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 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 \( \tau \). 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 \( t_a \), \( V_g \) is applied to the gate for a period \( t \), 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 \( V_m \) 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 \( N_{\text{Hi}}/N_{\text{Lo}} \) obtained from Fig. 2 is shown in Fig. 3 as a function of \( V_m \) with the dependence of \( \tau_{\text{Hi}}/\tau_{\text{Lo}} \) upon \( V_m \). This 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 \( N_{\text{Hi}}/N_{\text{Lo}} \) upon \( V_m \) instead of the dependence of \( \tau_{\text{Hi}}/\tau_{\text{Lo}} \) upon \( V_m \). The electron capture and emission processes in the trap can also be evaluated from the dependence of \( N_{\text{Hi}}/N_{\text{Lo}} \) upon \( t \) and \( t_{\text{trap}} \) 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 \( V_m \) (\( V_g = 1.6 \) V) is shown in Fig. 5. The relative frequencies \( N_{\text{Hi}}/N_{\text{total}} \) and \( N_{\text{Lo}}/N_{\text{total}} \) denote the electron capture rates of two traps named \( \beta \) and \( \gamma \) respectively. From the dependences of \( N_{\text{Hi}}/N_{\text{total}} \) and \( N_{\text{Lo}}/N_{\text{total}} \) upon \( t \) (Fig. 6), a value of \( \tau = 10 \) ms is derived for the two traps. Moreover, the trap positions and energy levels for the traps can be estimated from the dependence of \( N_{\text{Hi}}/N_{\text{Lo}} \) upon \( V_g \) (Fig. 7).

References