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Extraction of trap energy and location from random telegraph noise in gate leakage current (I_g RTN) of metal–oxide semiconductor field effect transistor (MOSFET)

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ABSTRACT

Study of random telegraph noise in gate leakage current (I_g RTN) through thin gate oxide (2.6 nm) as well as drain current random telegraph noise (I_d RTN) has been conducted in MOSFET. RTN having two discrete current levels was observed in gate leakage current. Capture and emission time constants of I_g fluctuation were found to depend on drain voltage as well as gate voltage. Capture time showed an increase while emission time showed a decrease with respect to gate voltage. New equations for extracting trap locations and its energy level were derived. The oxide trap extracted from I_g fluctuation was observed to react with the gate and have a deep trap energy level from the conduction band edge of oxide.

1. Introduction

As devices continue to scale down in metal–oxide semiconductor field effect transistor (MOSFET) technology, the low frequency noise of device becomes more and more important in determining MOSFET performance. The low frequency noise in small MOSFET devices for analog and digital applications is reported to be dominated by drain current random telegraph noise (I_d RTN) [1–3]. I_d RTN which is responsible for time dependence of I_d fluctuation takes a crucial role in the current transport of such small devices. The origin of I_d RTN is attributed to the random trapping and detrapping process of mobile carriers in traps located at SiO_2/Si interface or in gate oxide. The random process in single oxide trap is observed as two discrete levels; high current level during capture time and low current level during emission time when the trap is assumed to be acceptor type. Both time constants provide useful information about trap such as its location and energy level, because they depend on gate and drain voltages. Considerable research on the extraction of trap position in oxide has been performed due to its importance in characterizing gate oxide properties [4–7].

Recently, study on the random telegraph noise in gate leakage current (I_g RTN) has been drawing attention because gate current is more sensitive to oxide volume traps than drain current at ultra thin gate oxide or high-*k* gate dielectric [8–13]. I_g RTN has been observed in the MOSFET devices biased in accumulation [11,12] as well as inversion. Several behaviors in the time constants and the amplitude of current fluctuation with respect to gate voltages have been investigated and explained by the models based on trap assisted tunneling via a single electron trap [11] and Shockley–Read–Hall (SRH) theory [8,13]. However, there is no report about the drain bias effect on the I_g RTN, even though it is indispensable to study the exact trap location in oxide for characterizing gate oxide properties.

We reproductively found I_g RTN phenomenon in ~3% samples of several nMOSFET devices (400ea). All I_g RTN samples showed that the relative fluctuation amplitude ($\Delta I_g/I_g$) was below 1%. Two kinds of I_g RTN phenomena have been also observed. One group of devices showed that the time constant for high current level decreases and for low current level increases with the increase of gate voltage, respectively, whereas the other group showed the opposite tendency.

In this paper, we will discuss one of the I_g RTN samples having the opposite behavior. The time constants in the I_g RTN were observed to depend on drain bias as well as gate voltage. The vertical

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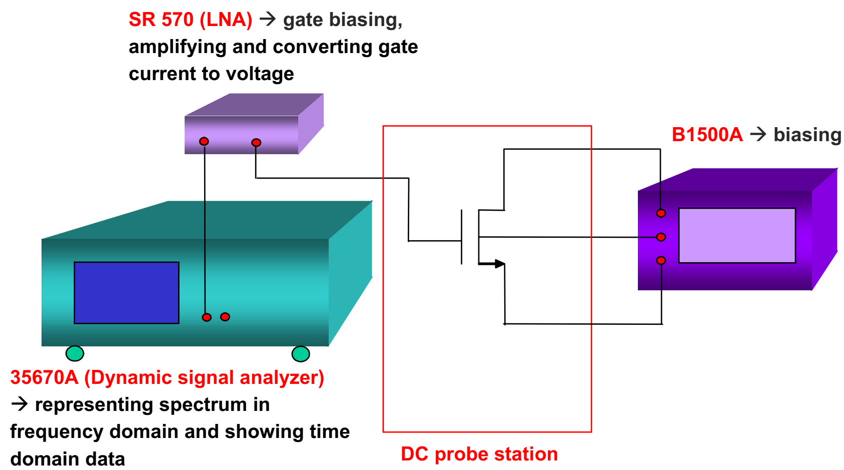

Fig. 1. Low frequency noise measurement system.

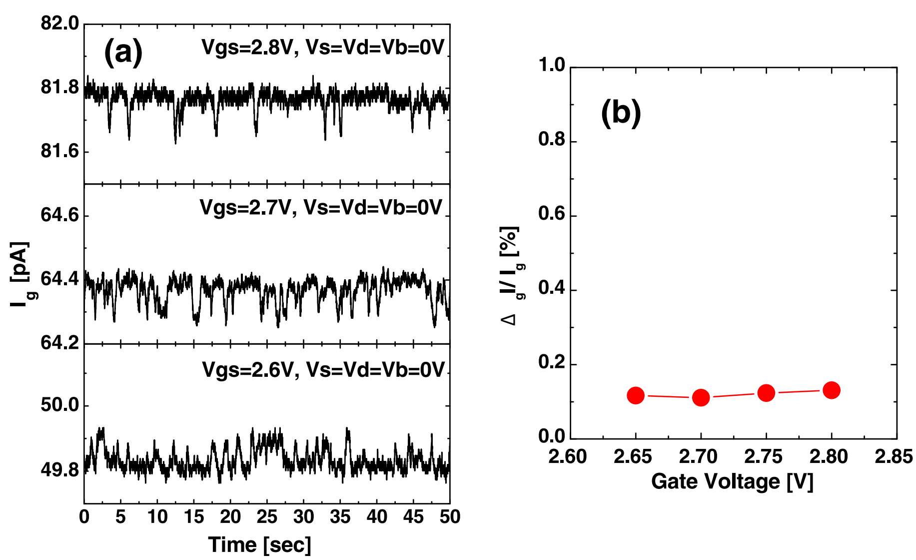

Fig. 2. Gate leakage current (I_g) fluctuation (a) at the gate voltage of 2.6–2.8 V and the relative fluctuation amplitude (b).

and lateral trap positions and its energy level in gate oxide were extracted by using the new equations.

2. Experimental

Fig. 1 shows a low frequency noise measurement system to measure RTN. SR 570 (LNA) amplifies the gate leakage current and converts it to voltage, then 35670A (dynamic signal analyzer) shows low frequency noise behavior both in time and frequency domains. To reduce external noise, SR 570 is operated by a battery and the device is shielded by shielding box. n + poly-Si gated nMOSFET were fabricated by using standard 80 nm DRAM technology on the p-type Si (1 0 0) substrate. The gate oxide thickness is 2.6 nm. The doping density in channel and poly-Si is $7.7 \times 10^{17}/cm^3$ and $4.0 \times 10^{20}/cm^3$, respectively. The tested devices have channel width of 7.25 μm and channel length of 0.13 μm. Prior to I_g RTN characterization, I_d RTN was analyzed first. Both I_d RTN and I_g RTN were observed in time and frequency domains by using the dynamic signal analyzer.

3. Results and discussion

Fig. 2a shows an I_g RTN characteristic at the V_{gs} of 2.6–2.8 V in time domain. There are two discrete levels of gate leakage current. The time constants vary with the gate voltages. The times for high and low current level are designated as capture time (τ_c) and emission time (τ_e), respectively, because each trapped electron in oxide during emission time blocks the current conduction through the gate oxide [8,11,13]. The amplitude between high and low current levels shows a slight increase from 60 fA to 110 fA as the gate voltage increases. However, $\Delta I_g/I_g$ shows ~0.1% and has relatively constant value as shown in Fig. 2b. Fig. 3a shows the power spectrum density (PSD) of the I_g fluctuation. The PSD of sample having I_g RTN displays Lorentzian form which consists of flat region and falling off region with $1/f^2$ trend. Compared to a sample without I_g RTN, the sample having I_g RTN has about one order of magnitude higher PSD in low frequency. Since drain current can be affected by the carrier number fluctuation and mobility fluctuation when electron is captured in an oxide trap [4], the trap causing I_g RTN is expected to also generate the fluctuations in drain current. However, no