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Simultaneous Extraction of Locations and Energies of Two Independent Traps in Gate Oxide From Four-level RTS noise

Seungwon Yang , Hochul Lee , and Hyungcheol Shin

Seoul National Univ. Dept. of EE, #059, San 56-1, Shinlim-dong, Kwanak-gu, Seoul 151-742, Korea
Phone: +82-2-880-7282, Fax: +82-2-882-4658, e-mail: sigma1984@snu.ac.kr

1. Introduction

The low-frequency noise performance of nano-scale gate area MOSFETs is dominated by the effects of carrier trapping and de-trapping into oxide traps [1]-[4]. The simplest RTS observed in MOSFETs is two-level and it corresponds to single carrier trapping and de-trapping by a trap. There are cases, however, where multilevel and complex RTS is observed [3].

In this paper, we characterized four level RTS and extracted the characteristics of two independent traps. Once the position of the trap is found in the oxide (x_T) and along the channel (y_T) with respect to source, we extracted difference between the oxide conduction band energy (E_{Cox}) and trap energy (E_T).

2. Results and Discussion

Fig. 1 shows the typical current fluctuations of a deep submicrometer MOSFET with L = 0.30 um and W = 0.40 um. The gate oxide thickness is 4.8 nm. There are two levels of current which represent existence of single active trap. However, we could observed multilevel RTS in some samples. Fig. 2 shows the four level RTS noise obtained. First the trap depth was extracted by using eq. (1) [5].

$$x_T = \frac{T_{ox}\left(\frac{kT}{q}\frac{d\ln\frac{\tau_c}{\tau_e}}{dV_g} + \frac{d\psi_s}{dV_g}\right)}{\left(\frac{d\psi_p}{dV_g} + \frac{d\psi_s}{dV_g} - 1\right)} \quad (1)$$

Here, T_{ox} is the oxide thickness and k is Boltzmann constant, τ_c and τ_e is capture and emission time, respectively. ψ_s is surface potential and ψ_p is poly depletion voltage drop. Through linear fitting process as shown in Fig. 3 and 4, the slope of time constant with respect to the gate voltage was obtained. Here, slow trap has long time constant, and fast trap has short time constant. The accurate vertical trap depths were obtained by using eq. (1) which are 1.69 nm for slow trap and 0.42 nm for fast trap.

Using information of vertical location of trap, we can extract lateral location of trap with eq. (2), where L_{eff} = 280nm.

$$y_T = \frac{\frac{kT}{q}\frac{T_{ox}}{x_T}\ln\left[\frac{(\tau_c/\tau_e)_f}{(\tau_c/\tau_e)_r}\right] + V_{ds\,r}}{\frac{V_{ds\,r} + V_{ds\,f}}{L_{eff}}} \quad (2)$$

Fig. 5 shows the results which are 157 nm from the source for slow trap and 120 nm for fast trap. Two traps both are located in the middle of channel.

As a final step, we extracted the difference between the oxide conduction band energy (E_{Cox}) and trap energy (E_T) with eq. (3) .

$$\ln\frac{\tau_c}{\tau_e} = -\frac{1}{k_B T}\left[(E_{Cox} - E_T) - (E_C - E_{Fp} + qV_C) - \phi_0 + q\psi_s + q\frac{x_T}{T_{ox}}(V_{gs} - V_{FB} - \psi_p - \psi_s)\right] \quad (3)$$

Here, Φ_0 is the difference between the electron affinities of Si and SiO_2, V_c is the channel potential at the point y in the channel measured from the source ($V_C \approx y_T V_{ds}/ L_{eff}$), V_{FB} is flat band voltage, and Vgs is the gate-source voltage. In the equation above, the Fermi level for electrons is written in terms of Fermi level for holes and the channel potential: E_{Fn} ($=E_{Fp} - qV_c$). Using the known values of x_T and y_T , eq. (3) was evaluated and result is shown in Fig. 6. Slow and fast trap are both located near the Fermi level for electrons, which is consistent with a repulsive type centre in an n-MOSFET.

3. Conclusions

Two independent traps that make four level RTS noise were observed. Their vertical, lateral locations in the oxide were obtained by using accurate equations. Fig. 7 shows trap locations in the oxide. Finally, by using the x_T and y_T of each trap, the trap energy (E_T) was extracted.

Acknowledgements

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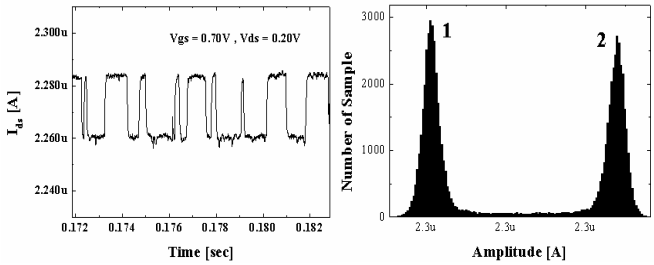

Fig. 1 Drain current two level fluctuations. (V_{gs} = 0.70V, V_{ds} = 0.20V)

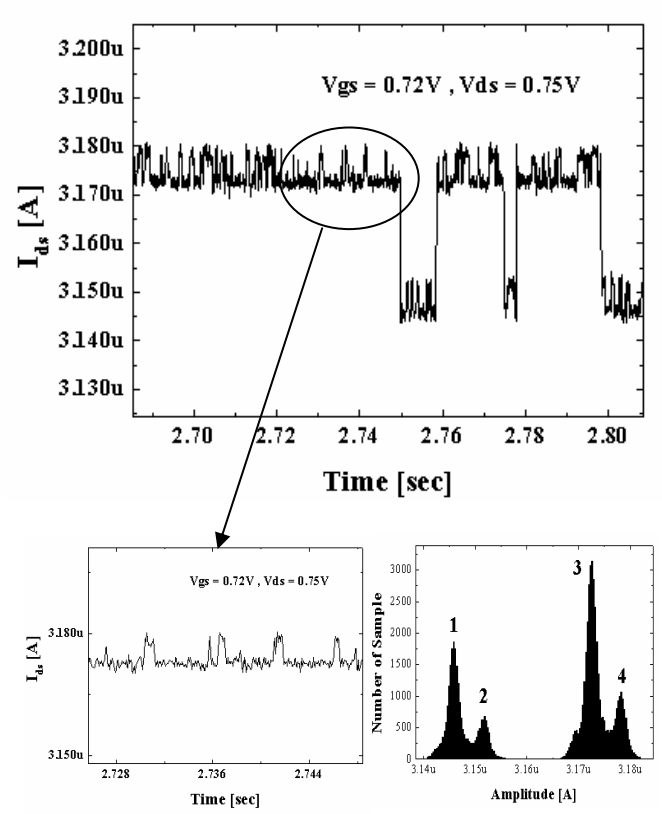

Fig. 2 Drain current four level fluctuations. (V_{gs} = 0.72V, V_{ds} = 0.75V)

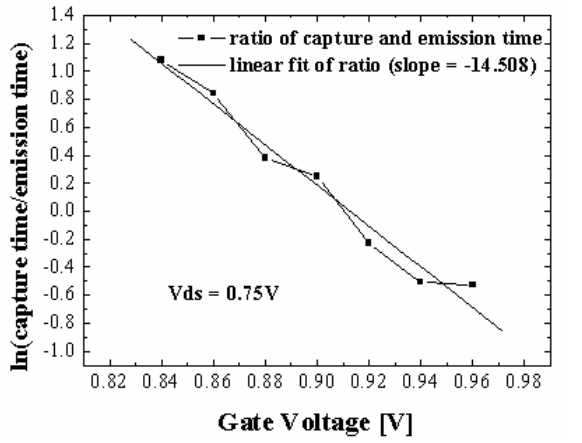

Fig. 3 ln(capture time/emission time) of slow trap.(V_{ds} = 0.75V)

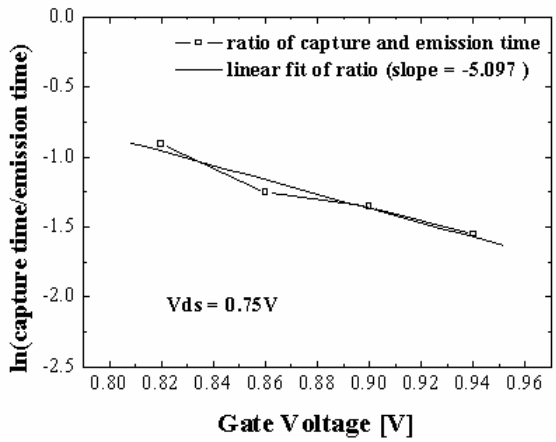

Fig. 4 ln(capture time/emission time) of fast trap.(V_{ds} = 0.75V)

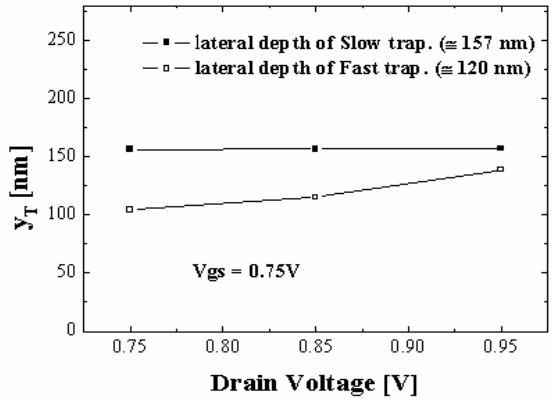

Fig. 5 Lateral depth of Traps calculated by eq. (2).(V_{gs} = 0.75V)

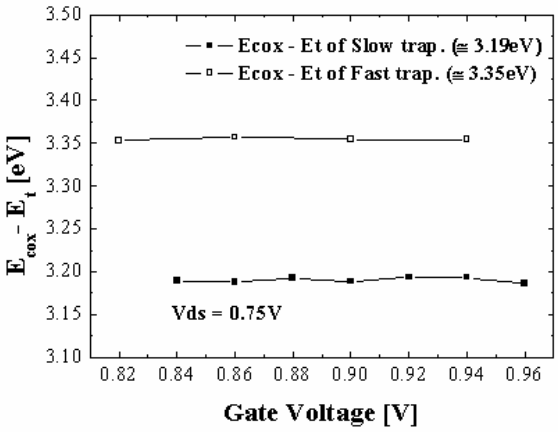

Fig. 6 $E_{Cox} - E_T$ of Traps calculated by eq. (3). (V_{ds} = 0.75V)

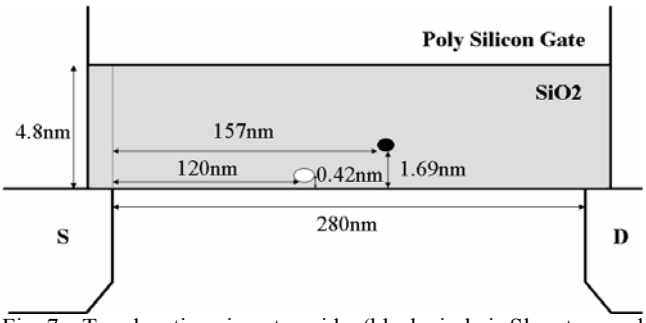

Fig. 7 Trap locations in gate oxide. (black circle is Slow trap and white circle is Fast trap)