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(54) **INTERCONNECT WITH RECESSED DIELECTRIC ADJACENT A NOBLE METAL CAP**

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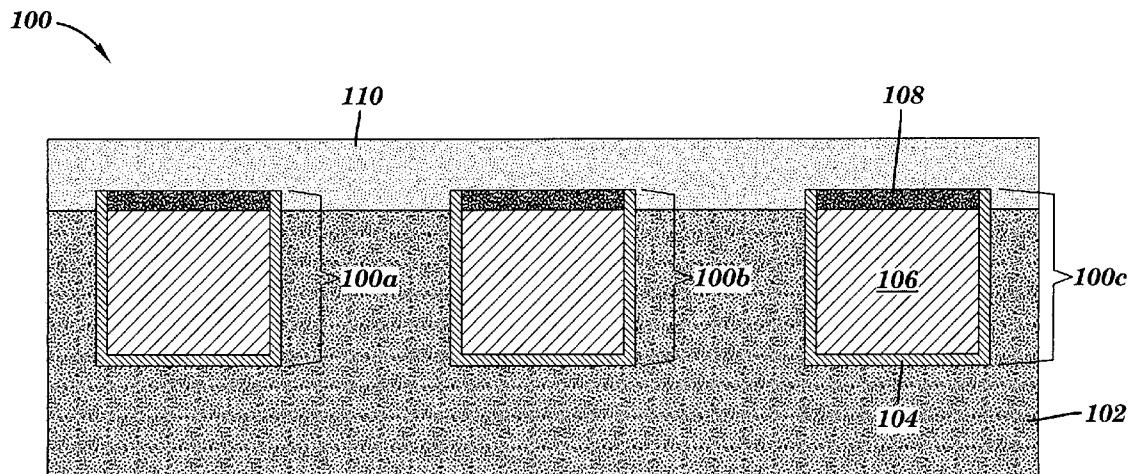
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(57) **ABSTRACT**

The invention comprises a copper interconnect structure that includes a noble metal cap with dielectric immediately adjacent the copper/noble metal cap interface recessed from the noble metal cap.

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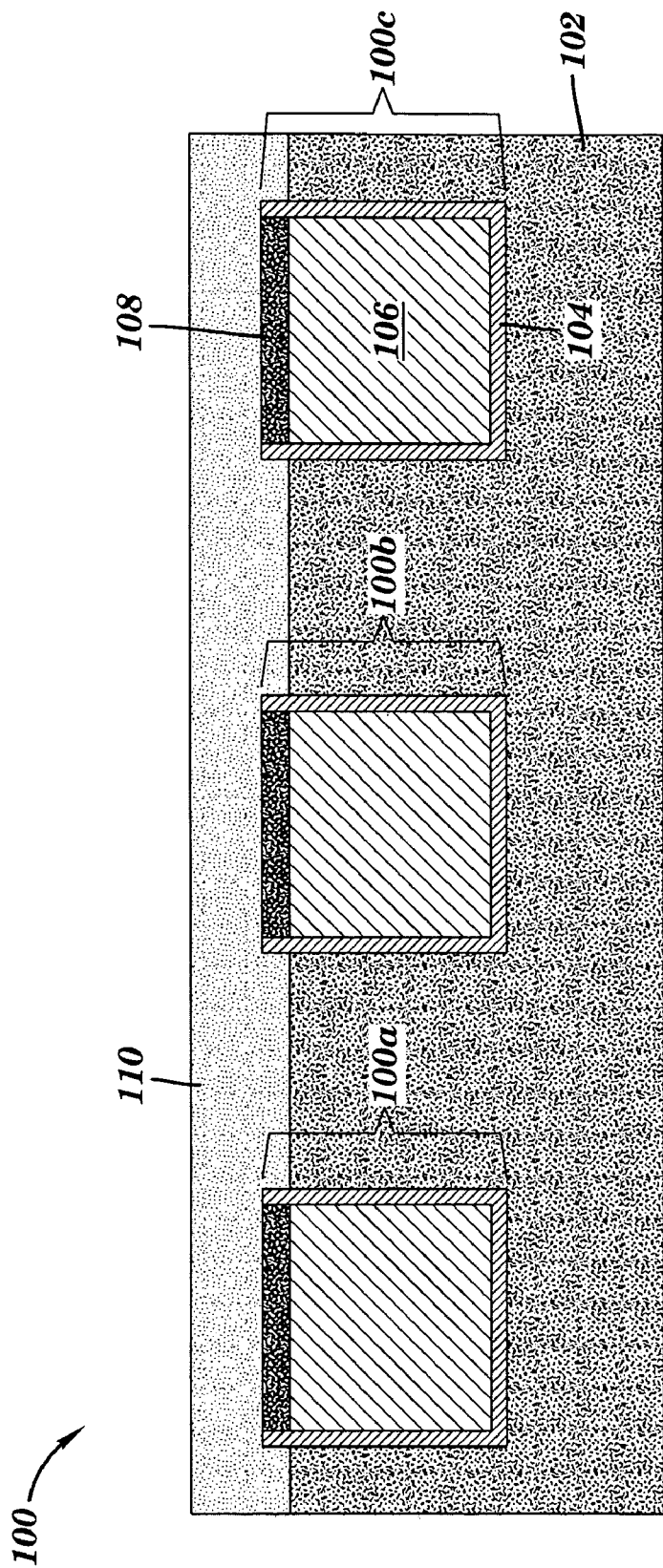


FIG. 1

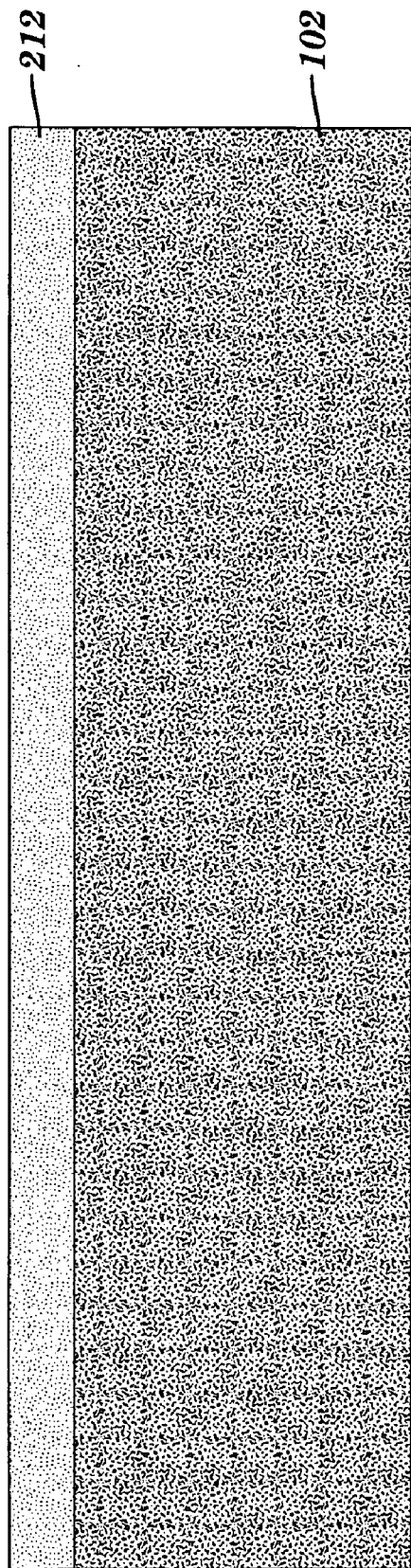


FIG. 2A

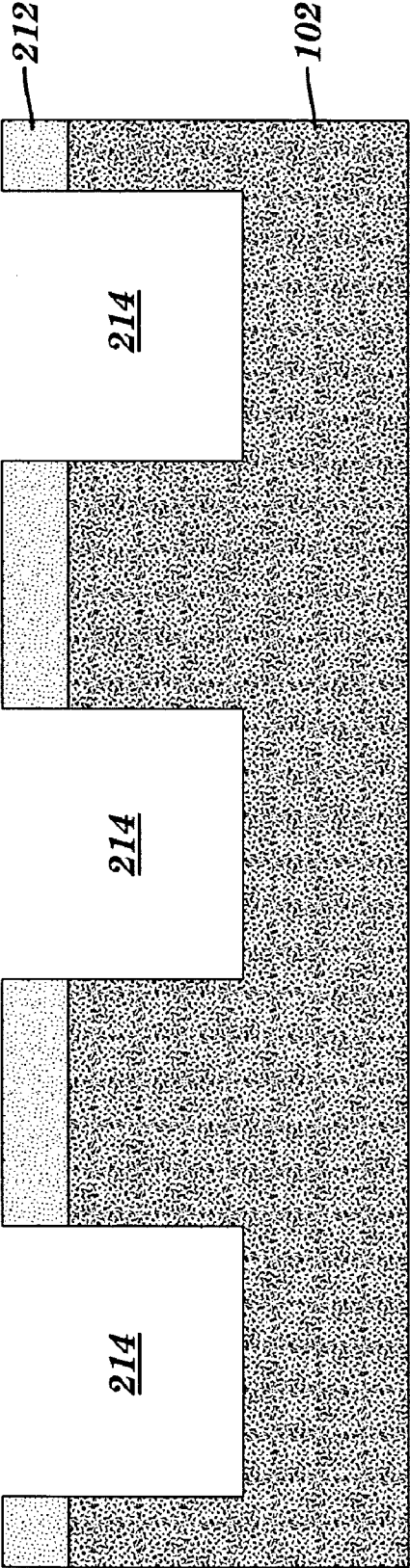


FIG. 2B

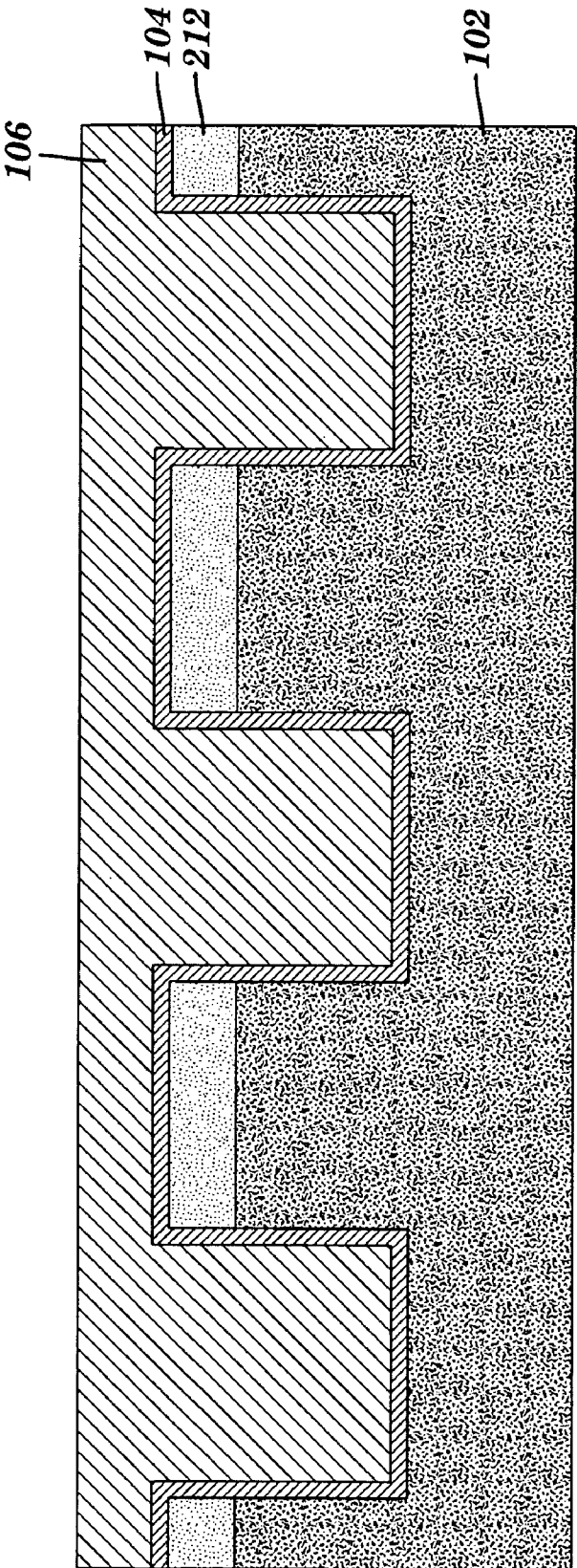


FIG. 2C

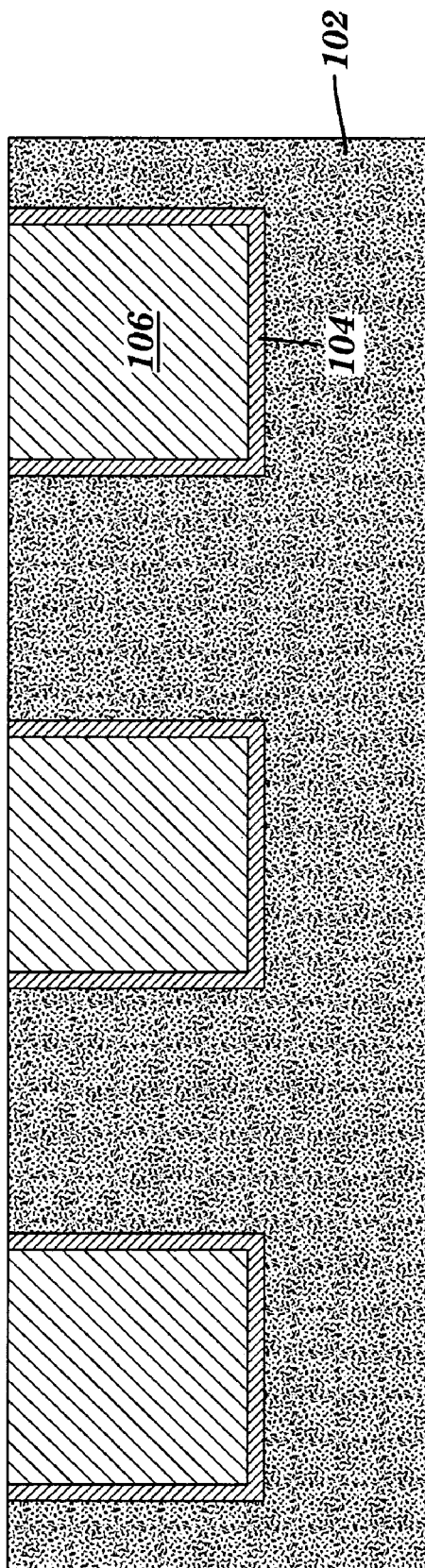


FIG. 2D

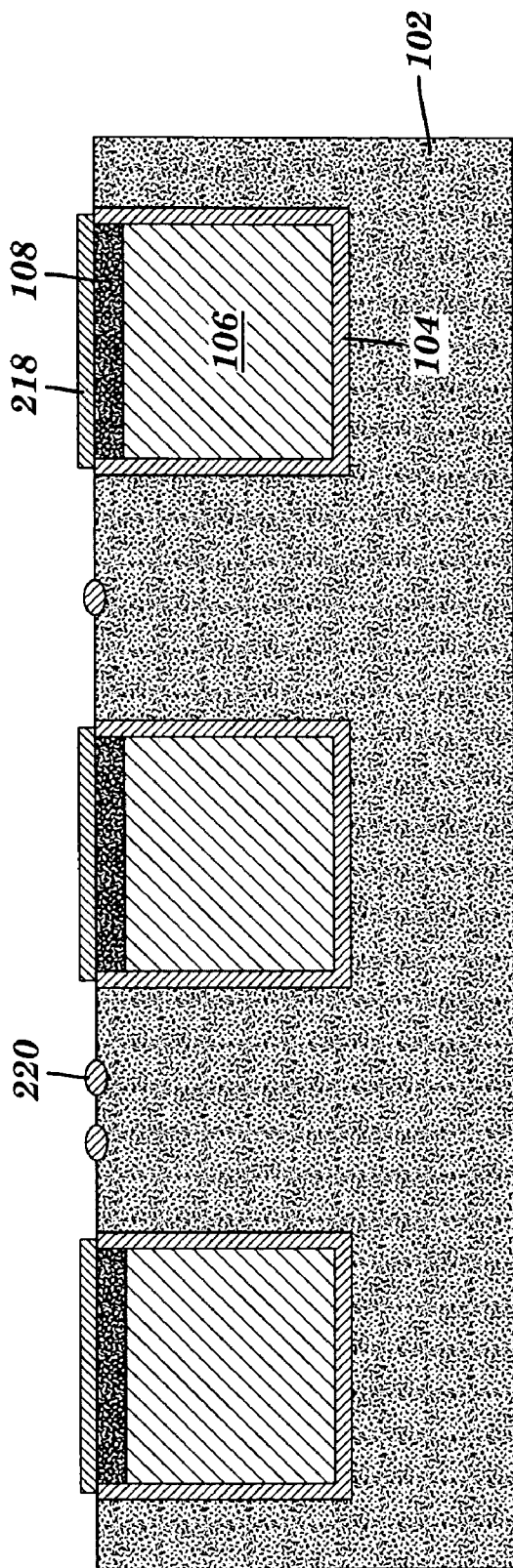


FIG. 2E

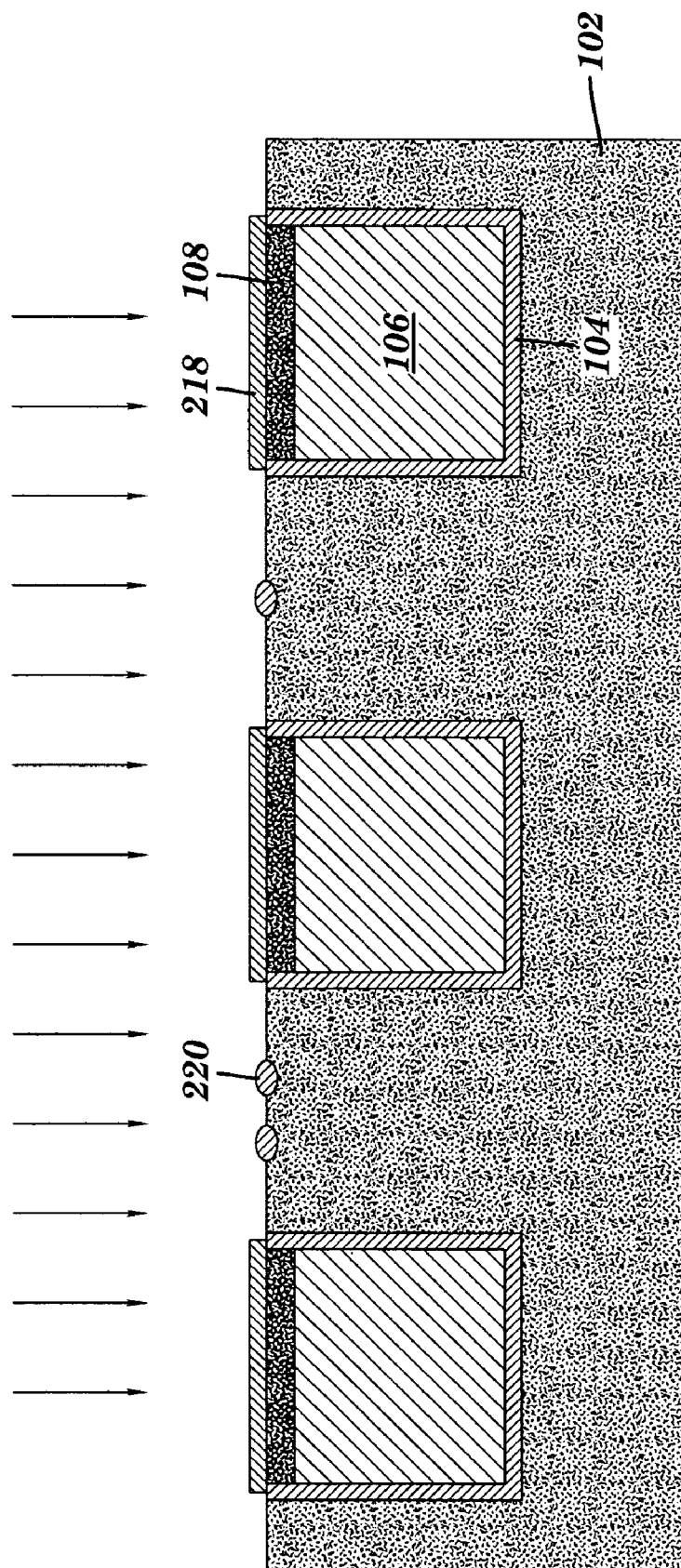


FIG. 2F

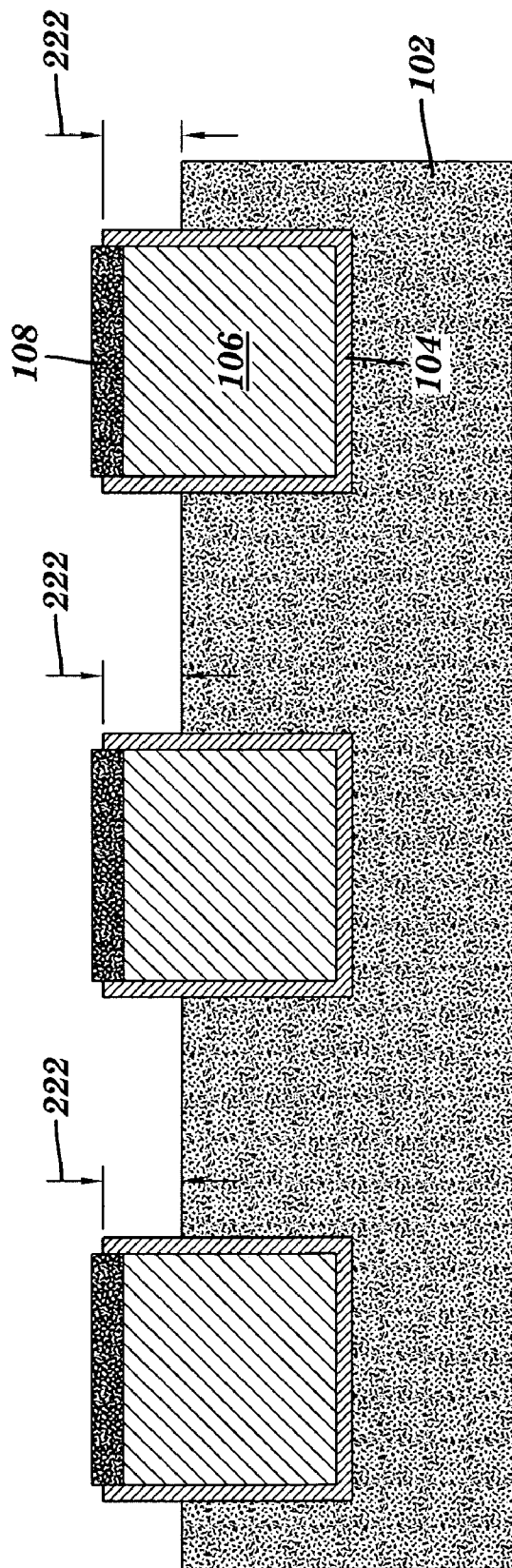


FIG. 2G

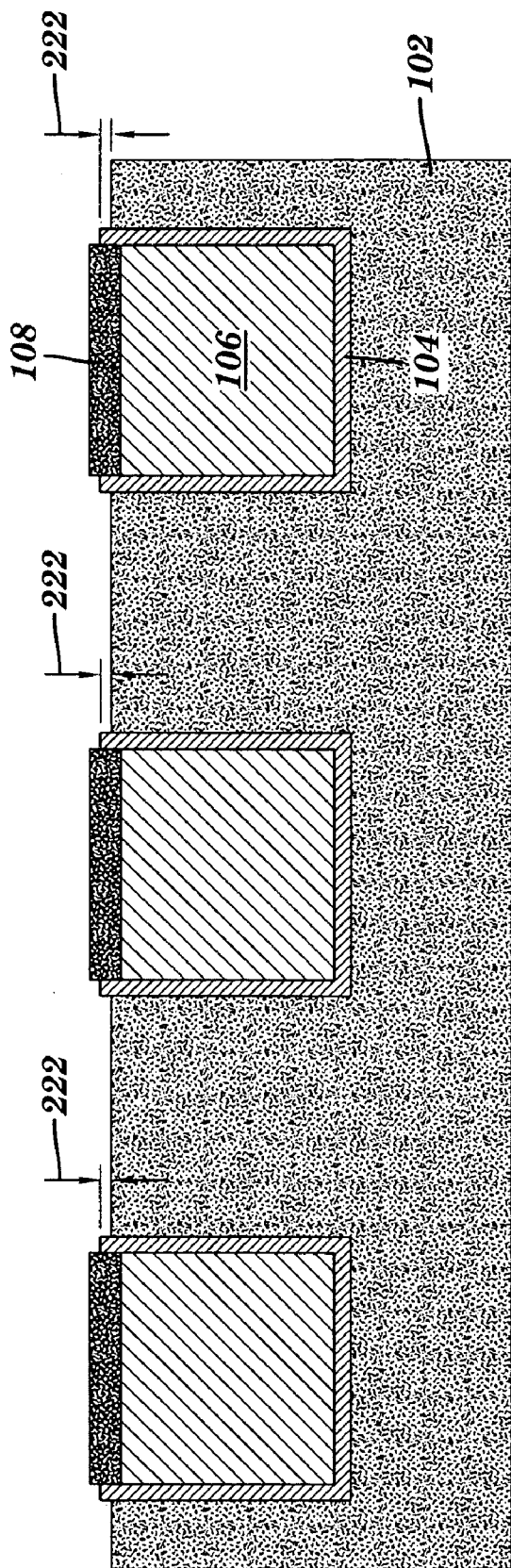


FIG. 2H

**INTERCONNECT WITH RECESSED
DIELECTRIC ADJACENT A NOBLE METAL
CAP**

BACKGROUND

[0001] The disclosure relates generally to integrated circuits (ICs), and, more particularly, to the fabrication of an interconnect structure with a noble metal cap and recessed dielectric adjacent such noble metal cap.

[0002] Electromigration (EM) has long been identified as the major metal failure mechanism. It is a reliability concern for Very Large Scale Integration (VLSI) circuits and manufacturing. EM not only needs to be overcome during process development period in order to qualify the process, but EM also persists through the lift time of the chip. Voids are created inside metal conductors due to metal ion movement caused by high density current flow. Although the fast diffusion path in copper (Cu) interconnects varies depending on the overall integration scheme and materials used for chip fabrication, it has been observed that Cu atom transport along the Cu/post-Chemical Mechanical Polish (CMP) dielectric cap interface plays an important role on EM lifetime projection. More specifically, the EM initiated voids nucleate at the Cu/dielectric cap interface and grow towards the bottom of the interconnect, which eventually results in a dead circuit open. It has been demonstrated that replacing Cu/dielectric cap interface with Cu/metal interface can enhance EM resistance. Observed electrical leakage related yield degradation, however, has delayed implementation of the Cu/metal interface.

BRIEF SUMMARY

[0003] A first embodiment of the invention comprises a method of forming an interconnect structure. The embodiment includes the step of depositing a first dielectric layer of ultra low-k material. The embodiment includes the step of forming a sacrificial dielectric layer over the first dielectric layer. The embodiment includes the step of forming an interconnect feature in the sacrificial dielectric layer and first dielectric layer by etching an opening in the sacrificial dielectric layer and first dielectric layer, depositing a liner over the sacrificial dielectric layer and within the opening, overfilling the opening with a conductive material, and, performing a chemical mechanical polishing process to remove a portion of the conductive material, a portion of the liner, and the sacrificial dielectric layer such that top surface of the conductive material filled opening is coplanar with the first dielectric layer. The embodiment includes the step of depositing a noble metal layer on top of the interconnect feature. The embodiment includes the step of annealing the interconnect feature such that an alloy layer forms in the conductive material adjacent the noble metal layer. The embodiment includes the step of removing the noble metal layer and a portion of the first dielectric layer using a gas cluster ion beam, leaving a portion of the liner and the alloy layer protruding from the first dielectric layer. The embodiment includes the step of depositing a second dielectric layer over the first dielectric layer and the protruding liner and alloy layer.

[0004] A second embodiment of the invention comprises an interconnect structure. The structure includes a liner layer disposed on an intermediate interconnect feature, the intermediate interconnect feature having an opening etched in a dielectric layer of ultra low-k material, the liner layer protruding from the dielectric layer of ultra low-k material. The

structure includes a conductive material disposed on the liner layer, the conductive material filling a portion of the opening. The structure includes an alloy layer disposed on the conductive material, the alloy layer filling remaining portion of the opening, the alloy layer protruding from the dielectric layer of ultra low-k material. The structure includes a dielectric layer disposed on top of the protruding liner, alloy layer, and dielectric layer of ultra low-k material.

BRIEF DESCRIPTION OF THE SEVERAL
VIEWS OF THE DRAWINGS

[0005] The features and the element characteristics of the invention are set forth with particularity in the appended claims. The figures are for illustrative purposes only and are not drawn to scale. Furthermore, like numbers represent like features in the drawings. The invention itself, however, both as to organization and method of operation, may best be understood by reference to the detailed description which follows, taken in conjunction with the accompanying figures, in which:

[0006] FIG. 1 depicts an embodiment of the invention; and,
[0007] FIGS. 2a-2h depict steps for creation of the embodiment depicted in FIG. 1.

DETAILED DESCRIPTION

[0008] The invention will now be described with reference to the accompanying figures. In the figures, various aspects of the structures have been depicted and schematically represented in a simplified manner to more clearly describe and illustrate the invention.

[0009] By way of overview and introduction, the embodiments of the invention are directed to an interconnect structure with a conductive material/noble metal cap interface. The dielectric adjacent the conductive material/noble metal cap interface is recessed such that the top of the noble metal cap protrudes above the recessed dielectric. A dielectric layer covers the interconnect with the conductive material/noble metal cap interface, as well as the recessed dielectric. A gas cluster ion beam (GCIB) process is used to create the recessed dielectric.

[0010] A gas cluster ion beam (GCIB) process, historically, has not been used for an etching process in semiconductor related applications. Historically, the GCIB process was used for surface treatments and to make substrate thicknesses optically uniform. With process optimization, the present embodiment evaluates the GCIB process as an alternative etching process for semiconductor related applications. With process optimization, the present embodiment has discovered that GCIB has improved selectivity as compared with conventional etching processes.

[0011] With reference now to FIG. 1, FIG. 1 depicts an embodiment of the invention. As depicted, three interconnects **100a**, **100b**, **100c** are depicted in FIG. 1. The interconnects **100a**, **100b**, **100c** are embedded partially in dielectric layer **102**. Dielectric layer **102** comprises an ultra low-k material, such as a porous or dense ultra-low k dielectric with a k value less than or equal to 4.0. A portion of the interconnects **100a**, **100b**, **100c** protrudes above the dielectric layer of ultra-low k material **102** or in other words the dielectric layer of ultra-low k material **102** is recessed from the interconnects **100a**, **100b**, **100c**. The depicted interconnects **100a**, **100b**, **100c** protrude approximately 2 Å to 100 Å above the dielectric layer of ultra-low k material **102**. The interconnects **100a**,

100b, 100c include a liner layer **104**, which has a thickness in the range of 10 Å to 200 Å. The liner layer **104** originates from any of the following materials: tantalum nitride (TaN), titanium nitride (TiN), ruthenium (Ru), and tungsten nitride (WN), iridium (Ir) or combinations of any of these materials. The purpose of the liner layer **104** is to prevent conductive material **106** from diffusing into dielectric **102**. A portion of the liner layer **104** of the interconnects **100a, 100b, 100c** extends above the dielectric layer of ultra-low k material **102** by a height of approximately 2 Å to 100 Å. The interconnects **100a, 100b, 100c** are filled with conductive material **106**, such as copper (Cu), aluminum (Al) or alloys thereof. Further, as depicted in FIG. 1, an alloy layer **108** fills surface of the interconnects **100a, 100b, and 100c**. The alloy layer **108** originates from any of the following materials: ruthenium (Ru), rhodium (Rh), iridium (Ir), cobalt (Co), tungsten (W), platinum (Pt) or alloys of such materials. Consequently, the alloy layer **108** becomes the noble metal cap **108** in interconnects **100a, 100b and 100c**. The alloy layer **108** has a thickness ranging from 1 Å to 100 Å. Finally, a dielectric layer **110** overlays the interconnects **100a, 100b, 100c**, as well as the dielectric layer of ultra-low k material **102**. The dielectric layer **110** is formed one of silicon nitride (Si₃N₄), silicon carbide (SiC), or nitrogen and hydrogen doped silicon carbide (SiC(N,H)). The purpose of the dielectric layer **110** is to act as an etching stop layer for the next level build.

[0012] The embodiment of the present invention with the described noble metal cap **108**/conductive material **106** interface has better electromigration resistance than a conventional dielectric/conductive material interface. Electromigration resistance is important with respect to high performance related applications. High performance related applications require both high current density and reliability.

[0013] The fabrication process for the interconnect **100a, 100b, 100c** with the noble metal cap **108** and recessed dielectric **102** is shown in FIGS. 2A-2G.

[0014] With reference to FIG. 2A, a sacrificial dielectric layer **212**, such as silicon dioxide (SiO₂), silicon nitride (Si₃N₄), or silicon carbide (SiC) is deposited over the dielectric layer of ultra low-k material **102**. The sacrificial dielectric layer **212** functions as a patterning mask. As will be seen in FIG. 2B, the openings that will ultimately form interconnects **100a, 100b, 100c** will be etched into both the sacrificial dielectric layer **212** and dielectric layer of ultra low-k material **102**.

[0015] With reference to FIG. 2b, openings **214** which will ultimately form interconnects **100a, 100b, 100c** are etched into both the sacrificial dielectric layer **212** and the dielectric layer of ultra-low k material **102**. The openings **214** are etched through conventional lithography and etching processes. The etching step used in forming the openings **214** could comprise a dry etching process (including reactive ion etching, ion beam etching, plasma etching or laser ablation), a wet chemical etching process or any combination thereof. Typically, reactive ion etching is used to form the openings **214**. Once the openings **214** for the interconnects **100a, 100b, 100c** are formed, a conductive material **106** for the interconnects **100a, 100b, 100c** will fill the openings **214**.

[0016] With reference to FIG. 2c, a diffusion barrier liner layer **104** is deposited onto the openings **214** followed by a deposition of a conductive material **106**, such as copper, aluminum or alloys of the same. The conductive material **106** overfills the openings **214**. In other words, the conductive material **106** fills not just the openings **214**, but also blankets the sacrificial dielectric layer **212**.

[0017] With reference to FIG. 2d, a chemical mechanical polish process removes a portion

of the conductive material **106**, a portion of the liner layer **104**, and the sacrificial dielectric layer **212** such that the top surface of the conductive material **106** and liner layer **104** in the filled opening **214** is coplanar with the dielectric layer of ultra-low k material **102**.

[0018] With reference to FIG. 2e, a noble metal layer **218** is selectively deposited on top of interconnects **100a, 100b, 100c**, and then annealed. The noble metal layer **218** is deposited by a chemical vapor deposition, atomic layer deposition, electroless plating or an electro plating technique. The material for the noble metal layer **218** is selected from a group consisting of ruthenium (Ru), rhodium (Rh), iridium (Ir), cobalt (Co), tungsten (W), platinum (Pt) or alloys thereof. The deposition of a noble metal layer **218** could leave behind metallic residues **220** on top of the dielectric surface **102**. Such metallic residues **220** are problematic because the metallic residues degrade leakage yield and cause reliability related concerns. The annealing process causes an alloy layer **108** to form between the noble metal layer **218** and the conductive material **106**. The alloy layer **108** is the noble metal cap **108** in the final interconnect structures **100a, 100b, 100c**. The annealing process can be performed in a H₂/N₂ ambient at 100~250° C. for 1~5 hours.

[0019] With reference to FIG. 2f, the noble metal layer **218** and a portion of the dielectric layer of ultra-low k material **102** is selectively removed through use of a Gas Cluster Ion Beam (GCIB) process. The optimized gas cluster ion beam contains a concentration of nitrogen trifluoride (NF₃) and nitrogen (N₂) of which the nitrogen trifluoride (NF₃) concentration is between 0.1% and 20.0% of total gas cluster ion beam concentration. The energy of the optimized gas cluster ion beam is between 0.1 keV and 40.0 keV. In addition to removing the metallic residues **220** caused by deposition of the noble metal layer **218** respectively, the GCIB process also removes the noble metal layer **218** and a portion of the dielectric layer of ultra-low k material **102** as will be depicted in FIGS. 2g and 2h. The GCIB etching process has selectivity better than 5 between noble metal layer **218** and alloy layer **108**. In other words, the selective GCIB etching process, etches the noble metal layer **218** at an etching rate that is at least five times faster than the GCIB etching process etches the alloy layer **108**.

[0020] With reference to FIGS. 2g and 2h, the results of the GCIB process are depicted. As shown, the GCIB process recessed the dielectric layer of ultra-low k material **102**, such that the top of the alloy layer **108** protrudes above the recessed dielectric **102**. FIG. 2g depicts an aggressive recess by which the dielectric layer of ultra-low k material **102** is below the conductive material **106**. FIG. 2h, on the other hand, depicts a less aggressive recess, by which the dielectric layer of ultra-low k material **102** is above the conductive material **106**. In either recess model depicted in FIGS. 2g and 2h, the alloy layer **108** protrudes at some height **222** above the dielectric layer of ultra-low k material **102**. As shown, the GCIB has removed the metallic residues **220**, which consequently prevents leakage problems between adjacent interconnects. The liner layer **104** and the alloy layer **108** protrude from the interconnects **100a, 100b, 100c** with a height **222** of between 2 Å and 100 Å. The alloy layer **108** is the noble metal cap **108** for interconnects **100a, 100b, 100c**. In a final step, a dielectric layer **110** is deposited over the dielectric layer of ultra-low k material **102** and protruding liner layer **104** and alloy layer **108** through use of a chemical vapor deposition process. The final structure is depicted as shown in FIG. 1.

[0021] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0022] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiment was chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

- 1. A method of forming an interconnect structure, comprising:
 - depositing a first dielectric layer of ultra low-k material;
 - forming a sacrificial dielectric layer over said first dielectric layer;
 - forming an interconnect feature in said sacrificial dielectric layer and first dielectric layer by:
 - etching an opening in said sacrificial dielectric layer and first dielectric layer;
 - depositing a liner over said sacrificial dielectric layer and within said opening;
 - overfilling said opening with a conductive material; and,
 - performing a chemical mechanical polishing process to remove a portion of said conductive material, a portion of said liner, and said sacrificial dielectric layer such that top surface of said conductive material filled opening is coplanar with said first dielectric layer;
 - depositing a noble metal layer on top of said interconnect feature;
 - annealing said interconnect feature such that an alloy layer forms in said conductive material adjacent said noble metal layer;
 - removing said noble metal layer and a portion of said first dielectric layer using a gas cluster ion beam, leaving a portion of said liner and said alloy layer protruding from said first dielectric layer; and,
 - depositing a second dielectric layer over said first dielectric layer and said protruding liner and alloy layer.
- 2. A method as in claim 1, wherein said sacrificial dielectric material layer is formed from a material selected from a group consisting of silicon dioxide (SiO₂), silicon nitride (Si₃N₄), and silicon carbide (SiC).
- 3. A method as in claim 1, wherein said noble metal layer is deposited by a method selected from a group consisting of chemical vapor deposition (CVD), atomic layer deposition (ALD), electroless plating and electro plating techniques.

- 4. A method as in claim 1, wherein said noble metal layer is selected from a group consisting of ruthenium (Ru), rhodium (Rh), iridium (Ir), cobalt (Co), tungsten (W), platinum (Pt) and alloys thereof.
- 5. A method as in claim 1, wherein said gas cluster ion beam contains a concentration of nitrogen trifluoride (NF₃) and nitrogen (N₂).
- 6. A method as in claim 5, wherein said nitrogen trifluoride (NF₃) concentration is between 0.1% and 20.0% of total gas cluster ion beam concentration.
- 7. A method as in claim 1, wherein said gas cluster ion beam has an energy greater than 0.1 keV and less than 40.0 keV.
- 8. A method as in claim 1, wherein said gas cluster ion beam etches said noble metal layer at a rate that is at least five (5) times faster than said gas cluster beam etches said alloy layer.
- 9. A method as in claim 1, wherein said second dielectric layer is deposited by chemical vapor deposition (CVD).
- 10. An interconnect structure, comprising:
 - a liner layer disposed on an intermediate interconnect feature, said intermediate interconnect feature having an opening etched in a dielectric layer of ultra low-k material, said liner layer protruding from said dielectric layer of ultra low-k material;
 - a conductive material disposed on said liner layer, said conductive material selected from a group consisting of copper (Cu), aluminum (Al) and alloys thereof, said conductive material filling a portion of said opening;
 - an alloy layer disposed on said conductive material, said alloy layer comprising a noble metal and said conductive material, said alloy layer filling remaining portion of said opening, said alloy layer protruding from said dielectric layer of ultra low-k material; and,
 - a dielectric layer disposed on top of said protruding liner layer, alloy layer, and dielectric layer of ultra low-k material.
- 11. A structure as in claim 10, wherein said liner layer is selected from a group consisting of tantalum nitride (TaN), titanium nitride (TiN), ruthenium (Ru), and tungsten nitride (WN), iridium (Ir) and combinations thereof.
- 12. A structure as in claim 10, wherein said liner layer has a thickness ranging from 10 Å to 200 Å.
- 13. A structure as in claim 10, wherein said liner layer protrudes from said dielectric layer of ultra low-k material by a height ranging from 2 Å to 100 Å.
- 14. A structure as in claim 10, wherein dielectric layer of ultra low-k material is formed from a material selected from a group consisting of porous and dense ultra-low k dielectrics.
- 15. (canceled)
- 16. A structure as in claim 10, wherein said alloy layer comprises a material selected from a group consisting of ruthenium (Ru), rhodium (Rh), iridium (Ir), cobalt (Co), tungsten (W), platinum (Pt) and alloys thereof.
- 17. A structure as in claim 10, wherein said alloy layer has a thickness ranging from approximately 1.0 Å to approximately 100.0 Å.
- 18. A structure as in claim 10, wherein said alloy layer protrudes from said dielectric layer of ultra low-k material by a height ranging from approximately 2.0 Å to approximately 100 Å.
- 19. A structure as in claim 10, wherein said dielectric layer is formed from a material selected from a group consisting of silicon nitride (Si₃N₄), silicon carbide (SiC), and nitrogen and hydrogen doped silicon carbide (SiC(N,H)).

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