DC AND AC NBTI STRESSES IN PMOSFETS WITH PE-SIN CAPPING

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INTRODUCTION

PMOS negative bias temperature instability (NBTI) is known to be a critical reliability concern and represents one of the major bottlenecks for product lifetime [1-2]. It had also been shown that the device lifetime under dynamic stress could be much longer than that under static stress [3]. Recently, using process technique to induce uniaxial strain in the channel [4-7] has received a lot of attention. However, the NBTI issue of these strained devices has not been carefully addressed. In this work, we investigate the static and dynamic NBTI of pMOSFETs with compressively strained channel.

DEVICE FABRICATION

PMOSFETs used in this study have an oxide thickness of 3nm, with 150nm-thick poly-SiGe layer as the gate material. Both 100nm-thick SiN capping and TEOS passivation layers were deposited by PECVD. The SiN capping had been shown previously to introduce significant compressive strain to the channel of pMOSFETs [8].

RESULTS AND DISCUSSION

The stress from PE-SiN layer was first examined by probing monitor samples deposited on blanket Si wafers. It was confirmed that the stress is compressive in nature, and its magnitude increases monotonically with thickness. The stress is around –95 MPa for 100nm-thick SiN. Figure 1 shows the percentage increase in the drive current of the SiN-capped devices compared to the controls as a function of channel length. It can be seen that enhancement in drive current is observed with the incorporation of SiN capping layer. These observations are consistent with the film stress measurements as well as previous literature reports on compressive SiN capping [4-5].

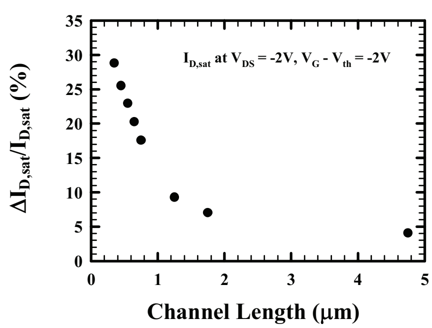

Fig. 1 Drain current increase (@V_G-V_{th} =-2V & V_D = -2V) for PMOSFETs with and without PE-SiN layer.

Figure 2 shows the results of NBTI stress performed at three different gate biases. It can be seen that the threshold voltage shift, ΔV_{th}, is larger for the devices with SiN capping. The shift curves depict a fractional power-law dependence on time ($\Delta V_{th} \propto t^n$). The values of the exponent are roughly 0.2 and 0.3 for samples without and with SiN-capping layer, respectively. Increase in interface state density, ΔN_{it}, is mainly responsible for the observed phenomena, as indicated in the figures. It is noted that both ΔV_{th} and ΔN_{it} approach saturation for devices with SiN capping when NBTI stress time exceeds 1000 sec. This is because nearly all the interfacial Si-H bonds were already broken by then [8]. From our previous study [8], the maximum transconductance also degrades significantly for devices with SiN layer. The above results clearly indicate that the use of PECVD SiN capping may aggravate NBTI, which is related to the higher density of Si-H bonds at the oxide/Si interface. The abundance of hydrogen species originated from the SiN layer where SiH_4 and NH_3 were used as precursors. Higher strain energy stored in the channel may also play a crucial role in the aggravated degradation process: the energy may help trigger the electrochemical reactions at the interface. This is consistent with the higher exponent value of the power-time dependence for devices with SiN capping.

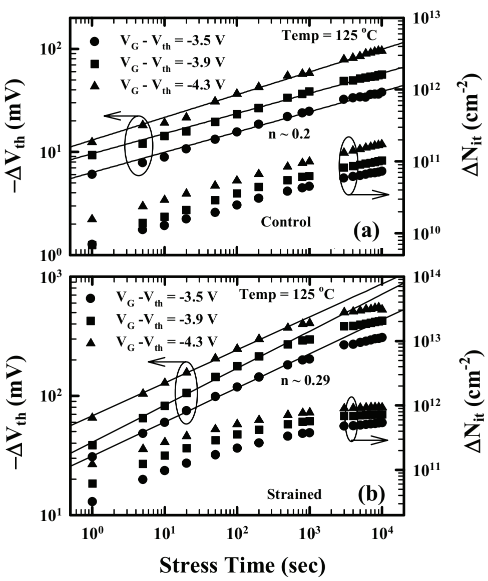

Fig. 2 ΔV_{th} and ΔN_{it} versus stress time at three different gate biases with L/W = 0.55μm/10μm.: (a) control devices, and (b) strained devices.

Figure 3 shows results of dynamic NBTI stress performed on both control and strained devices under two passivation voltage (V_P) conditions. ΔV_{th} and ΔN_{it} are found to be larger in the strained devices, similar to the trend observed in static stress case. Due to the saturation effect of ΔN_{it} in strained devices, ΔN_{it} reaches its peak when the stress time exceeds 2000s, as shown in Fig. 3(b). Similar trend, however, is not observed for the peak values of ΔV_{th}, indicating the existence of another major contributor for the NBTI degradation. Some of the results are normalized and shown in Fig. 4. Threshold voltage is largely recovered for the strained devices, as shown in Fig. 4(a). The dependence of recovery in ΔV_{th} on V_P indicates the contribution by some charged species. Since the dependence of ΔN_{it} on V_P is negligible (Fig. 4(b)), neutralization of trapped holes in the oxide [9] is suspected as the main culprit for the excessive recovery in V_{th} as V_P is increased from 0 to 1 V, as shown in Fig. 4(a). Although ΔN_{it} in strained devices is independent of V_P, as shown in Fig. 4(b), the recovery in ΔN_{it} still constitutes the major contribution of the recovered V_{th} even at V_P of 1 V. This is essentially consistent with the results of static stress shown in Fig. 2. Since the interface states would be passivated by hydrogen-related species [3], our results suggest that neutral hydrogen play a major role in the NBTI degradation and recovery processes [10].

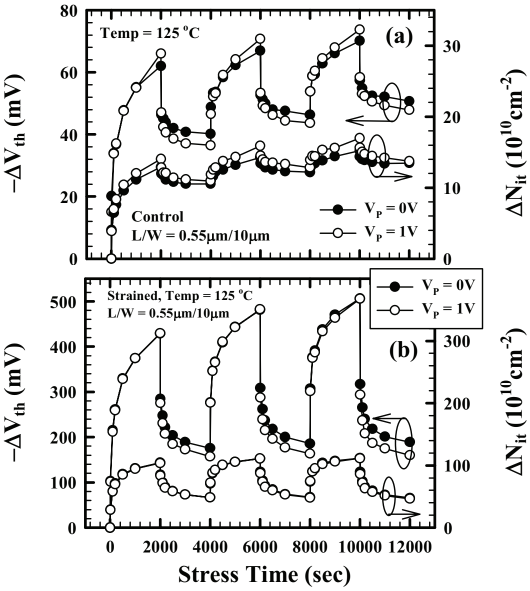

Fig. 3 ΔV_{th} and ΔN_{it} versus stress time for dynamic NBTI with stress voltage of $V_G - V_{th}$ = -4 V at L/W = 0.55μm/10μm. (a) Control devices. (b) Strained devices.

We have also investigated the effect of AC stress with 50% duty cycle on the devices. Figure 5 shows ΔV_{th} and ΔN_{it} in devices that were stressed at four different frequencies, both with and without SiN capping. It is seen that the interface state creation shows only weak frequency dependence in control devices. In reference to the analysis in previous reports [9][11], the observation is reasonable. In contrast, the strained devices depict strong frequency dependence on both ΔV_{th} and ΔN_{it}. The shift in ΔV_{th} and ΔN_{it} after 5000 sec stress are plotted as a function of stress frequency in Fig. 6. It is clear that both ΔV_{th} and ΔN_{it} are strongly dependent on stress frequency in the strained devices. ΔV_{th} decreases from 214 mV to 94.2 mV when the stress frequency increases from 1 kHz to 1 MHz. This observation indicates that excess hydrogen contained in the SiN capping layer initiates interface state generation by hydrogen bond breakage, and the process is very sensitive to the stress time. It also implies that aggravated NBTI degradation in the strained devices can be alleviated by high frequency operation. Our results indicate that significant Gm and on current enhancement relative to the control devices can be retained after the 5000 sec stress at high frequency.

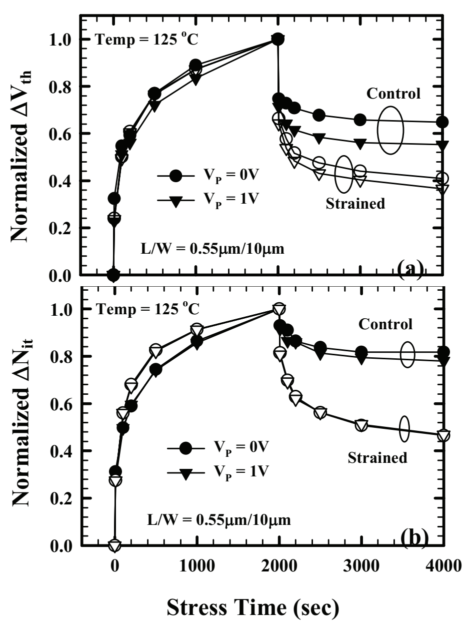

Fig. 4 Normalized ΔV_{th} and ΔN_{it} versus stress time. (a) Recovery behavior of ΔV_{th} in control and strained devices under V_P = 0 and 1 V. (b) Recovery behavior of ΔN_{it} in control and strained devices under V_P = 0 and 1 V.

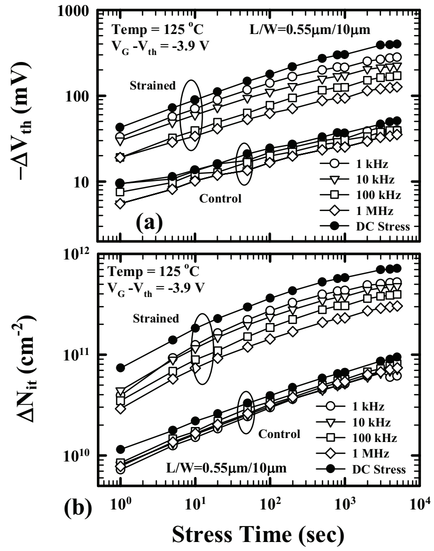

Fig. 5 (a) ΔV_{th} and (b) ΔN_{it} versus stress time for control and strained samples under AC stress at four different frequencies.

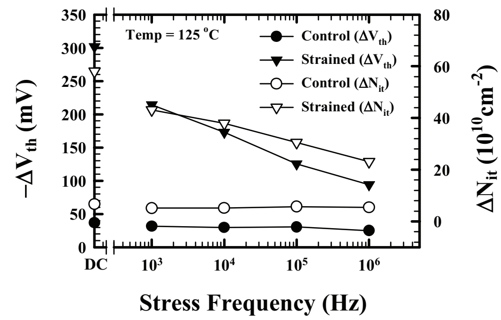

Fig. 6 ΔV_{th} and ΔN_{it} versus stress frequency after 5000 sec stress time.

CONCLUSION

Although the incorporation of a compressive PECVD SiN layer is highly coveted for enhancing the drive current, our results indicate that it may simultaneously aggravate the DC and AC NBTI characteristics of scaled PMOS devices. In other words, it acts like a double-edged sword that cuts both ways. An abundant hydrogen species contained in the PE-SiN layer as well as the strain energy stored in the channel are believed to be the culprits for the worsened reliability. In addition, the neutralization of trapped holes in the oxide is found to contribute to the recovery in V_{th}. Finally, a strong dependence on the frequency of AC stress is observed for the SiN-capped devices, which is ascribed to excess hydrogen species contained in the strained devices. Our observation also suggests that the aggravated NBTI in the strained devices could be alleviated by high frequency operation.

ACKNOWLEDGMENTS

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