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Investigation on Switching Kinetics of Interface Traps Through MOSFETs with Ultra Narrow Channels

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1. Introduction

Advancement of VLSI technology has resulted in continuous scaling down of MOSFETs. At the same time, it leads new challenges for device reliability. One of the most important reliability problems associated with these small size MOSFETs is the drain current fluctuation caused by interface traps or impurities, characterized with random telegraph signals (RTSs) and low frequency (LF) noise. Generally, there are two types of interface traps: Coulomb-attractive and Coulomb-repulsive centers, having two different mechanisms on the RTS amplitude and transition time constants, and on the dependence of gate bias and temperature. The related theoretical models have been developed[1-4]. However, the dynamic property of these two interface traps is not clear and remains subject of an on-going controversy. Especially, experimental evidences are very rare. In this paper, we report the investigation on the switching kinetics characteristics of interface traps through n-MOSFETs with ultra-narrow channels. It has been demonstrated experimentally that thermally activated process may dominate for Coulomb-repulsive centers and quantum mechanical tunneling is a favored process to Coulomb-attractive centers. The anomalous switching behaviors of RTS having very large amplitude in the MOSFETs with ultra-narrow channels are well understood with the quantum tunneling model.

2. Experimental

The devices used in this work were fabricated on SOI substrates. In order to fabricate ultra narrow channels, the thickness of the top silicon layer was firstly thinned to less than 20nm by thermal oxidation. EB lithography was used to pattern the channels, where the widths were reduced gradually with a step of 25nm from 200 to 60nm. The fabrication processing details have been previously described[5]. The MOSFETs have suitable I_d-V_g curves with reasonable on-currents (~μA), low off-currents (~pA), and subthreshold slope. The experimental setup for measuring RTS's consists of a HP5481 Infinum Oscilloscopes and EG&G PA970 low-noise current preamplifier. A noise spectrum analyzer was used for LF noise measurement. The sampling rate was selected to get 10^2-10^3 transitions experimentally.

3. Results and discussions

Electron/hole is trapped into the localized state by thermal activation over a barrier or quantum mechanical tunneling, which separates the state from the outside. It was suggested that activated trapping and emission may dominate for Coulomb-repulsive traps and tunneling is a favored mechanism for carrier trapping and emission into Coulomb-attractive traps. The detailed information about individual traps and interacting traps could be extracted from the gate-bias and temperature dependence of the trapping kinetics [1-3].

In the present paper, the measurement results are focused on two kinds of RTSs having small and large amplitudes. Fig. 1 shows the gate voltage dependence of capture time and emission time in a MOSFET whose designed channel length and width were 0.1 and 0.5μm, respectively. The inner set is an example of RTSs. It is interesting to note that the relative amplitude ($\Delta I_d/I_d$) of RTS1 is about 1%. The mean capture time decreases exponentially with increasing gate voltage, as expected. The emission time does not change obviously. These data can be explained by Coulombic interactions as charge trapping into individual metastable SiO_2 interface states, *i.e.* by a repulsive trap according to the suggestion proposed by Schulz[3].

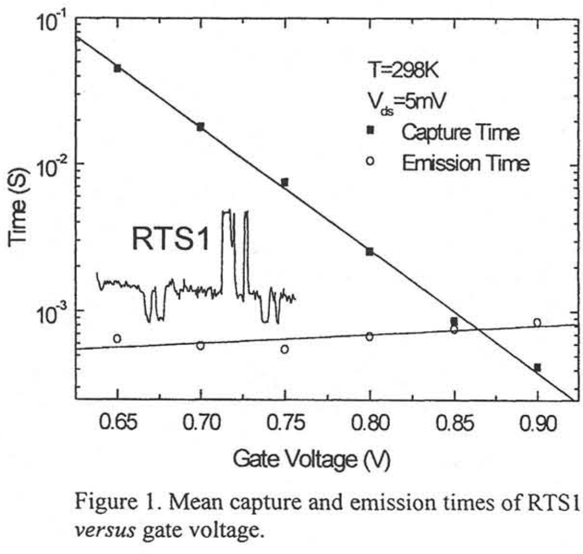

Figure 1. Mean capture and emission times of RTS1 *versus* gate voltage.

Figure 2 gives the gate voltage dependence of the RTS2 in a MOSFET with ultra-narrow channel. One characteristic feature of this RTS is that its relative amplitude reaches 70% at room temperature. The RTS2 with such large amplitude should be ascribed to mobility fluctuation rather than number fluctuation, which is also confirmed by numerical simulation [5]. The trap is found to be a Coulomb-attractive center, given that the time at low current state decreases with the gate voltage increasing.

Figure 2. Relative amplitude ($\Delta I_d/I_d$) of RTS2 *ersus* gate voltages.

The temperature dependence of the RTS1 and RTS2 shown in Figs.3 and 4, respectively. Here γ_c and γ_e are the reciprocals of the mean capture time and emission time, and the total switching rate $\gamma=\gamma_c+\gamma_e$. It can be seen from Fig.3 that both the capture rate and emission rate increase exponentially with the temperature increasing. This behavior is identical to those previous reported [1-3]. On the other side, as shown in Fig.4, it is surprising to note the RTS2 with large amplitude occurred from 100 to 300K. Since the measurement was done in a successive

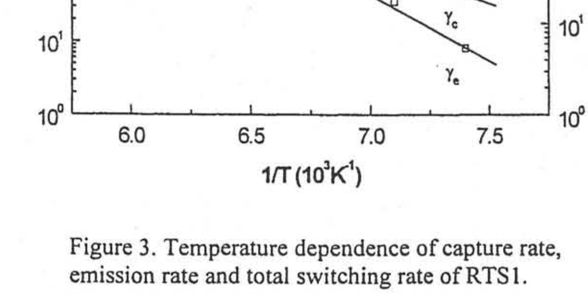

Figure 3. Temperature dependence of capture rate, emission rate and total switching rate of RTS1.

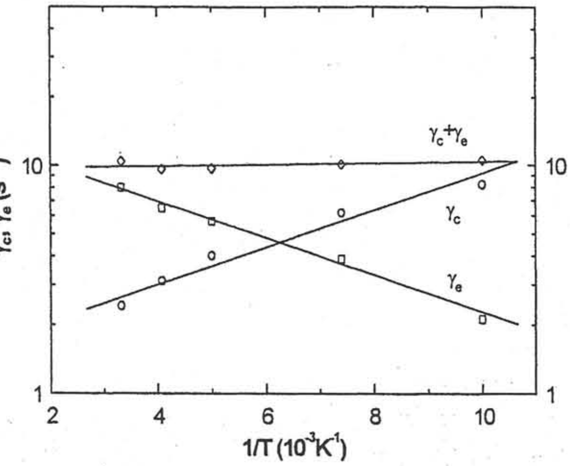

Figure 4. Temperature dependence of capture rate, emission rate and total switching rate of RTS2.

way, the signal couldn't be changed to another RTS source. The capture rate decreases gradually with the temperature increasing, while the reverse is for the emission rate. However, the variations of both the capture rate and emission rate are rather small compared with those of RTS1 shown in Fig.5. In addition, the total switching rate almost remains unchanged with the temperature increasing from 100 to 300K, which is coincident with the prediction of quantum mechanical tunneling model. This is the first clear experimental result for quantum tunneling process.

4. Conclusions

Two types of interface traps, Coulomb-repulsive and -attractive centers, in n-MOSFETs have been investigated experimentally by measuring RTSs and LF noise spectra. It has been demonstrated that the quantum tunneling process for the Coulomb-attractive centers differs from the thermally activated process for Coulomb-repulsive centers. Furthermore, RTSs with very large amplitude have been observed in the MOSFETs with ultra-narrow channels at room temperature, the anomalous switching behaviors can be attributed to quantum tunneling process.

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