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Influences of initial bulk traps on Negative Bias Temperature Instability of HfSiON

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Introduction

HfSiON film is one of the promising gate dielectrics to replace conventional SiO_2/SiON films in future ULSIs. There are some reports about the NBTI in HfSiON, but the time dependence of NBT-degradation reported are not unique[1,2]. It has an important impact for the lifetime projection because the predicted lifetime may change depending on stress time dependence. In this paper, we investigate the influence of initial traps for the stress time dependence of ΔVth under NBT-stress and propose the correct lifetime projection with consideration of the influence of initial traps.

Experimental

The devices used in this study were p+poly/pMISFET with HfSiON gate dielectrics fabricated by the conventional CMOS process. Hf concentration is about 50% (Hf/(Hf+Si)). The thickness of gate HfSiON film was around 4.5 nm and amorphous structures were confirmed by TEM observation. Threshold voltage (Vth) and Interface-state densities (Dit) were measured under negative constant voltage stress. The Vth was estimated by Id-Vg measurement and Dit was evaluated by the charge-pumping measurement.

Results and Discussion

It has been reported that ΔVth and ΔDit have a power low dependence of stress time (ΔVth (ΔDit) $=\boldsymbol{A}\cdot t^{\boldsymbol{B}}$) for SiO_2 and it was explained by reaction-diffusion model[3]. Figure 1 shows the NBT-stress time dependence of ΔVth and ΔDit for HfSiON and SiO_2 at Eox =7MV/cm and Temp.=125 °C. In SiO_2, time dependence factor ***B*** for ΔVth and ΔDit was almost the same (~0.25) and it indicated that ΔVth was caused by generated interface traps. However, in HfSiON, ***B*** of ΔVth are smaller than that of ΔDit. The time dependence factor ***B*** has an important impact for the lifetime projection. If the estimated ***B*** is smaller than real ***B***, we can overestimate the device lifetime. In order to investigate the origin of small ***B*** of ΔVth in HfSiON, we compared the NBT degradation behavior of ΔVth and ΔDit of SiO_2 and HfSiON. Figure 2 shows the stress time dependence of the normalized ΔVth and ΔDit of SiO_2 and HfSiON. The large jump was observed for the only ΔVth of HfSiON at initial NBT-stress. Then, We focused on the effects of this initial jump for the time dependence of ΔVth. Figure 3 shows the calculated results of the time dependence of ΔVth ; $\Delta Vth = \boldsymbol{A}\cdot t^{\boldsymbol{B}} + \Delta Vth_{ini}$ with several ΔVth_{ini}. Here, ΔVth_{ini} is initial jump of ΔVth. As shown in Fig.3, ***B*** depends on the ΔVth_{ini} in short time region. On the other hand, the sample with small ΔVth_{ini} shows no decrease of ***B***. These results indicate that the large initial jump of ΔVth causes the small ***B***, especially at short time. Therefore, the lack of universality in reported value of ***B*** is considered to be due to this initial jump.

The large jump of ΔVth in HfSiON can be caused by much trapped holes at initial NBT-stress, because large amounts of initial traps are included in HfSiON. In order to confirm the relation between stress time dependence of ΔVth and initial bulk traps, we investigate the stress time dependence of ΔVth for four samples with different initial trap density. The initial trap densities were controlled by positive stresses. Table.1 shows the stress conditions of each sample. The Dit did not increase under these stress conditions. Figure 4 shows the SILC characteristics and CV characteristics of each sample. Though Dit is independent of positive stress (Table.1), both SILC and CV hysteresis increase with increasing Qinj, which indicates that bulk traps increase in the films. Figure5 shows the stress time dependence of ΔDit and ΔVth for each sample under NBT-stress. Stress conditions were Vg=-2.5V, Temp.=125°C. Stress time dependence of ΔVth for the sample with bulk traps is similar to that for sample with initial jump (see Fig.3). The small time dependence of ΔVth was observed for the sample with large Qinj, in short time region. The solid lines are the fit using $\Delta Vth = \boldsymbol{A}\cdot t^{\boldsymbol{B}} + \Delta Vth_{ini}$, where ΔVth_{ini} was experimental data of the initial jump of ΔVth. ΔDit of each sample shows almost same stress-time dependence, as shown in Fig.5(B) . The solid line is the fit using $\Delta Dit = \boldsymbol{A}\cdot t^{\boldsymbol{B}}$; ***B*** ~0.25. Figure 6 shows the fitting parameter ***A***, ***B*** of ΔVth for each sample in Fig.5(A). ***A*** , ***B*** are independent of samples ; ***A***~1×10^{-2}, ***B***~0.24. Here, ***B*** for ΔVth without the influence of initial bulk traps is almost the same as ***B*** for ΔDit. Figure 7 shows the stress time dependence of ΔVth for each sample after filling in initial traps. In order to fill in initial traps, Vg=-2.5V were applied at very short time before NBTI measurement. Using this measurement, ΔVth of all samples shows unique curve. These results indicate that the stress time dependence of ΔVth except the influence of initial bulk traps is similar to that of ΔDit. Figure 8 (A) shows the temperature dependence of ΔVth and ΔDit of SiO_2[4]. The activation energies of both ΔVth and ΔDit are about ~0.2eV. According to this result, the origins of ΔDit and ΔVth are considered to be the same[4]. Figure 8 (B) shows the temperature dependence of ΔVth and ΔDit of HfSiON. NBT-Stress was applied at Vg = -2.5V and Temp.= 25~175°C for 5120sec. The activation energies of ΔVth and ΔDit are estimated as about 0.07eV and 0.1eV respectively. These ΔVth characteristics included the influence of initial bulk traps. However, the activation energy of ΔVth without the influence of initial bulk trap is estimated as about 0.09eV and is almost the same value as that of ΔDit. From these results, it was found that the ΔVth was mainly caused by ΔDit, except the influence of initial bulk traps, in HfSiON. The differences in NBT-degradation behavior of HfSiON from SiO_2 were caused by the influence of initial bulk traps.

Conclusion

The influence of initial bulk traps on Vth shift under NBT-stress has been investigated. The existence of large amounts of initial traps strongly influence on the time dependence and temperature dependence of ΔVth. Especially in HfSiON, the strong influence of bulk traps was included in NBT-degradation characteristics. We need to estimate the NBTI-lifetime with consideration of the effect of initial bulk traps, especially in short time measurement.

Reference

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[2] S.Fujieda et al. SSDM(2004) p.72
[3] K. O. Jeppson et al. J.Appl.Phys,48,(5).p2004,(1977)
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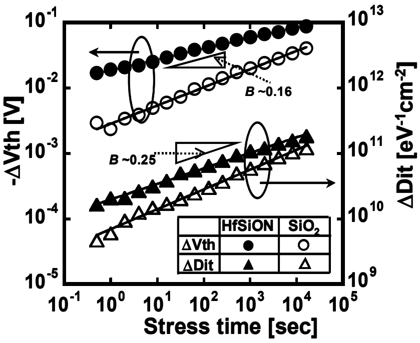

Fig.1 Stress time dependence of ΔVth and ΔDit of HfSiON and SiO_2 under NBT-stress. NBT-stress was performed at 125°C under Eox=7MV/cm. The time dependence factor ***B*** for ΔVth is smaller than that for ΔDit in HfSiON.

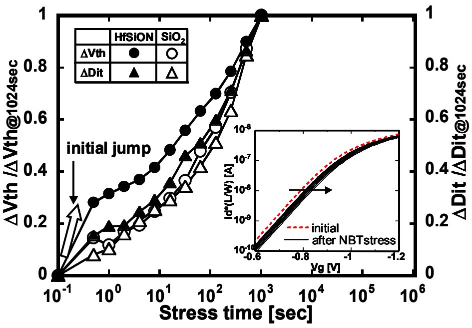

Fig.2 Stress time dependence of normalized ΔVth and ΔDit of HfSiON and SiO_2. The Vth of HfSiON jumped up at initial NBT-stress. The inset shows the initial and stressed Id-Vg curve. The large Vth shift was observed at initial NBT-stress.

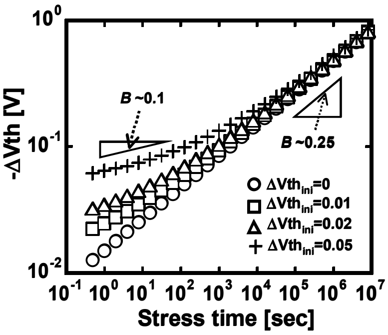

Fig.3 Stress time dependence of ΔVth of the sample with initial jump of Vth(ΔVth_{ini}). Small time dependences were observed for the sample with large ΔVth_{ini} at short stress time.

Table.1 Stress conditions, SILC, CV hysteresis and Dit of each sample.

Sample	Stress voltage[V]	Qinj[C/cm^2]	SILC ($\Delta J/J_0$ @ Vg-Vth=-0.5 V)	Vhys[V]	Dit [eV^{-1}cm^{-2}]
(a)	0	0	0	0.019	6.2×10^{11}
(b)	2.0	109.3	0.53	0.038	6.4×10^{11}
(c)	2.3	386.2	2.14	0.042	5.9×10^{11}
(d)	2.5	628.4	10.04	0.061	5.8×10^{11}

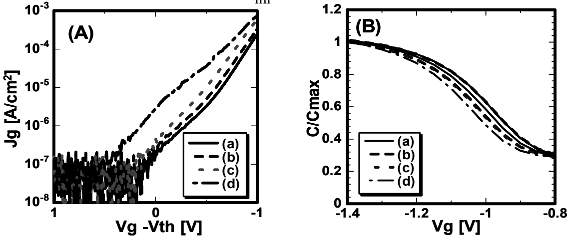

Fig.4 (A)Jg-Vg characteristics and (B) CV characteristics of each sample. SILC were observed for samples (b) ~ (d) and CV hysteresis were observed for all samples. Though Dit is independent of positive stress, both SILC and CV hysteresis increase with increasing Qinj, which indicates that bulk traps increase in the films.

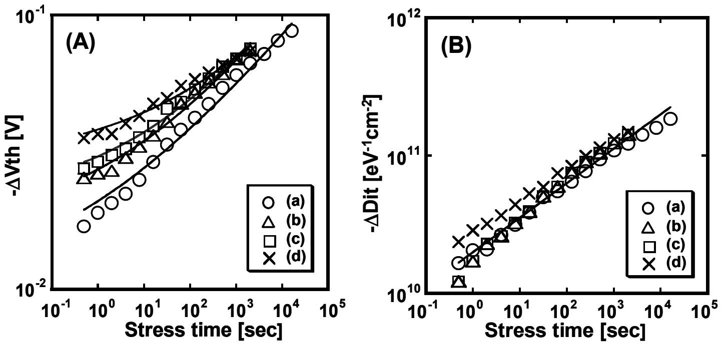

Fig.5 Stress time dependences of (A) ΔVth and (B) ΔDit for each sample under NBT-stress. (A) Stress time dependence of ΔVth of sample with bulk traps is similar to that of sample with initial jump (see Fig.3). The small time dependence of ΔVth was observed for the sample with large Qinj, in the short stress time region. The solid lines are the fit using $\Delta Vth = \boldsymbol{A} \cdot t^{\boldsymbol{B}} + \Delta Vth_{ini}$, where ΔVth_{ini} was experimental data of the initial jump of ΔVth.. (B) ΔDit of each sample shows almost the same stress-time dependence. The solid line is the fit using $\Delta Dit = \boldsymbol{A} \cdot t^{\boldsymbol{B}}$. Stress time factor ***B*** is about 0.25.

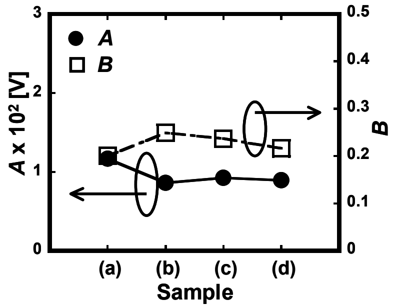

Fig.6 The fitting parameter ***A***, ***B*** of ΔVth for each sample in fig.5(B), A,B are almost same values; ***A***~1×10^{-2}, ***B***~0.24. The stress time factor ***B*** for ΔVth except the influence of initial bulk trap almost the same as the ***B*** for ΔDit (~0.25(see Fig.5(A)).

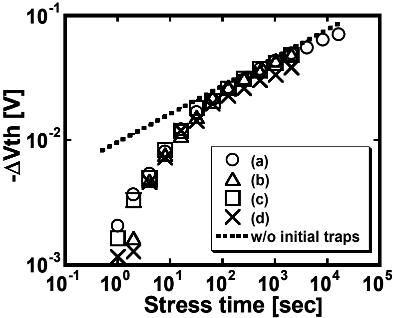

Fig.7 Stress time dependence of ΔVth for each sample. ΔVth were measured after filling in initial traps. The dotted line shows $\Delta Vth = 1\times10^{-2} \cdot t^{0.24}$ without ΔVth_{ini}, which are obtained from Fig.6. Except the influence of bulk traps, the stress time dependence of ΔVth show unique curve. The deviation from the dotted line at short stress time may be due to additional stress in trap filling process.

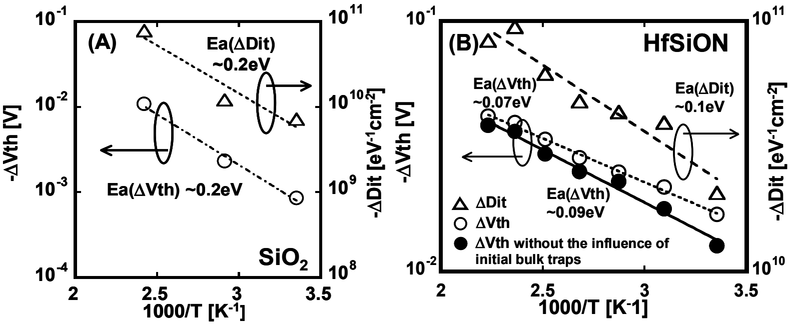

Fig.8 (A) Temperature dependence of ΔVth and ΔDit of SiO_2[4]. The activation energies of both ΔVth and ΔDit are about 0.2eV. (B) Temperature dependence of ΔVth and ΔDit of HfSiON. NBT-Stress was applied under Vg=-2.5V for 5120sec. The activation energies of ΔVth and ΔDit are estimated as about 0.07eV and 0.1eV respectively. Closed symbol shows the ΔVth without the influence of initial bulk traps, whose activation energy is estimated as about 0.09eV and is almost the same value as that of ΔDit.