NBTI EFFECTS OF pMOSFETS WITH DIFFERENT NITROGEN DOSE IMPLANTATION

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Abstract

NBTI effects with different nitrogen dose implantation and regions were investigated. High nitrogen dose implantation in the channel or source/drain extension results in serious NBTI degradation. Both the dynamic NBTI effects and substrate hot holes effects were also discussed. DNBTI and I_{CP} were measured simultaneously. Reduction of ΔV_{TH} and I_{CP} after positive gate bias stressing is related with the recovery of interface states.

I . Introduction

NBTI of p^+-gate MOSFETs has been reported as one of the serious issues for the reliability of ultra-thin gate dielectrics. In addition, nitrogen incorporation was often used to prevent boron penetration etc. However, several reports indicated that the nitrogen at the interface would enhance the degradation of NBTI. In this study, the nitrogen dose effects at different regions were investigated. Furthermore, to simulate switching operation of the inverter, the gate voltage of during NBTI stressing is switched between negative and positive bias (Dynamic NBTI, DNBTI)[1] for all splits. Charging pumping current I_{cp} for all splits was detected to investigate the interface states variation.

II . Device Fabrication

P-channel MOSFETs were fabricated on p-type wafers. LOCOS was used for device isolation. As^+ implant was for V_{TH} adjustment followed by nitrogen implantation (10 keV, 5×10^{13}, 1×10^{14}, 5×10^{14} cm^{-2} respectively). A 2.8 nm gate oxide was grown in N_2O ambient. Control sample was grown in O_2 ambient without or with nitrogen implantation of 10 keV, 5×10^{13} implantation for comparison. Then wafers were followed by a 200 nm poly-Si gate deposition. Shallow S/D extensions were formed by BF_2 implant. Nitrogen implantation (10keV, 5×10^{13}, 5×10^{14} cm^{-2}, respectively) both at S/D extension and poly-Si was then carried out to compare the different nitrogen incorporating regions effects. After the sidewall spacer, deep p^+-source/drain junctions were formed by BF_2 implantation. Afterwards, wafers were annealed by RTA at 1020℃ for 20sec.

III . Results and Discussion

Figure 1(a) shows the stress time dependence of V_{TH} degradation for pMOSFETs with different nitrogen implantation dose (N_2O oxide, 10 keV, 5×10^{13}, 10^{14}, 5×10^{14} cm^{-2}, and O_2 oxide w/o N_2 implantation, respectively) in the channel. Devices were stressed at E_{OX}=-13 MV/cm and 125℃ with other terminals grounded (L/W=0.8μm/ 100μm). It is noted that high nitrogen implantation in the channel would result in high V_{TH} degradation due to lower activation energy *Ea*. This increases the interface state N_{it} and increases the degradation of V_{TH} for devices with high nitrogen implantation dose. Furthermore, the split of O_2 oxide without nitrogen implantation depicts the best NBTI resistance among all splits. Fig. 1(b) shows comparison for device of N_2O oxide with different S/D extension nitrogen implantation dose (10keV, 5×10^{13}, 5×10^{14} cm^{-2}, respectively). Higher nitrogen implantation at the S/D extension also enhances the NBTI degradation. This is due to the locally enhanced degradation reactions between holes and oxide near the S/D, and the nitrogen might diffuse to the interface after following RTA process[2] or lateral scattering of ion implantation. Fig. 2(a) shows the recombined charge per cycle: Qss, which is deduced from Icp/ f. The slope of Qss versus log(f) was proportional to the interface state Dit [3]. Clearly, the slope in the split of O_2 oxide w/o N_2 implantation depicts the steep slope, which indicates the worst Dit behavior due to boron penetration[4]. In addition, due to less boron penetration, devices have nitrogen implantation show almost the same magnitude of Dit. Fig. 2(b) shows result with different nitrogen doses (N_2O oxide, 10kev, 5×10^{13}, 5×10^{14} cm^{-2}, respectively.) at S/D extension. These two splits depict smaller slope than those shown in Fig.2(a). This is due to the nitrogen implantation in the poly-Si gate during S/D extension implantation effectively suppress the boron penetration[5]. However, larger nitrogen dose at S/D extension may cause local defects that may enhance the degradation of NBTI. Fig. 3 shows the summary of the V_{TH} degradation under NBTI stressing with different substrate bias for all splits. As the V_{well}=2V, significant V_{TH} degradation larger than 25 mV was found as shown in Fig.3. Therefore, the substrate hot holes as V_{well}=2V dominate the V_{TH} degradation[5]. Figures 5(a) and (b) show the dynamic NBTI effects. Fig. 4(a) shows the stress time dependence of V_{TH} degradation for pMOSFETs with different nitrogen dose implantation in the channel. Fig. 4(b) shows the result for those with nitrogen ion implantation at the S/D extension. The conditions of negative state was for 125℃, E_{OX}=-13MV/cm, while that of positive state was set V_G=1V. Other terminals were grounded under both conditions. Under high temperature and negative bias stressing, the hole from the inversion layer would breaking the Si-H bond and increase interface trap N_{it}, and then diffuse to the gate electrode[7]. Under positive bias, the channel inversion was disappeared and hydrogen, breaking by hole, was then move back to the Si/SiO$_2$ interface. We found that the degradation in the periods of negative state was proportional to nitrogen implantation dose both in the channel and S/D extension. But no significant difference for nitrogen doses. This is similar to the result shown in Fig.1 and Fig.2. During DNBTI stressing, the I_{CP} was measured at the same time. Fig. 5(a) shows the stress time dependence of Icp_{max} (L/W=10μm/ 100μm, 100°C) during DNBTI for pMOSFETs with different nitrogen doses in the channel. Fig. 5(b) shows the result for nitrogen implantation at the S/D extensions. Triangle pulse and 1M Hz frequency was performed during Icp measurement. Although the interface state Dit of pure oxide was largest, as shown in Fig. 2(a), due to its poor boron penetration retardation, the ΔIcp_{max} of pure oxide splits was smaller than that of N_2O. The split of N_2O oxide with 5×10^{15} cm^{-2} depicts the worse ΔIcp_{max} degradation. Therefore, nitrogen dose in the channel contributes the degradation of ΔIcp_{max}. Furthermore, at positive state stressing, the ΔIcp_{max} only slightly decreased. This implies interface states recovered at positive state stressing. In Fig. 5(b) showed that higher nitrogen implantation at S/D extensions still causes larger ΔIcp_{max}. Fig. 6(a) shows the DNBTI effects for O_2 and N_2O oxide, 10keV, 1×10^{14} cm^{-2}. After positive state recovery, the ΔV_{TH} of both splits was close to each other.

Conclusion

Higher nitrogen dose, both in the channel and in the S/D extension, would cause seriously degradation of the V_{TH}. We found substrate hot hole injection would enhance the NBTI effects. The reduction of Icp_{max} after positive gate bias stressing enhanced the recovery ability of interface state. Therefore, the passivation of the threshold voltage was may be due to the recovery of interface state.

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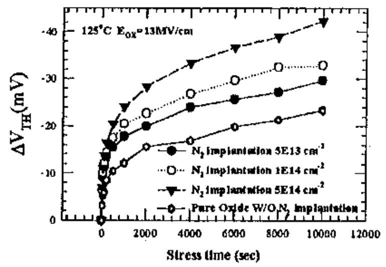

Fig.1 (a) Stress time dependence of ΔV_{TH} for pMOSFETs with different nitrogen dose implantation in the channel, and temperature was 125℃, E_{OX}=-13MV/cm.

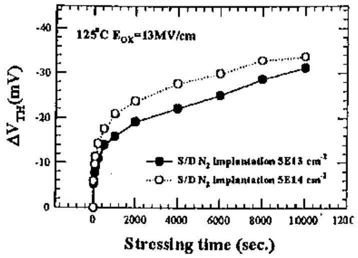

Fig.1 (b) implantation in the S/D extension

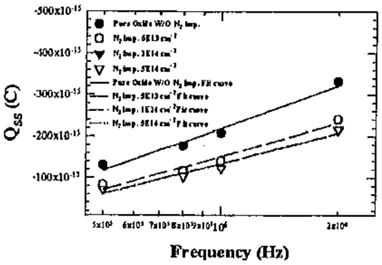

Fig.2(a) The Qss (Icp/ f) versus frequency on log scale for pMOSFETs with different nitrogen dose implantation in the channel.

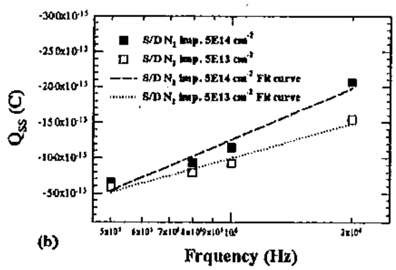

Fig.2 (b) implantation in the S/D extension.

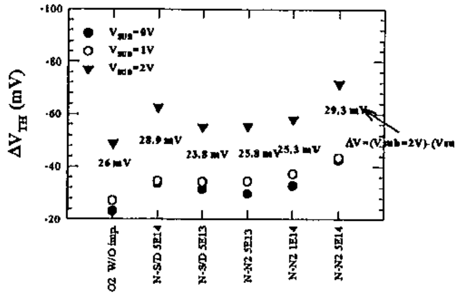

Fig.3 The ΔV_{TH} for pMOSFETs with different substrate bias: V_{well}=0, 1, 2V, respectively. The stressing was 125℃, E_{OX}=13MV/cm.

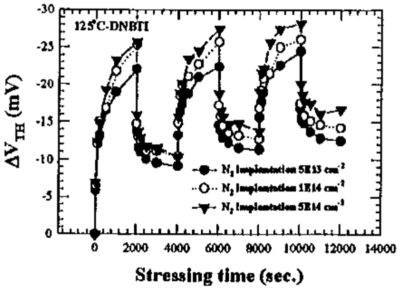

Fig.4(a) Stress time dependence of ΔV_{TH} for pMOSFETs with different nitrogen dose. The conditions of " high" state was for 125℃, E_{OX}=13MV/cm, that of " low" state was 125℃, V_G=1V.

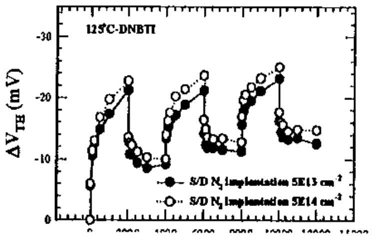

Fig.4(b) implantation in the S/D extension.

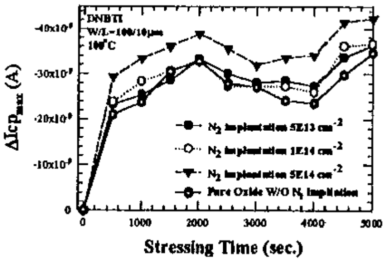

Fig.5(a) Stress time dependence of maximum Icp (L/W=10/100 μm) with different nitrogen dose implantation in the channel. The conditions of " high" state was for 100℃, E_{OX}=13MV/cm, that of " low" state was 100℃,

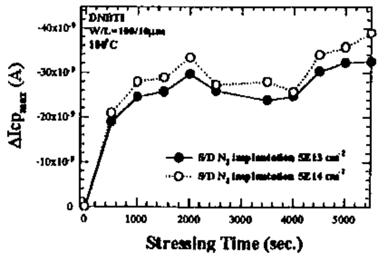

Fig.5(b) implantation in the S/D extension.

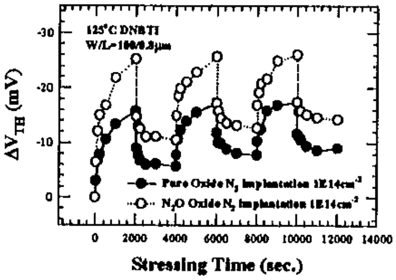

Fig.6(a) ΔV_{TH} for pMOSFETs with different nitrogen dose implantation in the channel. The conditions of " high" state was for 125 ℃, E_{OX}=13MV/cm, that of " low" state was 125℃, V_G=1V.

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