Mechanism and Optimization of Nitrogen Co-Implant for Suppressing Boron Penetration in P⁺-Poly-Si Gate of PMOSFET's

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The mechanism and the optimization of nitrogen co-implant for suppression the boron penetration in p⁺-poly-Si gate is present. Nitrogens combine with the boron to form a B-N complex, retarding the penetration of boron itself, was identified by FTIR measurements. The optimum nitrogen dosage is also found in this study.

1. Introduction

P⁺-poly-Si gate has been proposed for the fabrication of surface channel PMOSFET's in deep submicron CMOS [1-2]. This is because surface channel device exhibits a better threshold, subthreshold leakage control, and short channel effect than the conventional buried-channel using the n⁺-poly-Si gate. However, boron, which from BF₂⁺ for formation of p⁺-poly-Si gate, penetrates easily the poly-Si and the gate oxide during the following high temperature thermal cycles, especially at the presence of F. Recently nitrogens incorporate into the poly-Si or oxide, either nitrogen implantation or N₂O nitridation, have been reported to suppress the boron penetration, but the data is very limited [3-4]. The real mechanism of the suppression is also still unclear. In the paper, the mechanism and the optimum process of the nitrogen co-implant for suppression of boron penetration is reported. The effects of the nitrogen on boron penetration and the gate oxide integrity are studied comprehensively.

2. Experimental

Gate oxide, 80Å, is grown in dry O₂ at 900°C. After deposition of 300 nm poly-Si, nitrogen N₂⁺ implantation was performed at 80 keV to a dose of 1x10¹³ - 1x10¹⁶ /cm². Some of the samples were annealed to drive the nitrogen into poly-Si/SiO₂ interface at 900°C for 30 min. (AN). Then, samples were implanted by BF₂⁺ to a dose of 5x10¹⁵/cm² at 50 keV. The annealing condition is at 900°C for 30-50 minutes. Samples were then fabricated as MOS capacitors.

3. Result and Discussions

Figure 1 shows the high frequency C-V curves of AN. Clearly, nitrogen retards the diffusion of boron effectively. The C-V of the samples without drive-in after nitrogen implantation, NA, also exhibits an effective suppression of boron penetration and shown in Fig.2. No significant difference is found from those in the Fig.1. However, as they are annealed for 50 min., C-V curves distort significantly when nitrogen concentration is less than 1x10¹³ for AN and shown in Fig.3 which results from the serious penetration of boron. The distortion of C-V curve is also found as nitrogen is less than 1x10¹⁴ for NA samples. This indicates AN has a larger processing window than NA. The corresponded flat-band voltage is shown in Fig.4. The more the nitrogen concentration, the smaller the flat-band voltage.

SIMS analyses of nitrogen 1x10¹⁵ were performed and shown in Fig.5. Both AN and NA exhibit a shallower boron profile in the Si-substrate than the control sample. Fig.6 shows the Cinv/Cox and the sheet resistance, Rs, for AN. The Cinv/Cox ratios are still high as nitrogen dose is less than 1x10¹⁵, and maintaining the Rs in the same level at the same time. Although nitrogen of 1x10¹⁶ has the least boron penetration from the C-V results, a high Rs and low Cinv/Cox is found resulting from insufficient B concentration. NA has the similar result (in Fig.7). As nitrogen dosage is 1x10¹⁶, AN has a higher Cinv/Cox and a lower Rs than NA. This implies that the process which let the nitrogen pile up at the interface with a first drive-in step before BF₂⁺ implantation is more effective.

The result of FTIR spectrum can explain the reason clearly. Fig.8 shows the FTIR spectra of the NA. A clear absorption of B-N bond is found at 670 cm⁻¹. The absorption intensity increases as the nitrogen concentration increases. From these result, it is concluded that as nitrogen dosage is below 1x10¹⁵, nitrogen only combines with the excessive borons forming the B-N complex which results in no effect on Rs and Cinv/Cox, and a smaller flat-band voltage than control. However, as nitrogen dosage exceeds this level, most of the borons are combined with the nitrogen which result in the increase of Rs and decrease of Cinv/Cox for depletion of dopant B. Gate oxide integrity is also investigated. The charge-to-breakdown, Qbd, for AN annealed at 900°C for 30 minutes was shown in Fig. 9. Samples with nitrogen co-
implant exhibit an improved $Q_{bd}$. The $Q_{bd}$ increases as the nitrogen concentration increases. The interface trap densities of AN and NA are shown in Fig.10. Basically, the more the nitrogen dosage, the lower the interfacial trap density is obtained.

4. Conclusion

The mechanism and the optimization of nitrogen co-implant for suppression the boron penetration in p$^+$-poly-Si gate is present. Samples with the nitrogen implantation suppress the boron penetration significantly and exhibit an improved electrical performance. An optimum dosage of nitrogen is $1 \times 10^{15}$ cm$^{-2}$. Excessive nitrogens in the poly-Si, although still has some advantages, will increase the $R_s$ and decrease the $C_{inv}/C_{ox}$. This can be explained successfully by the formation a B-N complex identified from the FTIR measurement. From the result, it indicates a drive-in process after nitrogen implantation is also effective to retard the penetration of boron.

References:

Fig.1 The C-V of samples, AN, annealed at 900°C for 30-min with nitrogen co-implant from $1 \times 10^{12}$ to $1 \times 10^{16}$ cm$^{-2}$. The samples were annealed at 900°C, 30-min, before BF$_2$ implantation.

Fig.2 The C-V of samples, NA, annealed at 900°C for 30-min with nitrogen co-implant from $1 \times 10^{12}$ to $1 \times 10^{16}$ cm$^{-2}$. The samples were not annealed at 900°C, 30-min, before BF$_2$ implantation.

Fig.3 The C-V of sample, AN, annealed at 900°C for 50-min.

Fig.4 The flat-band voltage of AN, NA corresponding to the Fig.1 and Fig.2.
Fig.5 Boron profiles of samples of control, AN, NA, annealed at 900°C for 30-min with nitrogen implantation to a dose $1 \times 10^{15}$/cm$^2$.

Fig.6 $C_{inv}/C_{ox}$ and corresponding sheet resistance, $R_s$, of samples, AN, annealed at 900°C for 30-min.

Fig.7 $C_{inv}/C_{ox}$ and corresponding sheet resistance, $R_s$, of samples, NA, annealed at 900°C for 30-min.

Fig.8 FTIR spectrum of samples NA, after 900°C for 30-min. A absorption peak of B-N is found at 670 cm$^{-1}$.

Fig.9 Cumulative failure (%) of charge-to-breakdown, $Q_{bd}$, of AN annealed at 900°C for 30-min at $J = 100$ mA/cm$^2$.

Fig.10 Interface trap density of samples AN, NA, after annealed at 900°C for 30-min.