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Plasma Damage of Gate Oxide through the Interlayer Dielectric

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The degradation of thin gate oxides connected with the interconnect under the interlayer dielectric(ILD) by Ar plasma irradiation was observed. The electric field of gate oxide breakdown and the total charge to breakdown(Q_{BD}) were dependent on the material of the ILD. The current density through the ILD, calculated from Q_{BD}, was nearly equal to the measured value. Plasma damage through the ILD is caused mainly by the leakage current of the ILD.

1.Introduction

In VLSI fabrication, the degradation of thin gate oxide is a serious problem[1][2]. Thin gate oxide is often degraded due to the charge collected at the gate electrode during exposure to plasma processing. The interconnect covered with the interlayer dielectric(ILD) is often exposed to plasmas, such as depositing the ILD by plasma CVD and tapering the ILD for planarization. As a method of preventing the gate oxide degradation by plasma CVD, it has been reported that a thin dielectric film over the interconnect protects it from plasma damage[2].

In this study, we find that the gate oxide is degraded by plasma damage in spite of covering the interconnect with the ILD. We report the dependence of the gate oxide degradation on the material of the ILD, and the mechanism of plasma damage through the ILD.

2.Experiments

Figure 1 shows the cross sectional structure of test samples. MOS structure with poly Si gate and gate oxide thickness of 10 nm was fabricated. Aluminum alloy electrode(Metal-I) connected to gate electrode had zigzag line pattern or square pattern. This antenna electrode collected the charge incident on the Metal-I. The antenna ratio of the Metal-I area over gate area was between 10,000 and 50,000. Two types of ILD films were examined for the antenna damage.

P-TEOS ILD film was deposited on Metal-I by plasma CVD from Tetra-Ethyl-Ortho-Silicate. USG ILD film was deposited on Metal-I by atmospheric pressure CVD using SiH_4. Thickness of each film was 500 nm. Argon(Ar) plasma was used to irradiate the ILD films. The plasma condition were : 13.56 MHz, 2.5 W/cm^2 RF power density, 160 seconds. After irradiation, the ILD films were removed by wet etching. Field Dependent Dielectric Breakdown (FDDB) measurements were performed for examining the breakdown electric field(E_{BD}) of gate oxides.

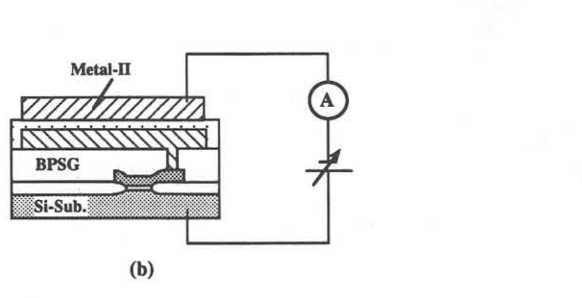

**Fig.1 (a) Cross sectional structure of test sample for TDDB and FDDB measurements.
(b) Cross sectional structure of test sample for V-I characteristic measurements.**

Total charge to breakdown(Q_{BD}) was extracted from Time Dependent Dielectric Breakdown(TDDB) measurement. Resistance of ILD films were observed by V-I measurement shown in Fig.1-(b).

3.Results and Discussion

Figure 2 shows the cumulative failure of gate oxide before and after plasma irradiation by FDDB measurement. The electric field of breakdown was defined as a field which yields a current density through the gate oxide of 1.0 mA/cm^2. The samples of P-TEOS without plasma irradiation showed the normal breakdown field over 10 MV/cm. However gate oxides of the samples with plasma irradiation began to break at the field of about 1 MV/cm, since the gate oxide having antenna metal covered with the ILD was degraded by Ar plasma irradiation. The gate oxide degradation of samples with P-TEOS was larger than that with USG. Figure 3 shows the relationship between the antenna ratio and the yield of the gate oxide. The failure was defined as a breakdown field under 10 MV/cm. The yield decreased with a increase of antenna ratio. The yield of samples with P-TEOS was lower than that with USG. The yield of samples with P-TEOS was dependent on the pattern of Metal-I. From the above results, we can conclude that the degradation of gate oxide is dependent on the material of ILD, the antenna ratio and the antenna pattern. Table 1 shows the yield at the gate oxide thickness of 10 nm or 12 nm and an antenna ratio of 8,000. The gate oxide of 10 nm thickness failed, while that of 12 nm was degraded a little. This degradation was conspicuous for gate oxide thickness less than 10 nm.

In Fig.4, the model of charge injection through the ILD was implemented for a clarification of the above breakdown mechanism. The surface charge(Q_s) was caused by the charge build-up on the ILD due to ion and electron currents from plasma. The surface charge causes a voltage at the gate(V_g) and at the ILD(V_D). The gate oxide is degraded by the current(I_g) through the gate oxide due to the gate voltage. If the resistance of the ILD(R_D) was infinite value, V_g would be determined only by $Q_s/(C_g+C_f)$, here C_g and C_f are the capacitance of the gate oxide and field oxide. Therefore V_g and I_g would be independent of the ILD. However the degradation of gate oxide is dependent on the material of the ILD as shown in Fig.2 and 3. So the resistance of ILD needs to be a finite value. The current, depending on the resistance of the ILD, is injected into the metal through the ILD owing to charge build-up, and degrading the gate oxide.

The total charge to breakdown(Q_{BD}) was extracted by TDDB measurement. The initial Q_{BD} was consumed during plasma processing due to the current flow in the gate oxide. Figure 5 shows the

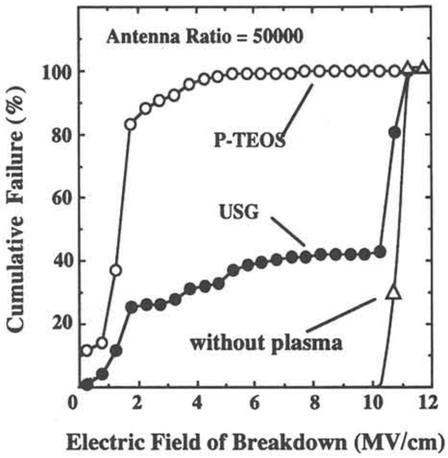

Fig.2 Breakdown field of gate oxide before and after plasma irradiation

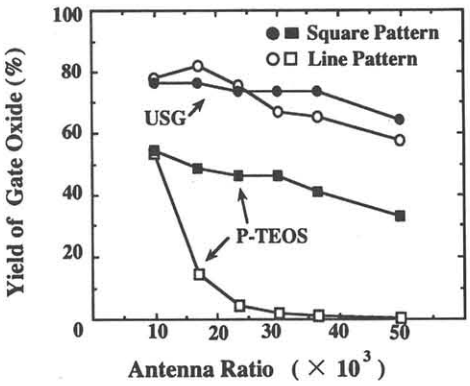

Fig.3 Dependence of gate oxide breakdown on antenna ratio and materials of interlayer dielectric.

Table 1 The dependence of the yield on the thickness of gate oxide at the antenna ratio of 8,000 in the case of P-TEOS.

Thickness of gate oxide	Yield
10 nm	71.2 %
12 nm	97.5 %

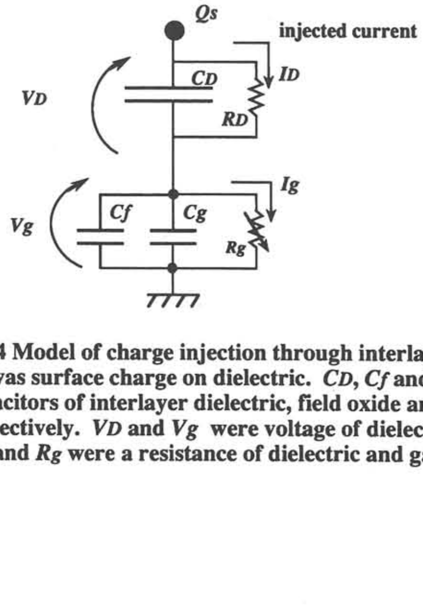

Fig.4 Model of charge injection through interlayer dielectric : *Qs* was surface charge on dielectric. *CD*, *Cf* and *Cg* were capacitors of interlayer dielectric, field oxide and gate oxide, respectively. *VD* and *Vg* were voltage of dielectric and gate. *RD* and *Rg* were a resistance of dielectric and gate oxide.

relationship between the antenna ratio and Q_{BD} in the case of P-TEOS. The Q_{BD} decreased with increasing antenna ratio. Assuming that total charge through the ILD flowed in gate oxide, the current density(I_D) of ILD during Ar plasma irradiation was calculated from ΔQ_{BD} using the expression of

$$I_D = \Delta Q_{BD} / (irradiation\ time \bullet \Delta antenna\ ratio\ ).$$

ΔQ_{BD} was the difference of Q_{BD} at the antenna ratio between 14000 and 29000 shown in Fig.5. Table 2 shows the current density(I_D) of ILD, considering the dependence of Q_{BD} on the substrate temperature[3]. The dependence of the I_D on the material of ILD corresponded to the results of FDDB measurement in Fig.3. The dependence of the gate oxide breakdown on the antenna pattern in Fig.3 is explained as follows: the ILD was etched for the thickness of 100 nm by Ar plasma irradiation, especially at the edge of interconnect the etched thickness was over 100 nm. The injected current at the edge of interconnect was larger than that at the top of it. Therefore the injected charge of line pattern was larger than that of square pattern.

Figure 6 shows the V-I characteristic of the sample shown in Fig.1-(b). The current density of P-TEOS was larger than that of USG above the voltage of 40 V. The current enough to gate breakdown flowed at about 100 V. From Fig.6 and Table 2, the dependence of gate oxide breakdown on the material of ILD films was caused by the resistance of ILD. The electric field due to the charge build-up caused by ion and electron currents from plasma injected charges into the metal through the interlayer dielectric. Even though the leakage current was very small, it damaged the gate oxide having a large antenna ratio.

4.Conclusion

Gate oxide breakdown through the interlayer dielectric by Ar plasma irradiation has been studied. The gate oxide breakdown occurred even if the interconnect metals were covered with a dielectric film. The measured current density through the interlayer dielectric almost corresponded to the one estimated from Q_{BD}. The degradation of gate oxide is caused mainly by the leakage current through the interlayer dielectric due to the charge build-up on it.

5.References

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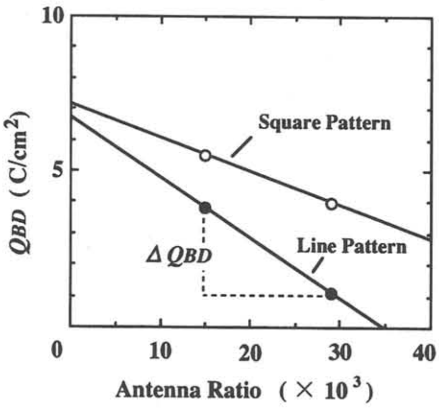

Fig.5 Dependence of Q_{BD} on antenna ratio in the case of P-TEOS.

Table 2 Current density through the ILD film calculated by ΔQ_{BD}

		ΔQ_{BD} (C/cm^2)		I_D (A/cm^2)
		T_{sub} = 35 ℃	T_{sub} = 200 ℃	
TEOS	Line	2.73	0.381	1.70E-07
	Square	1.54	0.214	9.57E-08
USG	Line	1.37	0.191	8.54E-08
	Square	0.97	0.136	6.06E-08

$Q_{BD} = Q_o \cdot \exp(E_a / kT)$ $E_a = 0.15$ eV

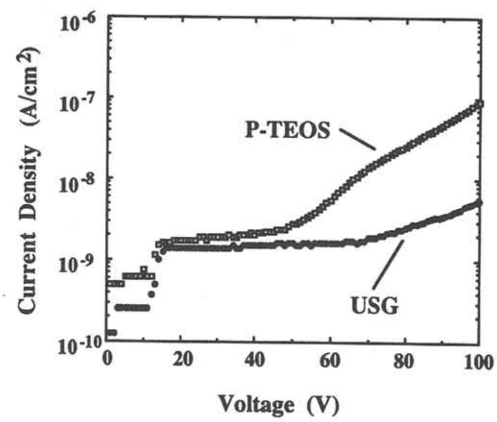

Fig.6 Current density versus voltage for the test sample in Fig.1-(b)