Influence of $\text{N}_2\text{O}$-Oxynitridation on Interface Trap Generation in Surface-Channel PMOSFETs

Toshimasa MATSUOKA*,**, Shigenari TAGUCHI*, Kenji TANIGUCHI*
Chihiro HAMAGUCHI*, Seizo KAKIMOTO** and Keiichiro UDA**

*Department of Electronic Engineering, Osaka University
2-1 Yamada-oka, Suita-shi, Osaka 655, Japan
**Central Research Laboratories, Sharp Corporation
2613-1 Ichinomoto-cho, Tenri-shi, Nara 632, Japan

Influence of $\text{N}_2\text{O}$-oxynitridation on hot-carrier-induced degradation of surface-channel PMOSFETs was investigated. $\text{N}_2\text{O}$-oxynitridation reduces electron trapping due to high barrier height for electron injection. $\text{N}_2\text{O}$-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 $\text{N}_2\text{O}$-oxynitridation (hydrogen-free process) of thin thermal gate oxides results in high quality gate dielectrics. 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 $\text{N}_2\text{O}$-oxynitridation enhances positive charge generation due to hole trapping for surface-channel PMOSFETs, 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 $\text{N}_2\text{O}$-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 $\text{N}_2\text{O}$ ambient (950°C for 20min.) to form $\text{N}_2\text{O}$-oxynitrided oxides. Both the control and $\text{N}_2\text{O}$-oxynitrided oxides have similar thickness ($T_{\text{ox}} = 7.8\text{nm}$). 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 $\Delta N_{\text{it}}$ was evaluated by charge pumping current technique. We used the midgap voltage shifts to evaluate trapped charge density $\Delta N_{\text{ct}}$.

3. RESULTS AND DISCUSSION

Figure 1 shows the substrate and gate currents for the control and $\text{N}_2\text{O}$-oxynitrided oxide samples. The gate current data indicate that the electrons are injected into the gate oxides for the low $|V_G - V_{\text{TH}}|$, while holes are for the high $|V_G - V_{\text{TH}}|$. $|V_{\text{H}} - V_{\text{TH}}|$(a) and (b) show $\Delta N_{\text{it}}$ and $\Delta N_{\text{ct}}$ as a function of effective stress gate bias, $(V_G - V_{\text{TH}})$, after the stressing $(V_D = -6.0\text{V}, T_{\text{STRESS}} = 10000\text{sec})$. There exist two features in Fig. 2 (a); (1) significant electron trapping at low $|V_G - V_{\text{TH}}|$, drain avalanche hot electron (DAHE) stress bias, and large hole trapping at high $|V_G - V_{\text{TH}}|$, channel hot hole (CHH) stress bias, and (2) slightly reduced electron trapping and enhanced hole trapping for $\text{N}_2\text{O}$-oxynitrided oxides compared to the control counterpart.

Figure 2 (b) shows that at low $|V_G - V_{\text{TH}}|$, the interface trap generation is significantly reduced for $\text{N}_2\text{O}$-oxynitrided gate oxides, while at high $|V_G - V_{\text{TH}}|$, no improvement was observed.

Figures 3 (a) and (b) show charge pumping currents $I_{\text{CP}}$ measured at DAHE stress for the control and $\text{N}_2\text{O}$-oxynitrided oxide samples, respectively.
circles) and N$_2$O-oxynitrided stress significantly that the stressing face, paths energy trons into the oxide, originating value. An analogously, the enhanced electron injection into the gate oxides, $q\phi_{imp,h}$ critical hole energy for impact ionization, and $\lambda_h$ and $\lambda_e$ mean free paths of hot holes and electrons. Note that N$_2$O-oxynitrided oxide samples have larger $\phi_{b,c,\lambda_h}/\phi_{imp,h,\lambda_e}$ value. Since the physical parameters, $\lambda_h$, $\lambda_e$ and $\phi_{imp,h}$ are process independent, the difference of the slopes originates from $\phi_{b,c}$. Compared with the control gate oxides, N$_2$O-oxynitrided gate oxides have larger $\phi_{b,c}$ 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$_2$O-oxynitrided oxides in Figs. 2 and 3 is attributed partially to large effective $\phi_{b,c}$ due to the existence of the nitrogen-rich region. Analogously, the enhanced hole trapping in N$_2$O-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$_2$O-oxynitrided gate oxides are compared. The slope for low $|V_G - V_{TH}|$ exhibits $-1 + \phi_{b,c,\lambda_h}/\phi_{imp,h,\lambda_e}$ and that for high $|V_G - V_{TH}|$ represents $-\phi_{b,c,\lambda_h}/\phi_{imp,h,\lambda_e}$ where $q\phi_{b,c}$ and $q\phi_{b,h}$ 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$_2$O-oxynitrided oxides are similar, indicating that
resulting in the interface generation by \( \text{Si}_3 \equiv \text{Si-H} + \text{H}^0 \rightarrow \text{Si}_3 \equiv \text{Si}^+ + \text{H}_2 \). 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 \( \Delta N_{\text{it}} \) and \( \Delta N_{\text{ox}} \), 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\(_2\)O-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\(_2\)O-oxynitridation on hot-carrier-induced degradation for surface-channel PMOSFETs was investigated. Lower electron trapping for MOSFETs with N\(_2\)O-oxynitrided gate oxide is found to be attributed to higher barrier height for electron injection. N\(_2\)O-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.

References