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High Quality CVD/Thermal Stacked Gate Oxide Films with Hydrogen-Free CVD SiO_2 Formed in the $SiCl_4$-N_2O System

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We have developed and evaluated CVD SiO_2 films formed in a hydrogen-free system. That is, $SiCl_4$ (tetrachlorosilane; TCS) and N_2O have been employed as LPCVD source gases. It was found that the hot-carrier degradation, the constant current TDDB and the charge-trapping characteristics of CVD SiO_2 films prepared from TCS and N_2O (TCS-SiO_2) are superior to those of conventional CVD SiO_2 films formed from SiH_2Cl_2 and N_2O. We have concluded that TCS-SiO_2 is appropriate for CVD/thermal stacked oxide films due to its lower electron trap density and due to its promise of higher reliability of gate oxide films.

1. INTRODUCTION

CVD/thermal stacked oxide films have received much attention as candidates for thin gate dielectrics in quarter micron devices [1,2]. These stacked oxide films show promise for the suppression of the thinning effect at isolation edges[3]. CVD oxide films prepared from SiH_2Cl_2 (DCS) and N_2O have been used conventionally. However, these films have a higher electron trap density attributed to the incorporation of hydrogen-containing species, i.e., Si-H and Si-OH bonds are generated in LPCVD reactions. Therefore, as an alternative to a conventional CVD oxide film, we propose the CVD SiO_2 film formed from a non-hydrogen-containing Si source ($SiCl_4$; TCS) and N_2O. In this paper, we present the electrical characteristics of a CVD/thermal stacked oxide film with CVD SiO_2 prepared from TCS and N_2O (TCS-SiO_2) and compare this film to both a dry oxide film and a CVD/thermal stacked oxide film with a conventional CVD SiO_2.

2. EXPERIMENTAL

We have investigated two types of CVD SiO_2 films (TCS-SiO_2 and conventional) and a thermal oxide film. MOS capacitors with n^+ poly-Si gates and n-channel MOSFETs (NMOSFETs) with Lightly Doped Drain (LDD) structure were fabricated using LOCOS isolation. All wafers received a 450℃ post anneal in a hydrogen ambient. Conventional CVD SiO_2 films were prepared with DCS and N_2O (DCS-SiO_2) preceded by thermal oxidation. The dry oxide film was grown in a dry O_2 ambient. The structures of the CVD/thermal stacked gate oxide films with these two types of CVD SiO_2 employed in this study are illustrated in Fig. 1. The thickness of the gate oxide films were 5-6 nm.

3. RESULTS AND DISCUSSION

Figures 2(a) and 2(b) show Si_{2p} and O_{1s} x-ray photoelectron spectroscopy (XPS) spectra of the films prepared with TCS and N_2O and prove that SiO_2 films are really formed because the spectra are almost identical with those of thermal oxide films.

Table 1 compares the etching rate of a TCS-SiO_2 film and a DCS-SiO_2 film with a HF ($HF:H_2O=1:200$) solution. The etching rate of a TCS-SiO_2 film is reduced to half of that of a DCS-SiO_2 film. It suggests that a TCS-SiO_2 film is denser than a DCS-SiO_2 film.

Figure 3 represents the gate voltage shift of MOS capacitors under constant current injection. The electron injection was performed from the gate at the current density of 0.1 mA/cm^2. The large shift in the gate voltage caused by electron traps can be observed in the sample with a DCS-SiO_2 film. On the other hand, the TCS-SiO_2 film shows less electron trap generation as compared with the DCS-SiO_2 film, which may be due to the reduction of hydrogen-containing species.

A comparison of the C-V measurements of MOS capacitors using a TCS-SiO_2 film versus a dry oxide film was also carried out. Figure 4 compares the mid-gap voltage shift after a 25 mC/cm^2 electron injection from the gate. It was found that the TCS-SiO_2 film has a much smaller positive charge trap density as compared with the dry oxide film. This result is consistent with the fact that the gate voltage shift of a MOS capacitor with a TCS-SiO_2 film is slightly smaller than that with a dry oxide film as shown in Fig. 3.

TDDB characteristics of MOS capacitors under constant current stress are illustrated in Fig. 5(a) and 5(b), where the electron injection was performed from the substrate at the current density of 0.1 A/cm^2. The TCS-SiO_2 film has a larger charge to breakdown value at 50 % cumulative failure (50 % Q_{BD}) than the dry oxide film. The DCS-SiO_2 film has a smaller 50 % Q_{BD} as compared with the TCS-SiO_2 film. This is attributed to the larger electron trap density in the oxide films as mentioned earlier. Figure 6 shows a 50 % Q_{BD} in constant current TDDB measurements of MOS capacitors, where the electron injection was performed from the gate at the current density of 0.01 A/cm^2. The TCS-SiO_2 film has a larger 50 % Q_{BD} as compared with dry oxide film; moreover, the electron injection was performed from the substrate. These results show that the TCS-SiO_2 films have great potential as reliable gate oxide films.

Figures 7 and 8 show the hot carrier degradation for

NMOSFETs, presenting the degradation of drain current and the variation of charge-pumping current caused by DAHC (Drain Avalanche Hot Carrier) injection. The TCS-SiO_2 film and the dry oxide film exhibit slightly higher hot-carrier-degradation tolerance as compared with the DCS-SiO_2 film. The measurements of charge pumping current show that the interface state generation is reduced for both the TCS-SiO_2 film and the DCS-SiO_2 film. It may be due to the incorporation of a small amount of nitrogen at the SiO_2/Si interface. Therefore, the improvement in the hot-carrier reliability of the TCS-SiO_2 film can be explained by the reduction of electron trap density in the gate oxide film.

4. CONCLUSION

We have developed and evaluated CVD SiO_2 films formed in a hydrogen-free system. That is, TCS and N_2O have been employed as LPCVD source gases. It was found that the hot-carrier degradation, the constant current TDDB and the charge-trapping characteristics of TCS-SiO_2 films are superior to those of conventional CVD SiO_2 films formed from DCS and N_2O. Moreover, the TDDB characteristics of a TCS-SiO_2 film under both bias conditions are superior to those of a dry oxide film. We have concluded that TCS-SiO_2 is appropriate for CVD/thermal stacked oxide films due to its lower electron trap density and due to its promise of higher reliability of gate oxide films.

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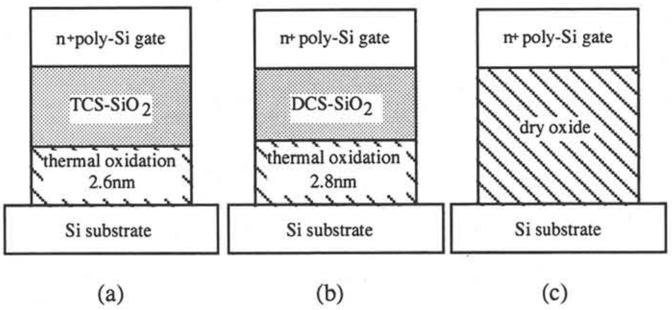

Fig. 1 Structures of gate oxide films with (a) TCS-SiO_2, (b) DCS-SiO_2 and (c) dry oxide, extracted from the measurement of film thickness with an ellipsometer.

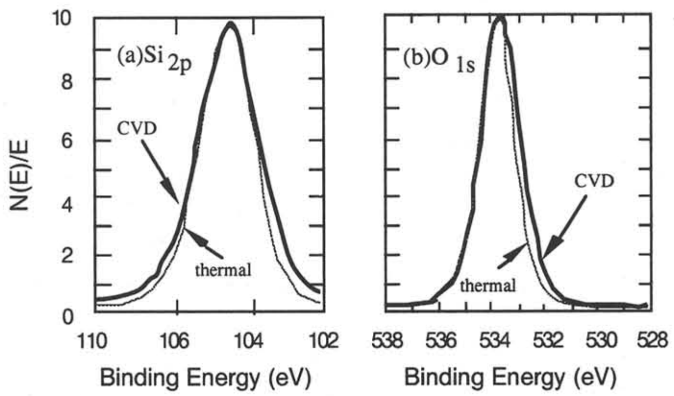

Fig. 2 (a) Si_{2p} and (b) O_{1s} XPS spectra of the CVD oxide films prepared with TCS and N_2O.

Table 1 Etching rate of two types of CVD SiO_2 films.

DCS-SiO_2	2.4 nm/min
TCS-SiO_2	1.2 nm/min

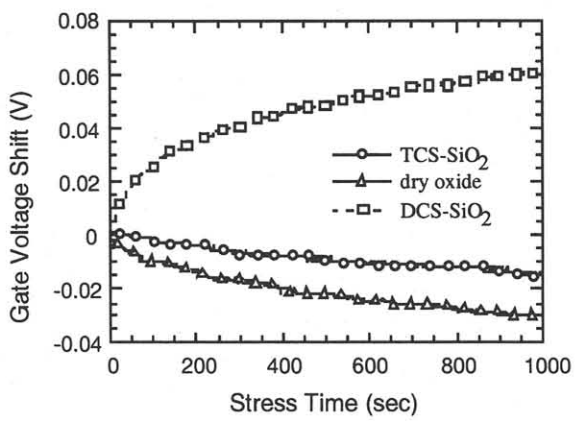

Fig. 3 Gate voltage shift of MOS capacitors during constant current stressing of -0.1 mA/cm^2.

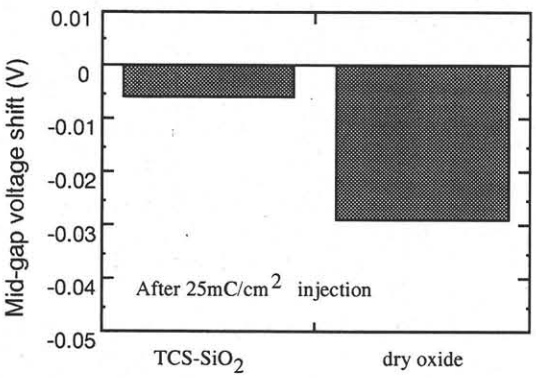

Fig. 4 Mid-gap voltage shift extracted from the C-V measurements after a 25 mC/cm^2 electron injection from the gate.

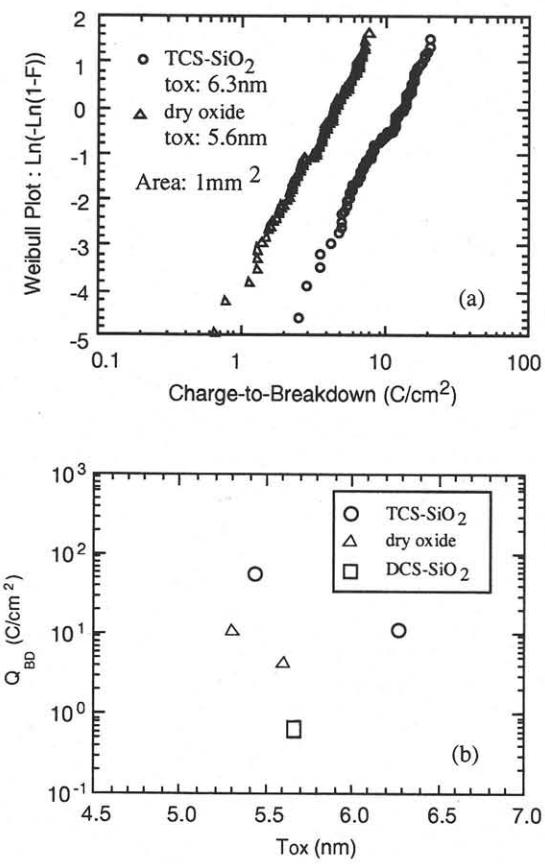

Fig. 5 (a) Weibull plots and (b) Q_{BD} at 50 % cumulative failure in constant current TDDB measurements. The electron injection was performed from the substrate at the current density of 0.1 A/cm^2.

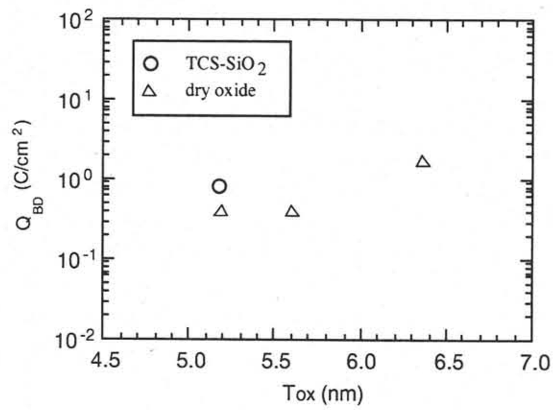

Fig. 6 Q_{BD} at 50 % cumulative failure in constant current TDDB measurements. The electron injection was performed from the gate at the current density of 0.01 A/cm^2.

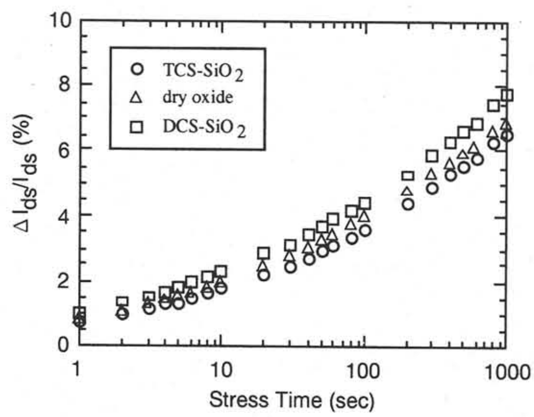

Fig. 7 Degradation of drain current for NMOSFETs (L=0.5 μ m, W=10 μ m) during the DAHC injection. The stress was applied at Vd=4.5V, Vg=V($I_{sub,max}$) for 1000 sec.

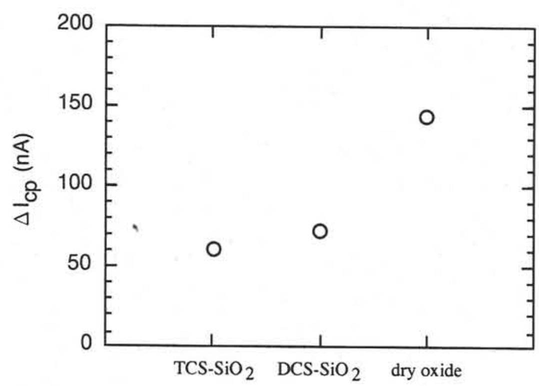

Fig. 8 Variation of the charge pumping current for NMOSFETs (L=100 μ m, W=100 μ m) during the DAHC injection. The stress was applied at Vd=8V, Vg=V($I_{sub,max}$) for 1000 sec.