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The Combined Effects of Nitrogen Implantation at S/D Extension and N_2O Oxide on 0.18 μm N- and P-Metal Oxide Field Effect Transistors (MOSFETs)

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The combined effects of N_2-implantation at S/D extension and N_2O oxide on 0.18 μm n- and p-Metal oxide field effect transistors (MOSFETs) were investigated. It is found that for n-channel transistors, V_{th} roll-off and drain-induced barrier lowering (DIBL) are enhanced by nitrogen incorporation through either N_2O oxide or N_2-implantation. However, for p-channel transistors, opposite trends are observed for N_2O oxide and N_2-implantation. Finally, nitrogen incorporation by either method is found to improve the interface quality for nMOSFETs. While for p-channel transistors, best results are obtained by the combined effects of N_2O oxide and N_2-implantation.

KEYWORDS: nitrogen, N_2O, MOSFETs, S/D extension

1. Introduction

Recently nitrogen implantation received lots of attention in the fabrication of deep sub-micron devices.[1–3] Nitrogen was proposed to be co-implanted into BF_2^+-implanted p^+-poly-Si gate to suppress the boron penetration,[1] or into the source-drain region to improve the junction leakage,[2] or into the channel region to improve the n-channel device performance.[3] Meanwhile, N_2O oxide has also been proposed as a promising gate oxide material for deep sub-micron devices.[4,5] Devices with N_2O oxide were shown to exhibit better hot-carriers immunity, lower charge trapping, higher breakdown field, and better radiation hardness over the conventional O_2 oxide. It is also known that nitrogen can form complex with boron in the BF_2^+-implanted p^+-poly-Si gate, resulting in the retardation of boron diffusion.[1] On the other hand, nitrogen implanted into the p-type silicon substrate reduces the activated boron concentration.[3] While for N_2O oxide, it is known that some nitrogen is incorporated at the SiO_2/Si interface and forms strong Si–N bonds. These strong Si–N bonds are more resistant to hot-carrier degradations over the Si–H and Si–OH bonds. In this paper, we report, for the first time, the combined effects of nitrogen implantation at S/D extension and N_2O gate oxide on 0.18 μm n- and p-channel metal oxide field effect transistors (MOSFETs).

2. Experimental

Both n- and p-channel 0.18-μm MOS transistors were fabricated. After growing a 4 nm-thick gate oxide in either N_2O or O_2 ambient at 900°C for 40 minutes, an *in situ* phorsphous-doped n^+-poly-Si and an undoped poly-Si layer, both with a thickness of 200 nm, was deposited on n- and p-channel MOSFETs, respectively. The incorporated nitrogen concentration for N_2O processing is less than 1 at%. Poly-Si films were etched by an electron cyclotron resonance (ECR) etcher using HBr : O_2 (50 : 1) as etchants. Low-energy implantation of As^+ (10 keV, $4 \times 10^{14}/cm^2$) and BF_2^+ (10 keV, $1 \times 10^{15}/cm^2$) was then employed to form the shallow S/D extension region for n- and p-MOSFETs, respectively. Some splits received an additional nitrogen implantation of 10 keV at a dosage of $5 \times 10^{13}/cm^2$ and $1 \times 10^{14}/cm^2$ for n- and p-MOSFETs, respectively, in order to study the effects of nitrogen implantation at the S/D extension on the transistor characteristics. A 150 nm-thick tetraethoxysilane (TEOS) layer was then deposited and reactive ion etching (RIE)-etched to form the sidewall spacer. Afterwards, As^+ (20 keV, $5 \times 10^{15}/cm^2$) and BF_2^+ (10 keV, $6 \times 10^{15}/cm^2$) were implanted to form the S/D regions for n- and p-MOSFETs, respectively. Finally, wafers were annealed at 800°C for 20 min and underwent a rapid thermal annealing (RTA) process at 1050°C for 20 s for dopant activation.

3. Results and Discussion

V_{th} roll-off characteristics for n-channel transistors are displayed in Fig. 1. The split that received both N_2O oxide and N_2-implantation at S/D extension (i.e., N_2O oxide + N_2) exhibits the largest, while the control split (i.e., O_2 oxide only) exhibits the smallest V_{th} roll-off. This is due to the combined effects of interface nitrogen incorporation both at the active channel region and S/D extension region. It has been reported that, due to implant-induced defects at the source-drain region, enhanced boron diffusion from the sub-surface punch-through-stopper-implant region to the silicon surface

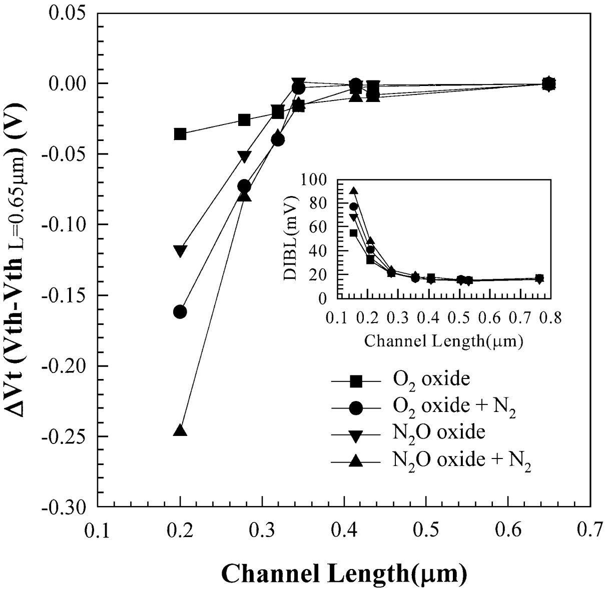

Fig. 1. The V_{th} roll-off characteristics for nMOSFETs. Insert shows the drain-induced-barrier-lowering (DIBL) characteristics, measured at drain current of 1 μA/μm and drain voltage at 1.5 and 0.1 V.

occurs at regions close to the source-drain edge. This enhanced boron diffusion results in a net increase in surface boron concentration close to the source-drain edge, causing the so-called "reverse short-channel effect (RSCE)".[6] Since this defect-induced enhanced boron diffusion is suppressed by the nitrogen incorporation,[7] boron redistribution is suppressed. Consequently, the RSCE is minimized, and the transistors display an enhanced V_{th} roll-off in return. This, together with the fact that the split which received O_2 oxide and N_2-implantation at S/D extension (i.e., O_2 oxide + N_2) displays the second largest V_{th} roll-off, suggests that nitrogen incorporation at the S/D extension is very effective in reducing the RSCE effect. This trend is consistent with recent results on MOSFETs fabricated with nitrogen implantation prior to growing the gate oxide,[8] and N_2O nitrided gate oxide.[9] The drain induced barrier lowering (DIBL) effect is plotted in the insert of Fig. 1. It can be seen that splits with N_2-implantation show a larger DIBL than those without N_2 implantation as channel length is smaller than 0.25 μm, confirming again that nitrogen incorporation at the S/D extension is very effective in reducing the RSCE.

The results on the V_{th} roll-off for pMOSFETs are shown in Fig. 2. It is interesting to note that while splits with N_2-implantation at S/D extension show a larger V_{th} roll-off, splits with N_2O oxide show instead a smaller V_{th} roll-off. This interesting behavior (i.e., N_2O oxide and N_2-implantation at S/D extension do not result in similar V_{th} roll-off trend, as in the case of n-channel transistors) can be explained by the boron penetration effects from the p^+-poly-Si gate for pMOSFETs. Since N_2O oxide is known to prevent boron penetration from p^+-poly-Si gate into the active channel region, a higher n-type channel surface concentration can be preserved, compared to samples with O_2 oxide. Consequently, the V_{th} roll-off is suppressed.

To evaluate the polysilicon depletion effect due to boron penetration from the BF_2^+-implanted p^+-poly-Si gate, quasi-static C–V measurements were conducted. The average values of the normalized $C_{\mathrm{inv}}/C_{\mathrm{ox}}$ (curves not shown) are 0.931, 0.929, 0.917, and 0.915 for $N_2O + N_2$, N_2O, $O_2 + N_2$, and O_2 oxide samples, respectively. These data seem to suggest that nitrogen incorporation can somehow improve the depletion effect of the BF_2^+ implanted p^+-poly-Si gate. The interface quality of nMOSFETs was analyzed by using charge pumping current measurement, and the results are shown in Fig. 3. Split with O_2 oxide but without N_2 implantation at the S/D extension has the largest charge pumping current. This implies that the interfacial quality of the sample can be improved by nitrogen incorporation, introduced either at the SiO_2/Si interface by N_2O oxide or at the S/D extension by N_2-implantation. It is also interesting to note that splits with N_2-implantation at the S/D extension, irrespective of whether it received O_2 or N_2O oxide, show almost identical charge pumping current, suggesting that N_2-implantation at the S/D

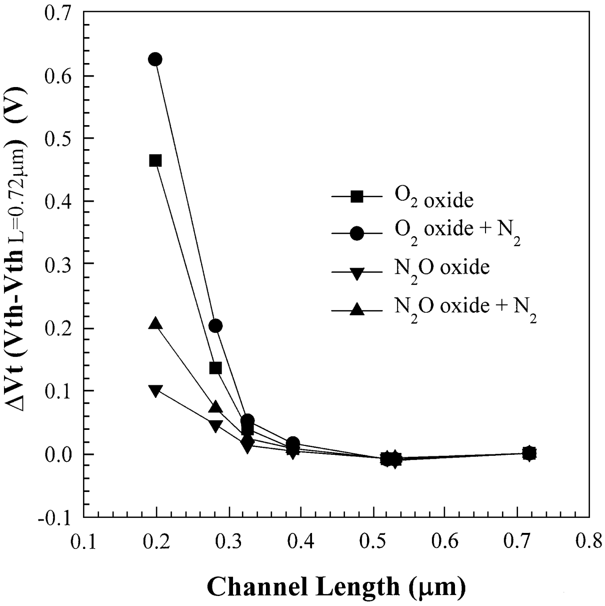

Fig. 2. V_{th} roll-off characteristics for pMOSFETs.

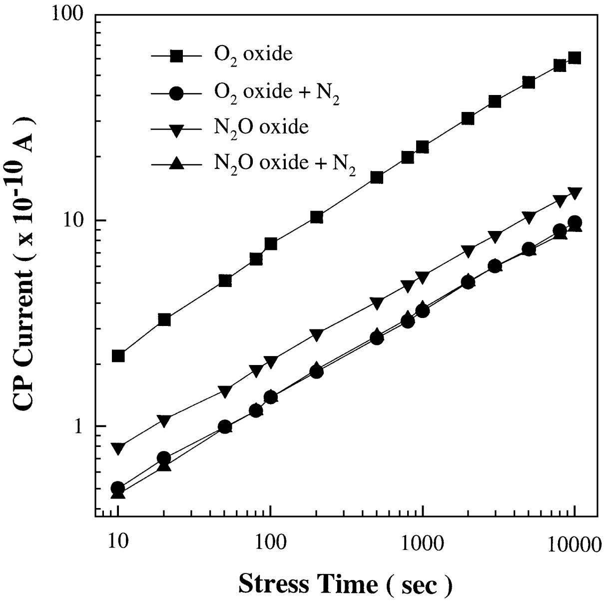

Fig. 3. Charge-pumping current for nMOSFETs under stressing at a drain bias of 3 V. Gate voltage is biased to yield maximum substrate current.

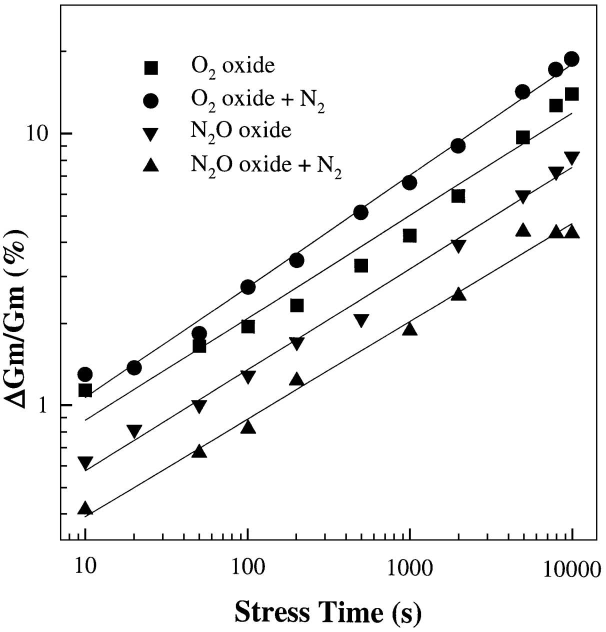

Fig. 4. Transconductance degradation for pMOSFETs under stressing at a drain bias of −3 V. Gate voltage is biased to yield maximum gate current.

alone is very effective in improving the interfacial quality. Figure 4 shows the transconductance (Gm) degradation of pMOSFET after 10000 s stressing at a drain bias of -3 V with the gate biased to yield the maximum gate current. It can be seen that while nitrogen implantation at the S/D extension alone worsens the hot-carrier degradations for samples with O_2 oxide, devices with N_2O oxide perform better than O_2 oxide. More importantly, split with combined N_2O oxide and N_2-implantation at the S/D extension has the lowest Gm degradation among the four splits used in this study.

4. Conclusion

N_2O oxide and nitrogen implantation at the S/D extension are found to have different effects on 0.18 μm n- and p-MOSFETs. For nMOSFETs, $V_{\rm th}$ roll-off and DIBL effect are enhanced by nitrogen incorporation, either through N_2O oxide or N_2-implantation at S/D extension. While for pMOSFETs, N_2O oxide and N_2-implantation at S/D extension cause opposite effects in $V_{\rm th}$ roll-off, which can be explained by the reduced boron penetration in the case of N_2O oxide. Nitrogen incorporation is also found to improve the interfacial quality in nMOSFETs. While for pMOSFETs, the combined effects of N_2O oxide and N_2-implantation result in the best performance in terms of reduced poly-depletion effects and better hot-carrier resistance.

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