Study of Negative V\textsubscript{th} Shift in PBTI and Positive Shift in NBTI for Yttrium Doped HfO\textsubscript{2} Gate Dielectrics

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1. Introduction
Bias temperature instability (BTI) is one of the most serious issues for high-k gate dielectrics [1]. And rare earth doping technology into Hf-based oxide is attractive for V\textsubscript{th} reduction in nMOSFETs [2]. There are several reports regarding the effect of such rare earth material doping on BTI [3-5]. These include reports that unusual V\textsubscript{th} shift in PBTI has been observed in La or Dy doped high-k gate dielectrics [4-5]. Specifically, that is, negative shift occurred at lower fields, although positive shift was observed at higher fields. Although Yttrium is also effective for V\textsubscript{th} reduction in nMOS [6], its impact on reliability has not been reported yet. This paper reports on the investigation of the PBTI and NBTI in Y doped high-k gate dielectrics, and observes that the opposite direction shift can be observed, not only in PBTI but also in NBTI, and that this unusual shift can be suppressed by nitrogen incorporation into the gate dielectrics.

2. Experimental
Fig.1 shows the sample fabrication flow in this study. Y\textsubscript{2}O\textsubscript{3} was deposited with an ALD technique on HfO\textsubscript{2}/SiO\textsubscript{2} or HfON/SiON. The number of deposition cycle of ALD varied from 2 to 10 cycles. (1.5E14 Y-atoms/cm\textsuperscript{2} for each cycle) A post deposition anneal was carried out to diffuse Y into the gate dielectrics. PBTI and NBTI were measured at temperature from 25 to 125\degree C.

3. Results and Discussion

\textbf{PBTI}

Fig. 2 shows the time evolution in PBTI of V\textsubscript{th} shift of Y doped HfO\textsubscript{2}. At low bias (1.4~1.6V) negative V\textsubscript{th} shift occurred. On the other hand, at higher bias, positive shift due to the electron traps in bulk high-k was observed [1]. This negative shift was not observed for non Y doped HfO\textsubscript{2} gate dielectrics as shown in Fig. 3. We have studied the unusual V\textsubscript{th} shift in PBTI and NBTI for Yttrium doped HfO\textsubscript{2} gate dielectrics. Both stress conditions introduce positive shift for Y doped HfO\textsubscript{2} in the lower stress region. This positive shift can be suppressed with nitrogen incorporation in contrast to nMOS. Fig. 12 shows the gate leakage current with carrier separation, with and without Y incorporation. This indicates that Y incorporation changes the J\textsubscript{g} component. Although dominant factor in J\textsubscript{g} for non Y doped HfO\textsubscript{2} is holes, dominant component in Y doped HfO\textsubscript{2} changes to electrons. Considering the high electron component in J\textsubscript{g} with the effect of Y doping, we speculate that this positive shift is due to the electron traps by the Y related defects (Fig.13) and the reason for electron current increase is thought to be due to the trap assisted tunneling through this Y related defect. This positive shift can be suppressed with N incorporation, as with PBTI, as shown in Fig.14.

4. Summary
We have studied the unusual V\textsubscript{th} shift in PBTI and NBTI for Y doped HfO\textsubscript{2} gate dielectrics. Both stress conditions introduce the opposite shift for Y doped HfO\textsubscript{2} in the lower stress region. This is due to the Y related defects, with electron de-traps in PBTI and electron traps in NBTI. Such defect formation can be suppressed with N incorporation into HfO\textsubscript{2}.

5. References
PBTI compared to electron traps. At low field, electron de-trap is dominant in doped HfO₂. At low field, electron trap is observed for Y doped HfO₂. While, hole is dominant for non Y doped HfO₂. When Y was doped, dominant carrier component in J_g was electrons. While, hole is dominant for non Y doped HfO₂.

Fig.1 Sample fabrication flow.

Fig.2 Time evolution of ΔV_th in PBTI under several voltages of Y doped HfO₂, negative V_th shift was observed at lower fields.

Fig.3 Time evolution of ΔV_th in PBTI under several voltages. Negative V_th shift was not observed. Positive shift was accelerated.

Fig.4 Time evolution of ΔV_th in PBTI with several amount of doped Y. With increasing Y incorporation, negative V_th shift was accelerated.

Fig.5 Gate leakage current of (a) Y doped and (b) non doped HfO₂ nMOS measured with carrier separation. Kink in valence electron current was observed for Y doped HfO₂.

Fig.6 Time evolution of G_m enhancement in PBTI under several voltages. At low voltage, G_m enhancement was observed.

Fig.7 Time evolution of ΔV_th in PBTI at several temperatures. With rising temperature, negative V_th shift was accelerated.

Fig.8 Schematic of PBTI of Y doped HfO₂. At low field, electron de-trap is dominant in PBTI compared to electron traps.

Fig.9 Time evolution of ΔV_th in PBTI under several voltages for Y doped HfO₂. Negative V_th shift was not observed.

Fig.10 Time evolution of ΔV_th in NBTI under several voltages for Y doped HfO₂. Positive V_th shift was observed at lower bias(-1.2--1.4V).

Fig.11 Time evolution of ΔV_th in NBTI under several voltages of HfO₂. Positive V_th shift was not observed.

Fig.12 Gate leakage current of pMOS measured with carrier separation. (a) Y doped HfO₂, (b) Y non doped HfO₂. Y related defect suppresses electron tunneling at low field. Electron trap assisted tunneling is dominant compared to hole trapping at low field.

Fig.13 Schematic of NBTI of Y doped HfO₂. At low field, electron trap is dominant compared to hole trapping.

Fig.14 Time evolution of ΔV_th in NBTI under several voltages of Y doped HfO₂. Positive V_th shift was suppressed.