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Suppressed Boron Penetration in p^+ poly-Si/Al_2O_3/Si Metal-Oxide-Semiconductor System by Remote Plasma Nitridation of Al_2O_3 Surface

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ABSTRACT

We examine boron penetration in p^+ poly-Si/Al_2O_3/n-Si pMOS capacitors with various treatments. Suppressed B penetration was attained in p^+ poly-Si/Al_2O_3/n-Si pMOS capacitors by the surface nitridation of Al_2O_3 gate dielectric using remote plasma nitridation (RPN). The flatband shift of pMOS capacitor was negligible up to 850℃, effectively blocking the B penetration using RPN- Al_2O_3 compared to the Al_2O_3 only or Al_2O_3/SiN_x structure. However, the gate leakage current of RPN-Al_2O_3/Si MOS capacitors was higher than that of nominal Al_2O_3 due to the reduced energy bandgap (E_g) of RPN-Al_2O_3.

INTRODUCTION

Al_2O_3 has attracted a lot of attention as an alternative gate dielectric because of good thermal stability when in direct contact with Si, excellent interface characteristics, and low leakage current [1,2]. Especially, good compatibility of Al_2O_3 with poly-Si gate allows us to maintain conventional CMOS technologies. However, the p^+ poly-Si/Al_2O_3/Si structure showed an extraordinary positive flatband shift ($\triangle V_{FB}$) due to the B penetration into the Si substrate through Al_2O_3 at elevated temperatures [3], resulting in the critical issues for CMOS applications. In this study, we employed an unique RPN approach on the Al_2O_3 surface to block the B penetration and attained negligible $\triangle V_{FB}$ up to 850℃.

EXPERIMENTAL

Poly-Si/RPN-Al_2O_3/Si MOS capacitors were fabricated on the n-type and p-type (100) Si substrates (8-inch dia.). HF last cleaning was carried out, followed by the atomic layer deposition (ALD) of Al_2O_3 (55Å) gate dielectric using $Al(CH_3)_3$ and H_2O vapor at 350℃. Some samples were subjected to the gate dielectric improvement anneal in O_2 at 800℃ for 30min. RPN process was employed on the Al_2O_3 surfaces at 650-850℃ using a remotely controlled He/N_2 plasma reactor. Undoped and n^+ poly-Si were deposited for pMOS and nMOS, respectively. Then, $^{11}B^+$ was implanted on the undoped poly-Si at 4 keV and 3×10^{15} B ions/cm^2. To activate the implanted B ions, furnace anneals were carried out from 800℃ to 900℃ in N_2 for 30 min. For comparison, p^+ poly-Si/Al_2O_3/SiN_x/n-Si MOS capacitors were also prepared using NH_3 anneals on the Si surfaces for SiN_x formation. Physical and electrical properties of MOS capacitors were examined.

RESULTS AND DISCUSSION

Shown in Figs. 1-2 are high-frequency C-V curves of p^+ poly-Si/Al_2O_3/n-Si and p^+ poly-Si/Al_2O_3/SiN_x/n-Si MOS capacitors with anneal temperatures. Our previous results showed that the $\triangle V_{FB}$ of Al_2O_3 only was +1.54V after activation anneal from 800℃ to 850℃ [3]. On the contrary, the $\triangle V_{FB}$ of Al_2O_3/SiN_x/n-Si was reduced to +0.15 V at the same condition, indicating somewhat retarded B penetration. However, the negative V_{FB} shift and non-ideal C-V hump of Al_2O_3/SiN_x/n-Si system was pronounced due to the SiN_x-Si interfaces. Fig. 3 exhibits C-V curves of RPN-Al_2O_3/n-Si pMOS capacitor, demonstrating negligible $\triangle V_{FB}$ (< 10 mV) up to 850℃. A normalized inversion capacitance (C_{inv}/C_{ox}) measured from this structure was about 83% at 850℃ (not shown). Fig. 4 shows B profiles in the p^+ poly-Si/RPN-Al_2O_3/n-Si structures, depicting an effective B blocking in the Al_2O_3 up to 850℃. This may be feasible because of the thermally stable RPN-Al_2O_3 surfaces at 850℃ (Fig.5). In addition, the $\triangle V_{FB}$ even after 900℃ was +0.52V, that is remarkably reduced value compared to the one of Al_2O_3 after 850℃ (Fig.1). Fig. 6 exhibits the conductance loss (G/ω)-V plots of RPN-Al_2O_3/Si MOS capacitors for D_{it} extraction. The D_{it} level was decreased from ~$8x10^{11}$ cm^{-2}-eV^{-1} to ~$2x10^{11}$ cm^{-2}-eV^{-1} with activation temperatures.

Figure 7 shows J-V characteristics of n^+ poly/Al_2O_3/p-Si nMOS capacitors as a function of RPN. An increase of leakage current (I_{LC}) at high electric field is noted with RPN, where the capacitance equivalent thickness (CET) with RPN is ~3Å thicker than that without RPN. For a better understanding of I_{LC} increase with RPN, the energy bandgap (E_g) of Al_2O_3 was measured using electron energy loss spectra of O 1s on Al_2O_3/Si-substrate [4]. The E_g of as-deposited Al_2O_3 is about 6.8 eV, while that of RPN-Al_2O_3 is 6.1eV. The E_g of those after N_2 anneal at 800℃ was increased to 6.94 eV for Al_2O_3 and 6.5 eV for RPN- Al_2O_3 (Table 1).

Shown in Fig. 9 are XPS core level spectra of Al 2p and N 1s as a function of RPN on Al_2O_3. The Al 2p spectra of Al_2O_3 only and RPN-Al_2O_3 showed no distinct difference between those because the binding energy (B.E.) of Al 2p for Al_2O_3 and AlN is similar (74 - 74.7 eV). On the other hand, the N 1s spectra exhibited two clear peaks at 396 eV and 403 eV after RPN. The B.E. at 396 eV corresponds to the atomic nitrogen and that at 403 eV to the adsorbed NO or N_2O on Al_2O_3 [5]. From the presence of N 1s peak at 403 eV after anneal at 800℃, the bonding at 403 eV appears to be stronger than the one at 397 eV. Based on our observation, the N incorporation into the interstitial or substitutional site is related with the formation of AlN. A partial modification of Al_2O_3 surfaces into AlN, of which has the E_g of ~5.9 eV [6], may result in the E_g decrease into 6.1 eV. It is thought that reduced E_g by RPN, in turn, decreases the barrier height of RPN-Al_2O_3/Si junction, led to the increase of the I_{LC} in Fig. 7. This can be inferred from the increase of E_g (6.5 eV) of RPN-Al_2O_3 after N_2 anneal at 800℃, which may be resulted from the N outdiffusion (Fig. 10). Our experiments suggest that an optimization process for a pertinent N content is required for the least B penetration and bandgap reduction.

CONCLUSION

The B penetration in the p^+ poly-Si/Al_2O_3/n-Si pMOS capacitors was effectively suppressed up to 850℃ by the surface nitridation of Al_2O_3 using RPN. We found I_{LC} increase due to the E_g reduction of RPN-Al_2O_3, that requires optimization for B suppression and bandgap engineering.

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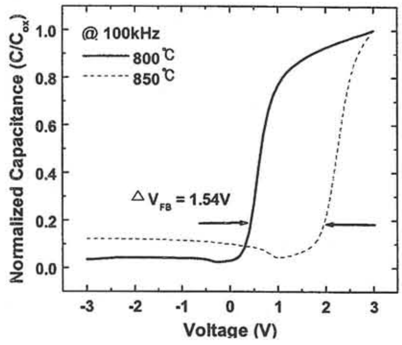


Fig. 1. C-V plots of p+ poly-Si/ Al_2O_3 /n-Si MOS capacitors with anneal temperatures. After Ref. [3].

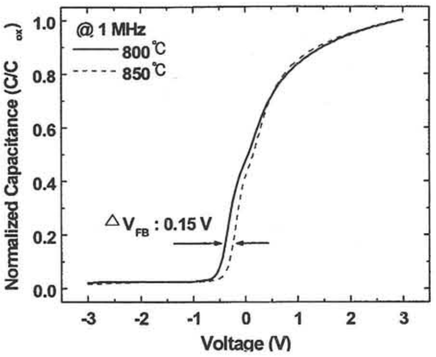


Fig. 2. C-V plots of p+ poly-Si/ Al_2O_3 /SiN_x/n-Si MOS capacitors with anneal temperatures.

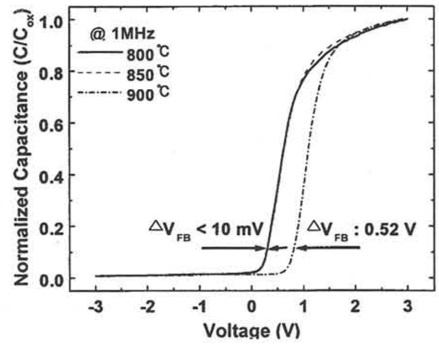


Fig. 3. C-V plots of p+ poly-Si/ RPN-Al_2O_3 /n-Si MOS capacitors with anneal temperatures.

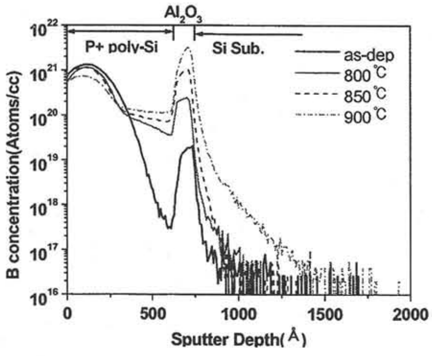


Fig. 4. B profiles in the p+ poly-Si/RPN-Al_2O_3/n-Si structure with temperatures using SIMS.

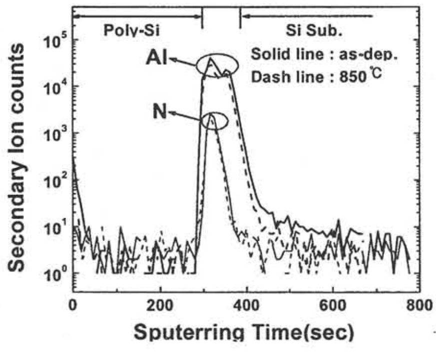


Fig. 5. SIMS profiles in the p+ poly-Si/RPN-Al_2O_3/n-Si with activation anneal.

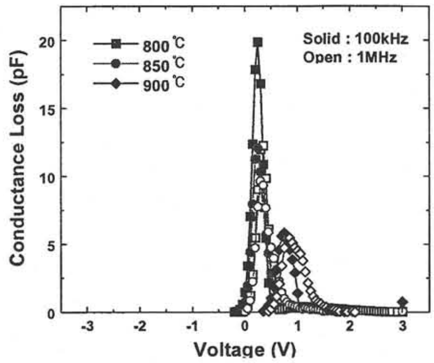


Fig. 6. Conductance loss (G/ ω) -V plot of the p+ poly-Si/RPN-Al_2O_3/n-Si with activation anneal.

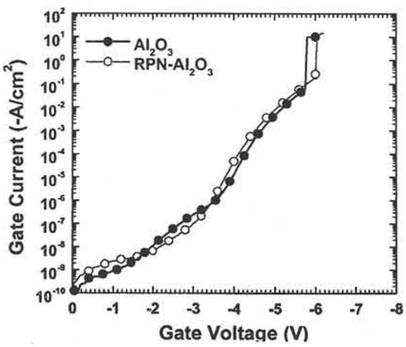


Fig.7. J-V curves of n+ poly-Si/Al_2O_3/p-Si nMOS capacitors as a function of RPN.

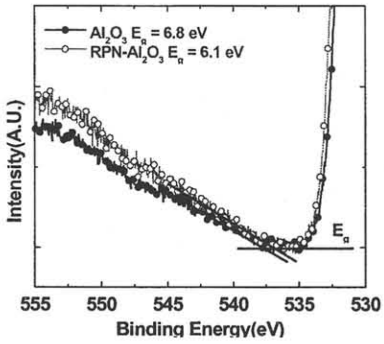
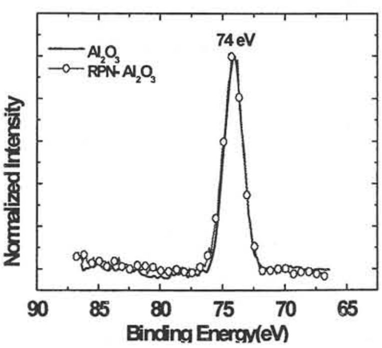


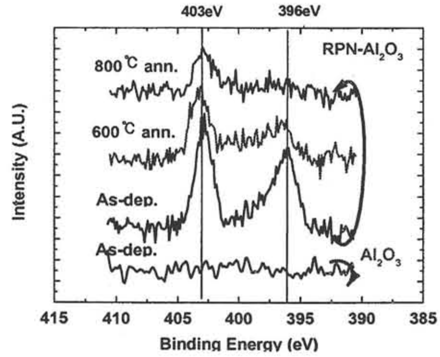
Fig. 8. XPS electron energy loss spectra of O 1s with Al_2O_3/Si sub. as a function of RPN.

	As-dep.	After ann. 800℃
Al_2O_3	6.8 eV	6.94 eV
RPN-Al_2O_3	6.1 eV	6.5 eV

Table 1. Energy bandgap (Eg) of Al_2O_3 as a function of RPN by electron energy loss spectra.



(a) core level spectra of Al 2p .



(b) core level spectra of N1s.

Fig. 9. XPS core level spectra of Al 2p and N 1s with Al_2O_3/Si sub. as a function of RPN.

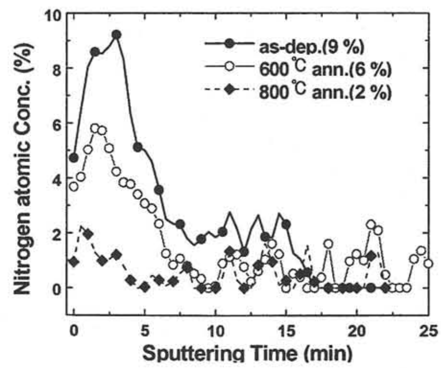


Fig. 10. AES depth profiles of RPN-Al_2O_3/Si sub. with anneal temperatures.