire 12.

The apparatus further include a solution spraying means, which in one embodiment comprises a solution delivery assembly which is composed of a hollow, tubular support bar,

20, and a hollow, tubular cross bar, 22, as shown in Figure 1. The tubular cross bar is mounted at its middle to one of the ends of the support bar and in perpendicular relation thereto. In this embodiment, the assembly therefore forms a T shaped structure. The other end of the support bar, the end not attached to the cross bar, is formed to fit into and extend through the hole in the anode and the hole in the opening in the bottom of the plating cell and into a plating cell manifold, 26, that is centrally mounted to the outer bottom of the plating cell. It is fitted into bearing assembly 25 that enables it to rotate about its vertical axis. Bearing assembly 25 comprises two ball bearing races disposed around the support bar and in the manifold as shown in Fig. 1.

The support bar is hollow and referred to and illustrated as tubular but it need not be circular in cross section. Any hollow shape will work as long as it performs the function of maintaining the cross bar in its proper position, which is in spaced-apart, horizontal relation to the cathode.

The cross bar 22 is hollow and is formed with a series of spaced-apart, solution spraying holes, 24, extending more or less from one end of the cross bar to the other end of the cross bar. The solution spraying holes are situated along the side of the cross bar facing the wafer and in a straight line as shown in Fig. 5. The cross bar is also formed with closed ends. Near each of the closed ends is at least one pair of cross bar side holes, 28. Each pair of cross bar side holes is positioned on the cross bar such that the pair straddles the top holes, i.e., one cross bar side hole of a pair is located on one side of the cross bar and the other cross bar side hole of the pair is located on the other side of the cross bar. See Fig. 5.

Like the support bar, cross bar 22 need not be circular in cross-section, i.e., round. It could be rectangular, square, triangular, oval - any shape that will still allow it to perform its function of spraying the surface of the semiconductor wafer to be plated with the plating solution. The height of solution delivery assembly is such that the cross bar is situated in close, spaced-apart relation to the cathode. The distance between the cross bar and the cathode should be in the range of about 5 to 50 mm. As shown, the cross bar is centrally mounted on the support bar so when the assembly rotates, the wafer is contacted with fluid from both halves of the cross bar.

The solution delivery assembly illustrated herein is exemplary. It is not required that the support bar be mounted to the middle of the cross bar to form a T-shaped structure as shown in Figure 5A. It can be mounted at the end to form an L-shaped structure as shown in Figure 5C. Alternatively, the assembly could comprise a support bar and three cross bars

mounted at one of their ends to the support bar as shown in Figure 5B or the assembly could comprise a support bare and four crossbars in a square or an "X" configuration as shown in Figure 5D.

Plating cell 6 is removably mounted in a plating solution holding tank, 1, as shown in Fig. 2. Acme thread 27 on manifold 26 threads into receiving port 17 which is fixed to the bottom of solution holding tank 1. Plating cell manifold 26 secures the plating cell in the holding tank and also serves as a conduit for the flow of the plating solution. Manifold 26 is connected to the outlet, 33, of a pump 32. The inlet, 31, of pump 32 is connected to the plating solution holding tank. Plating solution is pumped from the plating solution holding tank 1 into the pump through inlet 31. It exits the pump via outlet 33 and enters the plating cell via manifold 26. Solution exit holes 30 formed in the wall of plating cell 6 near its open top allow the plating solution to exit the plating cell and return to solution holding tank 1. Thus, the plating solution flows continuously through the assembly when in operation.

Plating solution is distributed from the plating solution holding tank to the plating cell via manifold 26 and the solution delivery assembly, 16. Solution from the conduit enters the support bar 20 of the solution delivery assembly 16, flows upward into cross bar 22 and flows out of the series of spaced-apart, solution exit holes 24 and onto the cathode. Solution exit holes 30 need to be located as close as possible to the wafer surface to prevent gas from being trapped on the wafer surface or to at least minimize the amount of trapped gas. Fluid also flows out of end holes 28 in the ends of cross-bar 22 and this forces solution delivery assembly 16 to rotate around its vertical axis. This results in a continuously rotating spray of plating solution impinging the cathode surface during plating.

In operation, the electroplating solution in plating solution holding tank 1 is pumped into plating cell 6 by pump 32 via manifold 26 and the support bar of solution delivery assembly 16. The solution flows upward from the bottom of the support bar into cross bar 22 and out of the solution delivery assembly via solution spraying holes 24 and end holes 28 into the plating cell. When plating cell 6 is filled with fluid, fluid flows out of the plating cell via plating cell solution exit holes 30 and back into plating solution holding tank 1. The force of the fluid flowing through the cross bar and out of the cross bar side holes 28 causes the solution delivery assembly to rotate about its vertical axis, which provides a continuously rotating spray of plating solution that contacts the stationary semiconductor wafer being plated as the fluid exits the series of holes in the cross bar. Alternatively, the solution delivery assembly may be formed without cross bar side holes and an external mechanical means may be employed to rotate the solution delivery assembly.

Optionally, the assembly includes an auxiliary shield 37 and/or a rotating shield 36 as shown in Fig. 4A. The purpose of the shields is to improve plating performance in terms of minimizing the thickness CV. Auxiliary shield 37 is composed of a circular disc shaped ring that can be mounted in the plating cell above or below the cross bar. The width of the shield can be determined experimentally by testing different widths and choosing the width that results in the smallest coefficient of variation. Our experiments have shown that the width of the auxiliary shield should be about 1 to about 2 cm. Triangular shield 36 is a flat, pie slice or triangularly shaped structure that is attached at it most acutely angled end to cross bar 22. In the embodiment in which the wafer is stationary and the solution spraying means rotates, the triangular shield rotates with the cross bar 22.

In an alternative embodiment, the semiconducting wafer is held in a rotating fixture and the solution spraying means is stationary. Electrical contact with the wafer is made via a conducting ring or fingers which rotate with the wafer. In this embodiment, the solution spraying means can be positioned in spaced-apart relation to the rotating wafer and supplied with fluid from the pump outlet, which can be positioned outside the tank.

In another alternative embodiment, the plating chamber may be situated outside of the plating solution reservoir. In this embodiment, solution exiting the plating chamber at openings 30 is collected by a trough which is fixed to the outside and upper perimeter of the plating chamber. The solution collected by this trough is connect via a pipe to a plating solution reservoir and flow by gravity from the trough to the reservoir. The solution from the reservoir may be supplied to the inlet of the plating chamber via a pump and piping. The present invention may be practiced with the plating chamber located either inside or outside of the solution reservoir tank.

I claim:

1. An apparatus for the electrodeposition of metals or metal alloys on semiconductor wafers comprising:
 - a plating cell;
 - an anode disposed within the plating cell;
 - a cathode comprising a semiconductor wafer positioned with the surface to be electroplated facing and in spaced-apart relation to the anode;
 - a power supply providing electrical contact between the anode and the cathode;
 - solution spraying means for delivering plating solution to the surface of the semiconductor wafer to be electroplated, the solution spraying means being disposed between the anode and the cathode, the solution spraying means comprising at least one hollow cross bar, the at least one hollow cross bar having a series of spaced-apart holes arranged in a line extending from one end or near one end of the cross bar to the other end or near the other end of the cross bar; and
 - means for rotating either the cathode or the solution spraying means about a central axis to spray the surface of the semiconducting wafer to be plated continuously and repeatedly as the cathode or the solution spraying means rotates.
2. The apparatus according to claim 1 wherein the apparatus further comprises an electroplating solution holding tank for holding and circulating electroplating solution into and out of the plating cell.
3. The apparatus according to claim 2 wherein the solution spraying means further comprises a pump positioned for pumping electroplating solution from the electroplating solution holding tank into the solution spraying means.
4. The apparatus according to claim 3 wherein the solution spraying means further comprises a hollow support bar attached at one of its ends to the middle of the hollow cross bar to form a T-bar with the support bar being the vertical portion of the T and the hollow cross bar positioned at the top of the support bar such that the line of spaced apart holes in the cross bar are directed at the cathode.
5. The apparatus according to claim 4 wherein the hollow cross bar includes means for propelling the solution delivery assembly about its axis.

6. The apparatus according to claim 5 wherein the means for propelling the solution delivery assembly about its axis includes at least one pair of side holes, one of the side hole pair being formed and positioned near the end of one side of the cross bar and the other

one of the side hole pair being formed and positioned near the end of the opposite side of the cross bar.

7. The apparatus according to claim 6 wherein the solution spraying means rotates about a central axis to spray the surface of the semiconducting wafer to be plated with electroplating solution in a repeated and continuous manner.

8. The apparatus according to claim 6 wherein the semiconducting wafer to be plated rotates about a central axis such that the electroplating solution is sprayed on the wafer by the solution spraying means in a repeated and continuous manner.

9. An apparatus for the electrodeposition of metals or metal alloys on semiconductor wafers comprising:

- a plating cell;

- an anode disposed within the plating cell;

- a cathode comprising a semiconductor wafer positioned with the surface to be electroplated facing and in spaced-apart relation to the anode;

- a power supply providing electrical contact between the anode and the cathode;

- solution spraying means for delivering plating solution to the surface of the semiconductor wafer to be electroplated, the solution spraying means being disposed between the anode and the cathode, the solution spraying means comprising at least one hollow cross bar, the at least one hollow cross bar having a series of spaced-apart holes arranged in a line extending from one end or near one end of the cross bar to the other end or near the other end of the cross bar; and

- means for rotating the solution spraying means about a central axis to spray the surface of the semiconducting wafer to be plated continuously and repeatedly as the solution spraying means rotates.

10. The apparatus according to claim 9 wherein the apparatus further comprises an electroplating solution holding tank for holding and circulating electroplating solution into and out of the plating cell.

11. The apparatus according to claim 10 wherein the solution spraying means further comprises a pump positioned for pumping electroplating solution from the electroplating solution holding tank into the solution spraying means.

12. The apparatus according to claim 11 wherein the solution spraying means further comprises a hollow support bar attached at one of its ends to the middle of the hollow cross bar to form a T-bar with the support bar being the vertical portion of the T and the hollow cross bar positioned at the top of the support bar such that the line of spaced apart holes in the cross bar are directed at the cathode.

13. The apparatus according to claim 12 wherein the hollow cross bar includes means for propelling the solution delivery assembly about its axis.

14. The apparatus according to claim 13 wherein the means for propelling the solution delivery assembly about its axis includes at least one pair of side holes, one of the side hole pair being formed and positioned near the end of one side of the cross bar and the other one of the side hole pair being formed and positioned near the end of the opposite side of the cross bar.

15. An apparatus for the electrodeposition of metals or metal alloys on semiconductor wafers comprising:

- a plating cell;

- an anode disposed within the plating cell;

- a cathode comprising a semiconductor wafer positioned with the surface to be electroplated facing and in spaced-apart relation to the anode;

- a power supply providing electrical contact between the anode and the cathode;

- solution spraying means for delivering plating solution to the surface of the semiconductor wafer to be electroplated, the solution spraying means being disposed between the anode and the cathode, the solution spraying means comprising at least one hollow cross bar, the at least one hollow cross bar having a series of spaced-apart holes arranged in a line extending from one end or near one end of the cross bar to the other end or near the other end of the cross bar; and

- means for rotating the cathode about a central axis to spray the surface of the semi-conducting wafer to be plated continuously and repeatedly as the cathode or the solution spraying means rotates.

16. The apparatus according to claim 15 wherein the apparatus further comprises an electroplating solution holding tank for holding and circulating electroplating solution into and out of the plating cell.

17. The apparatus according to claim 16 wherein the solution spraying means further comprises a pump positioned for pumping electroplating solution from the electroplating solution holding tank into the solution spraying means.

18. The apparatus according to claim 17 wherein the solution spraying means further comprises a hollow support bar attached at one of its ends to the middle of the hollow cross bar to form a T-bar with the support bar being the vertical portion of the T and the hollow cross bar positioned at the top of the support bar such that the line of spaced apart holes in the cross bar are directed at the cathode.

19. The apparatus according to claim 18 wherein the hollow cross bar includes means for propelling the solution delivery assembly about its axis.

20. The apparatus according to claim 19 wherein the means for propelling the solution delivery assembly about its axis includes at least one pair of side holes, one of the side hole pair being formed and positioned near the end of one side of the cross bar and the other one of the side hole pair being formed and positioned near the end of the opposite side of the cross bar.

21. An apparatus for the electrodeposition of metals or metal alloys on semiconductor wafers comprising:

- a plating cell;

- an anode disposed within the plating cell;

- a cathode comprising a semiconductor wafer positioned with the surface to be electroplated facing and in spaced-apart relation to the anode;

- a power supply providing electrical contact between the anode and the cathode;

- solution spraying means for delivering plating solution to the surface of the semiconductor wafer to be electroplated, the solution spraying means being disposed between the anode and the cathode, the solution spraying means comprising at least one hollow cross bar, the at least one hollow cross bar having a series of spaced-apart holes arranged in a line extending from one end or near one end of the cross bar to the other end or near the other end of the cross bar;

- means for rotating either the cathode or the solution spraying means about a central axis to spray the surface of the semiconducting wafer to be plated continuously and repeatedly as the cathode or the solution spraying means rotates; and

- wherein the solution spraying means further comprises a pump positioned for pumping electroplating solution from the electroplating solution holding tank into the solution spraying means.

22. The apparatus according to claim 21 wherein the apparatus further comprises an electroplating solution holding tank for holding and circulating electroplating solution into and out of the plating cell.

23. The apparatus according to claim 22 wherein the solution spraying means further comprises a hollow support bar attached at one of its ends to the middle of the hollow cross bar to form a T-bar with the support bar being the vertical portion of the T and the hollow cross bar positioned at the top of the support bar such that the line of spaced apart holes in the cross bar are directed at the cathode.
24. The apparatus according to claim 23 wherein the hollow cross bar includes means for propelling the solution delivery assembly about its axis.
25. The apparatus according to claim 24 wherein the means for propelling the solution delivery assembly about its axis includes at least one pair of side holes, one of the side hole pair being formed and positioned near the end of one side of the cross bar and the other one of the side hole pair being formed and positioned near the end of the opposite side of the cross bar.
26. A method of electroplating metals or metal alloys on semiconducting wafers comprising electrodepositing a metal or metal alloy on the semiconducting wafer using the apparatus according to claim 1.
27. A method of electroplating metals or metal alloys on semiconducting wafers comprising electrodepositing a metal or metal alloy on the semiconducting wafer using the apparatus according to claim 9.
28. A method of electroplating metals or metal alloys on semiconducting wafers comprising electrodepositing a metal or metal alloy on the semiconducting wafer using the apparatus according to claim 15.
29. A method of electroplating metals or metal alloys on semiconducting wafers comprising electrodepositing a metal or metal alloy on the semiconducting wafer using the apparatus according to claim 21.