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(54) **STRUCTURE INCLUDING VIA HAVING REFRACTORY METAL COLLAR AT COPPER WIRE AND DIELECTRIC LAYER LINER-LESS INTERFACE AND RELATED METHOD**

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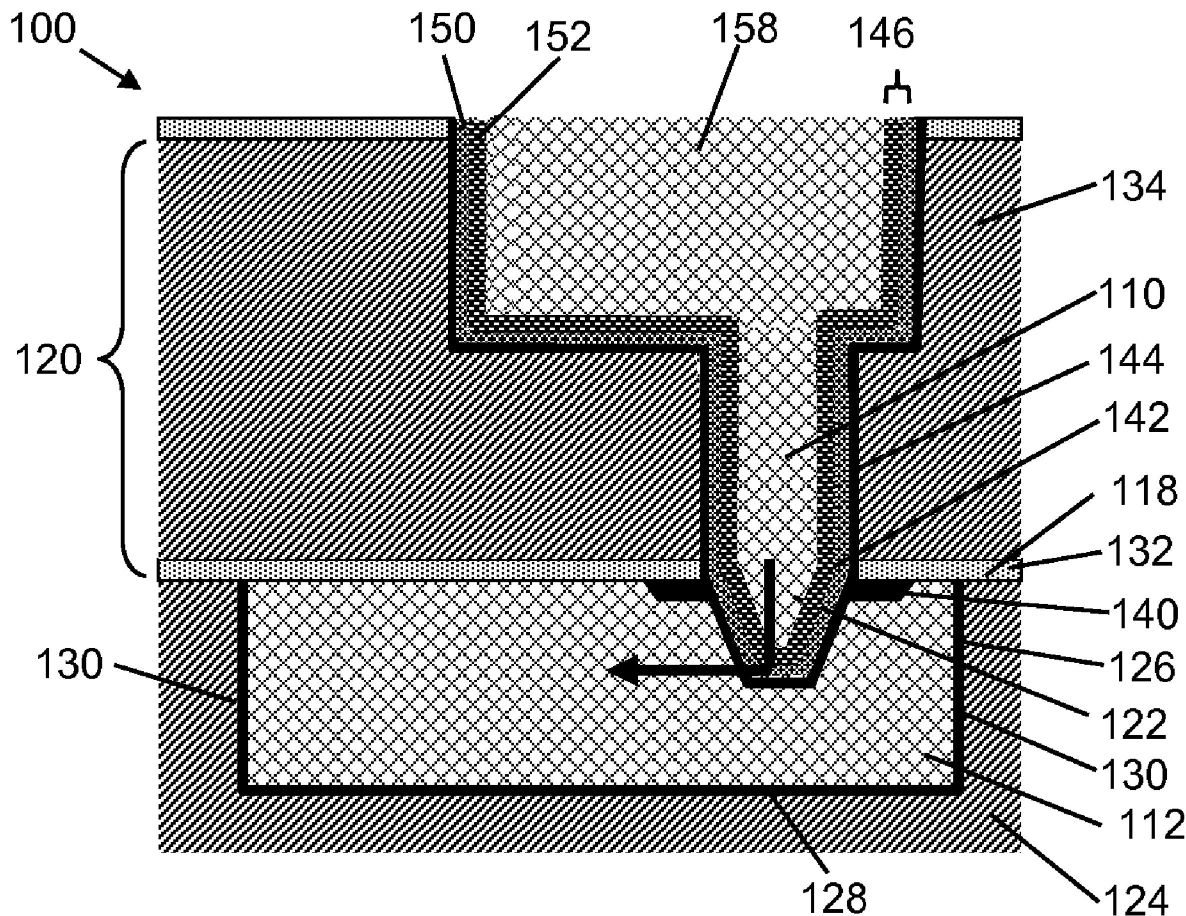
(57) **ABSTRACT**

Structures including a refractory metal collar at a copper wire and dielectric layer liner-less interface, and a related method, are disclosed. In one embodiment, a structure includes a copper wire having a liner-less interface with a dielectric layer thereabove; a via extending upwardly from the copper wire through the dielectric layer; and a refractory metal collar extending from a side of the via and partially along the liner-less interface. Refractory metal collar prevents electromigration induced slit voiding by improving the interface around the via, and prevents void nucleation from occurring near the via. Also, the refractory metal collar provides electrical redundancy in the presence of voids around the via and dielectric layer liner-less interface.



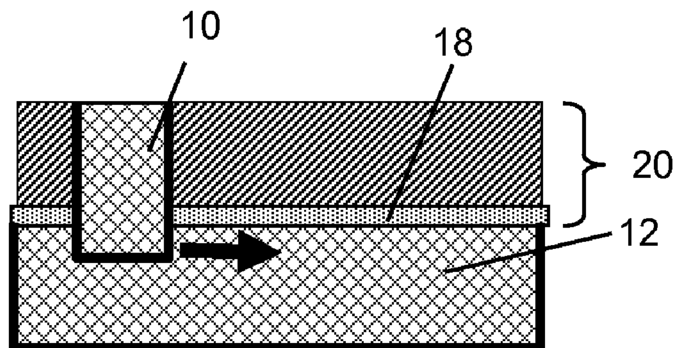


FIG. 1A (PRIOR ART)

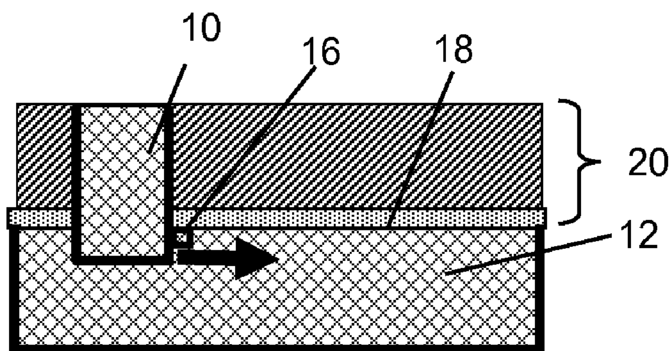


FIG. 1B (PRIOR ART)

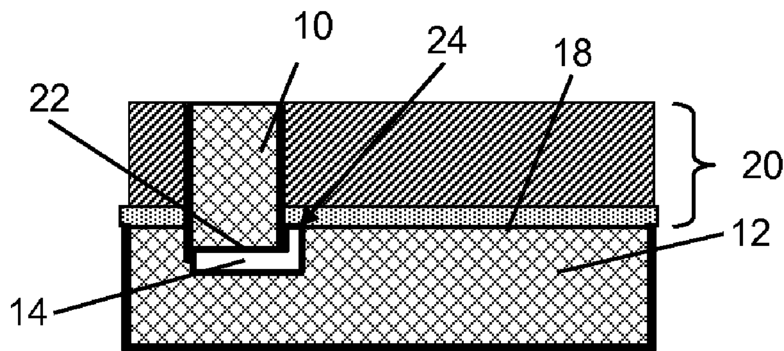


FIG. 1C (PRIOR ART)

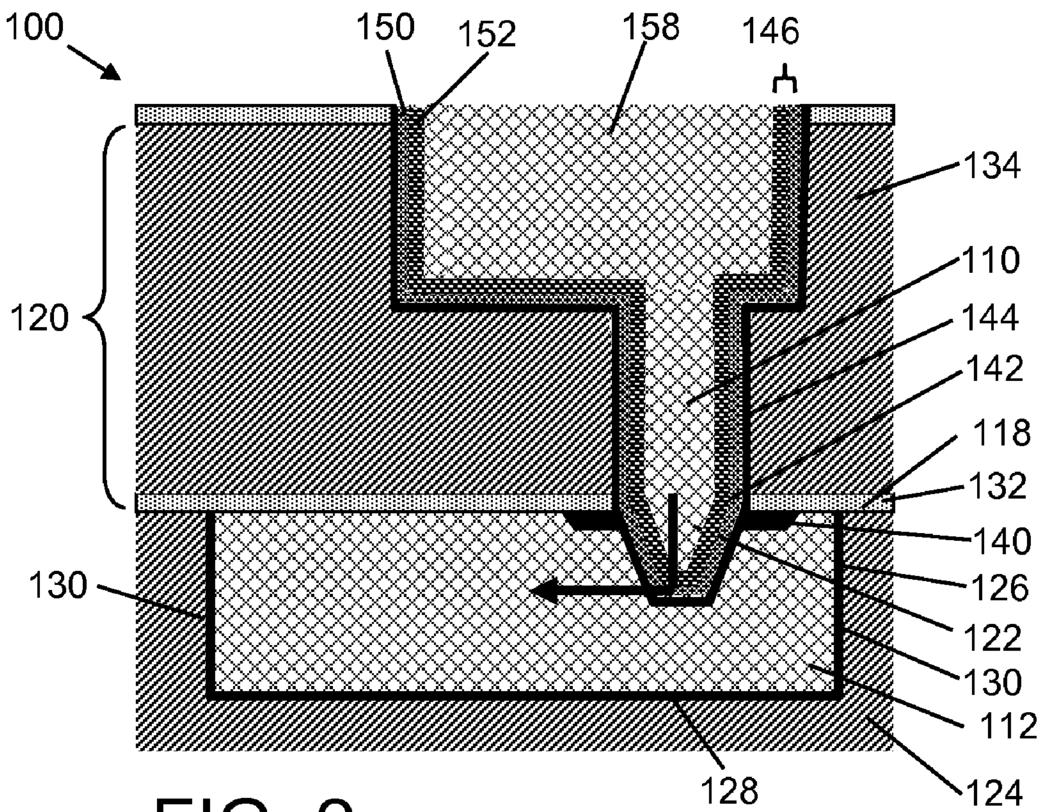


FIG. 2

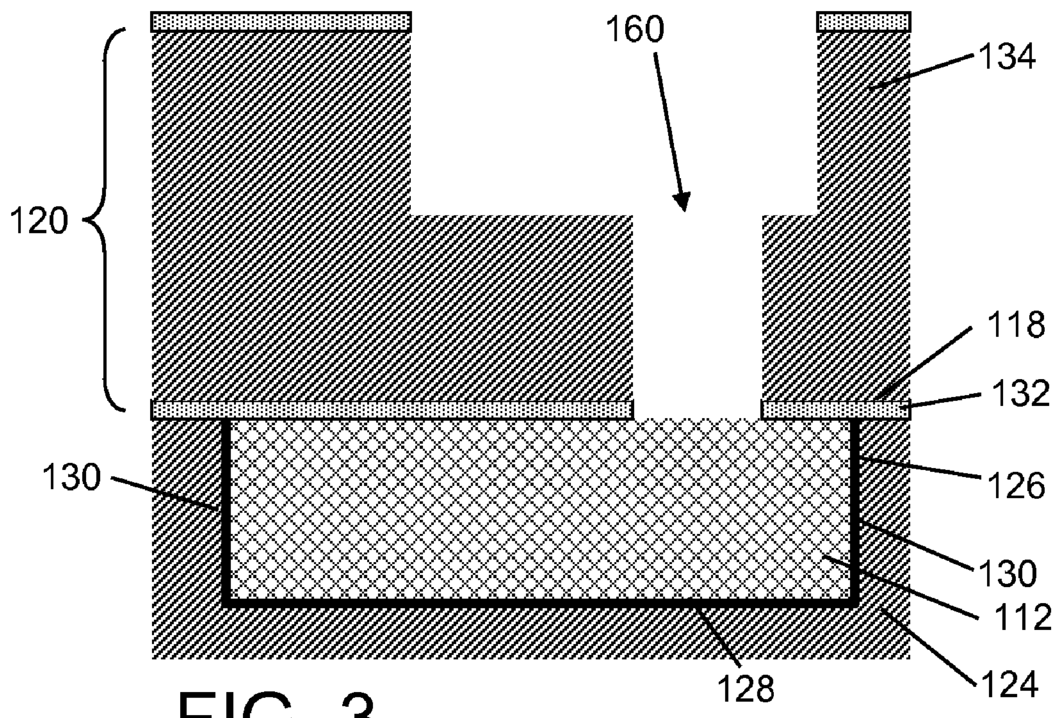


FIG. 3

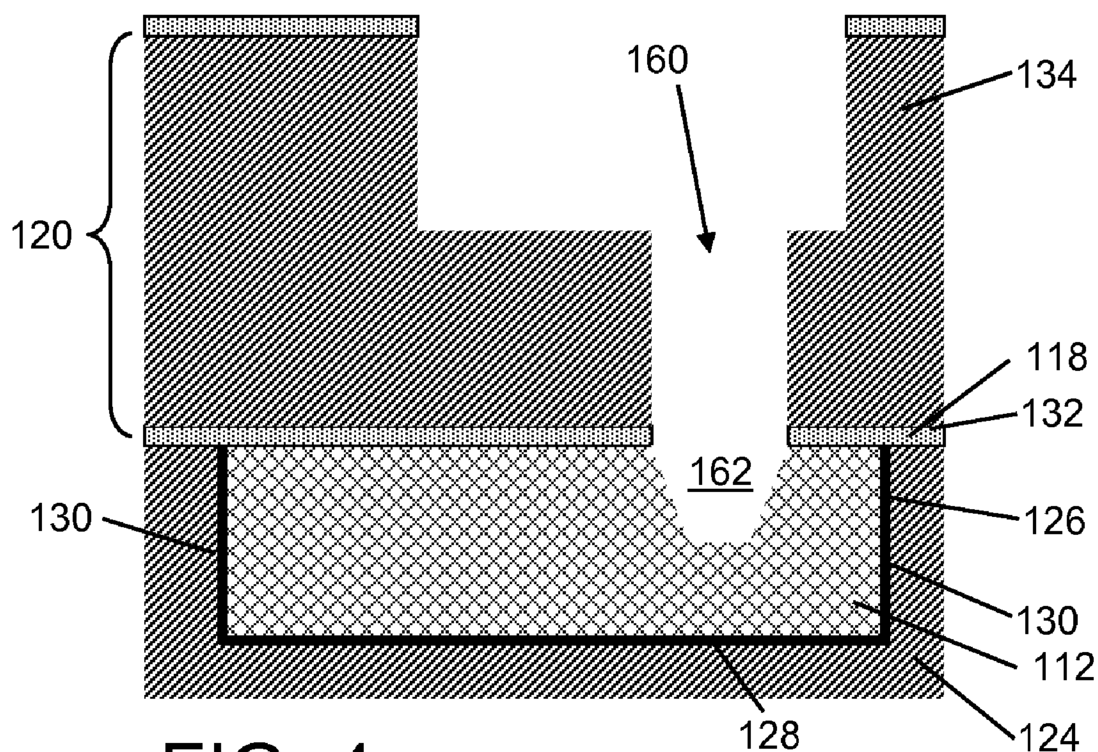


FIG. 4

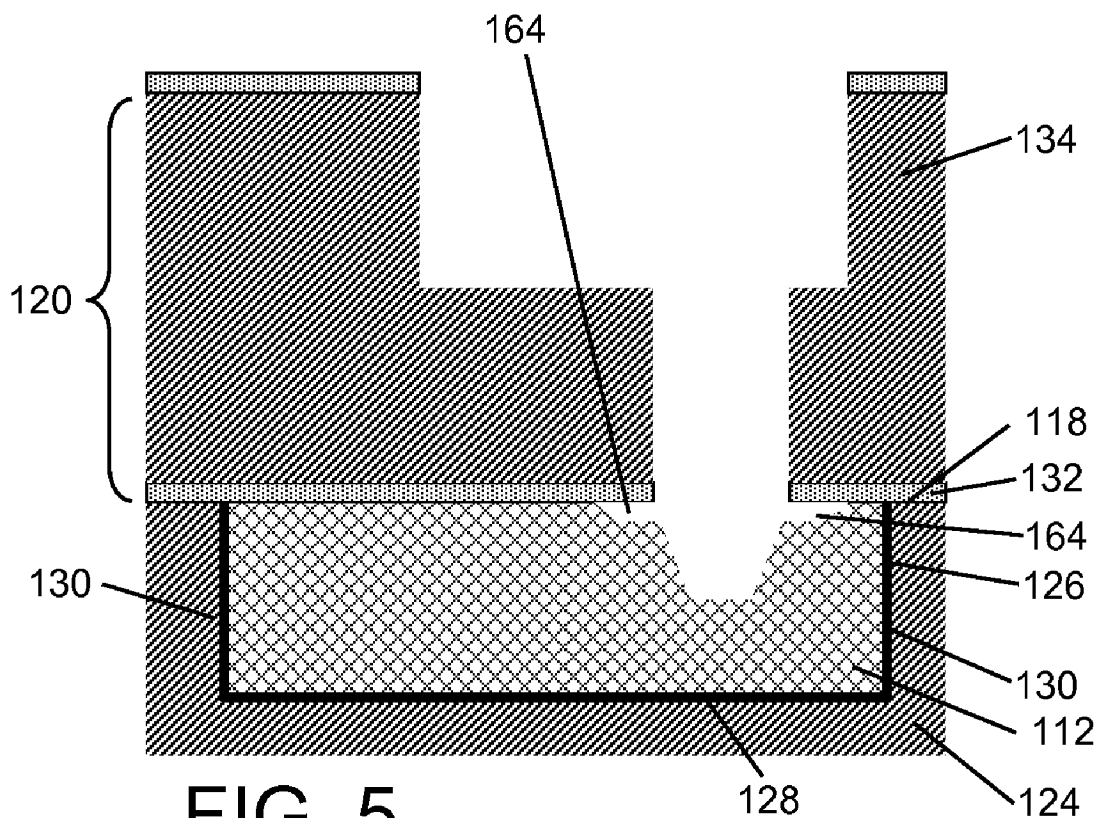


FIG. 5

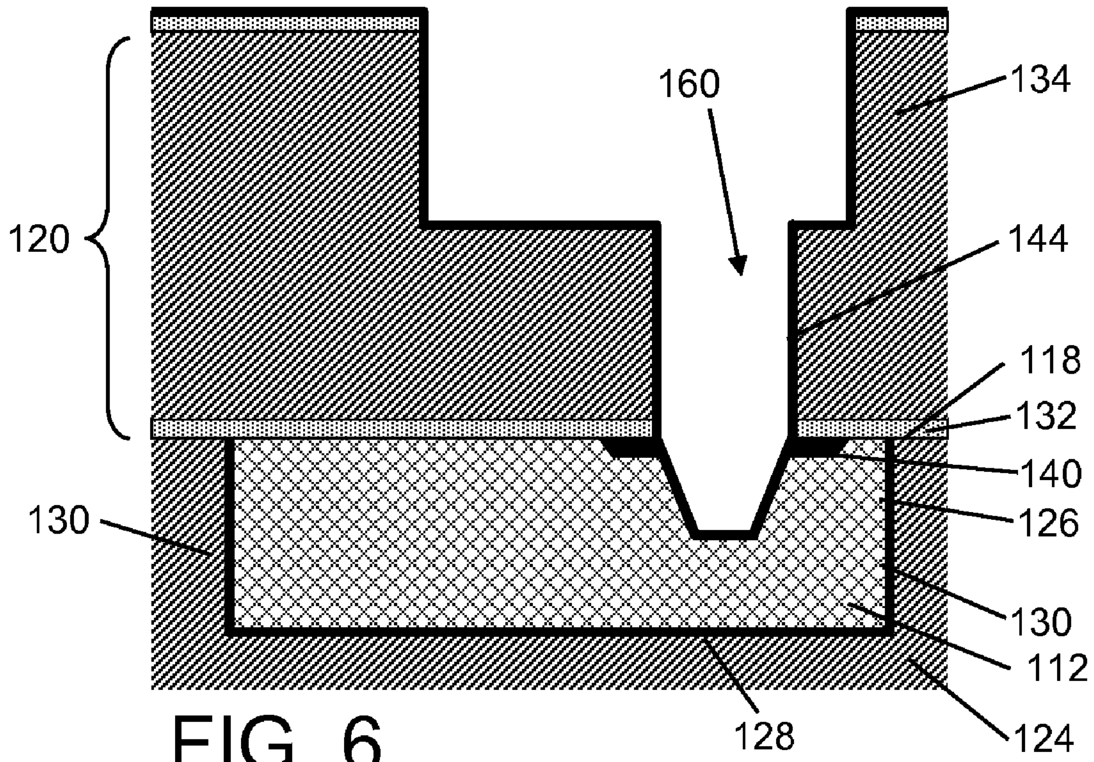


FIG. 6

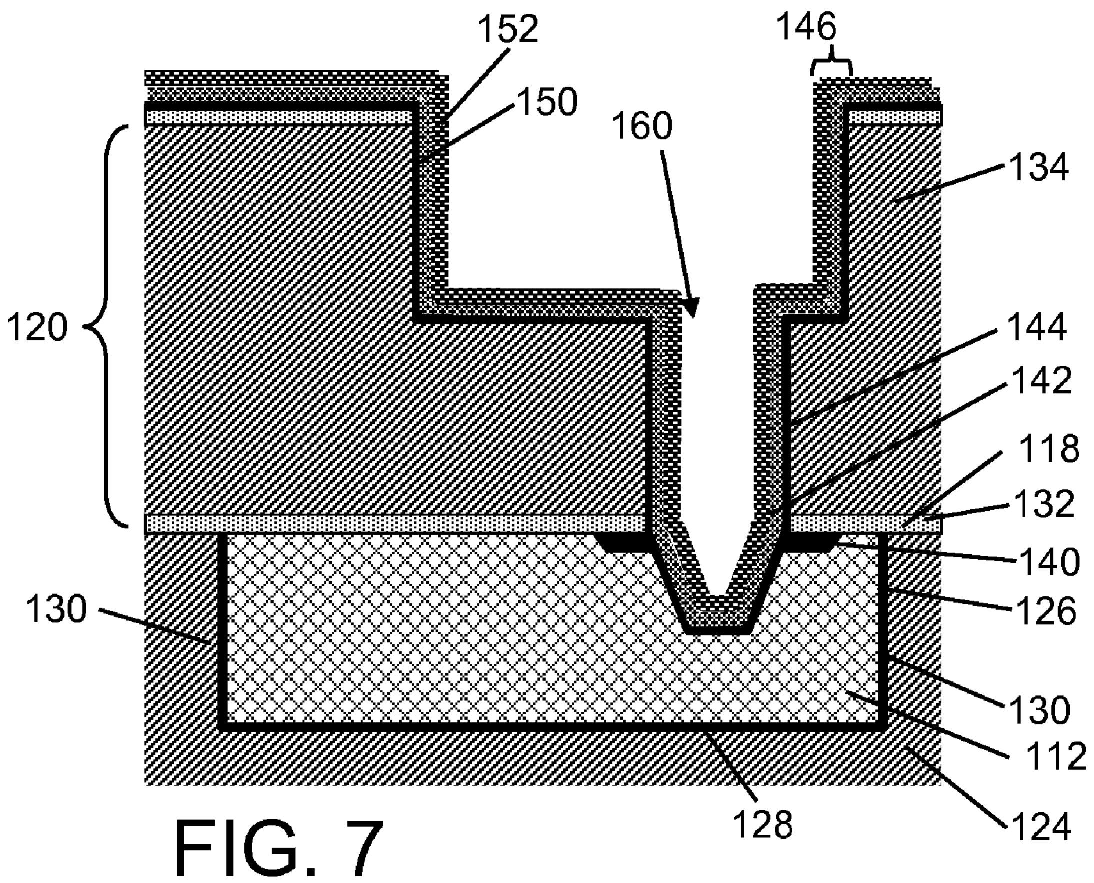


FIG. 7

STRUCTURE INCLUDING VIA HAVING REFRACTORY METAL COLLAR AT COPPER WIRE AND DIELECTRIC LAYER LINER-LESS INTERFACE AND RELATED METHOD

BACKGROUND

[0001] 1. Technical Field

[0002] The disclosure relates generally to integrated circuit (IC) chip fabrication, and more particularly, to structures including a via having a refractory metal collar at a copper wire and dielectric layer liner-less interface, and a related method.

[0003] 2. Background Art

[0004] In the integrated circuit (IC) chip fabrication industry, electromigration (EM) induced failure is a major concern for advanced back-end-of-line (BEOL) technology. Early EM induced failure, in particular, significantly reduces the projected current limit of product chip under operating conditions. One type of EM induced failure is referred to as "line-depletion." As shown in FIGS. **1**A-C, line-depletion EM includes electron current flowing from an upwardly extending via **10** down into a metal wire **12** below. As electron current flows, atoms move causing "slit void" failures **14** (FIG. **1**C) initiating, for example, at a site **16** (FIG. **1**B) between via **10** and a liner-less interface **18** between metal wire **12** and a dielectric layer **20** thereabove. It is well known that this slit void may cause very early fails under electromigration conditions during circuit operation, since it does not take much time to form such a small void. The arrows in FIGS. **1**A and **1**B show the direction of EM flux (i.e., the atom flow during electromigration). Typically, slit void failures **14** (FIG. **1**C) start (or nucleate) at defective sites **16** (FIG. **1**B) around an interface between via **10** and metal wire **12**, and grow into a bottom **22** of via **10** until it extends over an entire interface and causes an electrical open **24**, as depicted in FIG. **1**C. Slit void failures **14** occur in both structures with (as shown) or without via gouging, i.e., where via **10** extends into metal wire **12**.

SUMMARY

[0005] Structures including a refractory metal collar at a metal wire and dielectric layer liner-less interface, and a related method, are disclosed. In one embodiment, a structure includes a copper wire having a liner-less interface with a dielectric layer thereabove; a via extending upwardly from the copper wire through the dielectric layer, and a refractory metal collar extending from a side of the via and partially along the liner-less interface. Refractory metal collar prevents electromigration induced slit voiding by improving the interface around the via, and prevents void nucleation from occurring near the via. Also, the refractory metal collar provides electrical redundancy in the presence of voids around the via and dielectric layer liner-less interface.

[0006] A first aspect of the disclosure provides a structure comprising: a copper wire having a liner-less interface with a dielectric layer thereabove; a via extending upwardly from the copper wire through the dielectric layer; and a refractory metal collar extending from a side of the via and partially along the liner-less interface.

[0007] A second aspect of the disclosure provides a method comprising: providing a copper wire in a first dielectric layer; forming a second dielectric layer over the copper wire to form a liner-less interface between the copper wire and the second dielectric layer; forming an opening through the second dielectric layer and into the copper wire; creating an undercut from the opening under the second dielectric layer; forming a refractory metal collar in the undercut; and filling the opening with a metal to form a via.

[0008] A third aspect of the disclosure provides a structure comprising: a copper wire having a liner-less interface with a dielectric layer thereabove; a via extending upwardly from the copper wire through the dielectric layer, the via including a substantially frusto-conical portion within the copper wire; a first liner about the via, the first liner including a refractory metal; and a refractory metal collar extending from a side of the via and partially along the liner-less interface.

[0009] The illustrative aspects of the present disclosure are designed to solve the problems herein described and/or other problems not discussed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and other features of this disclosure will be more readily understood from the following detailed description of the various aspects of the disclosure taken in conjunction with the accompanying drawings that depict various embodiments of the disclosure, in which:

[0011] FIGS. **1**A-C show a conventional via and metal wire interface in which electromigration causes a failure.

[0012] FIG. **2** shows a structure according to embodiments of the disclosure.

[0013] FIGS. **3**-**7** show embodiments of a method of forming the structure of FIG. **2**.

[0014] It is noted that the drawings of the disclosure are not to scale. The drawings are intended to depict only typical aspects of the disclosure, and therefore should not be considered as limiting the scope of the disclosure. In the drawings, like numbering represents like elements between the drawings.

DETAILED DESCRIPTION

[0015] FIG. **2** shows a structure **100** according to embodiments of the disclosure. Structure **100** includes a via **110** extending upwardly from a metal wire **112**, e.g., copper, through a dielectric layer **120**. In one embodiment, via **110** includes a substantially frusto-conical portion **122** within metal wire **112**. However, the teachings of the invention are not limited to that type of via. Metal wire **112** is positioned within another dielectric layer **124**, and includes a liner **126** between metal wire **112** and dielectric layer **124**. Liner **126** may include any now known or later developed metal diffusion barrier material, for example, tantalum, tantalum nitride, titanium, titanium nitride, tungsten, tungsten nitride, ruthenium, ruthenium nitride, etc. Note, however, liner **126** separates metal wire **112** and dielectric layer **124** along only a bottom **128** and sides **130** of metal wire **112**. Accordingly, metal wire **112** includes a liner-less interface **118** with dielectric layer **120** thereabove.

[0016] Dielectric layer **120** includes a barrier layer **132** forming liner-less interface **118** with metal wire **112**, and an interlevel dielectric **134** above barrier layer **132**. Barrier layer **132** may include any now known or later developed dielectric barrier layer such as silicon carbide (SiC), silicon nitride (Si_3N_4) silicon dioxide (SiO_2), nitrogen or hydrogen doped silicon carbide (SiC(N,H)), etc. Interlevel dielectric **134** may include any now known or later developed porous or non-

porous interlevel dielectric material, such as silicon oxide, silicon nitride, hydrogenated silicon oxycarbide (SiCOH), silsesquioxanes, carbon (C) doped oxides (i.e., organosilicates) that include atoms of silicon (Si), carbon (C), oxygen (O), and/or hydrogen (H), thermosetting polyarylene ethers, SiLK (a polyarylene ether available from Dow Chemical Corporation), JSR (a spin-on silicon-carbon contained polymer material available form JSR Corporation), other low dielectric constant (<3.9) material, or layers thereof.

[0017] Structure **100** also includes a refractory metal collar **140** extending from a side **142** of via **110** and partially along liner-less interface **118**. In addition, a first liner **144** may be formed about via **110**, first liner **144** including the same refractory metal. In one embodiment, the refractory metal includes ruthenium; however, other refractory metals such as tantalum (Ta), titanium (Ti), tungsten (W), iridium (Ir), rhodium (Rh) and platinum (Pt), etc., or mixtures of thereof, may also be employed. Via **110** may also include a second liner **146** about the via, where second liner **146** includes at least one metal diffusion barrier **150** (i.e., liner) and a metal seed layer **152** for seeding for a metal **158** that forms via **110**. In one embodiment, metal **158** includes copper; however, other metals such as copper alloy, aluminum (Al), aluminum alloy, silver (Ag), etc. may be employed. Metal diffusion barrier(s) **150** may include, for example: tantalum/tantalum nitride titanium/titanium nitride, tungsten/tungsten nitride, ruthenium/ruthenium nitride. etc.; and metal seed layer **152** may include copper (Cu) or other alloy materials, where metal **158** is copper, for example: copper, copper aluminum, and other copper alloy such as copper iridium, copper nickel, and/or copper ruthenium.

[0018] Refractory metal collar **140** and metal wire **112** interface presents a slow electromigration (EM) path in which the EM flux (i.e., the atom flow during electromigration) is forced down, as shown by the arrow, into metal wire **110** instead of concentrating near liner-less interface **118** (as in FIGS. **1**A-B). In particular, the interface between metal wire **112** (e.g., of copper) and refractory metal collar **140** is very resistant to electromigration-induced voiding, since the adhesion at the interface is greatly enhanced compared to that between metal and dielectric-based barrier layer **132** materials. As a result, the local EM flux at liner-less interface **118** around via **110** is greatly reduced. Also, since refractory metal collar **140** is formed only around via **110**, but not directly under via **110** and metal wire **112** contact, the via contact resistance is not impacted by this feature. Refractory metal collar **140** around via **110** also serves as a redundant conducting path, even if a void forms underneath via **110**, thus preventing structure **100** from being electrically open.

[0019] Structure **100** also decreases thermal cycle failure. Thermal cycle testing is a required reliability test reflecting the temperature excursion experienced by the product. Due to mismatch in thermal expansion between metal and its surrounding dielectric(s), fatigue or cracks may occur at the via and metal wire interface, causing an electrical open. Refractory metal collar **140** (mechanically much stronger than copper) serves as an anchor to keep via **110** from pulling out of metal wire **110** under stress.

[0020] Turning to FIGS. **3**-**7**, embodiments of a method of forming structure **100** (FIG. **2**) will now be described. It is understood that a variety of methods may be employed and that the following is one example. In FIG. **3**, metal wire **112** is provided in dielectric layer **124** using any now known or later developed techniques. For example, depositing dielectric layer **124** on a substrate (not shown), photolithography include patterning a mask (not shown), etching the mask, etching an opening, depositing liner **126**, depositing a metal (wire **112**), and chemical mechanical polishing (CMP). As noted above, liner **126** separates metal wire **112** from dielectric layer **124** along only a bottom **128** and sides **130** of metal wire **112**.

[0021] FIG. **3** also shows forming dielectric layer **120** over metal wire **112** (and dielectric layer **124**) to form liner-less interface **118** between metal wire **112** and dielectric layer **124**. As noted above, dielectric layer **120** may include a dielectric barrier layer **132** (e.g., of silicon nitride) forming liner-less interface **118** with metal wire **112**, and interlevel dielectric **134** (e.g., SiCOH) above dielectric barrier layer **132**. FIG. **3** also shows forming an opening **160** through dielectric layer **134** and dielectric barrier layer **132** to metal wire **112**. Although opening **160** is shown as having been formed using a dual damascene process, it is understood that a via opening alone (single damascene process) may be used. Opening **160** may also extend into metal wire **112**, if desired.

[0022] FIG. **4** shows an optional process of a gaseous sputtering process to extend opening **160** into metal wire **112**. The gas used in the sputtering process may comprise one of argon (Ar), helium (He), neon (Ne), xenon (Xe), nitrogen (N_2), hydrogen (H_2), ammonia (NH_3), diazene (N_2H_2) or mixtures thereof, and preferably comprises Ar. A substantially frustoconical opening **162** results within metal wire **112**.

[0023] FIG. **5** shows creating an undercut **164** from opening **160** under dielectric layer **120**, i.e., under dielectric barrier layer **132**. In one embodiment, the undercutting may include performing an isotropic wet/dry etching.

[0024] FIG. **6** shows forming refractory metal collar **140** in undercut **164** (FIG. **5**), e.g., by atomic layer deposition (ALD) and/or chemical vapor deposition (CVD). As noted above, the refractory metal may include titanium (Ti), tantalum (Ta), tungsten (W), ruthenium (Ru), iridium (Ir), rhodium (Rh) and/or platinum (Pt), etc., or mixtures of thereof. FIG. **6** also shows forming first liner **144** within opening **160** prior to filling opening **160** with a metal (FIG. **2**). In this case, first liner **144** may include refractory metal used for refractory metal collar **130**.

[0025] FIG. **7** shows forming second liner **146** within opening **160** prior to filling opening **160** with a metal. As noted above, second liner **146** may include at least one metal diffusion barrier **150** (i.e., liner) and metal seed layer **152**. As noted above, metal diffusion barrier(s) **150** may include, for example: tantalum/tantalum nitride, titanium/titanium nitride, tungsten/tungsten nitride, ruthenium/ruthenium nitride, etc. As also noted above, where metal **158** (FIG. **2**) is copper, metal seed layer **152** may include, for example: copper, copper aluminum, and other copper alloy such as copper iridium, copper nickel, and/or copper ruthenium.

[0026] Returning to FIG. **2**, filling opening **160** (FIG. **7**) with a metal **158**, e.g., metal such as copper, to form via **110**, along with any necessary planarization finishes structure **100**. It is understood that the teachings of the disclosure may be repeated numerous times within a level of an IC chip and numerous times for different levels of the IC chip.

[0027] The structures and methods as described above are used in the fabrication of integrated circuit chips. The resulting integrated circuit chips can be distributed by the fabricator in raw wafer form (that is, as a single wafer that has multiple unpackaged chips), as a bare die, or in a packaged form. In the latter case the chip is mounted in a single chip package (such

as a plastic carrier, with leads that are affixed to a motherboard or other higher level carrier) or in a multichip package (such as a ceramic carrier that has either or both surface interconnections or buried interconnections). In any case the chip is then integrated with other chips, discrete circuit elements, and/or other signal processing devices as part of either (a) an intermediate product, such as a motherboard, or (b) an end product. The end product can be any product that includes integrated circuit chips, ranging from toys and other low-end applications to advanced computer products having a display, a keyboard or other input device, and a central processor.

[0028] The foregoing description of various aspects of the disclosure has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed, and obviously, many modifications and variations are possible. Such modifications and variations that may be apparent to a person skilled in the art are intended to be included within the scope of the disclosure as defined by the accompanying claims.

1. A structure comprising:
- a metal wire having a liner-less interface with a dielectric layer and an interlevel dielectric thereabove;
- a via extending upwardly from the metal wire through the dielectric layer and interlevel dielectric; and
- a refractory metal collar extending from a side of the via and partially along the liner-less interface.

2. The structure of claim **1**, wherein the via includes a substantially frusto-conical portion within the metal wire.

3. The structure of claim **1**, wherein the refractory metal collar includes a material selected from a group consisting of at least one of: tantalum (Ta), titanium (Ti), tungsten (W), ruthenium (Ru), iridium (Ir), rhodium (Rh) and platinum (Pt).

4. The structure of claim **1**, further comprising a first liner about the via, the first liner including the refractory metal.

5. The structure of claim **4**, further comprising forming a second liner about the via, the second liner including at least one metal diffusion barrier and a metal seed layer.

6. The structure of claim **5**, wherein the at least one metal diffusion barrier is selected from a group consisting of: tantalum, tantalum nitride, titanium, titanium nitride, tungsten, tungsten nitride, ruthenium and ruthenium nitride.

7. The structure of claim **5**, wherein the metal wire includes copper and the metal seed layer is selected from a group consisting of at least one of: copper, copper aluminum, copper iridium, copper nickel and copper ruthenium.

8. The structure of claim **1**, wherein the metal wire is positioned within another dielectric layer, and further comprising a liner between the metal wire and the another dielectric layer.

9. The structure of claim **1**, wherein the dielectric layer includes a barrier layer forming the liner-less interface with the metal wire, and the interlevel dielectric above the barrier layer.

10. A method comprising:
- providing a metal wire in a first dielectric layer;
- forming a second dielectric layer over the metal wire to form a liner-less interface between the metal wire and the second dielectric layer;
- forming an opening through the second dielectric layer and into the metal wire;
- creating an undercut from the opening under the second dielectric layer;
- forming a refractory metal collar in the undercut; and
- filling the opening with a metal to form a via.

11. The method of claim **10**, wherein the providing includes providing a liner between the metal wire and the first dielectric layer along only a bottom and sides of the metal wire.

12. The method of claim **10**, wherein the opening forming includes performing a damascene process to form the opening in the first dielectric layer, and performing a gaseous sputtering process to extend the opening into the metal wire.

13. The method of claim **10**, wherein the undercut creating includes performing an isotropic wet/dry etching.

14. The method of claim **10**, further comprising forming a first liner within the opening prior to the filling, the first liner including the refractory metal.

15. The method of claim **14**, further comprising forming a second liner within the opening prior to the filling, the second liner including at least one metal diffusion barrier and a metal seed layer.

16. The method of claim **15**, wherein the at least one metal diffusion barrier is selected from a group consisting of: tantalum, tantalum nitride, titanium, titanium nitride, tungsten, tungsten nitride, ruthenium and ruthenium nitride.

17. The method of claim **15**, wherein the metal wire includes copper and the metal seed layer is selected from a group consisting of at least one of: copper, copper aluminum, copper iridium, copper nickel and copper ruthenium.

18. A structure comprising:
- a copper wire having a liner-less interface with a dielectric layer and an interlevel dielectric thereabove;
- a via extending upwardly from the copper wire through the dielectric layer and interlevel dielectric, the via including a substantially frusto-conical portion within the copper wire;
- a first liner about the via, the first liner including a refractory metal; and
- a refractory metal collar extending from a side of the via and partially along the liner-less interface.

19. The structure of claim **18**, wherein the refractory metal collar includes a material selected from a group consisting of at least one of: tantalum (Ta), titanium (Ti), tungsten (W), ruthenium (Ru), iridium (Ir), rhodium (Rh) and platinum (Pt).

20. The structure of claim **18**, wherein the dielectric layer includes a barrier layer forming the liner-less interface with the copper wire, and the interlevel dielectric above the barrier layer.

* * * * *