

17 AUG 2000

**METHOD OF FABRICATION OF IMPROVED SILICON OXYNITRIDE ETCH
STOP LAYER**

FIELD OF THE INVENTION

The present invention relates generally to methods of formation etch stop layers used in semiconductor device fabrication, and specifically to a plasma enhanced chemical vapor deposition (PECVD) method of formation of an improved silicon oxynitride etch stop layer in semiconductor device fabrication.

BACKGROUND OF THE INVENTION

In the rapid shrinkage in device geometry and design complexity of modern microelectronics, high quality nitride film (which imposes no impact on the characteristics of metal-oxide semiconductor (MOS) devices), is required for a tungsten local interconnect/borderless contact etch stop layer. However current plasma enhanced chemical vapor deposition (PECVD) nitride poses several concerns from a process integration aspect, such as Si (silicon) - rich property and high H (hydrogen) content of the film.

Normally, SiN formed by current PECVD techniques is formed from SiH_4/N_2 or $\text{SiH}_4/\text{NH}_3/\text{N}_2$. An NH_3 - free SiN liner would cause high gate to source/drain leakage and active bridging problems due to its Si - rich property. On the other hand, an NH_3 - rich SiN film, which has high H content, gives rise to V_t (threshold voltage) shift due to the H diffusion.

U.S. Patent No. 5,773,100 to Chang et al. describes a method of depositing silicon nitrides, and silicon oxynitride, by plasma enhanced chemical vapor deposition (PECVD) by the use of a vacuum deposition chamber inlet gas manifold having inlet apertures which increase in diameter transverse to the direction of gas flow. This increases the rate of silicon nitride deposition without the

use of reactants such as ammonia. Ammonia may be used in the PECVD of silicon oxynitride, although better results are achieved without ammonia.

U.S. Patent No. 5,591,494 to Sato et al. describes a method of depositing silicon nitrides, having low carbon and hydrogen content and low wet etch rates, by plasma enhanced chemical vapor deposition (PECVD) from a precursor gas mixture of a silane, a nitrogen-containing organosilane, and a nitrogen-containing gas at low temperatures of 300 - 400°C, and pressure of 1 - 10 Torr.

U.S. Patent No. 5,399,387 to Law et al. describes a process of plasma CVD of silicon nitride thin films on large area glass substrates at high deposition rates. This is achieved by: adjusting the spacing between the gas inlet manifold and substrate; maintaining the temperature at about 300 - 350°C; and maintaining the pressure of at least 0.8 Torr.

U.S. Patent No. 5,851,603 to Tsai et al. describes a method for fabricating a PECVD multilayer passivation layer comprised of silicon oxide/silicon nitride/silicon oxide/silicon nitride deposited consecutively in a single PECVD system.

U.S. Patent No. 5,910,453 to Gupta et al. describes an etching process for deep ultraviolet (DUV) photolithography for etching a layer of anti-reflective coating (ARC) comprising spin-on organic ARC material which is formed beneath a layer of photoresist.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method of forming a nitride layer that avoids the problems of Si - rich property, i.e. high gate to source/drain leakage.

Another object of the present invention is to provide a method of forming a nitride layer that avoids the problems of high H content, i.e. V_t shift.

Yet another object of the present invention is to provide a method of forming silicon oxynitride that is admirably suited as an etch stop layer for tungsten local interconnect/borderless contact.

Other objects will appear hereinafter.

It has now been discovered that the above and other objects of the present invention may be accomplished in the following manner. Specifically, a precursor gas mixture comprising SiH_4 , NH_3 , N_2 , and N_2O is supplied to a vacuum chamber. A plasma is generated in the chamber from the precursor gas mixture, and a silicon oxynitride compound having the structure $\equiv \text{Si} - \text{N} = \text{O}$ is deposited on a substrate in said chamber. The ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 7 : 1

to 15 : 1; the ratio of N_2 : N_2O is from about 300 : 1 to 400 : 1; and the ratio of SiH_4 : N_2O is from about 4 : 1 to 8 : 1.

BRIEF DESCRIPTION OF THE DRAWINGS

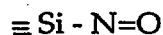
The features and advantages of the method of fabricating an improved silicon oxynitride etch stop layer according to the present invention will be more clearly understood from the following description taken in conjunction with the accompanying drawings in which like reference numerals designate similar or corresponding elements, regions and portions and in which:

Fig. 1 schematically illustrates in cross-sectional representation a tungsten local interconnect/borderless contact semiconductor device having an etch stop layer formed from the PECVD deposited silicon oxynitride compound made in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Accordingly, the present invention introduces the notion of isomerization of NO : ON bonds, which occurs naturally in silicon oxynitride (SiON) compounds. During the SiN film formation using SiH₄ (silane)/NH₃ (ammonia)/N₂ (nitrogen) chemistry, adding small amounts of N₂O (nitrous oxide) has been discovered to help prevent the formation of Si - Si bonds and also assists in reducing the H - bonds. Since NH₃ and N₂O are more reactive than N₂, NH₃ and N₂O would be broken down almost at the same time with SiH₄ to provide enough of a nitrogen source to form less Si - rich film.

In the meantime, a small amount of oxygen from N₂O passivates the Si and N dangling bonds to form a stable Si-N=O configuration so that the H absorption is reduced, thus reducing the H content in the film. Essentially, a new film is grown, SiNO having the structure:



when a relatively small amount of N₂O is used.

Table I lists the parameters of one example of a SiNO film deposition of the present invention and some of the characteristics of that SiNO film deposited

using a single wafer PECVD reactor. A precursor gas mixture of SiH_4 , NH_3 , N_2 , and N_2O was supplied to a vacuum chamber, a plasma was generated from this precursor gas mixture and a layer of silicon oxynitride was deposited on a substrate in the chamber.

TABLE I

Parameters/Results Value

RF power density, W/cm^2	HFRF: about 0.138; LFRF: about 0.138
Frequency	HFRF: about 13.56 MHz; LFRF: from about 250 to 270 kHz
Total pressure, Torr	about 2.2
Wafer temp., $^{\circ}\text{C}$	about 400
Gas chemistry: $\text{SiH}_4/\text{NH}_3/\text{N}_2/\text{N}_2\text{O}$ flow rates, sccm	about 80/130/4500/15 respectively
Electrode spacing, d (mils)	about 600
Dep. rate $\text{\AA}/\text{min.}$	about 1250
Refractive index	about 2.1
H content, atomic percent	< about 16%
Stress, dynes/cm^2	about 1.1279 (compressive)
Within wafer uniformity, %	+ about 1.5%

The ratios of $\text{NH}_3 : \text{N}_2\text{O}$ and $\text{N}_2 : \text{N}_2\text{O}$ are kept very high, i.e. $\text{NH}_3 : \text{N}_2\text{O}$ from about 7:1 to 15:1 and $\text{N}_2 : \text{N}_2\text{O}$ from about 300:1 to 400:1; as is the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$, i.e. $\text{SiH}_4 : \text{N}_2\text{O}$ from about 4:1 to 8:1. For example, if the mole rate of N_2O is 1, then the mole rate of NH_3 would be from about 7 to 15, the mole rate of N_2 would be from about 300 to 400, and the mole rate of SiH_4 would be from about 4 to 8. The corresponding flow rates are: SiH_4 - from about 48 to 96 sccm; NH_3 - from about 84 to 180 sccm; N_2 - from about 3600 to 4800 sccm; and N_2O - from about 10 to 15 sccm.

A refractive index of 2.0 is assumed in the industry as being indicative of high density and good quality for silicon nitride (SiN) films deposited using conventional high temperatures of CVD. The refractive index of the SiNO film formed in accordance with the present invention is from about 2.0 to 2.2.

Table II illustrates the gas chemistry comparison between the PECVD formation of silicon oxynitride (SiNO) in accordance with the present invention and the prior art standard PECVD formation of SiON films.

TABLE II

Gas chemistry ratios	Present Invention SiNO	Prior Art SiON Process
	Process Ratio Value	Ratio Value
NH ₃ : N ₂ O	7:1 to 15:1	0
N ₂ : N ₂ O	300:1 to 400:1	20:1 to 100:1
SiH ₄ : N ₂ O	4:1 to 8:1	0.5:1 to 2:1

As shown in Table II, the prior art standard PECVD formation of SiON utilizes no ammonia and a much greater amount of nitrous oxide. Further, the refractive index of the prior art standard PECVD SiON film formed is 1.8 to 3.0, while, as noted above, the silicon oxynitride film formed in accordance with the present invention has a refractive index of about 2.0 to 2.2.

As shown in Fig. 1, the silicon oxynitride film of the present invention may be used as an etch stop layer 14 in a tungsten local interconnect / borderless contact semiconductor device.

Semiconductor substrate 10 has shallow isolation trench (STI) regions 12 formed therein and separating a tungsten local interconnect / borderless contact transistor device 30. Semiconductor structure 10 is understood to possibly include a semiconductor wafer or substrate, active and passive devices formed within the

wafer, conductive layers and dielectric layers (e.g., inter-poly oxide (IPO), intermetal dielectric (IMD), etc.) formed over the wafer surface. The term "semiconductor structure" is meant to include devices formed within a semiconductor wafer and the layers overlying the wafer. Unless otherwise specified, all structures, layers, etc. may be formed or accomplished by conventional methods known in the prior art.

Silicide layers 16 are formed over device 30's source/drain (not shown) and silicide layer 24 is formed over gate conductor 20. Gate conductor 20 has gate oxide layer 18 and sidewall spacers 22. Silicon oxynitride etch stop layer 14 is formed over semiconductor substrate 10, STI 12, and silicide layers 16, 24. An oxide interlevel dielectric 26 is formed over the structure and contacts 28 are formed connecting device 30.

While particular embodiments of the present invention have been illustrated and described, it is not intended to limit the invention, except as defined by the following claims.



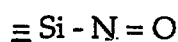
CLAIMS

We claim:

1. A PECVD method of forming an silicon oxynitride layer, comprising the steps of:

supplying a precursor gas mixture comprising SiH_4 , NH_3 , N_2 , and N_2O to a vacuum chamber;

5 generating a plasma in the chamber from said precursor gas mixture; and
depositing a layer of silicon oxynitride compound having the structure



10 on a substrate in said chamber.

2. The method of claim 1, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 7 : 1 to 15 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 300 : 1 to 400 : 1, and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 4 : 1 to 8 : 1 and the flow rate of the SiH_4 is from about 48 to 96 sccm, the flow rate of the NH_3 is from about 84 to 180 sccm, the flow rate of the N_2 is from about 3600 to 4800 sccm, and the flow rate of the N_2O is from about 10 to 15 sccm.



3. The method of claim 1, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 9 : 1 to 13 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 325 : 1 to 375 : 1, and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 5 : 1 to 7 : 1 and the flow rate of the SiH_4 is from about 60 to 84 sccm, the flow rate of the NH_3 is from about 108 to 156 sccm, the flow rate of the N_2 is from about 3900 to 4500 sccm, and the flow rate of the N_2O is from about 11 to 13 sccm.

4. The method of claim 1, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is about 11 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is about 350 : 1 and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is about 6 : 1 and the flow rate of the SiH_4 is about 72 sccm, the flow rate of the NH_3 is about 132 sccm, the flow rate of the N_2 is about 4200 sccm, and the flow rate of the N_2O is about 12 sccm.

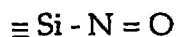
5. The method of claim 1, wherein said layer of silicon oxynitride compound having the structure



is an etch stop layer.



6. The method of claim 1, wherein said substrate is a silicon semiconductor substrate, and said layer of silicon oxynitride compound having the structure



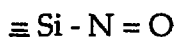
is an etch stop layer formed over a silicide layer over a gate on said silicon semiconductor substrate in said chamber.

7. The method of claim 1, wherein the refractive index of said layer of silicon oxynitride compound so formed is from about 2.0 to 2.2.

8. A PECVD method of forming an silicon oxynitride layer comprising the steps of:

supplying a precursor gas mixture comprising SiH_4 , NH_3 , N_2 , and N_2O to a vacuum chamber;

5 generating a plasma in the chamber from said precursor gas mixture; and
depositing a layer of silicon oxynitride compound having the structure



10 to form an etch stop layer over a silicide layer over a gate on a silicon semiconductor substrate in said chamber.



9. The method of claim 8, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 7 : 1 to 15 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 300 : 1 to 400 : 1, and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 4 : 1 to 8 : 1 and the flow rate of the SiH_4 is from about 48 to 96 sccm, the flow rate of the NH_3 is from about 84 to 180 sccm, the flow rate of the N_2 is from about 3600 to 4800 sccm, and the flow rate of the N_2O is from about 10 to 15 sccm.

10. The method of claim 8, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 9 : 1 to 13 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 325 : 1 to 375 : 1, and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 5 : 1 to 7 : 1 and the flow rate of the SiH_4 is from about 60 to 84 sccm, the flow rate of the NH_3 is from about 108 to 156 sccm, the flow rate of the N_2 is from about 3900 to 4500 sccm, and the flow rate of the N_2O is from about 11 to 13 sccm.

11. The method of claim 8, wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is about 11 : 1, the ratio of $\text{N}_2 : \text{N}_2\text{O}$ is about 350 : 1 and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is about 6 : 1 and the flow rate of the SiH_4 is about 72 sccm, the flow rate of the NH_3 is about 132 sccm, the flow rate of the N_2 is about 4200 sccm and the flow rate of the N_2O is about 12 sccm.



12. The method of claim 8, wherein the refractive index of said layer of silicon oxynitride compound so formed is from about 2.0 to 2.2.

13. A PECVD method of forming an silicon oxynitride layer, comprising the steps of:

supplying a precursor gas mixture comprising SiH_4 , NH_3 , N_2 , and N_2O to a vacuum chamber; wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 7 : 1 to 15 : 1, the
5 ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 300 : 1 to 400 : 1, and the ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 4 : 1 to 8 : 1 and the flow rate of the SiH_4 is from about 48 to 96 sccm, the flow rate of the NH_3 is from about 84 to 180 sccm, the flow rate of the N_2 is from about 3600 to 4800 sccm, and the flow rate of the N_2O is from about 10 to 15 sccm;

generating a plasma in the chamber from said precursor gas mixture; and

10 depositing a layer of silicon oxynitride compound on a substrate in said chamber.

14. The method of claim 13, wherein said ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 9 : 1 to 13 : 1, said ratio of $\text{N}_2 : \text{N}_2\text{O}$ is from about 325 : 1 to 375 : 1, and said ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is from about 5 : 1 to 7 : 1 and the flow rate of the SiH_4 is from about 60 to 84 sccm, the flow rate of the NH_3 is from about 108 to 156 sccm, the flow rate of the N_2 is from about 3900 to 4500 sccm, and the flow rate of the N_2O is from about 11 to 13 sccm.



15. The method of claim 13, wherein said ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is about 11 : 1, said ratio of $\text{N}_2 : \text{N}_2\text{O}$ is about 350 : 1 and said ratio of $\text{SiH}_4 : \text{N}_2\text{O}$ is about 6 : 1 and the flow rate of the SiH_4 is about 72 sccm, the flow rate of the NH_3 is about 132 sccm, the flow rate of the N_2 is about 4200 sccm and the flow rate of the N_2O is about 12 sccm.

16. The method of claim 13, wherein said layer of silicon oxynitride compound is an etch stop layer formed over a silicide layer over a gate on said silicon semiconductor substrate in said chamber.

17. The method of claim 13, wherein said layer of silicon oxynitride compound has the structure



18. The method of claim 13, wherein the refractive index of said layer of silicon oxynitride compound so formed is from about 2.0 to 2.2.

19. The silicon oxynitride compound prepared by a process comprising the steps of:

supplying a precursor gas mixture comprising SiH_4 , NH_3 , N_2 , and N_2O to a vacuum chamber; wherein the ratio of $\text{NH}_3 : \text{N}_2\text{O}$ is from about 7 : 1 to 15 : 1, the



5 ratio of $N_2 : N_2O$ is from about 300 : 1 to 400 : 1, and the ratio of $SiH_4 : N_2O$ is from about 4 : 1 to 8 : 1 and the flow rate of the SiH_4 is from about 48 to 96 sccm, the flow rate of the NH_3 is from about 84 to 180 sccm, the flow rate of the N_2 is from about 3600 to 4800 sccm, and the flow rate of the N_2O is from about 10 to 15 sccm;

generating a plasma in the chamber from said precursor gas mixture; and
10 depositing the silicon oxynitride compound on a substrate in said chamber.

20. The compound of claim 19, wherein said ratio of $NH_3 : N_2O$ is from about 9 : 1 to 13 : 1, said ratio of $N_2 : N_2O$ is from about 325 : 1 to 375 : 1, and said ratio of $SiH_4 : N_2O$ is from about 5 : 1 to 7 : 1 and the flow rate of the SiH_4 is from about 60 to 84 sccm, the flow rate of the NH_3 is from about 108 to 156 sccm, the flow rate of the N_2 is from about 3900 to 4500 sccm, and the flow rate of the N_2O is from about 11 to 13 sccm.

21. The compound of claim 19, wherein said ratio of $NH_3 : N_2O$ is about 11 : 1, said ratio of $N_2 : N_2O$ is about 350 : 1 and said ratio of $SiH_4 : N_2O$ is about 6 : 1 and the flow rate of the SiH_4 is about 72 sccm, the flow rate of the NH_3 is about 132 sccm, the flow rate of the N_2 is about 4200 sccm and the flow rate of the N_2O is about 12 sccm.



22. The compound of claim 19, wherein said silicon oxynitride compound is formed into an etch stop layer.

23. The method of claim 19, wherein the refractive index of said formed silicon oxynitride compound is from about 2.0 to 2.2.