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(54) DENSIFYING A RELATIVELY POROUS MATERIAL

(76) Inventors: **Steven W. Johnston**, Portland, OR (US); **Kevin P. O'Brien**, Portland, OR (US)

Correspondence Address:
Timothy N. Trop
TROP, PRUNER & HU, P.C.
STE 100
8554 KATY FWY
HOUSTON, TX 77024-1841 (US)

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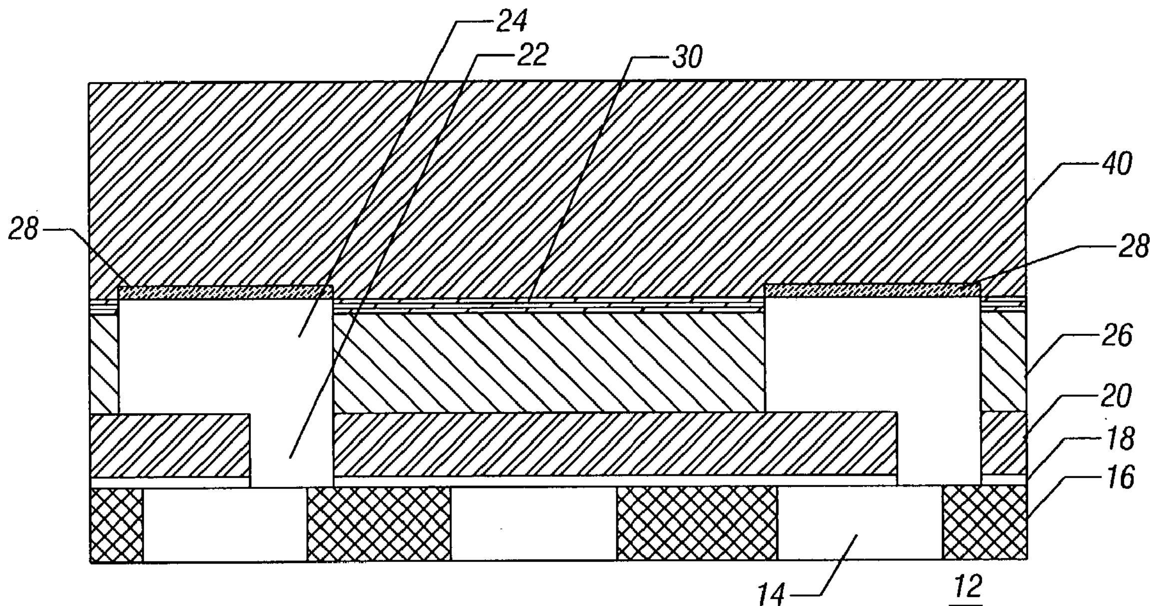
(57) **ABSTRACT**

An interlayer dielectric may be exposed to a gas cluster ion beam to densify an upper layer of the interlayer dielectric. As a result, the upper layer of the interlayer dielectric may be densified without separate deposition steps and without the need for etch stops that may adversely affect the capacitance of the overall structure.



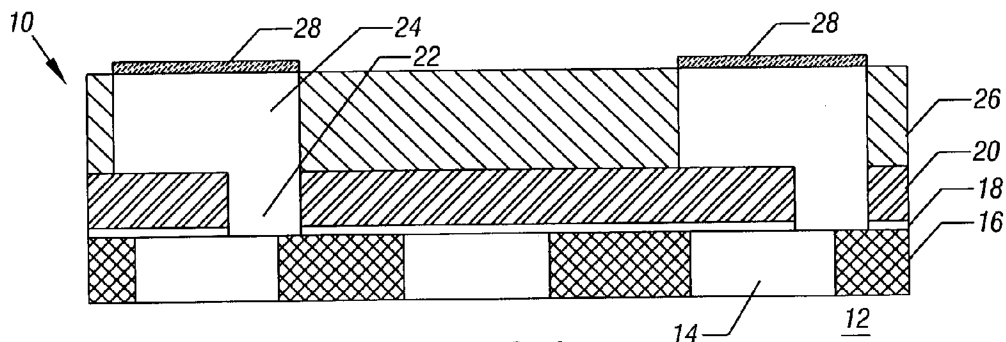


FIG. 1

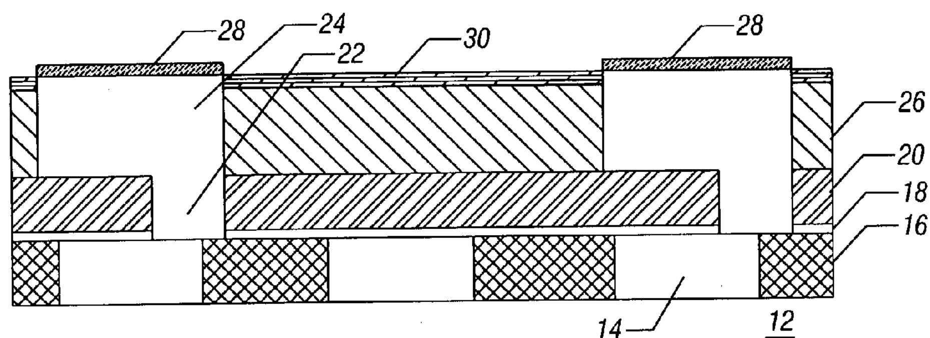


FIG. 2

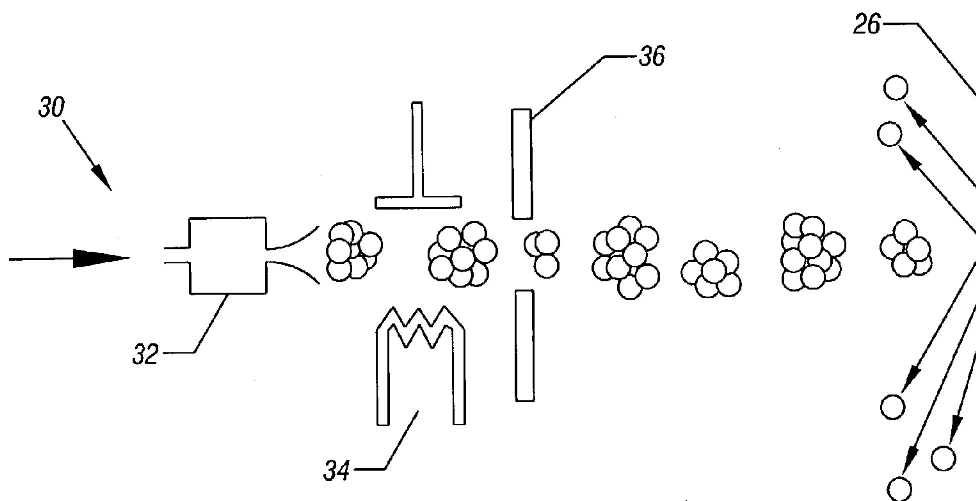


FIG. 8

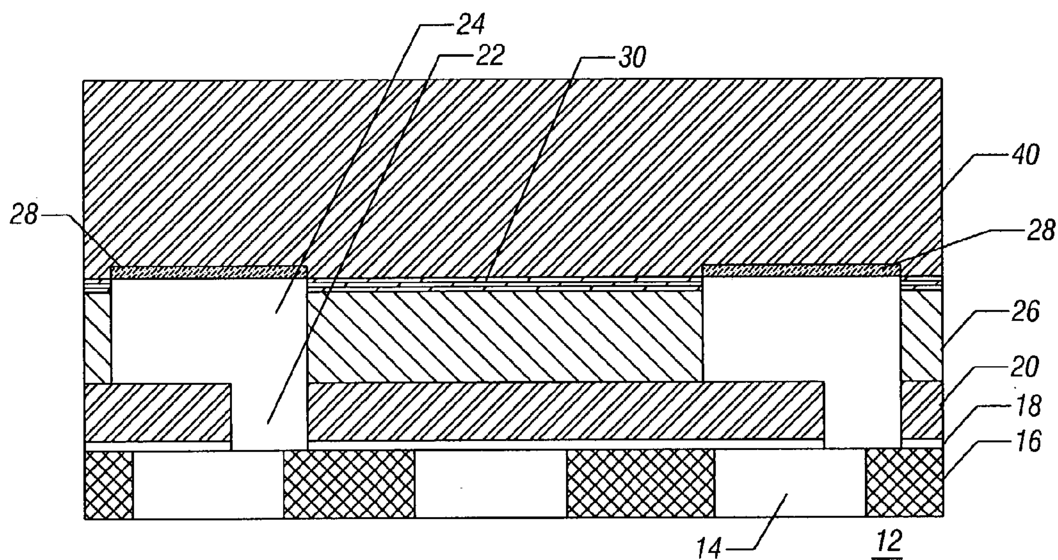


FIG. 3

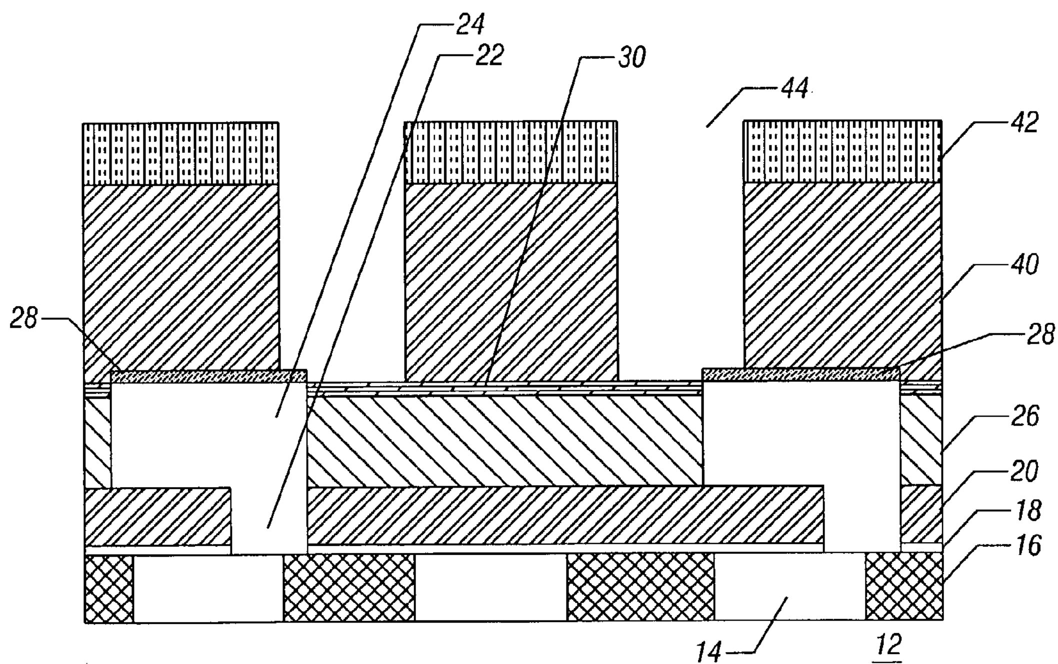


FIG. 4

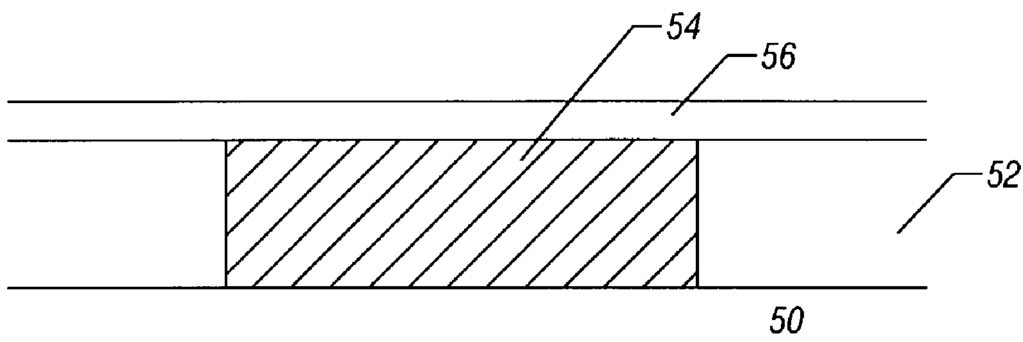


FIG. 5

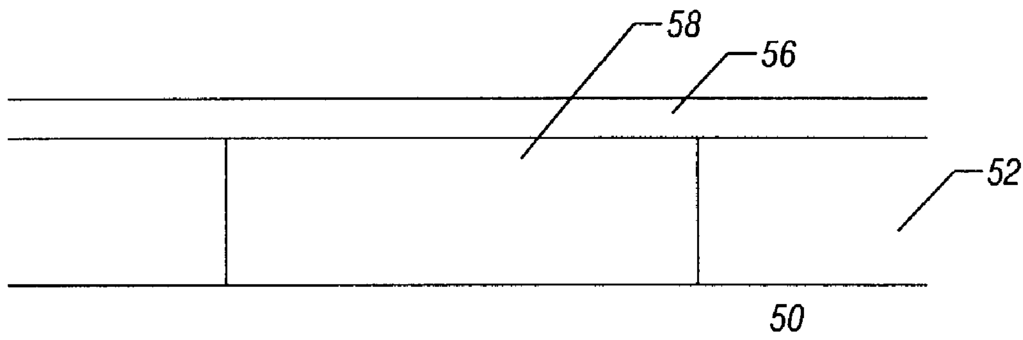


FIG. 6

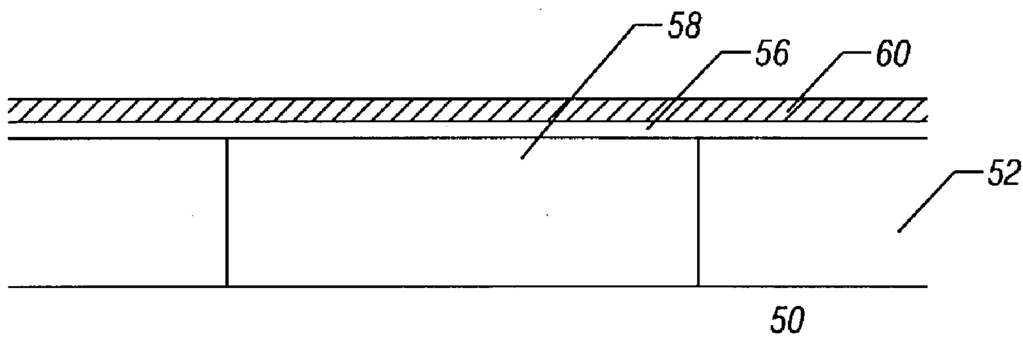


FIG. 7

DENSIFYING A RELATIVELY POROUS MATERIAL

BACKGROUND

[0001] This invention relates generally to processes for manufacturing semiconductor integrated circuits.

[0002] In a variety of different processes, it may be desirable to form what is called a hard mask. A hard mask is a mask that may be utilized as an etching mask for subsequent process steps. For example, in the damascene process, a hard mask may be formed that prevents etched vias from extending through the hard mask. The hard mask may be utilized to enable an unlanded via integration scheme.

[0003] One problem with hard masks is that they may require an extra processing step. Basically, a separate hard mask may be deposited on top of a previously deposited material, such as a low dielectric constant film. The use of such hard mask may increase etch complexity due to the nature of the stack, including the resist, hard mask and underlying film. In addition, moisture may infiltrate through the hard mask. The infiltrated moisture, for example, may increase the capacitance contributed by a low dielectric constant film.

[0004] Thus, there is a need for better ways to form a hardmask.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] **FIG. 1** is an enlarged, cross-sectional view of one embodiment of the present invention in the course of manufacture;

[0006] **FIG. 2** is an enlarged, cross-sectional view of the embodiment as shown in **FIG. 1** at a subsequent stage of manufacture;

[0007] **FIG. 3** is an enlarged, cross-sectional view of the embodiment as shown in **FIG. 1** at a subsequent stage of manufacture in accordance with one embodiment of the present invention;

[0008] **FIG. 4** is an enlarged, cross-sectional view of the embodiment shown in **FIG. 1** at a subsequent stage of manufacture in accordance with one embodiment of the present invention;

[0009] **FIG. 5** is an enlarged, cross-sectional view of another embodiment of the present invention;

[0010] **FIG. 6** is an enlarged, cross-sectional view of the embodiment shown in **FIG. 5** at a subsequent stage in accordance with one embodiment of the present invention;

[0011] **FIG. 7** is an enlarged, cross-sectional view of the embodiment shown in **FIG. 5** at a subsequent stage in accordance with one embodiment of the present invention; and

[0012] **FIG. 8** is a schematic depiction of an apparatus for forming gas cluster ions.

DETAILED DESCRIPTION

[0013] Referring to **FIG. 1**, a substrate **12** may be defined with the appropriate active and passive components, such as the metal elements **14** and the dielectric layer **16**. A masking layer **18** may then be deposited. A dielectric film **20** may be deposited over the layer **18**. The dielectric film **20** may be followed by a second interlayer dielectric film **26** in one embodiment.

[0014] Lithography, etching, and cleaning may be utilized to form trenches or vias through the dielectric films **26** and **20** using a damascene or dual damascene approach. Degassing, cleaning, barrier deposition, and seed deposition of the dielectric material may follow as desired. The resulting trenches may be filled with conductive material **22** and **24** using electroplating or any other fill technology.

[0015] The resulting wafer may be planarized down to the top of the dielectric film **26** by chemical mechanical polishing (CMP) or other planarization technology. If desired, deposition of a thin copper capping film **28** may be done using chemical vapor deposition, atomic layer deposition, or electroless methods to create a thin, continuous capping film.

[0016] The film **26** may be modified by the addition of carbon to form carbon-doped oxide (CDO) film. Other films **26** may also be used including porous silicon, spin-on glass, polymers, and other low dielectric constant materials. Then, as shown in **FIG. 2**, the exposed film **26** may be bombarded with a gas clustered ion beam. As a result of the mass and energy of the clustered ions used to bombard the film **26**, the upper layer **30** of the film **26** may be densified. The capping film **28** is not substantially affected by the densification. In effect, the bombarding clustered ions actually compress the atomic structure of the exposed film **26**. In one embodiment, a relatively porous material can be converted to a substantially non-porous hard mask.

[0017] Thereafter, another low dielectric constant interlayer dielectric layer **40** may be deposited in accordance with the damascene or dual damascene approach as shown in **FIG. 3**. The masking layer **42** may be formed and patterned to the desired trench characteristics as shown in **FIG. 4**. The masking layer **42** may then be used as a mask to pattern the layer **40** to form additional trenches for forming an additional layer of metal interconnects. Again, the metal interconnects may be arranged in an unlanded via configuration to repeat the sequence described in connection with **FIGS. 1 and 2**. In one application, the etched vias **44** may be filled with a sacrificial light activated material. The resulting structure may be covered by another masking layer, trenches may be etched, and then the sacrificial light activated material is etched to leave behind a trench and via that are filled with the material **22**, **24**. The techniques described herein can also be used to form embedded etch stops and to densify the bottom of trenches. Any surface layer may be converted in a directional fashion as described herein.

[0018] In another embodiment of the present invention, a similar process sequence to that described above may be utilized, except that a previously deposited, porous hard mask may be densified. Subsequent steps can then be built up to form multi-levels of vias and interconnects, all using the densified hard mask procedure described herein. As another example, a non-hermetic etch stop may have its top surface densified while the bulk of a silicon carbide etch stop is not altered. As a result, a low dielectric constant may be preserved for the material.

[0019] In one embodiment, a porous layer **56** may be formed over a sacrificial material **54** in a layer **52** over a

substrate **50**, as shown in **FIG. 5**. The porosity of the layer **56** enables the sacrificial material **54** to be evaporated and exhausted through the porous layer **56** in one embodiment, to create a void **58**, shown in **FIG. 6**. Then, the porous layer **56** may be densified to form a substantially non-porous hard mask **60**, sealing the void **58** as shown in **FIG. 7**.

[**0020**] Referring to **FIG. 8**, a typical gas clustered ion beam is illustrated. The desired gas is provided to a nozzle **32** and ejected by an ionizer **34** and accelerated by an accelerator **36**. The accelerated ion clusters then impact the target structure causing densification. The clustered ions may include oxygen ions in one embodiment. As a result, an unlanded via integration scheme may be enabled, as indicated by **22**.

[**0021**] The modified structure may result in a hard mask with lower interconnect capacitance since no silicon carbide etch stop layer may be utilized, a simpler etch process for the next metal layer since no separate hard mask is used on top of the next interlayer dielectric layer to etch through to form a via trench, a naturally self-aligned hard mask material, and a smoother copper or copper capped surface, which may have advantages in some embodiments.

[**0022**] Another advantage of using the gas cluster ions is that the total energy of the gas cluster can be high while the energy per atom is quite low. Thus, subsurface damage is reduced and is controllable to less than 20 Angstroms at low cluster energies. The gas cluster ion also tends to smooth the exposed metal surfaces, resulting in a smoother overlying via barrier interface.

[**0023**] While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is:

1. A method comprising:

forming a porous layer; and

exposing said porous layer to a gas clustered ion beam to densify said porous layer.

2. The method of claim 1 wherein forming a porous layer includes forming an interlayer dielectric.

3. The method of claim 2 including forming a carbon doped oxide interlayer dielectric.

4. The method of claim 1 including forming metallic features on said porous layer and exposing said metallic features and said porous layer to a clustered ion beam.

5. The method of claim 1 including densifying said porous layer to form a hard mask.

6. The method of claim 5 including using said hard mask to enable an unlanded via integration scheme.

7. The method of claim 5 including using said hard mask in a damascene or dual damascene process.

8. The method of claim 1 including forming said porous layer over a sacrificial layer.

9. The method of claim 8 including removing said sacrificial layer through said porous layer and after removing said sacrificial layer through said porous layer exposing said porous layer to said clustered ion beam to form said hard mask.

10. The method of claim 1 including densifying only a surface region of said porous layer while the remainder of said porous layer below said surface region remains undensified.

11. The method of claim 10 including controlling the thickness of a densified region to approximately 20 Angstroms or less.

12-19. (Canceled).

20. A method comprising:

forming a porous layer over a sacrificial layer;

exhausting at least a portion of said sacrificial layer through said overlying porous layer; and

densifying the porous layer.

21. The method of claim 20 including densifying the porous layer using a clustered ion beam.

22. The method of claim 21 including forming a non-porous region in said porous layer by densifying.

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