The method generally includes filling features in a substrate by plating metal ions from a gap fill solution onto the substrate, reducing plating activity in the features in a polymer treatment step by conditioning the substrate surface with a conditioning solution, and plating the substrate surface to a desired thickness by plating metal ions from a bulk fill solution onto the substrate surface. The method may also include treating the substrate with a conditioning solution comprising suppressors after a seed layer deposition to substantially eliminate conformal deposition in features of the substrate and plating metal ions from a plating solution onto the substrate.
BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention generally relates to a method for plating a metal on a substrate, whereby feature overfill is reduced.

[0003] 2. Description of the Related Art

[0004] Metallization for sub-quarter micron sized features is a foundational technology for present and future generations of integrated circuit manufacturing processes. In devices such as ultra large scale integration-type devices, i.e., devices having integrated circuits with more than a million logic gates, the multilevel interconnects that lie at the heart of these devices are generally formed by filling high aspect ratio interconnect features with a conductive material, such as copper or aluminum, for example. Conventionally, deposition techniques such as chemical vapor deposition (CVD) and physical vapor deposition (PVD), for example, have been used to fill these interconnect features. However, as interconnect sizes decrease and aspect ratios increase, void-free interconnect feature fill via conventional metallization techniques becomes increasingly difficult. As a result thereof, plating techniques, such as electrochemical plating (ECP) and electrolysis plating, for example, have emerged as viable processes for filling sub-quarter micron sized high aspect ratio interconnect features in integrated circuit manufacturing processes.

[0005] In an ECP process, for example, sub-quarter micron sized high aspect ratio features formed into the surface of a substrate may be efficiently filled with a conductive material, such as copper. ECP plating processes are generally two stage processes, wherein a seed layer is first formed over the surface features of the substrate, and then the surface features of the substrate are exposed to an electrolyte solution while an electrical bias is simultaneously applied between the substrate and an anode positioned within the electrolyte solution. The electrolyte solution is generally rich in ions to be plated onto the surface of the substrate. Therefore, the application of the electrical bias causes these ions to be urged out of the electrolyte solution and to be plated onto the seed layer.

[0006] FIG. 1 (Prior Art) illustrates feature filling in a conventional electroplating process. Conventional electroplating fill processes generally include depositing a conformal layer 102 in the features 100, which generally lasts up to about 20 seconds. The conformal layer 102 is generally followed by bottom-up fill 104 to substantially fill the feature 100. However, one challenge associated with ECP processes is that the surface over the sub micron features 100 after filling may be higher than the field areas, i.e., the areas between the features. The uneven substrate topography occurs as a result of an accelerated feature growth rate that is achieved for bottom-up fill 104, as the accelerated feature growth generally continues beyond filling of the feature, thereby resulting in overspill 106, e.g., raised locations above the filled features.

[0007] The overspill is subsequently removed, such as by a planarization process, wherein the excess metal is removed from the entire surface of the substrate to form an even, planar surface. During the planarization process, a substantially uneven substrate topography may lead to substrate defects, such as excess shear and incompatibility with non-abrading removal processes, e.g., electropolishing and chemical dissolution. Therefore, there is a need for an apparatus and method for reducing feature overspill.

SUMMARY OF THE INVENTION

[0008] Embodiments of the invention generally relate to a method for plating metal onto a substrate. The method generally includes substantially filling features in the substrate by plating metal ions from a gap fill solution onto the substrate, reducing plating activity in the features prior to completely filling the features by conditioning the substrate with a conditioning solution.

[0009] Embodiments of the invention further include a method for plating a metal on a substrate. The method generally includes plating a substrate with metal ions from a gap fill solution to substantially fill features in the substrate, rinsing the substrate with a conditioning solution to substantially terminate plating activity in the features, and then plating the substrate with metal ions from a bulk fill solution.

[0010] Embodiments of the invention further include disposing a substrate in a plating cell containing a plating solution, applying an electrical current to the plating cell to substantially fill features in the substrate by plating metal ions from the plating fill solution onto the substrate, terminating an electrical current supplied to the plating cell for a time sufficient to allow diffusion of the plating solution to a point of equilibrium, and providing the electrical current to the plating cell to plate the substrate to a desired thickness.

[0011] Embodiments of the invention further include treating the substrate with a conditioning solution comprising suppressors after a seed layer deposition to substantially eliminate conformal deposition in features of the substrate, and plating metal ions from a plating solution onto the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the above-recited features of the present invention are obtained may be understood in detail, a more particular description of the invention briefly summarized above may be had by reference to the embodiments thereof, which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments of the invention, and are therefore, not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0013] FIGS. 1A-1C (Prior Art) illustrate conventional electroplating feature fill.

[0014] FIG. 2 illustrates a perspective view of an exemplary electroplating system.

[0015] FIG. 3 illustrates a cross sectional view of a cell for electroplating a metal onto a substrate.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0016] FIG. 2 illustrates a perspective view of an electroplating system 200 including a mainframe 214, an electro-
plating solution replenishing system 220, and a control system 222. The mainframe generally includes a thermal anneal chamber 211, a loading station 210, a spin rinse dry station 212, and a plurality of processing stations 218. The loading station 210 generally includes one or more substrate cassette receiving areas 224, generally known as pod loaders, one or more loading station transfer robots 228, and at least one substrate orientor 230. Each processing station 218 includes one or more processing cells 240.

[0017] The control system 222 may be a programmable microprocessor configured to interface with the various components of the system 200 and provide controlling signals thereto. The electroplating solution replenishing system 220 is positioned adjacent to the electroplating system 200 in fluid communication with the process cells 240 in order to circulate electroplating solution to the cells 240.

[0018] FIG. 3 illustrates a partial cross sectional schematic view of an exemplary electroplating cell 240 of the invention. The exemplary electroplating cell 240 may be used for all of the steps described in detail below, such as polymer treatment, gap fill, and bulk fill. In addition, other plating cells known to those skilled in the art may be used for any of the above steps. The electroplating cell 240 generally includes a container body 342 having an opening on a top portion of the container body 342 to receive and support a pivotally mounted lid 344. The container body 342 may be manufactured from an electrically insulative material, such as a plastic, Teflon, or ceramic, for example. The lid 344 serves as a top cover having a substrate supporting surface 346 disposed on the lower portion thereof. A substrate 348 is shown in parallel abutment to the substrate supporting surface 346, and may be secured in this orientation via conventional substrate chucking methods, such as vacuum chucking, for example. The container body 342 may be cylindrically shaped in order to accommodate a generally circular substrate 348 at one end thereof. However, other substrate shapes can be used as well.

[0019] An electroplating solution inlet 350 may be disposed at the bottom portion of the container body 342. An electroplating solution may be pumped into the container body 342 by a suitable pump 351 connected to the inlet 350. The solution may flow upwardly inside the container body 342 toward the substrate 348 to contact the exposed deposition surface 354. A consumable anode 356, for example, may be disposed in the container body 342 and configured to dissolve in the electroplating solution in order to provide metal particles to be deposited onto the substrate 348 to the plating solution. The anode 356 generally does not extend across the entire width of the container body 342, thus allowing the electroplating solution to flow between the outer surface of the anode 356 and the inner surface of the container body 342 to the deposition surface 354. Alternatively, an anode 356 consisting of an electrode and consumable metal particles may be encased in a fluid permeable membrane, such as a porous ceramic plate, to provide metal particles to be deposited onto the substrate to the plating solution. A porous non-consumable anode may also be disposed in the container body 342 so that the electroplating solution may pass therethrough. However, when a non-consumable anode is included, the electroplating solution may include a metal particle supply to continually replenish the metal particles to be deposited on the substrate 348.

[0020] The container body 342 generally includes an egress gap 358 bounded at an upper limit by a shoulder 364 of a cathode contact ring 352. The gap 358 generally leads to an annular weir 343 that is substantially coplanar with (or slightly above) the substrate seating surface 368, and thus, the deposition surface 354. The weir 343 is positioned to ensure that the deposition surface 354 is in contact with the electroplating solution when the electroplating solution is flowing out of the egress gap 358 and over the weir 343. During processing, the substrate 348 may be secured to the substrate supporting surface 346 of the lid 344 by a plurality of vacuum passages 360 formed in the surface 346, wherein passages 360 are generally connected at one end to a vacuum pump (not shown). The cathode contact ring 352, which is shown disposed between the lid 344 and the container body 342, may be connected to a power supply 349 to provide power to the substrate 348. The contact ring 352 generally has a perimeter flange 362 partially disposed through the lid 344, a sloping shoulder 364 conforming to the weir 343, and an inner substrate seating surface 368, which defines the diameter of the deposition surface 354. The shoulder 364 is provided so that the inner substrate seating surface 368 is located below the flange 362. This geometry allows the deposition surface 354 to come in contact with the electroplating solution before the solution flows into the egress gap 358 as discussed above. However, as noted above, the contact ring design may be varied from the design shown in FIG. 1 without departing from the scope of the present invention. Thus, the angle of the shoulder portion 364 may be altered or the shoulder portion 364 may be eliminated altogether so that the contact ring is substantially planar. Where a planar design is used, seals may be disposed between the contact ring 352, the container body 342 and/or the lid 344 to form a fluid tight seal therebetween.

[0021] The substrate seating surface 368 preferably extends a minimal radial distance inward below a perimeter edge of the substrate 348, but a distance sufficient to establish electrical contact with a metal seed layer on the substrate deposition surface 354. The exact inward radial extension of the substrate seating surface 368 may be varied according to application. However, in general this distance is minimized so that a maximum deposition surface 354 is exposed to the electroplating solution. In an exemplary embodiment, the radial width of the seating surface 368 may be between about 2 mm and about 5 mm from the edge of the substrate 348, for example.

[0022] In operation the contact ring 352 is negatively charged to act as a cathode and is configured to electrically communicate with the substrate 348. Therefore, as electroplating solution flows across the substrate surface 354, the ions in the electroplating solution are attracted to the surface 354 by the negative charge. The ions then plate the surface 354 and form the desired film. In addition to the anode 356 and the cathode contact ring 352, an auxiliary electrode 367 may be used to control the shape of the electrical field over the deposition surface 354. An auxiliary electrode 367 is shown disposed through the container body 342 adjacent an exhaust channel 369. By positioning the auxiliary electrode 367 adjacent to the exhaust channel 369, the electrode 367 is able to maintain contact with the electroplating solution during processing and affect the electrical field.

[0023] Substrates 348 generally include small scale, e.g., sub quarter micron, dense clusters of features. These features are typically about one micron deep and are generally separated by field, i.e., non-patterned, areas, which are typically tens of microns in width. Embodiments of the invention generally include a seed layer deposition step, one or more metal deposition steps, and a planarization step. The metal deposition steps include a gap fill step and a bulk fill
The gap fill step generally continues for a time sufficient to substantially fill the substrate features, utilizing methods known in the art for bottom-up fill. The bulk fill step generally follows the gap fill step and continues to plate the surface of the substrate to a desired level.

Embodiments of the invention generally employ copper plating solutions having copper sulfate at a concentration between about 5 g/L and about 100 g/L, an acid at a concentration between about 5 g/L and about 200 g/L, and halide ions, such as chloride, at a concentration between about 10 ppm and about 200 ppm. The acid generally includes sulfuric acid, phosphoric acid, and/or derivatives thereof. In addition to copper sulfate, the electroplating solution generally includes other copper salts, such as copper fluoride, copper gluconate, copper sulfamate, copper sulfonate, copper pyrophosphate, copper chloride, or copper cyanide.

The electroplating solution may further include one or more additives. Additives, which may be, for example, levelers, inhibitors, suppressors, brighteners, accelerators, or other additives known in the art, are typically organic materials that adsorb onto the surface of the substrate being plated. Useful suppressors typically include polyethylenes, such as polyethylene glycol, or other polymers, such as polypropylene oxides, which adsorb on the substrate surface, slowing down copper deposition in the adsorbed areas. Useful accelerators typically include sulfides or disulfides, such as bis(3-sulfopropyl) disulfide, which compete with suppressors for adsorption sites, accelerating copper deposition in adsorbed areas. Useful inhibitors typically include sodium benzoate and sodium sulfite, which inhibit the rate of copper deposition on the substrate. During plating, the additives are consumed at the substrate surface, but are being constantly replenished by the electroplating solution. However, differences in diffusion rates of the various additives result in different surface concentrations at the top and the bottom of the features, thereby setting up different plating rates in the features. Ideally, these plating rates should be higher at the bottom of the feature for bottom-up fill. Thus, an appropriate composition of additives in the plating solution is required to achieve a void-free fill of the features.

Generally, embodiments of the invention further include a polymer treatment step. The polymer treatment step generally operates to condition the substrate surface with a polymer, e.g., a conditioning solution, in order to reduce the plating activity over the features. The conditioning solution may include any combination of polymers capable of suppressing the plating activity, such as suppressors, including polyethylene and polypropylene. Alternatively, the conditioning solution may include deionized water in order to flush out the localized high concentration of accelerators at the feature openings.

The gap fill step and the bulk fill step may occur in separate processing cells, utilizing different plating solutions. For example, the gap fill solution may include accelerators and suppressors, while the bulk fill solution generally may include levelers and accelerators. In addition, the polymer treatment step may occur while the substrate is being transferred from a gap fill cell to a bulk fill cell. The substrate may be rinsed with the conditioning solution upon removal from the gap fill cell. The polymer treatment may alternatively occur in an intermediate polymer treatment cell containing the conditioning solution. An alternative embodiment may include maintaining a high suppressor concentration in the bulk fill cell, thereby removing the need for a separate polymer treatment step.

The gap fill step and the bulk fill steps may alternatively occur in the same processing cell. The polymer treatment step may comprise turning off the electrical current applied to the plating solution, upon completion of the gap fill step. The period of no current may last for a time sufficient to allow diffusion of the plating solution to a point of equilibrium, for example, from about 1 second to about 100 seconds. The deposition process within the features is generally controlled by diffusion of the reactants to the feature. Therefore, diffusion is significant in conformal plating and filling of the features. Reducing the additive diffusion in the feature thereby reduces the plating activity in the feature. As a result of the diffusion, the accelerators no longer dominate the reaction within the features, thereby reducing the areas of local high accelerator concentration at the features.

Alternatively, the plating solution may be drained from the cell upon completion of the gap fill step. The substrate may then be rinsed with the conditioning solution for a time sufficient to stop the accelerator reaction at the features. The substrate may be rinsed in a separate rinsing cell. Alternatively, the cell may be rinsed in the same cell if the cell volume is small. The cell may then be filled with a bulk fill solution that is different than the gap fill and conditioning solutions.

Although not wishing to be bound by theory, it is believed that conformal plating attributes to the time generally necessary for the additives to diffuse to the substrate surface. Therefore, to eliminate the effect of conformal plating and provide immediate bottom up fill, embodiments of the invention may, in addition to, or alternatively include a polymer pre-treatment step between a seed layer step and a metal plating step. The metal plating step is generally continuous when the polymer treatment step between the gap fill and bulk fill steps is not included. The polymer pre-treatment step may reduce the conformal deposition at the outset of plating. The polymer pre-treatment step may include conditioning the surface of the substrate with a suppressor rich solution either by rinsing or by soaking the substrate in a cell containing the suppressor rich conditioning solution. The cell may be the same cell as is used for the plating step, or, alternatively, may be a separate cell, whereby the substrate is transferred to the plating cell.

While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A method for plating metal onto a substrate, comprising:

   substantially filling features in the substrate by plating metal ions from a gap fill solution onto the substrate; and

   reducing plating activity in the features prior to completely filling the features and plating a surface of the substrate by conditioning the substrate surface with a conditioning solution.

2. The method of claim 1, further comprising plating the substrate with metal ions from a bulk fill solution.

3. The method of claim 1, wherein the conditioning solution comprises deionized water.

4. The method of claim 1, wherein the conditioning solution comprises suppressors.
5. The method of claim 1, wherein the gap fill solution comprises accelerators and suppressors.

6. The method of claim 1, wherein the reducing plating activity occurs during substrate transfer from a gap fill cell to a bulk fill cell by rinsing the substrate with the conditioning solution.

7. The method of claim 2, wherein the substrate is transferred from a gap fill cell to a conditioning cell and then to a bulk fill cell, wherein the bulk fill solution comprises levelers and accelerators.

8. The method of claim 2, wherein the bulk fill solution and the conditioning solution are contained in a bulk fill cell.

9. The method of claim 2, wherein the reducing plating activity comprises providing a period of no-current for a time sufficient to allow diffusion of the gap fill solution to form the bulk fill solution.

10. The method of claim 1, further comprising pre-treatment of the substrate with a solution comprising suppressors to substantially eliminate conformal deposition in the features prior to substantially filling the features.

11. A method for plating metal onto a substrate, comprising:

- disposing a substrate in a gap fill solution to substantially fill features in the substrate by plating metal ions onto the substrate;
- rinsing the substrate with a conditioning solution to substantially terminate plating activity in the features;
- transferring the substrate from the gap fill solution to a bulk fill solution; and then
- plating metal ions from the bulk fill solution onto the substrate.

12. The method of claim 11, wherein the conditioning solution comprises suppressors.

13. The method of claim 11, wherein the conditioning solution comprises deionized water.

14. The method of claim 11, wherein the gap fill solution comprises accelerators and suppressors.

15. The method of claim 11, wherein the bulk fill solution comprises levelers and accelerators.

16. A method for plating metal onto a substrate, comprising:

- disposing a substrate in a gap fill cell containing a gap fill solution to substantially fill features in the substrate by plating metal ions from the gap fill solution onto the substrate;
- transferring the substrate from the gap fill cell to a conditioning cell containing a conditioning solution to substantially terminate plating activity in the features; and
- transferring the substrate from the conditioning cell to a bulk fill cell containing a bulk fill solution to plate a surface of the substrate to a desired thickness by plating metal ions from the bulk fill solution onto the substrate surface.

17. The method of claim 16, wherein the conditioning solution comprises suppressors.

18. The method of claim 16, wherein the conditioning solution comprises deionized water.

19. The method of claim 16, wherein the gap fill solution comprises accelerators and suppressors.

20. The method of claim 16, wherein the bulk fill solution comprises levelers and accelerators.

21. A method for plating metal onto a substrate, comprising:

- disposing a substrate in a plating cell containing a gap fill solution to substantially fill features in the substrate by plating metal ions from the gap fill solution onto the substrate;
- draining the gap fill solution from the plating cell upon completion of substantially filling the features;
- rinsing the substrate with a conditioning solution;
- filling the plating cell with a bulk fill solution; and
- plating the surface for the substrate to a desired thickness by plating metal ions from the bulk fill solution onto the substrate.

22. The method of claim 21, wherein the conditioning solution comprises suppressors.

23. The method of claim 21, wherein the conditioning solution comprises deionized water.

24. The method of claim 21, wherein the gap fill solution comprises accelerators and suppressors.

25. The method of claim 21, wherein the bulk fill solution comprises levelers and accelerators.

26. A method for plating metal onto a substrate, comprising:

- disposing a substrate in a plating cell containing a plating solution;
- applying an electrical current to the plating cell to substantially fill features in the substrate by plating metal ions from the plating solution onto the substrate;
- terminating an electrical current supplied to the plating cell for a time sufficient to allow diffusion of the plating solution to a point of equilibrium; and then providing the electrical current to the plating cell to plate the substrate to a desired thickness.

27. A method for plating metal onto a substrate, comprising:

- treating the substrate with a conditioning solution comprising suppressors after a seed layer deposition to substantially eliminate conformal deposition in features of the substrate; and
- plating metal ions from a plating solution onto the substrate.