

New Observation of NBTI Degradation and Recovery Effect of Plasma Nitrided Oxide in Nano Scale PMOSFET's

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Introduction

Negative Bias Temperature Instability (NBTI) has become a major reliability issue in PMOSFET with ultrathin gate oxide^[1]. Oxynitride or nitrided SiO₂ such as thermally nitrided oxide (TNO) are widely used for preventing boron penetration and increasing dielectric constant and recently plasma nitrided oxide (PNO) has been proposed for further improvement of PMOSFETs^[2-3]. Along with the effort to improve NBTI characteristics using the nitridation in silicon dioxide, nitrogen effect on the NBTI degradation has been widely carried out^[1-6] and there were reports that oxynitride can enhance the NBTI degradation^[4-5]. In addition, recovery of NBTI degradation due to the neutralization of trapped holes and/or positive charged slow states is reported^[6]. There are, however, few reports on the concurrent investigation of the dependence of NBTI degradation on the temperature and on the nitrogen concentration in plasma nitrided oxide. Moreover, dependency of recovery effect on the nitrogen concentration in PNO has not yet been fully clarified.

In this paper, we investigated the dependency of NBTI degradation on the biased temperature and nitrogen concentration. Recovery effect of PNO is also characterized with respect to TNO in Nano scale PMOSFET.

Experiments

Figure 1(a) shows key process flow for fabrication of PMOSFETs. Shallow trench isolation, retrograde twin well and dual gate oxide processes are applied. Then, two kinds of nitrided oxides i.e., TNO (Annealing thermally grown SiO₂ in NO ambient : N concentration-4%) and PNO (Exposing the thermally grown SiO₂ to high-density nitrogen plasma at low temperature ~450°C) are applied. N concentration of PNO was split from 6% to 15% for further analysis of the effect of nitrogen effects. Fig. 1(b) shows the HR-TEM (High-Resolution Transmission Electron Microscope) picture of fabricated PMOSFET with a physical gate oxide thickness of 18.7Å.

Results and discussions

1) Dielectric and Device Performance

I_{Dsat} vs. I_{OFF} characteristics has little dependency on the nitridation method as in Fig. 2(a). However, threshold voltage of TNO is larger than those of PNOs and threshold voltage increases as the N concentration increases in PNO due to the suppression of boron penetration as in Fig 2(b). Figure 3 shows that gate oxide capacitance (C_{ox}) of PNO is larger than TNO due to the larger N concentration of PNO than TNO as in Fig. 4. By the same token, C_{ox} increases as the N concentration. V_{FB} shows the difference of about 0.1V between the TNO (4%) and PNO (6%), which exhibits good agreement of V_{th} roll-off characteristics of Fig. 2(b). However, in case of high concentration (15%) PNO, the V_{FB} shift is well below 30mV as desired. Moreover, Gate leakage current (I_g) increment on the stress time under the NBT stress in PNO is reduced by 5x compared to TNO as in Fig. 5.

2) NBTI Degradation and Recovery Effect

Figure 6 shows the NBTI degradation for each oxide. ΔV_{th} of PNO is smaller than TNO with no change of the degradation slope. The activation energy (E_a) of NBTI lifetime of PNO is higher than TNO as in Fig. 7. Moreover, higher N concentration in PNO shows the decrease of E_a , which means that generation of positively charged slow states due to the hydrogen diffusion is decreased in PN oxide because the peak nitrogen concentration is located near the Poly/SiO₂ interface as in Fig. 4(b)^[4]. Furthermore, higher N concentration increases the generation of positively charged slow states due to lower E_a . Hence, NBTI characteristic is improved by PNO and the larger N concentration results in more degradation. Fig. 8 shows that NBTI lifetime of PNO at high temperature stress (200°C) is similar to TNO due to the easily enhanced generation of the positively charged slow states under the high temperature stress. It also shows that higher N concentration in PNO shows decrease of NBTI lifetime. Therefore, it can be said that higher N concentration decreases the allowable maximum operation temperature even in PNO, like the TNO^[5].

Fig. 9 shows the relative shift for the ΔV_{th} versus stress time, where recovery amount is defined as the difference of ΔV_{th} between Point A (NBTI stress for 1000s) and Point B (Recovery for 10s). Figs. 10 and 11 shows the dependence of recovery amount on the recovery voltage (V_{RE}) and stress temperature (T_S), where recovery amount of TNO is larger than PNO for all V_{RE} and T_S ranges. Moreover, contrary to $V_{RE}=0\sim 2V$ range, recovery amount is reduced for $V_{RE}=3V$ case. This is because $V_{RE}=3V$ degrades the ΔV_{th} as in Fig. 12. Figs. 10 and 11 also shows that recovery increases as N concentration increases for all V_{RE} and T_S ranges in PNO. This is possibly because the positively charged slow states are easily neutralized along with higher N concentration under the high recovery voltage and high stress temperature in Fig. 13. Therefore, N at Poly/SiO₂ interface as well as N at Si/SiO₂ interface has a great influence on NBTI degradation and recovery effect.

Conclusions

We investigated the NBTI degradation and recovery effect for TN and PN oxides in Nano scale PMOSFET. PNO shows the improvement of NBTI than TNO while NBTI of PNO with high N concentration can be worse than TN oxide at high temperature. Moreover, recovery of threshold voltage of PNO was lower than TNO and it increased as the N concentration increases in PNO. It is believed that positively charged states due to hydrogen diffusion in oxide bulk play a critical role for NBTI degradation and recovery effect. Therefore, nitrogen concentration even in plasma nitride oxide has to be optimized for Nano scale MOSFET.

References

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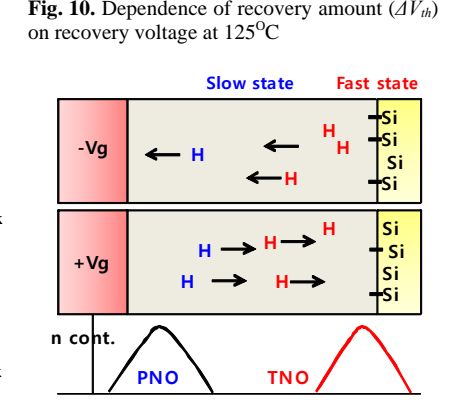
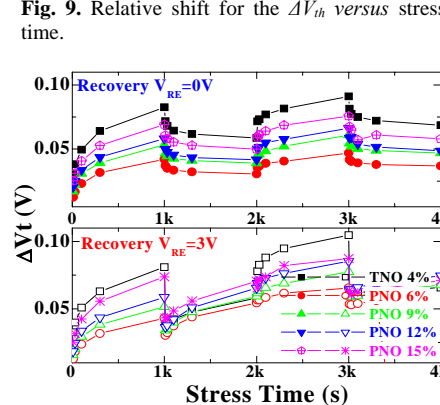
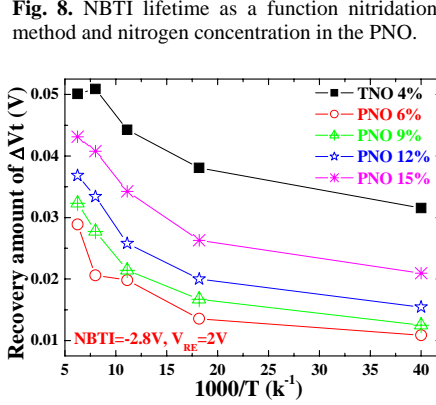
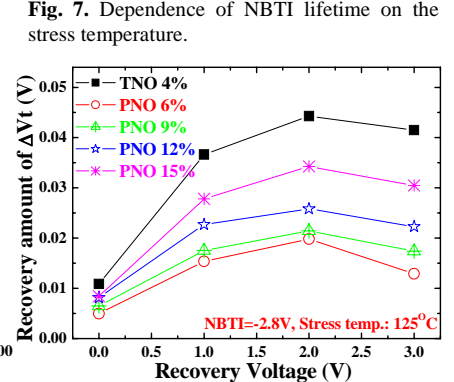
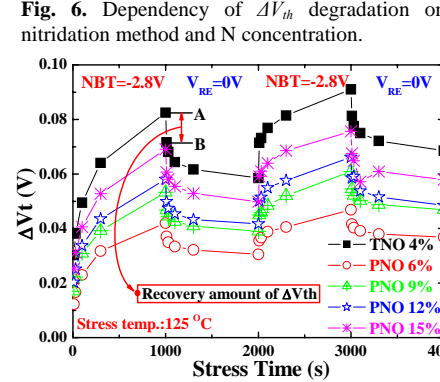
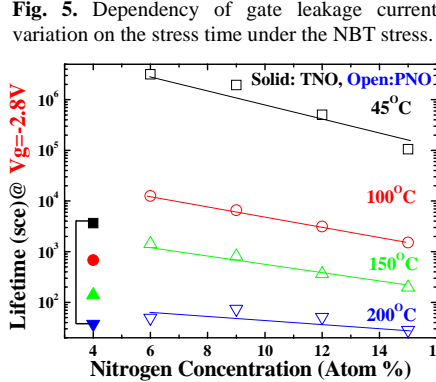
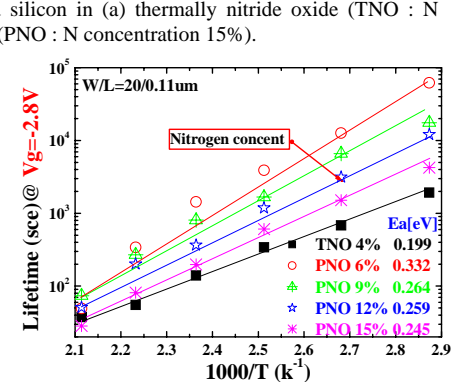
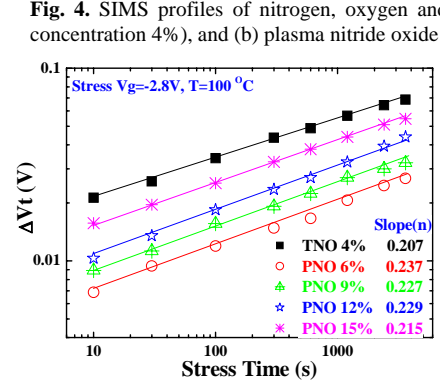
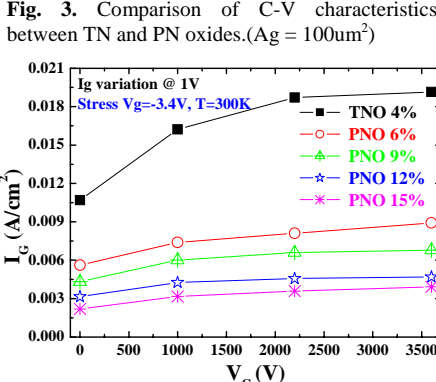
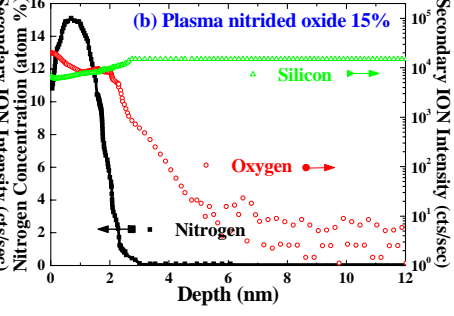
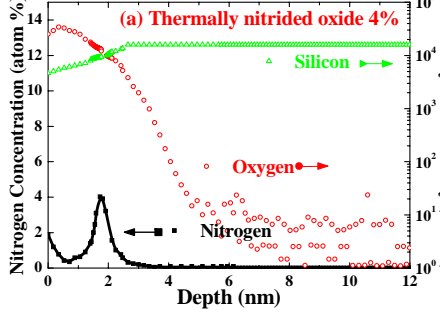
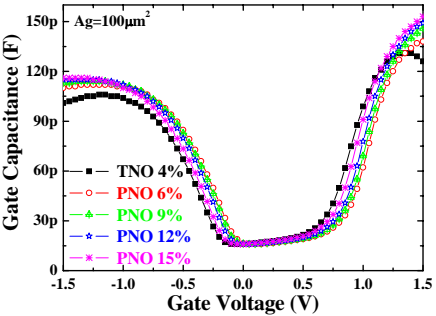
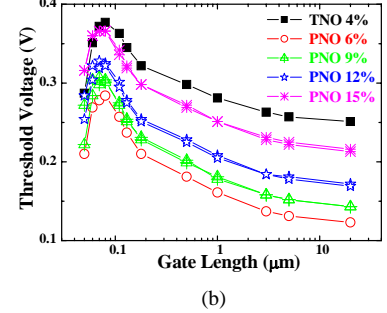
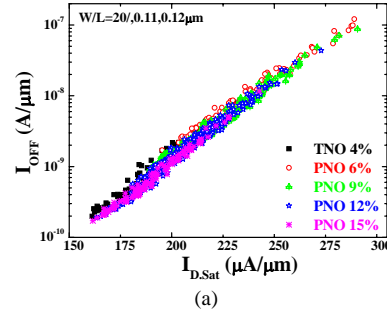
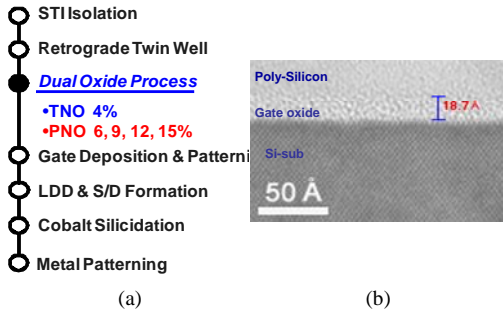


Fig. 11. Dependence of recovery amount (ΔV_{th}) of on different stress temperature

Fig. 12. Comparison of recovery characteristics with a different recovery voltage for TNO and PNO.

Fig. 13. Schematic diagram of the behavior of positively charged states in gate oxide.