



METHOD FOR MAKING LOW-RESISTANCE BARRIER LAYER USING THE COPPER PROCESS

BACKGROUND OF THE INVENTION

Field of Invention

The invention pertains to the manufacturing method of a barrier layer using the copper process and, in particular, the manufacturing method that form a low-resistance TaN barrier layer with a gradient concentration profile during the IC copper process.

Related Art

With rapid development in IC production processes, the multilevel conductor interconnect process has been received a lot of attention. In the field of deep submicron devices, increasing the device operating speeds in IC's is a key issue for the manufacturers and an important criterion for consumers during selection. In particular, the RC time constant delay resulted from metal interconnects seriously affects the operating speed of devices. One way to improve the performance is to select a low-resistance metal (such as Cu, Au, and Ag) as the material of the metal interconnects. The copper has at least the advantages of: (1) a lower resistance than gold and aluminum; (2) a superior electromigration resistance; and (3) a better thermal conductivity. Moreover, it can be grown using the physical vapor deposition (PVD), chemical vapor deposition (CVD), and electroplating. Therefore, the copper process has gradually been accepted by almost all IC manufacturers.

However, some chemical properties of copper limit its applications in IC devices. These include: (1) copper is likely to have reactions with many elements (such as Si or Si-substrate to form Cu_3Si within the IC structure) at a low temperature of about 200 °C to make the device ineffective; (2) Copper cannot grow a self-protecting oxide layer as aluminum. Therefore, it is likely to be oxidized and corroded, affecting the conductive stability of metal interconnects. (3) The adhesive property between copper and the dielectric layer is not so good that the mechanical strength of the coating structure in the IC is insufficient. (4) Copper atoms can be rapidly spread out. Accelerated by the electric field, copper atoms penetrate through the dielectric layer and rapidly spread out. Spreading the copper atoms into the silicon substrate will cause the degeneration and ineffectiveness of the device.



A good barrier layer has to be an effective adhesive layer, which does not only adhesive to the copper atoms but also the dielectric layer. At the same time, the distribution of copper atoms into the silicon device has to be effectively suppressed under high temperatures. It should have a good thermal stability to promote the lifetime and reliability of the device. In the most commonly used copper process, the barrier layer material is TaN. As shown in FIG. 1, a copper interconnect 14 is already formed inside the substrate 10. The substrate 10 is further formed with a dielectric layer 18 with an opening 20. An etching stop layer 12 is formed between the substrate 10 and the dielectric layer 18 for the process of making an opening 20 with a metal embedded structure. The opening 20 is deposited with a barrier layer 22 of TaN. The copper layer 24 is then formed using a seed layer, electroplating and chemical mechanical polishing (CMP) to finish another copper interconnect structure.

However, the pull-back phenomena often occur to the copper layer 24 in the prior art, as shown in FIG. 1. The pullback phenomena may result from the imperfect adhesiveness between the TaN barrier layer 22 and the copper layer 24, or the electrical and thermal pressure imposed in subsequent process or when using the product. Such pull-back effects will affect the conductive stability and product reliability of the multilevel interconnects in the copper process.

SUMMARY OF THE INVENTION

In view of the foregoing, an objective of the invention is to provide a manufacturing method for low-resistance barrier layers using the copper process. The method can obtain better barrier layers in quality.

Another objective of the invention is to provide a manufacturing method for TaN barrier layers using the copper process to solve the pull-back problem on copper interconnects encountered when using TaN as the barrier layer material.

In accordance with the above objectives, the disclosed method includes the steps of: providing a substrate; forming an opening on the substrate; and performing a deposition. After depositing a barrier layer of a certain thickness, the nitrogen-rich reaction gas flux is reduced while the barrier layer is kept forming to cover the opening. The barrier layer is comprised of metal atoms and nitrogen atoms. The concentration of nitrogen atoms decreases from the bottom to top of the barrier layer. In this method, the opening can be a trench, via, or damascene structure. The deposition step can be achieved using PVD or CVD. In a preferred embodiment of the invention, the metal is

Ta and the nitrogen-rich reaction gas is nitrogen gas. The barrier layer is thus made of TaN_x . At the bottom of the barrier layer, the preferred X range is between 0.5 and 0.8 and the exact value is determined according to practical needs. Moreover, the above-mentioned nitrogen-rich reaction gas flux decreases to zero at the top surface. Therefore, the nitrogen concentration is zero on the top surface of the barrier layer. According to the invention, copper is provided in the opening to form the copper interconnects structure.

Using the disclosed method, a TaN barrier layer with a gradient concentration variation can be made. Its adhesivity with copper is better than the conventional ones. It can reduce the resistance of the barrier layer and promote the electromigration resistance and conductive stability.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects and advantages of the invention will become apparent by reference to the following description and accompanying drawings which are given by way of illustration only, and thus are not limitative of the invention, and wherein:

FIG. 1 is a schematic view of the copper interconnects structure using TaN as the barrier layer material in the prior art;

FIG. 2 is a schematic view of the low-resistance barrier layer structure using the copper process according to the invention;

FIG. 3 is an exploded schematic view of the low-resistance barrier layer structure using the copper process according to the invention; and

FIG. 4 is a schematic view of the copper interconnects structure using the disclosed low-resistance barrier layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the prior art, a layer of TaN is formed in a damascene structure as the barrier layer. However, as a result of electrical and thermal pressure during subsequent processes or actual uses, voids and pull-back phenomena happen to the copper

interconnects. This results in instability in the conductivity of the interconnects and, therefore, decrease in the IC reliability. Therefore, the invention provides a manufacturing method for low-resistance barrier layers using the copper process. It can solve the problem of copper pull-back effects occurring to the TaN barrier layer, thereby promoting the reliability of the IC devices that involves the copper process.

With reference to FIG. 2, the substrate 50 is already formed with copper interconnects 54. However, the invention is not limited to the structure of a substrate 50 necessarily with copper interconnects 54. Afterwards, the substrate 50 is formed with a dielectric material, such as a dielectric layer 58, for insulating metal interconnects. An opening 60 is formed in the dielectric material. The opening can be either a trench, a via, or a damascene structure as shown in FIG. 2. If one wants to form the opening 60 using the damascene process, an etching stop layer 52 has to be formed between the substrate 50 and the dielectric layer 58 to prevent over-etching. It should be emphasized that the above-mentioned method of forming a trench, a via, or a damascene structure is not a feature of the invention. The operation principles are well known to people skilled in the art and, therefore, are not repeated herein.

After the opening 60 is formed, the invention uses the PVD or CVD to form a barrier layer 62 on the opening 60. To increase the gradient coverage rate during coating, one can choose the CVD to obtain a film homogeneous in its thickness. If TaN is used as the copper barrier layer material, however, the TaN barrier thin film formed by the PVD in high vacuum has a better quality. The invention is not limited by the preferred selection in practice. During the TaN thin film formation process, the flux of the nitrogen-rich reaction gas used in the invention is fixed. Therefore, the TaN film thus made is very homogeneous. That is, the distribution of nitrogen atoms in the film is very smooth. However, the feature of the invention is that the nitrogen-rich reaction gas flux is changed once a certain thickness of TaN is deposited in either the PVD or CVD method. The flux is gradually reduced so that the nitrogen atoms have a decreasing gradient concentration in the film.

FIG. 3 is an exploded view of the position 64 in FIG. 2. The barrier layer 62 deposited in the opening 60 has several nitrogen atoms 66. The number of nitrogen atoms 66 is the biggest in the first deposited part 70 as the nitrogen-rich reaction gas has the largest flux. Afterwards, as the reaction gas flux reduces, the middle part 72 has fewer nitrogen atoms than that first part 70. When the gas flux become very small, the number of nitrogen atoms 66 in the last part 74 becomes very small.

In a preferred embodiment of the invention, a TaN_x barrier layer is deposited where X refers to the ratio of the number of Ta atoms to that of nitrogen atoms. At the bottom of the barrier layer, X ranges between 0.5 and 0.8 (depending upon actual applications) in the first part. When the flux of the nitrogen-rich reaction gas gradually reduces, the value of X also gets lower, even to zero. In other words, if necessary, the nitrogen-rich reaction gas may be eventually shut down during the deposition of TaN. In this way, a metal structure with only Ta atoms on the surface of the barrier layer can be formed. Such a barrier layer inherits the nice properties of both Ta atoms and TaN. It should be noted that in addition to the TaN barrier layer, the manufacturing method for the low-resistance barrier layer using the copper process can be used in the making of other metal nitride barrier layers. Moreover, decreasing X to zero as described above is simply an example of the invention. One can select the decreasing extent according to the practical needs of the product or manufacturing process. That is, one can control the X value to obtain the desired gradient concentration variation. In addition to the opening structure of a dielectric layer with a substrate at the bottom, the disclosed manufacturing method can be used for the opening of the interconnect metal dielectric layer. That is, in the copper process the disclosed method can be used at places where a low-resistance barrier layer is required.

Finally, with reference to FIG. 4, a copper layer 80 is formed in the structure shown in FIG. 2. This completes the structure of copper interconnects. Utilizing the disclosed method can make a barrier layer (such as TaN) with a gradient concentration variation. The adhesivity between the Ta and Cu formed on the surface is better than purely TaN as in the prior art. Moreover, the bottom of the barrier layer uses TaN to obtain a nice insulating effect. Therefore, using the disclosed method can simultaneously obtain a barrier layer with good adhesive and insulating properties. When applied to the copper damascene process, the via resistance can be lowered. The electromigration resistance of the multilevel interconnects can be increased to promote the conductive stability of the device.

While the invention has been described by way of example and in terms of the preferred embodiment, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements as would be apparent to those skilled in the art. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

CLAIMS

What is claimed is:

1. A method for manufacturing a low-resistance barrier layer using the copper process, comprising the steps of:

providing a substrate;

forming an opening in the substrate; and

performing a depositing step, in which a barrier layer with a certain thickness is first deposited, the flux of a nitrogen-rich reaction gas is then reduced, the barrier layer is kept forming to cover the opening;

wherein the barrier is comprised of a plurality of metal atoms and a plurality of nitrogen atoms, with the concentration of the latter decreasing from one bottom surface of the barrier layer toward the other upper surface of the barrier layer.

2. The method of claim 1, wherein the opening is a trench structure.

3. The method of claim 1, wherein the opening is a via structure.

4. The method of claim 1, wherein the opening is a damascene structure.

5. The method of claim 1, wherein the depositing step uses the physical vapor deposition (PVD) method.

6. The method of claim 1, wherein the depositing step uses the chemical vapor deposition (CVD) method.

7. The method of claim 1, wherein the metal is Ta.

8. The method of claim 7, wherein the barrier layer at the bottom surface is

comprised of TaN_x where X is a ratio of the number of the Ta atoms to that of the nitrogen atoms and ranges between 0.5 and 0.8.

9. The method of claim 1, wherein the nitrogen-rich reaction gas is nitrogen gas.
10. The method of claim 1, wherein the nitrogen atom concentration on the upper surface vanishes as the nitrogen-rich reaction gas flux decreases to zero.
11. A manufacturing method for making a TaN barrier layer using the copper process, comprising the steps of:
 - providing a substrate, the surface of which has a dielectric layer;
 - forming at least one opening in the dielectric layer; and
 - performing a depositing step, in which the flux of a nitrogen-rich reaction gas is reduced after depositing a TaN barrier layer to a certain thickness, the TaN barrier layer is formed continuously to cover the opening; wherein the TaN barrier layer contains a plurality of Ta atoms and N atoms, with the concentration of the latter decreasing from a bottom surface to an upper surface of the TaN layer.
12. The method of claim 11, wherein the opening is a trench structure.
13. The method of claim 11, wherein the opening is a via structure.
14. The method of claim 11, wherein the opening is a damascene structure.
15. The method of claim 11, wherein the depositing step uses the physical vapor deposition (PVD) method.
16. The method of claim 11, wherein the depositing step uses the chemical vapor deposition (CVD) method.
17. The method of claim 11, wherein the TaN barrier is made of TaN_x with X

being a ratio of the number of the Ta atoms to the number of the N atoms and ranging from 0.5 to 0.8.

18. The method of claim 11, wherein the nitrogen-rich reaction gas is nitrogen gas.

19. The method of claim 11, wherein the nitrogen atom concentration on the upper surface vanishes as the nitrogen-rich reaction gas flux decreases to zero.

20. A method for manufacturing copper interconnects, comprising the steps of:

providing a substrate, whose surface has a dielectric layer;

forming at least one opening in the dielectric layer;

performing a depositing step, in which the flux of a nitrogen-rich reaction gas is reduced after depositing a TaN barrier layer to a certain thickness, the TaN barrier layer is formed continuously to cover the opening; wherein the TaN barrier layer contains a plurality of Ta atoms and N atoms, with the concentration of the latter decreasing from a bottom surface to an upper surface of the TaN layer; and

forming a copper layer on the barrier layer and filling the opening.

21. The method of claim 20, wherein the opening is a trench structure.

22. The method of claim 20, wherein the opening is a via structure.

23. The method of claim 20, wherein the opening is a damascene structure.

24. The method of claim 20, wherein the depositing step uses the physical vapor deposition (PVD) method.

25. The method of claim 20, wherein the depositing step uses the chemical vapor deposition (CVD) method.

26. The method of claim 20, wherein the TaN barrier is made of TaN_x with X being a ratio of the number of the Ta atoms to the number of the N atoms and ranging from 0.5 to 0.8.

27. The method of claim 20, wherein the nitrogen-rich reaction gas is nitrogen gas.

28. The method of claim 20, wherein the nitrogen atom concentration on the upper surface vanishes as the nitrogen-rich reaction gas flux decreases to zero.