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Revisited Study for Fluorine Implantation Impact on NBTI for Automotive I/O Device

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Abstract

We investigated the effect of Fluorine (F) implanted in poly-Si gate and S/D region on NBTI improvement. It is found that there was trade-off of implantation energy de pendency of NBTI between F in poly-Si gate and F in S/D region. F implanted in poly-Si gate contributed to NBTI improvement under low energy implantation. On the other hand, NBTI was improved by F implanted in S/D region under high energy. We concluded that the two times implantation process with high and low energy is ideal for NBTI improvement.

1. Introduction

Negative Bias Temperature Instability (NBTI) has become one of serious concerns for reliability of pMOSFET [1]. Since Micro Controller Units (MCUs) for automotive products are operated under high temperature, eminent NBTI reliability, which is worse at higher temperature, is required. F incorporation in the gate oxide is well known to suppress NBTI degradation [2,3]. However, as shown in Fig.2, the effects of F implanted in Poly-Si gate and S/D region on NBTI improvement are still not fully understood. The purpose of this study is to clarify the effect of F implanted in Poly-Si gate and S/D region on NBTI and propose the most suitable condition to improve NBTI.

2. Experiments

The samples used in this study were 5.0 V I/O pMOS with poly-Si / SiO_2. The gate length (Ld) was 0.85 um, unless otherwise specified. The electrical thickness of SiO_2 in inversion was 19.0 nm. We prepared sample (A), (B) and (C). Figure 1 shows three process flows for each sample. Figure 2 shows the schematics of device structure of sample (A) and (B) when F was implanted. F implantation of sample (A) was performed after cap-SiN removal. Sample(B) was implanted after lightly doped drain (LDD) and before cap SiN removal. Two times F implantation process for sample (C) was after LDD implantation and after SiN removal. Table.1 shows these conditions in detail. NBTI measurement was performed by Measurement-Stress-Measurement (MSM) method [4]. Stress temperature was 150°C. Stress voltage and time were -14 V and 1 ksec.

3. Results and Discussion

(a) Sample(A): Without cap SiN on poly-Si

At first, the impact of energy of F implantation on NBTI was investigated. Figure 3 shows NBTI degradation as a function of F implantation energy. The implant dose was 2.3 x 10^{15} /cm^2. NBTI was improved with increasing F implantation energy from 10 keV to 20 keV, but was degraded at 30 keV. Figure 4 shows the simulation of F profiles after implantation. F in poly-Si gate got closer to poly- Si / oxide interface as F implantation energy increases. 30keV F implantation penetrated channel region through SiO_2. F implantation through SiO_2 is presumed to cause oxide damage, resulting in NBTI degradation as shown in Fig.5. Therefore, it is found that F in poly-Si contributed to NBTI improvement under lower energy enough to avoid the oxide damage.

To study the impact of F dose on NBTI, we investigated the dependence of F dose on NBTI. Figure 6 shows NBTI degradation as a function of F dose. The implantation energy was 15 keV. Although NBTI was improved compared with sample without F implantation, F dose had the smaller effect on NBTI performance.

To understand the effect of F implanted in S/D region, we investigated the dependence of NBTI on Ld. We think that F in S/D region could improve NBTI at gate edge region, which can lead to reduction of NBTI in shorter Ld. Figure 7 shows NBTI degradation as a function of Ld. The implantation energy and dose were 10 keV and 2.3 x 10^{15} /cm^2. NBTI was improved but the Ld dependency with F implantation was almost the same as that without implantation. We assume that the implantation energy (10 keV) is low and F doesn't reach to the gate edge. To confirm this effect, we prepared sample(B) with higher energy F implantation in S/D region. F of Sample(B) was implanted after LDD implantation. Device structure was with cap SiN on poly-Si to avoid the oxide damage by F implantation, mentioned in previous section. We will discuss the result in the next section (b).

(b) Sample (B): With cap SiN on poly-Si.

Figure 8 shows NBTI degradation as a function of Ld with F implantation energy from 20 keV to 30 keV. The implant dose 2.3 x 10^{15} /cm^2. Compared with sample without F implantation, NBTI with 30 keV F implantation was remarkably improved with shorter Ld. This result suggests that higher energy F in S/D region improve NBTI.

(c) Sample (C)

F implanted in poly-Si gate contributed to NBTI improvement under low energy. On the other hand, NBTI was improved by F implanted in S/D region under high energy. there was trade-off of implantation energy dependency of NBTI between F in poly-Si gate and F in S/D region. To obtain both the effect of F in poly-Si gate and in S/D region, we prepared sample(C) (see, experiment). Two times implantation were performed after LDD implantation and after cap SiN removal. Figure 9 shows NBTI degradation as a function of Ld. Sample (A) and (B) of one time implantation were also shown to compare with sample (C). For sample (C), NBTI was improved to the same level as sample (A) at larger gate length and also ameliorated as sample (C) in shorter region. This result indicates NBTI degradation of sample(C) has become smaller than one time implantation sample (A), (B) in whole gate length region. Therefore, we concluded that two times implantation process with high and low energy of F implantation is ideal for NBTI improvement.

4. Conclusion

F implanted in both poly-Si gate and S/D region contributed to NBTI improvement. There was trade-off of F implantation energy dependency of NBTI between the F in poly-Si gate and F in S/D region to improve NBTI. The combination process of two times F implantation with high and low energy is ideal for NBTI improvement.

Acknowledgements

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Reference [1] N. Kimizuka, *et al*., Symp on VLSI Technol., p 73 (1999), p. 92 (2000) [2] T.B Hook., *et al*, Electron Devices, IEEE Transactions on, 2001. 48(7): pp. 1346-1353. [3] Y. Mitani, *et al*., IEDM2002, pp. 509-512. [4] S. Mahapatra, *et al.*, Electron Devices, IEEE Transactions on, 2013. 60(3): pp. 901-916.

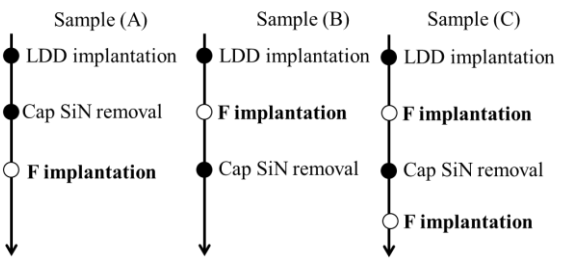


Fig.1 Three process flows for F implantation.

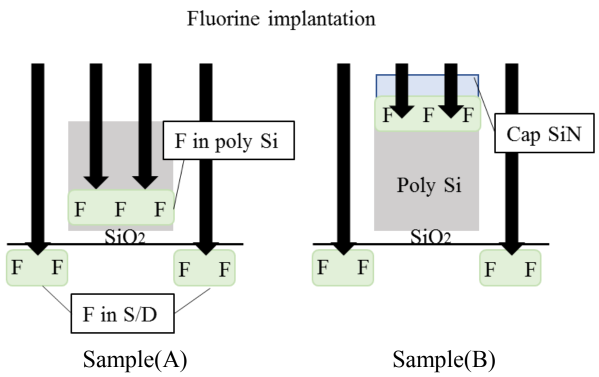


Fig.2 Schematics of device structure when F was implanted.

Table.1 F implantation condition of samples

	F implantation process	Dose(x 10^{15} /cm^2)	Energy (keV)	Implantation number of times
Sample(A)	After cap SiN removal	1.0 ~ 4.0	10 ~ 30	1
Sample (B)	After LDD implant	2.3	20 ~ 30	1
Sample (C)	(1) After LDD implant (2) After cap SiN removal	(1) 1.0 (2) 2.3	(1) 30 (2) 10	2

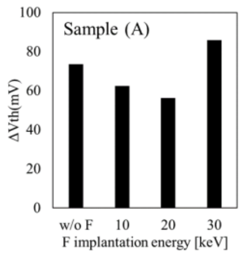


Fig.3 Dependence of F implantation energy on NBTI.

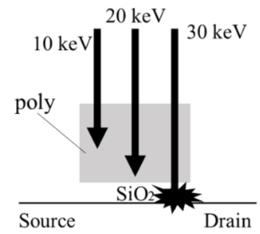
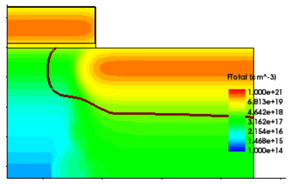
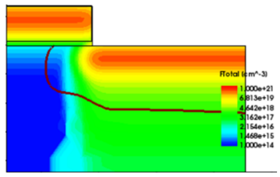


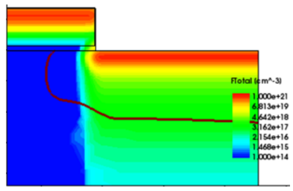
Fig.5 Schematic of oxide damage for sample (A).



(a) 30 keV



(b) 20 keV



(c) 10 keV

Fig.4 The simulation of F profiles after F implantation for sample (A).

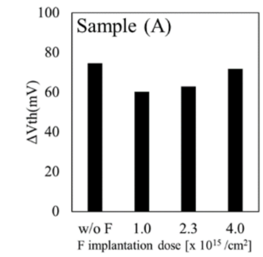


Fig.6 Dependence of NBTI on F implantation dose.

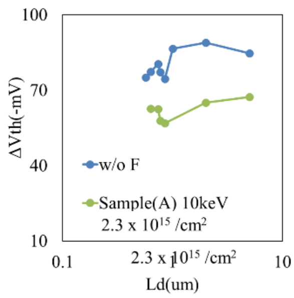


Fig.7 Dependence of NBTI on Ld with and without F implantation.

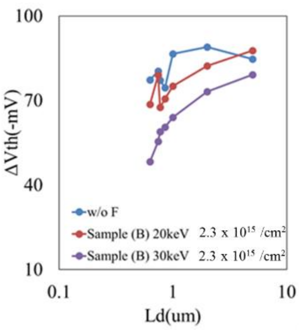


Fig.8 Dependence of NBTI on Ld with various implantation energy.

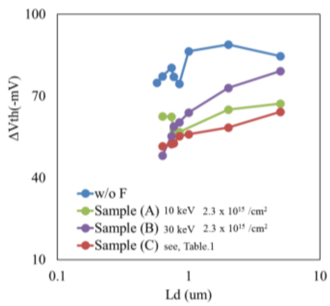


Fig.9 Dependence of NBTI on Ld for sample(A), (B) and (C).