~~OXYGEN DOPED SiC FOR Cu BARRIER AND ETCH STOP LAYER IN DUAL~~
DAMASCENE FABRICATION

## FIELD OF THE INVENTION

The invention relates to the field of fabricating integrated circuits and other electronic devices and in particular to a dual damascene structure with high performance and improved reliability and a method for forming the same.

## BACKGROUND OF THE INVENTION

The manufacture of an integrated circuit in a semiconductor device involves the formation of a metal layer that typically contains a wiring pattern which is overlaid on another conductive pattern. This process is repeated several times to produce a stack of metal layers. Metal interconnects which form horizontal and vertical electrical pathways in the device are separated by insulating or dielectric materials to prevent crosstalk between the metal wiring that can degrade device performance by slowing circuit speed. A popular method of forming an interconnect structure is a dual damascene process in which vias and trenches are filled with metal in the same step. A single damascene process is also commonly employed to form a metal pattern in one or more dielectric layers. The most frequently used dual damascene approach is a via first process in which a via is formed in a stack of dielectric layers and then a trench is formed above the via. Recent improvements in dual damascene processing include lowering the resistivity of the metal interconnect by switching from aluminum to copper and reducing the dielectric constant (k) of insulating materials to avoid capacitance coupling between the metal interconnects.

# COMPOSITE BARRIER/ETCH STOP LAYER COMPRISING OXYGEN DOPED SIC AND SIC FOR INTERCONNECT STRUCTURES

This is a Divisional application of U.S. Patent application serial number 10/785,520, filed on 2/24/04, which is herein incorporated by reference in its entirety, and assigned to a common assignee.

## FIELD OF THE INVENTION

The invention relates to the field of fabricating integrated circuits and other electronic devices and in particular to a dual damascene structure with high performance and improved reliability and a method for forming the same.

## BACKGROUND OF THE INVENTION

The manufacture of an integrated circuit in a semiconductor device involves the formation of a metal layer that typically contains a wiring pattern which is overlaid on another conductive pattern. This process is repeated several times to produce a stack of metal layers. Metal interconnects which form horizontal and vertical electrical pathways in the device are separated by insulating or dielectric materials to prevent crosstalk between the metal wiring that can degrade device performance by slowing circuit speed. A popular method of forming an interconnect structure is a dual damascene process in which vias and trenches are filled with metal in the same step. A single damascene process is also commonly employed to form a metal pattern in one or more dielectric layers. The most frequently used dual damascene approach is a via first process in which a via is formed in a stack of dielectric layers and then a trench is formed above the via. Recent improvements in dual damascene processing include lowering the resistivity of the metal interconnect by switching from aluminum to copper and reducing the dielectric constant (k) of insulating materials to avoid capacitance coupling between the metal interconnects.

We claim:

1. A damascene method, comprising:

(a) providing a substrate;

(b) depositing a composite barrier/etch stop layer comprised of a lower silicon carbide (SiC) layer and an upper oxygen doped SiC layer on said substrate;

(c) forming a first dielectric layer on said oxygen doped SiC layer;

(d) forming an opening with sidewalls and a bottom in said first dielectric layer;

(e) removing said composite barrier/etch stop layer that is exposed at the bottom of said opening;

(f) depositing a conformal diffusion barrier layer on the sidewalls and bottom of said opening; and

(g) depositing a metal layer on the conformal diffusion barrier layer that fills said opening.

2. The method of claim 1 wherein the substrate is comprised of a conductive layer with a top surface and said opening exposes a portion of the top surface of the conductive layer.

3. The method of claim 2 wherein the conductive layer and the metal layer are comprised of copper.

4. The method of claim 1 wherein the diffusion barrier layer is comprised of Ta, TaN, TaSiN, Ti, TiN, W, or WN and has a thickness in the range of about 50 to 300 Angstroms.

5. The method of claim 1 wherein said first dielectric layer is comprised of Black Diamond™, CORAL™, fluorine doped $SiO_2$, hydrogen silsesquioxane (HSQ), methyl silsesquioxane (MSQ), a fluorinated polyimide, a polyarylether, or benzocyclobutene.

6. The method of claim 1 wherein the lower SiC layer has a thickness from about 50 to 150 Angstroms and the oxygen doped SiC layer has a thickness between about 50 and 1000 Angstroms.

7. The method of claim 1 wherein the oxygen doped SiC layer is deposited by a PECVD process that includes an oxygen flow rate from about 20 to 200 standard cubic centimeters per minute (sccm), a helium flow rate of about 700 to 1000 sccm, a trimethylsilane or tetramethylsilane flow rate of about 280 to 350 sccm, a substrate temperature of from 300°C to 400°C, a chamber pressure of 2 to 8 Torr, and a RF power of about 100 to 1000 Watts that is generated with a RF frequency of 13.56 MHz.

8. The method of claim 7 wherein the substrate temperature is 350°C, the RF power is 460 Watts, chamber pressure is 3.5 Torr, the $O_2$ flow rate is about 30 sccm, the He flow rate is about 800 sccm, and the trimethylsilane flow rate is about 320 sccm to give an oxygen doped SiC deposition rate in the range of 850 to 950 Angstroms per minute.

9. The method of claim 7 wherein the oxygen doped SiC layer has a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %.

~~10. The method of claim 7 wherein the oxygen doped SiC layer has a good etch~~ selectivity to Black Diamond™ or CORAL™ of about 1:6 to 1:10 in a plasma etch comprised of $C_4F_8$ and Ar gases.

11. The method of claim 1 further comprised of treating said oxygen doped SiC layer with a $N_2$, He, or Ar plasma before said first dielectric layer is formed.

12. The method of claim 1 further comprised of a chemical mechanical polish process to planarize said metal layer.

13. A dual damascene method, comprising:

(a) providing a substrate with a conductive layer formed within a first dielectric layer, said conductive layer has an exposed top surface that is coplanar with the top surface of said substrate;

(b) depositing a barrier/etch stop layer comprised of a lower silicon carbide (SiC) layer and an upper first oxygen doped SiC layer on said substrate;

(c) forming a second dielectric layer on said first oxygen doped SiC layer;

(d) depositing a second oxygen doped SiC etch stop layer on said second dielectric layer;

(e) forming a third dielectric layer on said second oxygen doped SiC layer;

(f) forming an opening comprised of a via that exposes said conductive layer and a trench aligned above said via wherein the via has sidewalls and a bottom and extends through said second and third dielectric layers, second oxygen doped SiC layer, and through the composite barrier/etch stop layer and wherein the trench has sidewalls and a bottom and is formed in the third dielectric layer; and

(g) depositing a conformal diffusion barrier layer on the sidewalls and bottom of said trench and via and depositing a metal layer on said conformal diffusion barrier layer that fills said trench and via.

14. The method of claim 13 further comprised of forming a cap layer on the third dielectric layer and wherein the trench is aligned above a via that exposes the conductive layer and said trench is formed in the cap layer and third dielectric layer.

15. The method of claim 13 wherein said conductive layer and metal layer are comprised of copper.

16. The method of claim 13 wherein the diffusion barrier layer is comprised of Ta, TaN, TaSiN, Ti, TiN, W, or WN and has a thickness in the range of about 50 to 300 Angstroms.

17. The method of claim 13 wherein said first, second, and third dielectric layers are a low k dielectric material comprised of Black Diamond™, CORAL™, fluorine doped $SiO_2$, hydrogen silsesquioxane (HSQ), methyl silsesquioxane (MSQ),a fluorinated polyimide, a polyarylether, or benzocyclobutene.

18. The method of claim 13 wherein said second and third dielectric layers have a thickness in the range of about 1000 to 10000 Angstroms.

19. The method of claim 14 wherein the SiC in said barrier/etch stop layer has a thickness from about 50 to 150 Angstroms and the first and second oxygen doped SiC layers have a thickness between about 50 and 1000 Angstroms.

20. The method of claim 13 wherein said first and second oxygen doped SiC layers are deposited by a PECVD process that includes an oxygen flow rate from about 20 to 200 sccm, a helium flow rate of about 700 to 1000 sccm, a trimethylsilane or

tetramethylsilane flow rate of about 280 to 350 sccm, a substrate temperature of from 300°C to 400°C, a chamber pressure of 2 to 8 Torr, and a RF power of about 100 to 1000 Watts that is generated with a RF frequency of 13.56 MHz.

21. The method of claim **20** wherein the substrate temperature is 350°C, the RF power is 460 Watts, chamber pressure is 3.5 torr, the $O_2$ flow rate is 30 sccm, the He flow rate is 800 sccm, and the trimethylsilane flow rate is 320 sccm to give an oxygen doped SiC deposition rate in the range of 850 to 950 Angstroms per minute.

22. The method of claim **20** wherein the first and second oxygen doped SiC layers have an etch selectivity to Black Diamond™ or CORAL™ of about 1:6 to 1:10 in a plasma etch comprised of $C_4F_8$ and Ar gases.

23. The method of claim **21** wherein the composition of the first and second oxygen doped SiC layers has a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %.

24. The method of claim **13** further comprised of treating the first oxygen doped SiC layer with a $N_2$, Ar, or He plasma prior to depositing the second dielectric layer and treating the second oxygen doped SiC layer with a $N_2$, Ar, or He plasma prior to depositing the third dielectric layer.

25. A dual damascene structure comprising:

(a) a semiconductor substrate;

(b) a silicon carbide barrier layer formed on said substrate;

(c) a first oxygen doped SiC etch stop layer formed on said silicon carbide layer;

(d) a first dielectric layer formed on said first oxygen doped SiC layer;

(e) a second oxygen doped SiC etch stop layer formed on said first dielectric layer;

(f) a second dielectric layer formed on said second oxygen doped SiC layer;

(g) an opening comprised of a via with sidewalls and a bottom that exposes a portion of said substrate and a trench aligned above said via, said trench has sidewalls and a bottom and is formed in said second dielectric layer; and

(h) a conformal diffusion barrier on the sidewalls and bottoms of said via and trench and a metal layer on said diffusion barrier layer that fills said opening and is coplanar with the second dielectric layer.

26. The dual damascene structure of claim 25 wherein the substrate is comprised of a conductive layer with an exposed top surface and the bottom of the via exposes a portion of the top surface of said conductive layer.

27. The dual damascene structure of claim 26 wherein said conductive layer and metal layers are comprised of copper.

28. The dual damascene structure of claim 25 wherein the metal layer has a width that is less than about 0.25 microns.

29. The dual damascene structure of claim 25 wherein the diffusion barrier layer is comprised of Ta, TaN, TaSiN, Ti, TiN, W, or WN and have a thickness in the range of about 50 to 300 Angstroms.

30. The dual damascene structure of claim 25 wherein said first and second dielectric layers are comprised of Black Diamond™, CORAL™, fluorine doped $SiO_2$, hydrogen silsesquioxane (HSQ), methyl silsesquioxane (MSQ), a fluorinated polyimide, a polyarylether, or benzocyclobutene.

31. The dual damascene structure of claim 25 wherein said first and second dielectric layers have a thickness in the range of about 1000 to 10000 Angstroms.

32. The dual damascene structure of claim 25 wherein the SiC barrier layer has a thickness in the range of about 50 to 150 Angstroms.

33. The dual damascene structure of claim 25 wherein said first and second oxygen doped SiC layers have a thickness between about 50 and 1000 Angstroms.

34. The dual damascene structure of claim 25 wherein the first and second oxygen doped SiC layers have a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %.

35. The dual damascene structure of claim 25 wherein the dielectric constant of said first and second oxygen doped SiC layers is between about 3.7 and 4.3.

36. The dual damascene structure of claim 25 wherein the breakdown field of said first and second oxygen doped SiC layers is greater than about 4 milliVolts/cm.

37. The damascene structure of claim 25 which is repeated a plurality of times to form a stack of metal layers on said substrate.

We claim:

1. A dual damascene structure comprising:

a substrate;

a composite barrier/etch stop layer formed over the substrate, the composite barrier/etch stop layer comprising a lower silicon carbide (SiC) layer and an upper first oxygen doped SiC layer wherein the upper first oxygen doped SiC layer has a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %;

a first dielectric layer formed over the upper first oxygen doped SiC layer;

a second oxygen doped SiC etch stop layer formed over the first dielectric layer wherein the second oxygen doped SiC etch stop layer has a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %;

a second dielectric layer formed over the second oxygen doped SiC layer;

an opening having sidewalls and a bottom, the opening extending through the second dielectric layer, the second oxygen doped SiC etch stop layer, the first dielectric layer, the upper first oxygen doped SiC layer and at least a portion of the lower silicon carbide SiC layer, the opening comprising a via and a trench located in the second dielectric layer aligned above said via; and

a conformal diffusion barrier lining the sidewalls and the bottom of said opening and a metal layer formed on the diffusion barrier layer, the metal layer filling the opening.

2. The dual damascene structure of claim 1 wherein the substrate is comprised of a conductive layer with an exposed top surface and the opening is coextensive with a portion of the top surface of the conductive layer.

3. The dual damascene structure of claim 2 wherein the conductive layer and the metal layer are comprised of copper.

4. The dual damascene structure of claim 1 wherein the metal layer has a width that is less than about 0.25 microns.

5. The dual damascene structure of claim 1 wherein the diffusion barrier layer is comprised of Ta, TaN, TaSiN, Ti, TiN, W, or WN and has a thickness in the range of about 50 to 300 Angstroms.

6. The dual damascene structure of claim 1 wherein the first and second dielectric layers are comprised of Black Diamond™, CORAL™, fluorine doped SiO2, hydrogen silsesquioxane (HSQ), methyl silsesquioxane (MSQ), a fluorinated polyimide, a polyarylether, or benzocyclobutene.

7. The dual damascene structure of claim 1 wherein the first and second dielectric layers have a thickness in the range of about 1000 to 10000 Angstroms.

8. The dual damascene structure of claim 1 wherein the lower silicon carbide (SiC) layer has a thickness in the range of about 50 to 150 Angstroms.

9. The dual damascene structure of claim 1 wherein the first and second oxygen doped SiC layers have a thickness between about 50 and 1000 Angstroms.

10. The dual damascene structure of claim 1 wherein the dielectric constant of the first and second oxygen doped SiC layers is between about 3.7 and 4.3.

11. The dual damascene structure of claim 1 wherein a breakdown field of the first and second oxygen doped SiC layers is greater than about 4 milliVolts/cm.

12. The damascene structure of claim 1 which is repeated a plurality of times to form a stack of metal layers on said substrate.

13. An integrated circuit comprising:

a substrate;

a composite barrier/etch stop layer formed over the substrate, the composite barrier/etch stop layer comprising a lower silicon carbide (SiC) layer and an upper first oxygen doped SiC layer wherein the upper first oxygen doped SiC layer has a silicon content from about 25 to 35 atomic weight %, a carbon content of about 17 to 25 atomic wt. %, an oxygen content of about 5 to 15 atomic wt. %, and a hydrogen content from about 20 to 40 atomic wt. %;

a first dielectric layer formed over the upper first oxygen doped SiC layer;

an opening having sidewalls and a bottom, the opening extending through the first dielectric layer, the upper first oxygen doped SiC layer and at least a portion of the lower SiC layer.

14. An integrated circuit of claim 13, further comprising a conformal diffusion barrier layer lining the sidewalls and the bottom of the opening and a metal layer formed on the diffusion barrier layer, the metal layer filling the opening.