ELECTROLESS PLATING OF METAL CAPS FOR CHALCOGENIDE-BASED MEMORY DEVICES

The present invention relates to the field of electrochemical deposition, and more particularly to a method of electroless plating a metal cap over a conductive interconnect and to chalcogenide-based memory devices that include such structure.

The performance characteristics and reliability of integrated circuits have become increasingly dependent on the structure and attributes of the vias and interconnects which are used to carry electronic signals between semiconductor devices on integrated circuits or chips. Advances in the fabrication of integrated circuits have resulted in increases in the density, number of semiconductor devices contained on a typical chip, and speed. Interconnect structure and formation technology has not advanced as rapidly, and is increasingly becoming a limitation on the signal speed of integrated circuits.

Present-day, high-performance integrated circuits typically have multiple layers of metal conducting lines. These metal layers are separated by relatively thick, insulating layers of materials such as silicon dioxide. Vias are made through the insulating layers to make connections between the metal lines. It is often desirable that the metal conducting lines be maintained in as much of a plane as possible to avoid undue stresses on the metal lines. A tungsten metal plug is often used to fill the via in the insulating layer covering a first metal pad or line so that the overlying film remains on the planar surface of the insulating layer. Without the plug, the overlying film must dip into the via to make contact with the underlying first metal.

A layer of titanium (Ti) is typically placed in contact with the underlying first metal as an adhesion layer for the subsequent tungsten contacts. The via is then filled by depositing tungsten metal, typically by a chemical vapor deposition (CVD) process. When high aspect ratio vias are to be filled, tungsten deposited on the sidewalls of the via during the deposition process may pinch off

the opening, leaving a void termed a "keyhole" buried within the via. When excess tungsten from the CVD deposition process is removed, typically using a chemical-mechanical planarizing (CMP) process, the buried "keyholes" may be opened up, leaving exposed voids at the tops of the vias. Such voids adversely affect the subsequent formation of other layers and the electrical connections between layers.

Accordingly, the need still exists in the art for a process of providing metal-filled high aspect ratio vias that result in good electrical connections to subsequent layers of a fabrication process for semiconductor devices.

The present invention meets that need and provides a method of forming a metal cap over a conductive plug, via, or interconnect to cover or fill the keyhole in the plug, via, or interconnect and provide good electrical contact for subsequent layers in the semiconductor device. The metal cap is preferably formed of cobalt, silver, copper, gold, nickel, palladium, platinum, or alloys thereof. The metal cap is preferably formed by the electroless deposition of the metal over, for example, a tungsten plug or interconnect. Chalcogenide-based memory devices that employ the metal cap construction are also disclosed.

More particularly, in accordance with one aspect of the invention, a method of forming a metal cap over a conductive interconnect in a chalcogenide-based memory device is provided and includes forming a layer of a first conductive material over a substrate and depositing an insulating layer over the first conductive material and the substrate. An opening is formed in the insulating layer to expose at least a portion of the first conductive material, and a second conductive material is deposited over the insulating layer and within the opening. Portions of the second conductive material are removed to form a conductive area within the opening, and the conductive area is recessed within the opening to a level below an upper surface of the insulating layer. A cap of a third conductive material is formed over the recessed conductive area within the opening. A chalcogenide material is deposited over the cap, and a conductive material is deposited over the chalcogenide material to form the memory device.

The third conductive material is selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof. The cap of the third conductive material is preferably formed by electroless plating. Where an electroless plating process is used, the surface of the recessed conductive area may optionally be activated prior to electroless deposition of the third conductive material.

In another embodiment of the invention, a method of forming a metal cap over a conductive interconnect in a chalcogenide-based memory device is provided and includes providing an insulating layer over a substrate, the insulating layer having an opening therein and the opening exposing at least a portion of a first conductive material on the substrate. A second conductive material is deposited over the insulating layer and within the opening. Portions of the second conductive material are removed to form a conductive area within the opening, and the conductive area within the opening is recessed to a level below an upper surface of the insulating layer. A cap of a third conductive material is formed over the recessed conductive area within the opening. Preferably, the third conductive material is selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof. A stack of chalcogenide based memory cell material is deposited over the cap, and a conductive material is deposited over the chalcogenide stack.

In another embodiment of the invention, a method of forming a metal cap over a conductive interconnect in a chalcogenide-based memory device is provided and includes providing an insulating layer over a substrate, the insulating layer having an opening therein and the opening exposing at least a portion of a first conductive material on the substrate. A second conductive material is deposited over the insulating layer and within the opening. Portions of the second conductive material are removed to form a conductive area within the opening, and the conductive area within the opening is recessed to a level below an upper surface of said insulating layer. A cap of cobalt metal is formed over the recessed

conductive area. A stack of chalcogenide based memory cell material is deposited over the cap, and a conductive material is deposited over the chalcogenide stack.

In yet another embodiment of the invention, a method of forming a metal cap over a tungsten interconnect in a chalcogenide-based memory device is provided and includes forming a tungsten interconnect recessed within an opening in an insulating layer, and forming a metal cap over the recessed tungsten layer by electroless deposition of a metal. The metal is preferably selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof.

In yet another embodiment of the invention, a method of forming a conductive metal interconnect for a semiconductor circuit is provided and includes providing a semiconductor structure having semiconductor devices formed thereon, forming an insulating layer over the semiconductor structure, and forming a trench in the insulating layer down to the semiconductor structure. The trench is substantially filled with tungsten, and the tungsten is recessed to a level below the upper surface of the insulating layer. A metal cap is electrolessly deposited over the recessed tungsten. Preferably, the metal cap comprises a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof.

In yet another embodiment of the invention, a conductive interconnect for a chalcogenide-based memory device is provided and includes an insulating layer having an opening therein on a semiconductor substrate, a recessed tungsten layer in the opening, and an electrolessly deposited metal cap on the tungsten layer. The metal cap preferably comprises a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof. A stack of chalcogenide based memory cell material is over the cap, and a conductive material is over the chalcogenide stack.

In yet another embodiment of the invention, a processor-based system is provided and includes a processor and a chalcogenide-based memory device coupled to the processor. The chalcogenide-based memory device comprises an insulating layer having an opening therein on a semiconductor substrate, a recessed tungsten layer in the opening, and an electrolessly deposited metal cap on the tungsten layer. The metal cap preferably comprises a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof. A stack of chalcogenide based memory cell material is over the cap, and a conductive material is over the chalcogenide stack.

Accordingly, it is a feature of the present invention to provide a method of forming a metal cap over a conductive plug, via, or interconnect to both protect the conductive plug, via, or interconnect and provide good electrical contact for subsequent layers in the semiconductor device. It is also a feature of the present invention to provide chalcogenide-based memory devices that employ the metal cap construction. These and other features and advantages of the invention will be more apparent from the following detailed description, which is provided in connection with the accompanying drawings, which illustrate exemplary embodiments of the invention.

FIG. 1 is a cross-sectional view of an example of a portion of a partially fabricated chalcogenide-based memory device including metal 1 layers on a substrate surface in accordance with an embodiment of the invention;

FIG. 2 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device including an insulating layer over the surface of the substrate;

FIG. 3 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device including openings formed in the insulating layer;

FIG. 4 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device that includes an optional conformal adhesion layer;

FIG. 5 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device that includes a conductive material filling the openings in the insulating layer;

FIG. 6 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device in which excess conductive material has been removed;

FIG. 7 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device in which the surface of the conductive material has been recessed below the upper surface of the insulating layer;

FIG. 8 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device that includes a cap of a conductive material on the conductive material filling the opening;

FIG. 9 is a cross-sectional view of a portion of a partially fabricated chalcogenide-based memory device in which a stack of chalcogenide based memory cell material is positioned over the cap, and a layer of another conductive material is positioned over the chalcogenide based memory cell stack; and

FIG. 10 illustrates a processor system having one or more chalcogenide-based memory devices according to additional embodiments of the present invention.

It is observed that the process steps and structures described herein do not form a complete process flow for manufacturing integrated circuits. Embodiments of the present invention can be practiced in conjunction with a variety of integrated circuit fabrication techniques currently used in the art. As such, commonly practiced process steps are included in the description herein only if those steps are necessary for an understanding of the invention.

The term "substrate" as used herein may include any semiconductor-based structure that has an exposed semiconductor surface. The

term includes structures such as, for example, silicon, silicon-on insulator (SOI), silicon-on sapphire (SOS), doped and undoped semiconductors, epitaxial layers of silicon supported by a base semiconductor foundation, and other semiconductor structures. The semiconductor need not be silicon-based. The semiconductor may be silicon-germanium, or germanium. When reference is made to a "substrate" herein, previous process steps may have been utilized to form regions or junctions in or on the base semiconductor or foundation. As used herein, the term "over" means formed above a surface of an underlying layer or substrate.

Referring now to the drawings, where like elements are designated by like reference numerals, FIGS. 1 through 9 illustrate an exemplary embodiment of a method of fabricating a chalcogenide-based memory device having at least one interconnect that includes a metal cap. The process begins subsequent to the formation of the integrated circuit structure 10. However, the process may be applied at any level of integrated circuit fabrication. For purposes of simplification, this embodiment of the invention is described with reference to an upper metalization layer.

FIGS. 1 through 9 illustrate a partially-fabricated integrated circuit structure 10 having a base substrate 11 and a plurality of fabricated layers collectively shown by 13. A series of conductive areas 21 which are electrically connected to one or more layers or devices in the circuit below are formed on the circuit structure by conventional techniques. Although not shown, it is to be understood that the integrated circuit structure 10 may contain transistors, capacitors, word lines, bit lines, active areas, or the like fabricated in layer 13 over substrate 11.

As shown in FIG. 2, an insulating layer 20 is provided over structure 10. Insulating layer 20 preferably comprises tetraethylorthosilicate (TEOS) or other dielectric material such as, for example, borophosphosilicate glass (BPSG), borosilicate glass (BSG), or other non-conductive oxides (doped or undoped), nitrides, and oxynitrides. Insulating layer 20, which may itself be formed of multiple layers, is preferably from about 5,000 to about 20,000 Angstroms in

thickness. As shown in Fig. 3, at least some of the openings 22 are provided at locations where interconnects will electrically communicate with conductive areas 21 provided in the uppermost portion of structure 10.

Referring again to FIG. 3, a plurality of openings such as interconnect trenches 22 are patterned and etched in insulating layer 20. Openings 22 are aligned to expose portions of conductive areas 21. As shown in Fig. 4, an optional adhesion layer 24 is deposited over the surface of structure 10 so that it conformally covers insulating layer 20 and lines interconnect trenches 22. Optional adhesion layer 24 may be used, as is conventional in the art, to improve the bond between conductive areas 21 and subsequently deposited conductive materials. Depending on the materials used in the fabrication of the device, there will be instances where no adhesion layer 24 is necessary.

Optional adhesion layer 24 is preferably formed of a refractory metal such as titanium (Ti). As shown in FIG. 4, in one embodiment, an optional thin Ti film 24 may be deposited using physical vapor deposition (PVD), chemical vapor deposition (CVD), or atomic layer deposition (ALD). However, any suitable material may be used for the adhesion layer, for example, tungsten-nitride, tungsten-tantalum, tantalum silicon nitride, or other ternary compounds. Optional adhesion layer 24 is preferably between about 100 Angstroms to about 500 Angstroms thick, and more preferably about 200 Angstroms thick.

Referring now to FIG. 5, a conductive interconnect material, preferably comprising tungsten, is formed over the structure 10 and in the interconnect trenches 22. The conductive interconnects 30 may be formed using any technique that is conventional in this art including, for example, CVD or ALD techniques. Both techniques result in a conformal fill of trenches 22. However, depending on the aspect ratio and width of the trenches, such conformal deposition techniques may result in keyhole formation within the tungsten plug. Typically, the interconnects 30 will have a thickness of from about 1,000 to about 5,000 Angstroms, and preferably about 2,000 Angstroms. Referring now to FIG. 6, excess material from conductive interconnects 30 is removed. Typically, such

material is removed using chemical-mechanical planarization (CMP) techniques that are well known in the art. Desirably, the removal of excess material is stopped substantially level with an upper surface 25 of insulating layer 20.

Referring now to FIG. 7, conductive interconnect 30 is further planarized or over-polished to create a dish or recess for a suitable distance below the upper surface 25 of insulating layer 20. Any suitable method for recessing the interconnect material may be used. For example, conductive interconnect 30 may be selectively over-polished, chemical mechanically planarized, wet etched, or dry etched to recess the interconnect material within the trenches 22 and below the surface of insulating layer 20. Typically, a recess of from about 200 to about 500 Angstroms is preferred.

In one embodiment, the recessed surface of interconnect material 30 may be optionally activated to render that surface selective to the metal plating to follow. However, in some embodiments, those persons skilled in this art will recognize that surface activation is not necessary. Surface activation may be accomplished using a number of techniques. Preferably, the surface is activated by exposure to any activation solution known in the art of electroless plating such as, for example, a palladium chloride solution. A typical time frame for surface exposure may be for from about 10 seconds to about two minutes depending upon the particular activation solution that is selected.

Referring now to FIG. 8, metal is then selectively deposited into the recesses using an electroless plating process. The metal layers formed in the recesses may comprise any suitable metal which is compatible with adjacent materials in the semiconductor structure. Preferably the metal layers comprise cobalt, silver, gold, copper, nickel, palladium, platinum, or alloys thereof. Most preferably, the metal comprises cobalt because cobalt is readily available and provides a fine grain structure which promotes a smoother surface for subsequent processing.

Preferably, metal caps having a thickness of from about 200 to about 500 Angstroms are formed. By controlling the rate of plating of the caps,

one can produce caps that are substantially co-planar with the upper surface of insulating layer 20. Where excess metal is plated over the substrate, the excess may be removed by conventional processing methods such as planarization of the structure shown in FIG. 8 to isolate the metal layer into individual metal caps 40 as shown. The FIG. 8 structure may then be further processed to create a functional circuit.

As shown in Fig. 9, a memory device is formed by depositing a stack of suitable chalcogenide materials 50 over insulating layer 20 and metal caps 40. The chalcogenide material may be formed from a chalcogenized glass such as Ge_3Se_7 Ge_4Se_6 which are capable of forming conductive paths for diffused metal ions such as silver in the glass in the presence of an applied voltage. A second conductive electrode 60 is deposited over chalcogenide stack 50 to complete the formation of the memory device. An example of a nonvolatile memory device is shown in Moore and Gilton, U.S. Patent No. 6,348,365. By "stack," we mean one or more layers of chalcogenide glass material, including diffused metal ions, sufficient to form a memory cell.

Referring now to FIG. 10, a typical chalcogenide-based memory system 400 is shown which includes an integrated circuit 448. Integrated circuit 448 employs a conductive interconnect and chalcogenide-based memory fabricated in accordance with one or more embodiments of the invention. A processor system, such as a computer system, generally comprises a central processing unit (CPU) 444, such as a microprocessor, a digital signal processor, or other programmable digital logic devices, which communicates with an input/output (I/O) device 446 over a bus 452. The chalcogenide-based memory in integrated circuit 448 communicates with the system over bus 452 typically through a memory controller.

In the case of a computer system, the system may include peripheral devices such as a floppy disk drive 454 and a compact disc (CD) ROM drive 456, which also communicate with CPU 444 over the bus 452. Integrated circuit 448 may include one or more conductive interconnects and chalcogenide-based

memory devices. If desired, the integrated circuit 448 may be combined with the processor, for example CPU 444, in a single integrated circuit. Other examples of devices and systems which may include chalcogenide-based memory devices include clocks, televisions, cellular telephones, automobiles, aircraft, and the like.

It will be apparent to those skilled in the art that various changes may be made without departing from the scope of the invention which is not considered limited to the specific embodiments described in the specification and drawings, but is only limited by the scope of the appended claims.

What is claimed is:

1. A method of forming a metal cap over a conductive interconnect in a chalcogenide-based memory device comprising, forming a layer of a first conductive material over a substrate, depositing an insulating layer over said first conductive material and said substrate, forming an opening in said insulating layer to expose at least a portion of said first conductive material, depositing a second conductive material over said insulating layer and within said opening, removing portions of said second conductive material to form a conductive area within said opening, recessing said conductive area within said opening to a level below an upper surface of said insulating layer, forming a cap of a third conductive material over the recessed conductive area within said opening, said third conductive material selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof, depositing a stack of a chalcogenide based memory cell material over said cap, and depositing a conductive material over said chalcogenide stack.

2. A method as claimed in claim 1 in which said third conductive material comprises cobalt.

3. A method as claimed in claim 1 in which said third conductive material comprises silver.

4. A method as claimed in claim 1 in which said third conductive material comprises gold.

5. A method as claimed in claim 1 in which said third conductive material comprises copper.

6. A method as claimed in claim 1 in which said third conductive material comprises nickel.

7. A method as claimed in claim 1 in which said third conductive material comprises palladium.

8. A method as claimed in claim 1 in which said third conductive material comprises platinum.

9. A method as claimed in claim 1 in which said second conductive material comprises tungsten.

10. A method as claimed in claim 1 including removing portions of said cap to planarize said cap.

11. A method as claimed in claim 1 in which said cap is formed to have a thickness of from about 200 to about 500 angstroms.

12. A method as claimed in claim 1 in which said insulating layer is selected from the group consisting of borophosphosilicate glass, tetraethylorthosilicate glass, and silicon nitride.

13. A method as claimed in claim 1 wherein said cap of third conductive material is formed by electroless plating.

14. A method as claimed in claim 13 including activating the surface of the recessed conductive area.

15. A method as claimed in claim 1 including the step of depositing a refractory metal or refractory metal nitride layer in said opening prior to the deposition of said second conductive material.

16. A method as claimed in claim 15 in which said refractory metal comprises titanium.

17. A method as claimed in claim 15 in which said refractory metal nitride comprises titanium nitride.

18. A method of funning a metal cap over a conductive interconnect in a

chalcogenide-based memory device comprising, providing an insulating layer over a substrate, said insulating layer having an opening therein, said opening exposing at least a portion of a first conductive material on said substrate, depositing a second conductive material over said insulating layer and within said opening, removing portions of said second conductive material to form a conductive area within said opening, recessing said conductive area within said opening to a level below an upper surface of said insulating layer, forming a cap of a third conductive material over the recessed conductive area within said opening, said third conductive material selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof, depositing a stack of a chalcogenide based memory cell material over said cap, and depositing a conductive material over said chalcogenide stark.

19. A method of forming a metal cap over a conductive interconnect in a chalcogenide-based memory device comprising, providing an insulating layer over a substrate, said insulating layer having an opening therein, said opening exposing at least a portion of a first conductive material on said substrate, depositing a second conductive material over said insulating layer and within said opening, removing portions of said second conductive material to form a conductive area within said opening, recessing said conductive area within said opening to a level below an upper surface of said insulating layer, forming a cap of a cobalt metal over said recessed conductive area, depositing a stack of a chalcogenide based memory cell material over said cap, and depositing a conductive material over said chalcogenide stack.

20. A method as claimed in claim 19 including removing portions of said cap to planarize said cap.

21. A method as claimed in claim 19 wherein said cap of cobalt metal is fanned by electroless plating.

22. A method as claimed in claim 21 including the step of activating the surface of the recessed conductive area.

23. A method of forming a metal cap over a tungsten interconnect in a chalcogenide-based memory device comprising, forming a tungsten interconnect recessed within an

opening in an insulating layer, and forming a metal cap over said recessed tungsten layer by electroless deposition of a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof.

24. A method as claimed in claim 23 in which said metal comprises cobalt.

25. A method as claimed in claim 23 in which said metal comprises silver.

26. A method as claimed in claim 23 in which said metal comprises gold.

27. A method as claimed in claim 23 in which said metal comprises copper.

28. A method as claimed in claim 23 in which said metal comprises nickel.

29. A method as claimed in claim 23 in which said metal comprises palladium.

30. A method as claimed in claim 20 in which said metal comprises platinum.

31. A method as claimed in claim 23 including activating the surface of the recessed tungsten layer.

32. A method as claimed in claim 23 including removing portions of said cap to planarize said cap.

33. A method of forming a conductive metal interconnect for a semiconductor circuit comprising, providing a semiconductor structure having semiconductor devices formed thereon, forming an insulating layer over said semiconductor structure, forming a trench in said insulating layer down to said semiconductor structure exposing at least a portion of said semiconductor devices, substantially filling said trench wit tungsten, recessing said tungsten to a level below the upper surface of said insulating layer, and electrolessly depositing a metal cap over the recessed tungsten, said metal cap comprising a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof, depositing a stack of a chalcogenide

based memory cell material over said cap, and depositing a conductive material over said chalcogenide stack.

34. A method as claimed in claim 33 in which said metal comprises cobalt.

35. A method as claimed in claim 33 in which said metal comprises silver.

36. A method as claimed in claim 33 in which said metal comprises gold.

37. A method as claimed in claim 33 in which said metal comprises copper.

38. A method as claimed in claim 33 in which said metal comprises nickel.

39. A method as claimed in claim 33 in which said metal comprises palladium.

40. A method as claimed in claim 33 in which said metal comprises platinum.

41. A method as claimed in claim 33 including activating the surface of the recessed tungsten prior to electrolessly depositing said metal cap.

42. A method as claimed in claim 33 including removing portions of said cap to planarize said cap.

43. A conductive interconnect for a chalcogenide-based memory device comprising, an insulating layer having an opening therein on a semiconductor substrate, a recessed tungsten layer in said opening, an electrolessly deposited metal cap on said tungsten layer, said metal cap comprising a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof, a stack of a chalcogenide based memory cell material over said cap, and a conductive material over said chalcogenide stack.

44. A conductive interconnect as claimed in claim 43 in which said metal comprises cobalt.

45. A conductive interconnect as claimed in claim 43 in which said metal comprises silver.

46. A conductive interconnect as claimed in claim 43 in which said metal comprises gold.

47. A conductive interconnect as claimed in claim 43 in which said metal comprises copper.

48. A conductive interconnect as claimed in claim 43 in which said metal comprises nickel.

49. A conductive interconnect as claimed in claim 43 in which said metal comprises palladium.

50. A conductive interconnect as claimed in claim 43 in which said metal comprises platinum.

51. A conductive interconnect as claimed in claim 43 in which said metal cap is planarized to be coplanar with an upper surface of said insulating layer.

52. A processor-based system comprising a processor, and a chalcogenide-based memory device coupled to said processor, said chalcogenide-based memory device comprising an insulating layer having an opening therein on a semiconductor substrate, a recessed tungsten layer in said opening, an electrolessly deposited metal cap on said tungsten layer, said metal cap comprising a metal selected from the group consisting of cobalt, silver, gold, copper, nickel, palladium, platinum, and alloys thereof, a stack of a chalcogenide based memory cell material over said cap, and a conductive material over said chalcogenide stack.

53. A system as claimed in claim 52 in which said metal comprises cobalt.

54. A system as claimed in claim 52 in which said metal comprises silver.

55. A system as claimed in claim 52 in which said metal comprises gold.

56. A system as claimed in claim 52 in which said metal comprises nickel.

57. A system as claimed in claim 52 in which said metal comprises copper.

58. A system as claimed in claim 52 in which said metal comprises palladium.

59. A system as claimed in claim 48 in which said metal comprises platinum.

60. A system as claimed in claim 52 in which said metal cap is planarized to be coplanar with an upper surface of said insulating layer.