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Experimental NBTI Investigation for 14 nm FinFETs Utilizing Sub-1 ns Fast V_{th} Measurement (FVM) Technique

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Abstract

In this study, NBTI behaviors, especially for the recovering phenomena, of 14-nm-node Si pFinFETs have been characterized with the measurement time down to 1 ns utilizing the fast V_{th} measurement (FVM) technique. The stress voltage dependency and the temperature dependency of NBTI behaviors have been systematically evaluated. Within the recovery time of 100 ns down to 1 ns, it is revealed that the charge trapping based on the switching oxide traps could be the dominant mechanism for NBTI.

1. Introduction

The negative bias temperature instability (NBTI) in pMOSFETs has become one of the most critical reliability issues for silicon-based CMOS circuits [1-4]. The key challenge for understanding the NBTI mechanism is that the time gap between the stress and recovery phases of the NBTI characterization process would lead to the underestimation of V_{th} shift [5-6]. According to the present NBTI models, the transient recovery could happen within 1 μs or even faster [1, 7-8]. However, the experimental data of NBTI behaviors with the recovery time less than 1 μs is still missing due to the instrumental limitation on measurement time. Recently, a fast V_{th} measurement (FVM) technique has been demonstrated, which could perform V_{th} measurement within 1 ns [9-10]. In this study, based on the FVM technique, the NBTI behaviors in 14-nm-node Si pFinFETs have been characterized including the stressing and recovering phenomena with the rise time (t_r) of V_{th} measurement down to 1 ns, for the first time. V_{th} shift (ΔV_{th}) caused by rapid recoverable component (within 1 μs) is characterized. In addition, the dependencies of NBTI-induced ΔV_{th} on stress voltage (V_{str}) and the characterization temperature are also evaluated with measurement t_r = 1 ns.

2. Experiment

The Si pFinFETs characterized in this study are fabricated with a 14 nm-node technology. The device under test (DUT) includes 20 fins and the total equivalent width is about 1.8 μm, with the gate length of 72 nm. Commercial fast I-V measurement system which is used for the NBTI characterization is shown in Fig. 1. With the recently proposed FVM technique, V_{th} measurement within 1 ns can be realized [9-10]. The details of the measurement setup and the validity of the system have been discussed in Ref.[9].

3. Results and Discussion

With the FVM technique, the evolution of ΔV_{th} with t_r from 10 μs to 1 ns is characterized (Fig. 2), where ΔV_{th} increases as t_r reduces. The extracted time exponent, n, keeps reducing from around 1/6 (R-D model [11]) to 0.08, which is consistent with the data from the commercially available ultra-fast measurements [12]. For comparison, ΔV_{th} as a function of stress and recovery time with measurement t_r = 1 μs and 1 ns are shown in Fig. 3. The difference between ΔV_{th} with different t_r could be due to the influence of fast recoverable components which would recover within 1 μs. For t_{str} < 10 s, the NBTI behavior would be dominated by the fast recoverable components. Whereas, as compared with ΔV_{th} with t_r = 1 ns, larger ΔV_{th} at recovery phase with t_r = 1 μs is observed, although the recovery time is the same. This could be attributed to the additional stress introduced within the rise edge of the measurement signal. As shown in Fig. 4, t_r of 1 μs would lead to a ΔV_{th} of ~15 mV. In order to evaluate the influence of V_{str} to the NBTI behaviors, ΔV_{th} in stress and recovery phase with different V_{str} was characterized (Fig. 5). Similar stress and recovery behaviors could be observed among different V_{str}. For a clearer understanding of the influence of the rapid recoverable component, the fast recoverable ratios are derived by Eq. (1) and shown in Fig. 6.

$$r(t_{str}) = \frac{\Delta V_{th}(t_r = 1\,\text{ns}, t_{str}) - \Delta V_{th}(t_r = 1\,\mu\text{s}, t_{str})}{\Delta V_{th}(t_r = 1\,\text{ns}, t_{str})} \quad (1)$$

It is found that the fast recoverable ratio *r* decreases as t_{str} or V_{str} increases, indicating the increase of permanent or slow recoverable components [13]. Besides, ΔV_{th} recovery with different t_{str} was characterized (Fig. 7). Similar ΔV_{th} recovery behavior is achieved for different t_{str}. ΔV_{th} at the same t_{str} were plotted as a function of t_r for comparison. It is found that the ΔV_{th} with a rise time t_{r1} are at the similar level with the ΔV_{th} in the recovery phase if $t_{rec} = t_{r1}$. These results suggest that the ΔV_{th} with large t_r in stress phase could be considered the same as the ΔV_{th} recovered for a similar time after V_{str} removal. Furthermore, ΔV_{th} as a function of stress and recovery time at different temperatures were extracted (Fig. 8). The extracted time exponents are slightly reduced as the temperature decreases. Therefore, with the FVM technique, NBTI could be characterized more accurately and closer to its intrinsic behaviors.

3. Conclusions

In this study, NBTI behaviors of 14-nm node Si FinFETs have been investigated with t_r down to 1 ns. ΔV_{th} caused by rapid recoverable component and induced by measurement itself have been clarified experimentally. Furthermore, the correlation between the NBTI characteristics and V_{str} as well as temperature has also been evaluated. FVM method could be utilized to investigate the unclear NBTI behaviors in advanced technology nodes.

Acknowledgements

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References

[1] S.E. Liu, et al., *IRPS*, 4A.4.1 (2014). [2] T. Grasser, et al., *TED*, 3652(2011). [3] B. Kaczer, et al., *IRPS*, 20(2008). [4] C. Shen, et al., *IEDM*, 756(2006). [5]C. Han, et al., *IEDM*, 3.1.1(2014). [6] A. Steegen, *IEDM*, short course (2016).[7] T. Grasser, et al., *IRPS*, 33(2009). [7] T. Grasser, et al., *IRPS*, 33(2009). [8] R. Gao, et al., *IEDM*, 778(2016). [9] X. Yu, et al., *EDL*, 172(2018). [10] Y. Qu, et al., *MR*, 93(2018). [11] E. N. Kumar, er al., *IEDM*, 809(2007). [12] M. –F. Li, et al., *TDMR*, 62(2008). [13] T. Grasser, et al., *IEDM*, 618(2011).

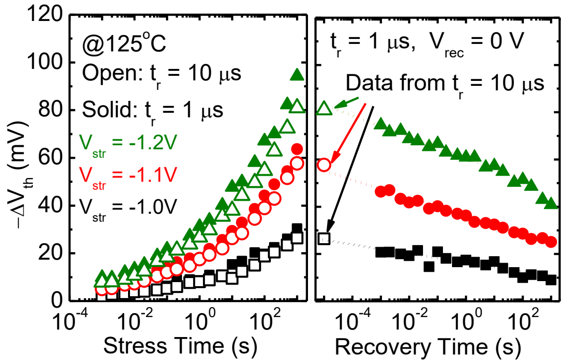

Fig. 1. ΔV_{th} as a function of stress and recovery time at 125 °C with measurement t_r = 1 μs. Difference in ΔV_{th} at different t_r could be attributed to the fast recovery.

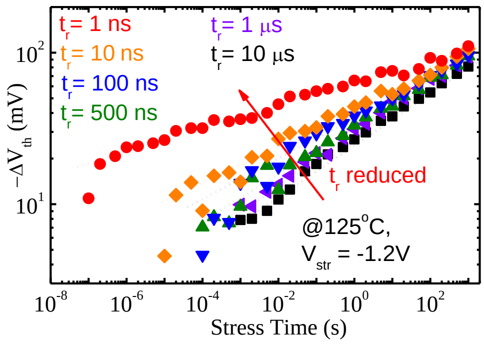

Fig. 2. ΔV_{th} as a function of stress time with measurement t_r ranging from 10 μs to 1 ns.

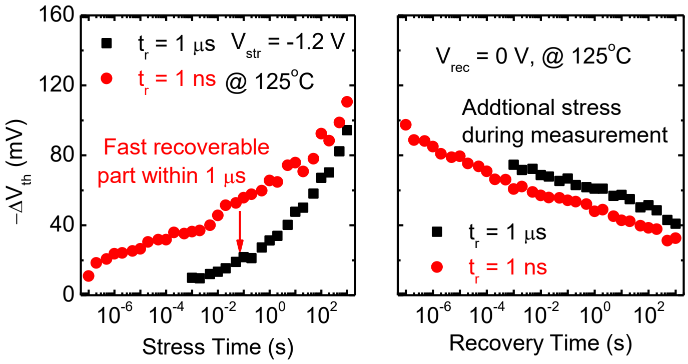

Fig. 3. Comparison of ΔV_{th} as a function of stress and recovery time at 125°C with measurement t_r = 1 μs and 1 ns. Lower ΔV_{th} during recovery could be observed.

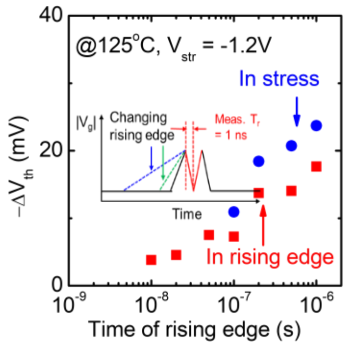

Fig. 4. ΔV_{th} measured for rising edge with different rising time. ΔV_{th} with constant stress are also plotted.

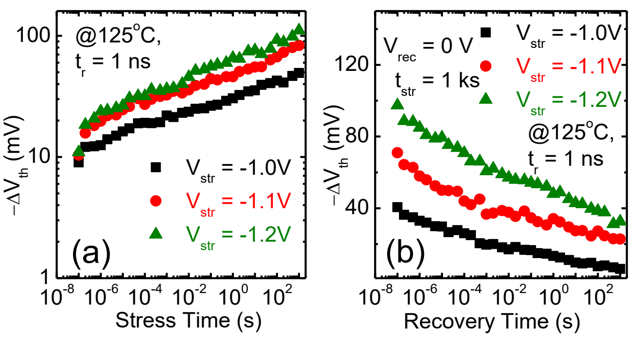

Fig. 5. Comparison of ΔV_{th} as a function of (a) stress and (b) recovery time at 125 °C with t_r = 1 ns and with different V_{str}.

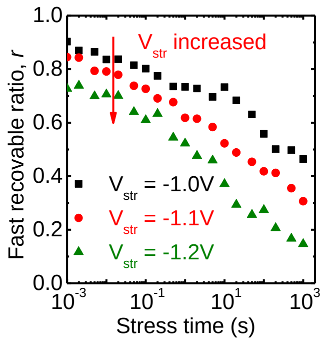

Fig. 6. Fast recoverable trap ratio as a function of stress time in different V_{str} at 125 °C.

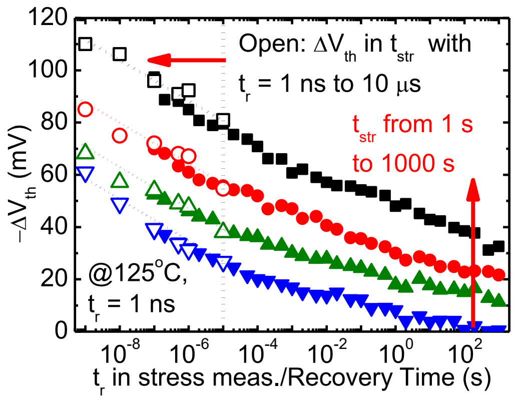

Fig. 7. ΔV_{th} recovery for different stress time at 125 °C with measurement t_r = 1 ns. ΔV_{th} at the same t_{str} with different t_r are also plotted for comparison.

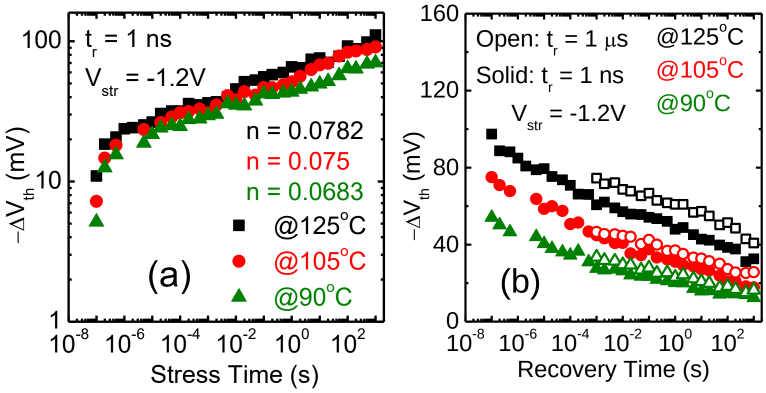

Fig. 8. Comparison of ΔV_{th} as a function of (a) stress and (b) recovery time with t_r = 1 ns at different temperatures. Recovery curves measured with t_r = 1 μs are also shown for comparison.