Experimental Clarification of Hydrogen-related Mechanism in NBT Degradation

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1. Introduction

Negative bias temperature instability (NBTI) has become increasingly serious in the context of efforts to realize highly reliable integrated CMOS devices, because of the severe degradation of threshold voltage shift and interface-state generation [1]. The threshold voltage shift is generally attributed to the creation of interface traps and positive fixed charges consequent on the dissociation of Si-H bonds at Si/SiO2 interface by holes, and subsequent diffusion of the released hydrogen-related species towards the gate electrode [2-7]. According to this reaction-diffusion (R-D) model [6, 7], threshold voltage shifts are dominated only by the quantity of the released hydrogen atoms from Si/SiO2 interface. However, the experimental evidence concerning the validity of this R-D model has not been sufficiently obtained yet.

In this work, in order to clarify the correlation between NBTI and hydrogen which is released from SiON/Si interface, the effect of H2 ambient annealing on NBT degradation and the recovery was investigated.

2. Recovery of NBTI by H2 Annealing

Fig. 1 shows the recoveries of the threshold voltage shift ($\Delta V_{TH}$) and the increment of charge-pumping current ($\Delta I_{CP}$) for several annealing condition after NBT stress during 640 sec. Recoveries of $\Delta V_{TH}$ and $\Delta I_{CP}$ are observed under the condition without any annealing (A in Fig. 1). The recoveries are enhanced with using N2 ambient annealing (B in Fig. 1). Surprisingly the degradations are completely recovered with the H2 ambient annealing (C in Fig. 1).

The recovery with H2 ambient annealing is available for the periodical NBT stress as shown. Figure 3 shows the reciprocal characteristics of degradation and recovery of $\Delta V_{TH}$ and $\Delta I_{CP}$. Namely, the NBT measurement and H2 annealing were repeated alternately as shown in Fig. 2. Note that $\Delta V_{TH}$ and $\Delta I_{CP}$ values of H$_2$-annealed devices completely coincide with those in the case of the first NBT stress, irrespective the number of both the stress time and the H$_2$ annealing time. That is, NBTI leaves no trace in gate oxides and these interfaces after H2 annealing. This result indicates that the defects generated by applying NBT stress can be completely recovered by hydrogen incorporation.

3. Correlation between $\Delta V_{TH}$ and $\Delta I_{CP}$

Next, we have verified whether the NBT degradation is dominated only by the hydrogen release from the Si/SiO2 interface. It was reported that the forming gas annealing condition has an effect on NBTI [8]. Therefore, in order to verify the NBT degradation model concerning hydrogen, the devices which were annealed respectively in the different condition have been utilized.

Fig. 4 shows the average $\Delta I_{CP}$ after NBT stress as a function of the initial (prestressed) $I_{CP}$ values. It should be noted that $\Delta I_{CP}$ is independent of the initial $I_{CP}$, i.e. the annealing condition. On the other hand, $\Delta V_{TH}$ does not coincide among three kinds of the devices in spite of the same $\Delta I_{CP}$ as shown in Fig.

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5. It was found that $\Delta V_{TH}$ values of the devices which were annealed at 450 °C is larger than that in the case of hydrogen annealing at 400 °C. In addition, Fig. 6 shows the correlation between $\Delta I_{CP}$ and $\Delta V_{TH}$ of these devices. It has been reported that $\Delta V_{TH}$ strongly depends on the interface-state generation under NBT stress [9, 10]. From the result in Fig. 6, it was found that higher temperature annealing enhances the $V_{TH}$ degradation, even if the same quantity of the interface-states was generated as shown in Fig. 4. These experimental results as shown in Figs. 4-5 indicate that $\Delta V_{TH}$ under NBT stress depends on not only the quantity of released hydrogen from Si/SiO$_2$ interface, i.e. the R-D model. The additional mechanism for the $V_{TH}$ enhancement has not been clarified yet. However, from the experimental results in this work, it can be concluded at least that the traps (or the defects) which enhance $\Delta V_{TH}$ are unrelated to the released hydrogen from Si/SiO$_2$ interface, but these can be completely vanished by hydrogen incorporation. Furthermore, it is inferred that this additional NBT degradation depends on the temperature of the forming gas annealing.

4. Conclusion

In this work, the correlation between hydrogen and NBT degradation have been investigated. As a result, it was found that $\Delta V_{TH}$ and $\Delta I_{CP}$ after NBT stress are completely recovered by H$_2$ annealing and no trace is left. On the other hand, $\Delta V_{TH}$ depends on the annealing condition, in spite of the same quantity of generated interface-states. From these experiments, it can be concluded that the defects generated by applying NBT stress is completely repaired by hydrogen incorporation, but the additional mechanism of $V_{TH}$ shift which is unrelated to the released hydrogen from the gate oxide interface is also involved with NBTI.

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References