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Influence of N_2O-Oxynitridation on Interface Trap Generation in Surface-Channel PMOSFETs

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Influence of N_2O-oxynitridation on hot-carrier-induced degradation of surface-channel PMOSFETs was investigated. N_2O-oxynitridation reduces electron trapping due to high barrier height for electron injection. N_2O-oxynitridation has little effects on electron and hole energies for interface trap creation. For drain avalanche hot electron injection, the role of nitrogen-rich region as the diffusion barrier of hydrogen species reduces interface trap generation by the chemical reaction between hydrogen atoms and $Si_3\equiv Si-H$ precursors at the Si/SiO_2 interface. However, interface trap generation is enhanced by the existence of nitrogen atoms at the Si/SiO_2 interface for channel hot hole injection. This phenomenon cannot be explained with the above role of nitrogen-rich region. Enhancement of hole trapping due to decreased compressive stress at the Si/SiO_2 interface by nitrogen incorporation may be important.

1. INTRODUCTION

Recent studies show that furnace N_2O-oxynitridation (hydrogen-free process) of thin thermal gate oxides results in high quality gate dielectrics[1,2]. It is reported that this originates from the existence of rigid Si-N bonds at the Si/SiO_2 interface. However, Woltjer *et al.* found that N_2O-oxynitridation enhances positive charge generation due to hole trapping for surface-channel PMOSFETs[3], although the cause of this phenomenon is not clarified yet. In this study, we clarify physical mechanisms of degradation caused by hot-carriers in surface-channel PMOSFETs with N_2O-oxynitrided gate oxides.

2. EXPERIMENTAL

The samples used in this study were surface-channel PMOSFETs with p^+ poly-Si gate electrodes fabricated on n-type (100)-oriented Si wafers. The gate oxides were grown at 800°C in dry O_2/HCl ambient. Some of the wafers were then processed in N_2O ambient (950°C for 20min.) to form N_2O-oxynitrided oxides. Both the control and N_2O-oxynitrided oxides have similar thickness (T_{OX} = 7.8nm). The p^+ poly-Si gate electrodes and source/drain region were doped with boron ion implantation. Then, the wafers were annealed at 1000°C for 10 sec. in N_2 ambient.

Generated interface trap density ΔN_{it} was evaluated by charge pumping current technique[4]. We used the midgap voltage shifts to evaluate trapped charge density ΔN_{ot} [5].

3. RESULTS AND DISCUSSION

Figure 1 shows the substrate and gate currents for the control and N_2O-oxynitrided oxide samples. The gate current data indicate that the electrons are injected into the gate oxides for the low $|V_G - V_{TH}|$, while holes are for the high $|V_G - V_{TH}|$.

Figures 2 (a) and (b) show ΔN_{it} and ΔN_{ot} as a function of effective stress gate bias, $(V_G - V_{TH})$, after the stressing ($V_D = -6.0$V, T_{STRESS} = 10000sec). There exist two features in Fig. 2 (a); (1) significant electron trapping at low $|V_G - V_{TH}|$, drain avalanche hot electron (DAHE) stress bias, and large hole trapping at high $|V_G - V_{TH}|$, channel hot hole (CHH) stress bias, and (2) slightly reduced electron trapping and enhanced hole trapping for N_2O-oxynitrided oxides compared to the control counterpart.

Figure 2 (b) shows that at low $|V_G - V_{TH}|$, the interface trap generation is significantly reduced for N_2O-oxynitrided gate oxides, while at high $|V_G - V_{TH}|$, no improvement was observed.

Figures 3 (a) and (b) show charge pumping currents I_{CP} measured at DAHE stress for the control and N_2O-

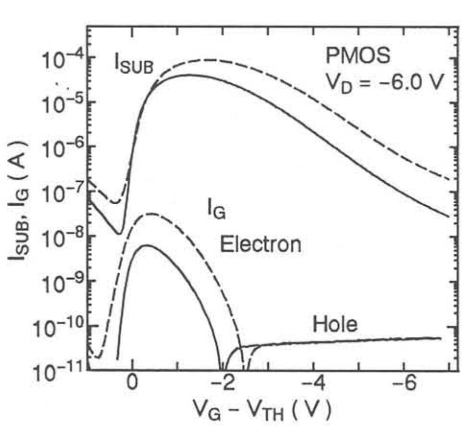

Fig. 1 Substrate and gate currents of surface-channel PMOSFETs (L = 0.5μm, W = 20μm). The solid and dashed lines are the data for the control and N_2O-oxynitrided oxide samples, respectively.

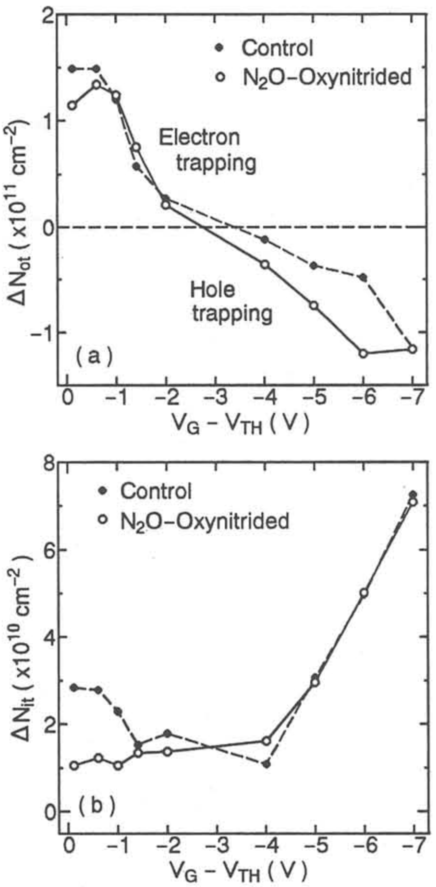

Fig. 2 Dependence of (a) ΔN_{ot} and (b) ΔN_{it} on effective stress gate bias ($V_G - V_{TH}$) for surface-channel PMOSFETs ($L = 0.5\mu m$, $W = 20\mu m$) with control (closed circles) and N_2O-oxynitrided (open circles) oxides, after the stressing ($V_D = -6.0V$, $T_{STRESS} = 10000sec$).

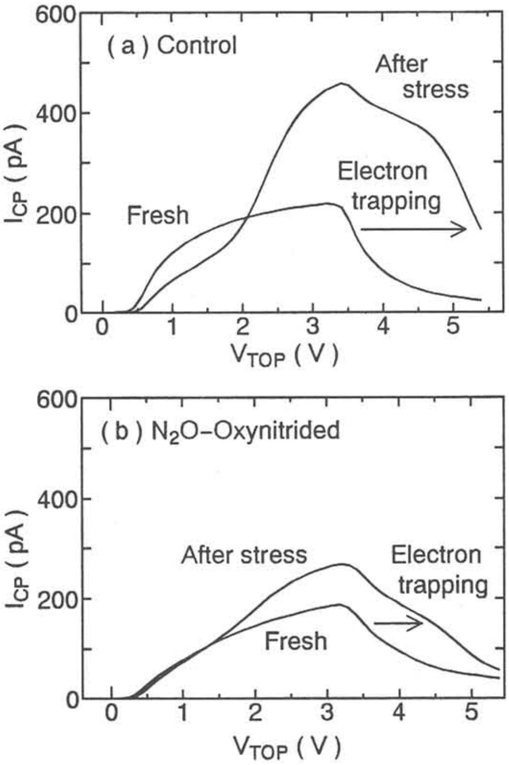

Fig. 3 Charge pumping currents I_{CP} versus V_{TOP} with a fixed gate pulse amplitude ($\Delta V_G = 3.5V$) for (a) the control and (b) the N_2O-oxynitrided oxide samples ($L = 0.5\mu m$, $W = 20\mu m$). The charge pumping currents for the fresh samples and the samples after the stress ($V_G - V_{TH} = -0.1V$, $V_D = -6.5V$, $T_{STRESS} = 10000sec$) are shown.

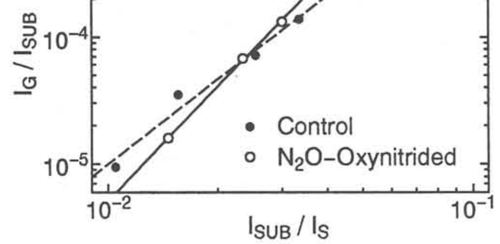

Fig. 4 Relation between I_G/I_S and I_{SUB}/I_S for surface-channel PMOSFETs ($L = 0.5\mu m$, $W = 20\mu m$) with control (closed circles) and N_2O-oxynitrided (open circles) oxide samples measured at $V_G - V_{TH} = -0.1V$.

oxynitrided oxides, respectively. These figures indicate that electron trapping and interface trap generation are significantly reduced in N_2O-oxynitrided gate oxides.

Figure 4 shows I_G/I_{SUB} (injection efficiency of electrons generated by hot holes through impact ionization) vs. I_{SUB}/I_S (impact ionization efficiency of hot holes) in DAHE region. Slope of the lines indicates $\phi_{b,e}\lambda_h/\phi_{imp,h}\lambda_e$, where $q\phi_{b,e}$ is barrier height for electron injection into the gate oxides, $q\phi_{imp,h}$ critical hole energy for impact ionization, and λ_h and λ_e mean free paths of hot holes and electrons. Note that N_2O-oxynitrided oxide samples have larger $\phi_{b,e}\lambda_h/\phi_{imp,h}\lambda_e$ value. Since the physical parameters, λ_h, λ_e and $\phi_{imp,h}$ are process independent, the difference of the slopes originates from $\phi_{b,e}$. Compared with the control gate oxides, N_2O-oxynitrided gate oxides have larger $\phi_{b,e}$ due to the existence of nitrogen atoms at the Si/SiO_2 interface, resulting in lower DAHE injection efficiency. The slight reduction of electron trapping in N_2O-oxynitrided oxides in Figs. 2 and 3 is attributed partially to large effective $\phi_{b,e}$ due to the existence of the nitrogen-rich region. Analogously, the enhanced hole trapping in N_2O-oxynitrided oxides in Fig. 1 may be explained by the reduced effective $\phi_{b,h}$ due to the existence of nitrogen atoms.

The lifetime plots are shown in Fig. 5 in which energies for interface trap generation in control and N_2O-oxynitrided gate oxides are compared. The slope for low $|V_G - V_{TH}|$ exhibits $-(1+\phi_{it,e}\lambda_h/\phi_{imp,h}\lambda_e)$ and that for high $|V_G - V_{TH}|$ represents $-\phi_{it,h}/\phi_{imp,h}$, where $q\phi_{it,e}$ and $q\phi_{it,h}$ are critical energies for interface trap creation by electrons and holes, respectively. Figure 5 shows that, at each stress condition, the slopes of the control and N_2O-oxynitrided oxides are similar, indicating that

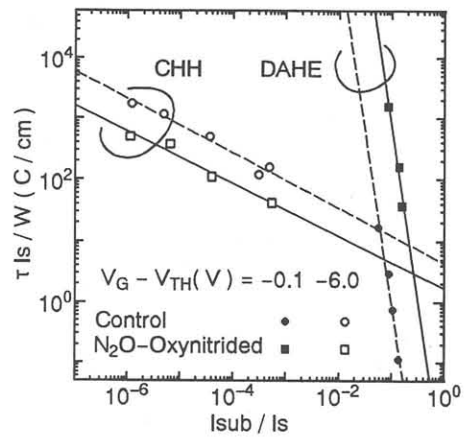

Fig. 5 Lifetime plots for the control and the N_2O-oxynitrided oxide samples ($L = 0.5\mu m$, $W = 20\mu m$) at effective stress gate bias of -0.1V (DAHE) and -6.0V (CHH). The lifetime τ is defined as the stress time for $\Delta I_{CP} = 80pA$.

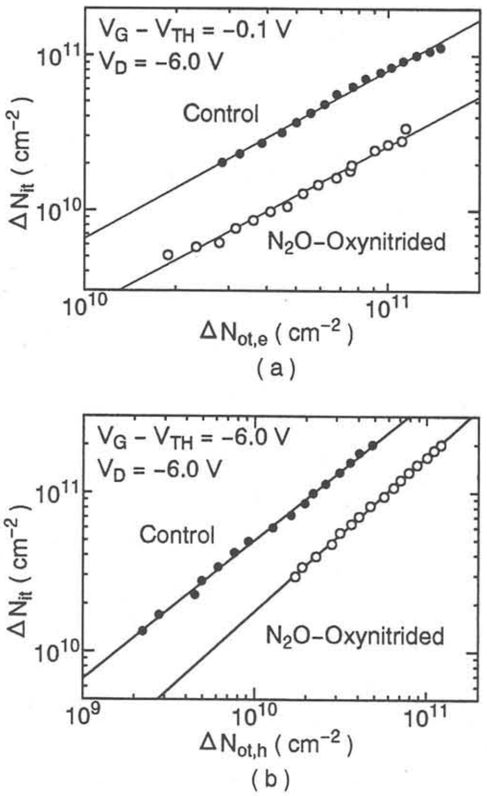

Fig. 6 Relation between interface trap density ΔN_{it} and trapped charge density ΔN_{ot} for (a) DAHE and (b) CHH injections.

$\phi_{it,e}$ and $\phi_{it,h}$ are almost independent of oxidation processes. This means that the critical energy of interface trap creation does not depend on effective barrier height for injected carriers. The parallel shift of the lifetime plots for the DAHE stress is due to the fact that the nitrogen-rich region near the interface blocks the diffusion of hydrogen species. At the DAHE stress, trapped electrons break Si-H bonds in the gate oxide and generated hydrogen species diffuse to the Si/SiO_2 interface, resulting in the interface generation by $Si_3 \equiv Si\text{-}H + H^0 \rightarrow Si_3 \equiv Si\bullet + H_2$. Nitrogen-rich region prevents the generated hydrogen species from diffusing toward the Si/SiO_2 interface. This model is supported by the good correlation between the ΔN_{it} and ΔN_{ot}, as shown in Fig. 6 (a). As shown in Fig. 6 (b), the blocking effect of hydrogen atom diffusion in the nitrogen-rich region is also confirmed for the CHH stressing conditions. However, the enhanced degradation of N_2O-oxynitrided oxides at CHH stress in Fig. 5 cannot be explained by the hydrogen species diffusion but it may be related to the enhanced hole trapping due to decreased compressive stress at the Si/SiO_2 interface by nitrogen incorporation[6].

4. CONCLUSIONS

Influence of N_2O-oxynitridation on hot-carrier-induced degradation for surface-channel PMOSFETs was investigated. Lower electron trapping for MOSFETs with N_2O-oxynitrided gate oxide is found to be attributed to higher barrier height for electron injection. N_2O-oxynitridation has little effects on electron and hole energies for interface trap creation. The experiments for drain avalanche hot electron injection reveal that the nitrogen-rich region blocks hydrogen species diffusion and reduces interface trap generation. On the other hand, interface trap generation is enhanced by the existence of nitrogen atoms at the Si/SiO_2 interface for channel hot hole injection. This phenomenon cannot be explained with the above role of nitrogen-rich region. Enhancement of hole trapping may be due to the decreased compressive stress at the Si/SiO_2 interface by nitrogen incorporation.

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