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The Polarity Dependence of Soft-Breakdown Characterization for Ultra-Thin Gate Oxides Affected by Nitrogen and Fluorine

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1. Introduction

Nitrogen and fluorine effects on the soft-breakdown characterization of ultra-thin gate dielectrics below 4nm are investigated including that the time–to–soft-breakdown was improved and the polarity dependence of gate leakage current was very deferent. Nitrogen and fluorine incorporated near the SiO_2/Si interface is confirmed to affect the charge to soft-breakdown strongly and its polarity dependence of gate tunneling current.

2. Experimental

MOS capacitors with native-oxide-free ultra-thin gate oxide (T_{ox}=3.8nm) were fabricated by an advance clustered vertical furnace (ASM - A400/3). After the SC-1 cleaning, native oxides were stripped by a diluted HF-dip (HFD) or HF-vapor (HFV). Then gate oxides were grown by a conventional O_2 or N_2O oxidation at 800°C. Samples with fluorine implanted (1×10^{13} ~1×10^{15} /cm^2) into the silicon substrate were prepared also. All samples were summarized in table I.

Table I Samples prepared for this work.

Wafer No. / Process	HFD-O_2	HFV-O_2	HFV-N_2O
HF vapor cleaning		✓	✓
HF dip	✓		
Oxidation	O_2	O_2	N_2O

3. Results and Discussions

The characterization of soft-breakdown was investigated by the constant F-N current stressing. The difference between analog and digital soft-breakdown of HFD and HFV O_2 gate oxides are evaluated by the current-voltage (I-V) characteristics. Fig. 1 shows the gate voltage shift as a function of stress time under a negative constant current -5mA/cm^2 stressing. It shows that the time-to-soft-breakdown was increased from 6 seconds to 82 seconds, for the samples with HFV. The time to analog (T_{asbd}) and digital (T_{dsbd}) soft-breakdown of HFV-O_2 are higher than those of HFD-O_2 as shown in Fig. 2. It's believed to that HFV-O_2 has more fluorine incorporation at the SiO_2/Si-substrate interface. Analog modes were dominated the soft-breakdown for higher stress current levels for both samples.

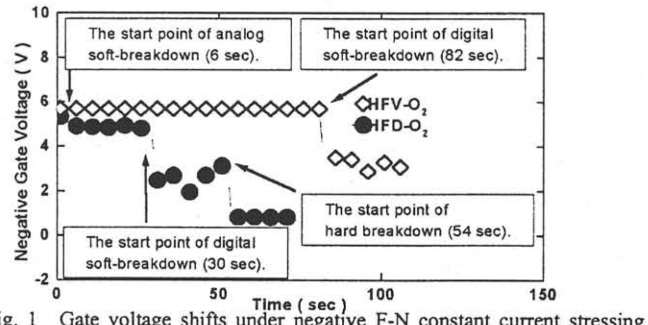

Fig. 1 Gate voltage shifts under negative F-N constant current stressing (-5mA/cm^2) for HFD-O_2 and HFV-O_2, respectively.

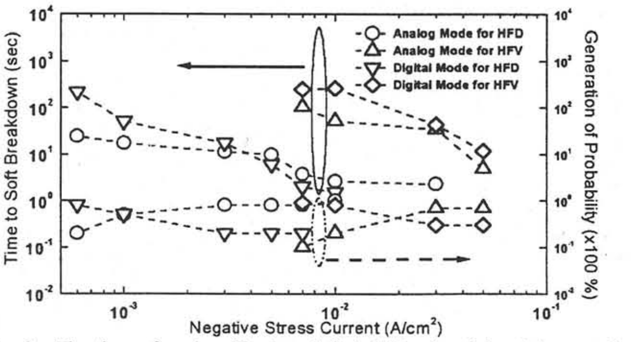

Fig. 2 The time of analog (T_{asbd}) and digital (T_{dsbd}) soft-breakdown and generation probability for HFD-O_2 and HFV-O_2 samples.

However, the improvement by fluorine incorporation was saturated, as the fluorine dosage was higher than 1×10^{13}/cm^2 as shown in Fig. 3.

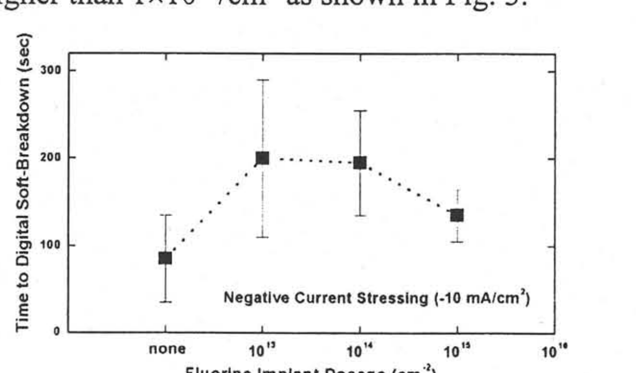

Fig. 3 The fluorine implant dosage versus the time-to-digital soft-breakdown.

Nitrogen effects were investigated. Comparing to the O_2 gate oxide, the T_{asbd} was much improved for the N_2O gate oxide, increasing from 291 seconds to 451 seconds. The polarity dependence of I-V characteristics was shown in Fig. 4, 5 and 6 for HFD-O_2, HFV-O_2 and HFV-N_2O, respectively.

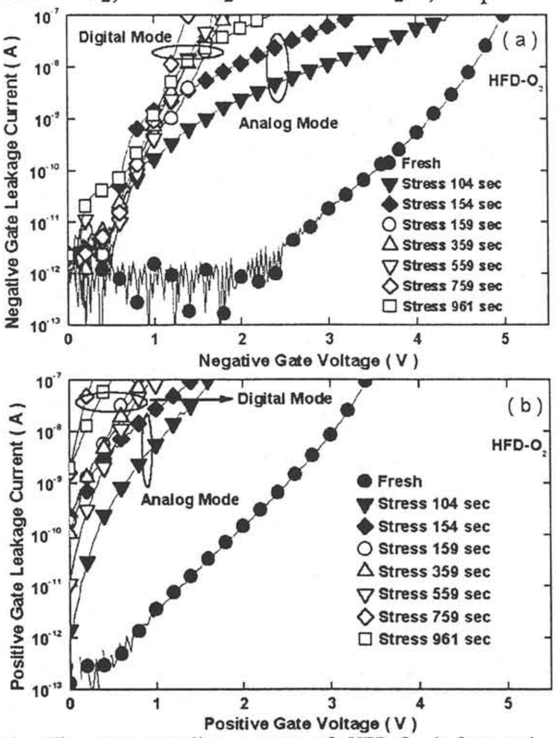

Fig. 4 The gate tunneling current of HFD-O_2 before and after soft-breakdown for (a) negative and (b) positive gate polarity. The shifts of tunneling current for negative polarity after digital soft-breakdown is less than that of positive polarity. Solid markers show the analog mode and open markers show the digital soft-breakdown

It should be noted that post-soft-breakdown I-V distributions under negative polarity are tighter than positive polarity. Solid and open markers show the analog and digital soft breakdown, respectively. The polarity dependence is strongly dependent on the STL near the SiO_2/Si interface [1]. The polarity dependence of gate leakage current is more obvious for HFD-O_2 due to that the trap-density is higher. The gate tunneling current, post digital soft-breakdown, is much higher for positive polarity. It was due to the trap-location is near SiO_2/Si interface. For the HFV-N2O, the polarity dependent characterization was eased due to the incorporation of nitrogen at the SiO_2/Si interface and resulted in the lower trap creation and trap location apart from the SiO_2/Si interface [3]. For all samples in this work, for the digital mode, the polarity dependence of the HFV-N_2O sample is the least.

4. Conclusions

Nitrogen and fluorine incorporated near the SiO_2/Si interface improves the charge to soft-breakdown, lower the post-analog-soft-breakdown tunneling current with negative polarity, and lower the post-digital-soft-breakdown tunneling current with positive polarity.

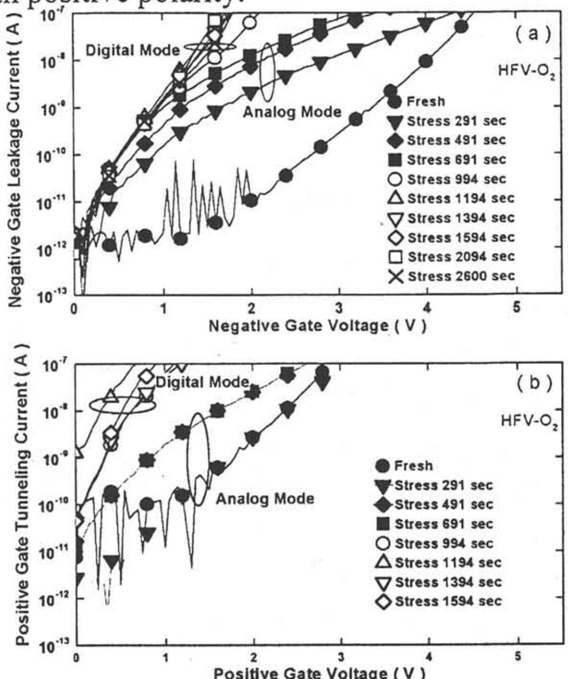

Fig. 5 The gate tunneling current of HFV-O_2, before and after soft-breakdown for (a) negative and (b) positive gate polarity. For negative polarity, the shift of gate tunneling current after digital mode is negligible.

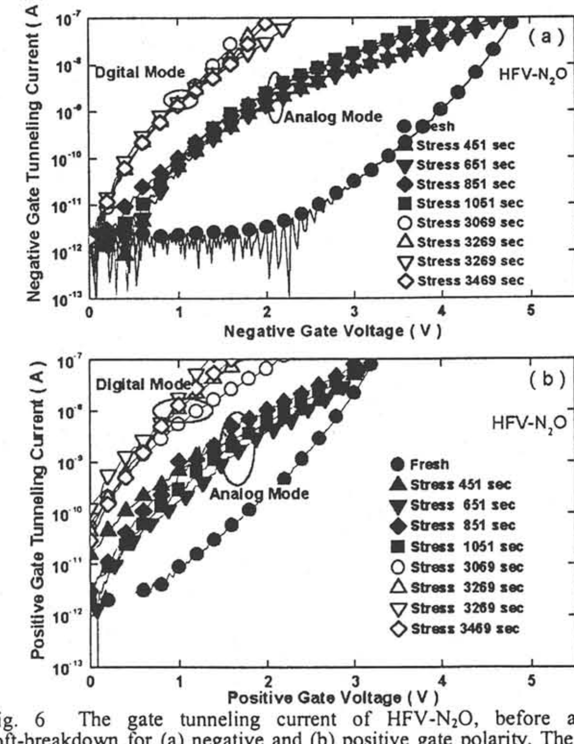

Fig. 6 The gate tunneling current of HFV-N_2O, before and after soft-breakdown for (a) negative and (b) positive gate polarity. The shifts of tunneling current for negative polarity after digital soft-breakdown is less than that of positive polarity.

5. References:

1. K. Eriguchi et al., in *IEDM Tech Dig.* , 1998.
2. T. Sakura et al , in *IEDM Tech Dig.*, 1998.
3. C. S. Lai et al., IEEE T-ED, 1996.