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Low Damage Magnetron Enhanced Reactive Ion Etching

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Damage formation mechanism of Magnetron Enhanced Reactive Ion Etching (MERIE) and the ways to suppress etching damage have been investigated. Deep damaged layers are induced by light weight ions such as C, F and H formed by the decomposed from the reactant gases in the magnetic field. Damage formation in MERIE is closely related to plasma density. However low damage etching has been achieved by using high molecular weight fluorocarbon compounds as etching gases.

1. Introduction

Dry etching for the fabrication of deep sub-micron VLSI devices should realize higher anisotropy, lower radiation damage, higher selectivity and higher etching rate. MERIE [1] is one of the promising etching technology, because etching can be done under low pressure with high density plasma.

However, recently, there was a report that MERIE causes heavy damage in the Si substrate while SiO2 etching [2].

This paper describes the damage formation mechanism of MERIE and the ways to suppress etching damage.

2. Experimental

The MERIE etcher used in this experiment was equipped with two pairs of Helmholz coils and with a 13.56 MHz RF generator attached to the wafer (bottom) electrode. The magnetic field is rotated electrically at the frequency of 0.5Hz by modulating the DC current supplied to the coils.

Etching of SiO2 and Si were done using fluorocarbon gases such as CHF3, CF4, C2F6 and C4F8 gases. Two kinds of sample are prepared. One is crystal Si (100) without patterning. The other is thermally grown SiO2 film with resist pattern. Process parameters such as RF power (300-700W), magnetic field (0-120 Gauss), gas flow ratio (CHF3/CF4=2.75-8) and pressure (50-200 mTorr) were varied. Transmission electron microscopy (TEM), rutherford back scattering (RBS), X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectroscopy (SIMS) were used to study the structural change.

3. Results and Discussion

3-1 Analysis of the damaged layer

Figure 1 shows the cross-sectional TEM picture after MERIE, where etching gases are CHF3/CF4/Ar, pressure is 50mTorr, and the selectivity of SiO2 to Si is about 30. Heavily damaged region is about 500Å deep from the surface and the region with low defect density is extended down to 1600Å.

In the case of RIE using the same gases as MERIE, however, heavily damaged region is not observed and low defect density region is extended down within 200Å from the surface. The selectivity between them is about 6 at higher pressure of 1800mtorr.

Thus, the damaged region depths are different between MERIE and RIE. This result suggests that the mechanism of damage formation depends on the etching method and the selectivity between oxide and Si.

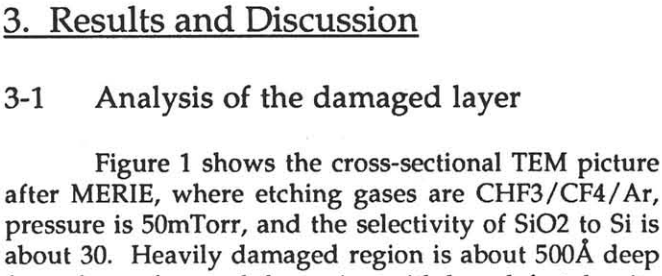

Fig.1 Cross-sectional TEM picture of Si substrate after etching of SiO_2 by CHF_3/CF_4 MERIE.

Figure 2 shows contact resistance of Al/P^+Si, where contact hole with 0.8μm diameter are etched by MERIE as a function of the etched depth of the Si substrate. Removing the damaged layer to the 500Å depth, contact resistance shows the minimum value of 120 Ω. However, this process needed the etching of damaged layer cannot be applicable to VLSI fabrication process with a shallow junction.

Figure 3 shows depth profiles of C and F in the Si substrate after MERIE. This SIMS analysis indicates that C and F are implanted 900Å and 600Å in depth, respectively, and that lighter atoms are deeper to the substrate. There exists C and F atoms of 10E16/cm2, large enough to form crystalline defects. These results suggest that implanted fluorocarbon ions produced in CHF3 and CF4 plasma form damage layer in the Si substrate and that the crystalline defect in the damage layer causes the increase of contact resistance. In order to suppress the damage formation in MERIE, both of the implanted depth and the amount of C, F and H must be reduced.

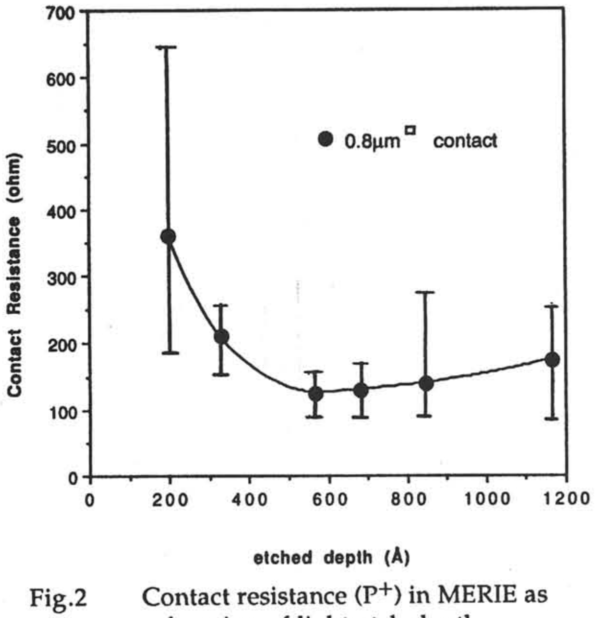

Fig.2 Contact resistance (P^+) in MERIE as a function of light etch depth.

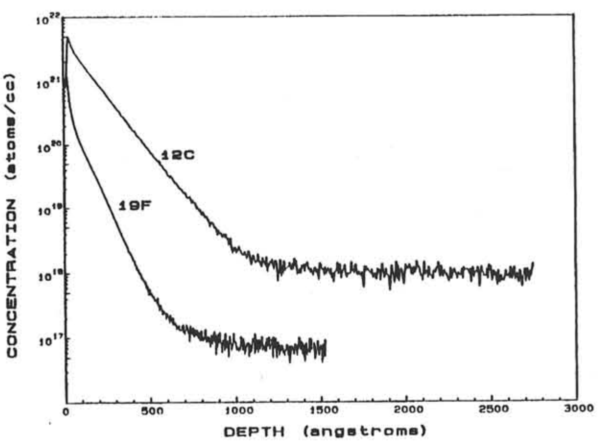

Fig.3 SIMS in-depth profiles for C and F.

3-2 Relation between the damaged layer and etching parameter

Displaced atom density (Dda) formed by MERIE are shown in Fig. 4, as a function of RF Power and magnetic field, where Dda is measured by RBS. TEM analysis indicates that damaged layer depth increased as RF power and magnetic field are increased. When the power density is high, Si surface is heavily damaged, due to high energy ions. However, it was also found that the increase of magnetic field caused the deeper damaged region, even though energy of incident ions is reduced by magnetic field. It is well known that magnetic field increases plasma density. These result suggest that damage formation in MERIE is closely related to plasma density.

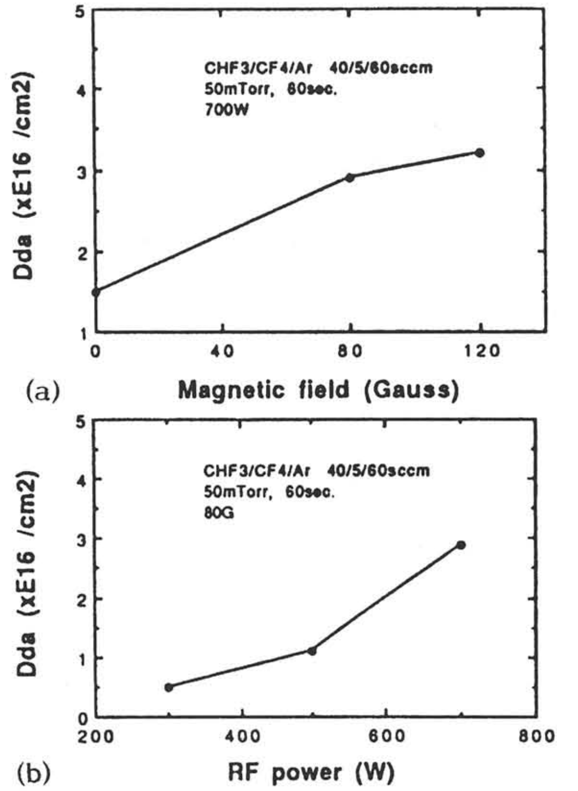

Fig.4 The dependence of Dda on
(a) Magnetic field and (b) RF power.

3-3 Relation between the damaged layer and etching gases

The relation of etching gases upon the damage formation were investigated by using CHF3, CF4, C2F6 and C4F8 gases. Figure 5 (a) and (b) show TEM cross - sectional pictures after MERIE using C2F6 and C4F8 gases respectively. It was confirmed that no damaged layer was observed for both cases. Table1 shows the damaged layer depths for various etching gases. In the case of CHF3/CF4/Ar, damaged layer depth decreases as the selectivity decreases. However, CHF3/CF4/Ar causes deeper damaged layer than C2F6/Ar, in spite of providing the same selectivities in the both two gases.

This result suggests that damage formation in MERIE is closely related to etching gases.

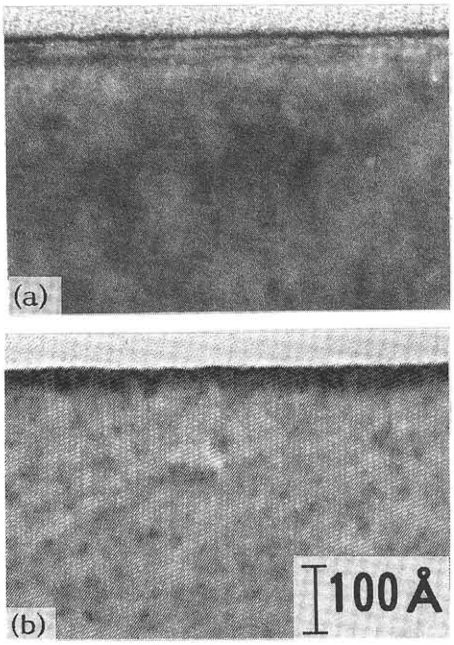

Fig.5 Cross-sectional TEM pictures of Si substrate after etching of SiO_2 by (a) C_2F_6 and (b) C_4F_8 MERIE.

Table 1 Damaged layer depths for various etching gases.

Gas	Selectivity	Damaged region	
		high density layer (Å)	low density layer (Å)
CHF3/CF4/Ar	30	500	1600
CHF3/CF4/Ar	13	320	1200
CF4/Ar	8	0	200
C2F6/Ar	12	0	0

3-4 A model for damage formation during MERIE

A model for damage formation during MERIE and RIE of SiO2 is proposed in Fig.6. Ions of light molecular weight are produced by the following reactions.

$$\mathrm{CHF3} \xrightarrow{\text{1st step}} \mathrm{CHF2 + F} \xrightarrow{\text{2nd step}} \mathrm{CHF + 2F}$$

$$\mathrm{CF4} \xrightarrow{\text{1st step}} \mathrm{CF3 + F} \xrightarrow{\text{2nd step}} \mathrm{CF2 + 2F} \xrightarrow{\text{3rd step}} \mathrm{CF + 3F}$$

In the conventional RIE, 2nd and 3rd step reactions are negligible because of its lower plasma density. In the case of MERIE, however, cyclotron motion of secondary electrons in the magnetic field accelerates decomposition of reactant gases, and the number of light weight ions produced through 2nd and 3rd reaction steps is increased.

Fluorocarbon gases of high molecular weight are effective to suppress damage formation in MERIE, as described above. The formation of light ions, which induce deep damage, is suppressed with C4F8, because decomposed species contain a double bond and are stable. On the other hand, polymerization is enhanced by heavy fluorocarbon gases with high C/F ratio [3], and polymers expect to protect the surface from ion attack [4].

Moreover, in the case of heavy molecules, most of the collision energy to the substrate is expected to be spent in the decomposition of the molecules, which is another reason for reduced damage.

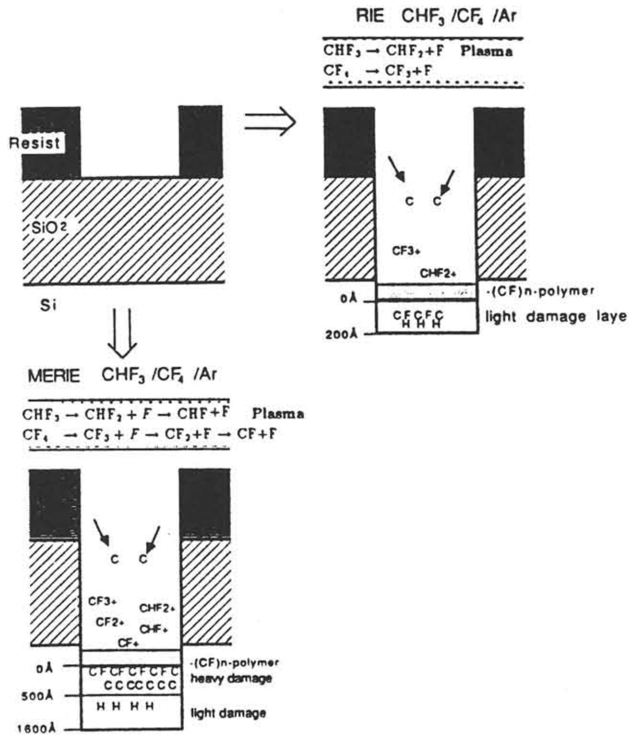

Fig.6 Schematic diagrams of Si near-surface modification during MERIE and RIE.

4. Conclusion

A model for damage formation in MERIE using gases of low molecular weight such as CHF3 and CF4 has been proposed. MERIE with low etching damage has been achieved with fluorocarbon gases of high molecular weight.

5. Acknowledgments

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6. References

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