Abstract #2245, 224th ECS Meeting, © 2013 The Electrochemical Society

Characterization of Oxide Traps Participating in Random Telegraph Noise Using Charging History Effects in Nano-Scaled MOSFETs

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Random telegraph noise (RTN), caused by the capture/emission of electrons from oxide traps is regarded as one of the most serious reliability issues in scaled-down CMOS devices [1-3]. Proper characterization of oxide traps is important to understand the RTN phenomena and to reduce their influence on device reliability. In this paper, we propose a novel method to characterize oxide traps that participate in RTN by using 'charging history effects' in traps. In this method, changes in the frequency of the high/low drain currents in RTN due to the charging history are monitored instead of the time-scale parameters that are usually used, such as the capture/emission time τ_c/τ_e. This method is particularly effective for multi-trap RTN.

The sequence of gate voltages V_G in the novel method is shown in Fig. 1. After accumulation at V_a for a period t_a, V_i is applied to the gate for a period t_i, representing an RTN period that will be evaluated in the following V_m period. The history of the electrical conditions of the oxide traps at the end of period V_i is evaluated from the drain current histogram at the beginning of period V_m, as shown in Fig. 2. These histograms are quite different from those obtained from RTN waveforms that are ordinarily measured at V_G=1.0 V (which corresponds to V_m in Fig. 2).

The ratio of higher/lower current frequencies $N_{H\text{-}ID}/N_{L\text{-}ID}$ obtained from Fig. 2 is shown in Fig. 3 as a function of V_i, with the dependence of $\langle\tau_c\rangle/\langle\tau_e\rangle$ upon V_G obtained from RTN waveforms measured in the conventional way. They agree quite well, which demonstrates the validity of the new method. Therefore, we can easily estimate the trap position and the energy level using the dependence of $N_{H\text{-}ID}/N_{L\text{-}ID}$ upon V_i instead of the dependence of $\langle\tau_c\rangle/\langle\tau_e\rangle$ upon V_G, and the electron capture and emission processes in the trap can also be evaluated form the dependences of $N_{H\text{-}ID}/N_{L\text{-}ID}$ upon t_i and t_{mp}, respectively. We also confirmed that all of these means are equally applicable to 2-trap (4-level) RTN.

Moreover, we investigated the applicability of the novel method to multi-level RTN, as shown in Fig. 4, which is 7-level (3-trap) RTN and which is quite difficult to characterize using the conventional method. For this purpose we established a method of judging the number of traps participating in RTN, the charging condition of each trap for each current level, and the transition between the current levels due to the capture or emission of an electron. Using this method, the electron capture rates of the traps under investigation were derived from the relative current frequencies of the charged states in the traps. An example of a drain current histogram at the beginning of period V_m (V_i=1.6 V) is shown in Fig. 5. The relative frequencies N_c/N_{Total} and N_b/N_{Total} denote the electron capture rates of two traps named β and γ, respectively. From the dependences of N_c/N_{Total} and N_b/N_{Total} upon t_i (Fig. 6), a value of τ_c=10 μs is derived for the two traps. Moreover, the trap positions and energy levels for the traps can be estimated from the dependence of N_d/N_c and N_d/N_b upon V_i (Fig. 7).

References

[1] N. Tega, et al., *Symp. VLSI Tech. Dig.*, 2009, p. 50.
[2] H. Miki, et al., *IEDM Tech. Dig.*, 2010, p. 620.
[3] T. Nagumo, et al., *IEDM Tech. Dig.*, 2010, p. 628.

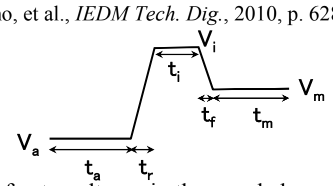

Fig. 1 Sequence of gate voltages in the novel characterization method using trap charging history for oxide traps participating in RTN.

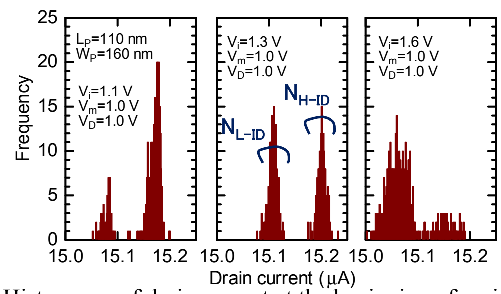

Fig. 2 Histograms of drain current at the beginning of period V_m for three values of V_i (Sample A). V_m=1.0 V, 512 measurements for each V_i.

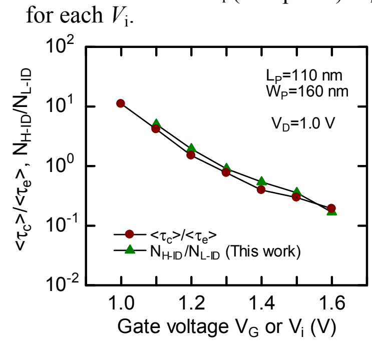

Fig. 3 The dependence of $N_{H\text{-}ID}/N_{L\text{-}ID}$ at the beginning of period V_m upon V_i, and the dependence of $\langle\tau_c\rangle/\langle\tau_e\rangle$ upon V_G obtained from conventional RTN waveforms (Sample A).

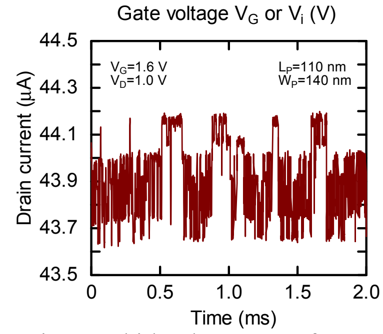

Fig. 4 Multi-level RTN waveform at V_G=1.6 V (Sample B).

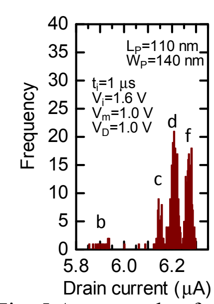

Fig. 5 An example of a drain current histogram at the beginning of period V_m (Sample B).

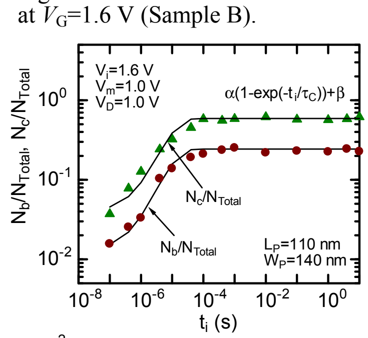

Fig. 6 The dependences of relative frequencies (N_b/N_{Total} and N_c/N_{Total}) upon t_i, representing electron capture process for traps γ and β, respectively (Sample B).

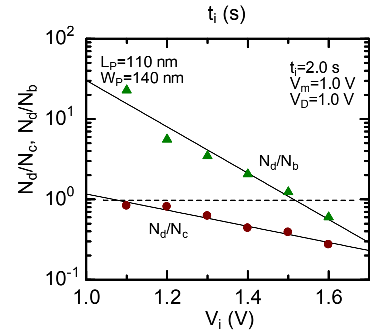

Fig. 7 The dependences of the ratio of the frequencies (N_d/N_c and N_d/N_b) upon V_i, corresponding to the dependence of $\langle\tau_c\rangle/\langle\tau_e\rangle$ upon V_G for traps β and γ, respectively (Sample B).