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Extraction of Time Constants Ratio over Nine Orders of Magnitude for Understanding Random Telegraph Noise in MOSFETs

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Abstract

The numerous RTN characteristics in MOSFETs were evaluated accurately for a wide time range by the array test circuit. The time constants were extracted for over six orders of magnitude and there were no correlation between time to emission τ_e and time to capture τ_c. The time constant ratios were distributed over nine orders of magnitude. Measuring small amplitude and extracting time constants for wide range are useful to understand the trap properties in MOSFETs.

1. Introduction

Random Telegraph Noise (RTN) is caused by capture/emission of the carriers by/from traps in the insulator film [1]. The impact of RTN on the MOSFETs becomes larger as the progression of CMOS circuit scaling down continues. The amplitude and time constants are important parameters of RTN. Small amplitude also causes fatal problems to the devices for example a flash memory and a CMOS image sensor [2, 3]. The measurement methods for one transistor with long-time range [4] and for numerous transistors with short time range [5] have been reported. However numerous transistors have not been measured with short sampling period and long-time range yet. It is important to measure the numerous transistors with short sampling period and long-time for extracting the average values of $<\tau_e>$, $<\tau_c>$ and time constant ratio $<\tau_c>/<\tau_e>$ over a wide time range, and it is also important to investigate the distribution and correlation of them, because they are very useful for understanding capture and emission process of traps in MOSFETs.

2. Experimental

Fig.1 shows the array test circuit chip (a) and measurement board (b) to evaluate RTN. The circuit can measure very large amount of MOSFETs in a very short time [6, 8]. The test circuit was fabricated by the standard 0.22 μm CMOS technology. The gate oxide thickness (T_{ox}), the gate length and the gate width of MOSFETs were 5.7 nm, 0.22 μm and 0.28 μm, respectively. 131072 MOSFETs were measured in this experiment. A root mean square of V_{out} in time domain (V_{RMS}) were extracted for the MOSFETs to detect MOSFETs with RTN (V_{RMS} > 680 μV_{RMS}) with the sampling period of 0.7 sec/frame [7, 8]. Then, we selected the MOSFETs with large RTN and measured them with the short sampling period of 1 μsec for the long-time of 10 min [9] (sampling points $=6\times10^8$).

3. Results and Discussions

Figs. 2 (a) and (b) show distribution of V_{RMS} in new and previous systems [10] and (b) is enlarged view of (a). It is clear that the background noise level was reduced from 400 to 59 μV_{RMS} by improving the measurement system.

Fig. 3 shows the typical RTN waveforms. The V_{RMS} of (A) and (B) are almost the same. In sample (A), RTN cannot be detected by the previous system, on the contrary in sample (B), RTN was detected the RTN by the system with small back ground noise. Fig 3 (C) shows RTN waveform with middle V_{RMS} value in Fig. 2 (a). Fig. 3 (D) shows the multi states RTN waveform (six states). Two, three and more states RTN have been reported [11]. By the reduction of the back ground noise, the multi states RTN as shown in (D) was measured which could have been observed as two states RTN by the previous system is measured.

Fig. 4 shows a ratio of two states RTN and the others. Here, the total number of transistors with RTN was 1211. Two states type RTN accounts for 38 % of all the appeared RTN. Two states type RTN were analyzed in this experiment, because two states RTN is the most simple and basic phenomenon in RTN and an analyzing the basic phenomenon helps us to understand the trap properties.

Fig. 5 shows the extraction method of the time constants (time to emission τ_e and time to capture τ_c) and the amplitude (ΔV_{gs}) from the RTN waveform [5]. Assuming that the RTN follows the Poisson process, the histograms of τ_e and τ_c were fitted by the function which is described in Fig. 5 to detect average values of the time constants ($<\tau_e>$ and $<\tau_c>$) [1] and amplitude was extracted by taking the difference of two peaks on V_{gs} histogram. We extracted $<\tau_e>$ and $<\tau_c>$ for the RTN with the amplitude larger than 1 mV and the determinant coefficient r^2 between the measured and the fitted histograms of τ_e and τ_c larger than 0.80.

Fig. 6 shows the distribution of the extracted $<\tau_e>$ and $<\tau_c>$ and typical RTN waveforms. The time constants were extracted from 5 μsec to 6sec, that is, over six orders of magnitude. The result shows the $<\tau_e>$ and $<\tau_c>$ are distributed randomly and the correlation was not observed (coefficient of correlation r = -0.047). Four typical RTN waveforms (A) ~ (D) were picked up from the corner of the time constants distribution. By enlarging the measurement time range, the pairs of long τ_e/short τ_c and short τ_e/long τ_c were observed. As a result, it was found the correlation between $<\tau_e>$ and $<\tau_c>$ was not observed.

Fig. 7 shows the histogram of time constant ratio $<\tau_c>/<\tau_e>$. The values were distributed for over nine orders of magnitude. The $<\tau_c>/<\tau_e>$ was distributed broadly because the RTN such as Fig. 6 (A) and (C) was measured by the high speed and long-time measurement. This result implies the broad distribution of traps by means of energy and position. However for finding the limits of $<\tau_c>/<\tau_e>$, the effort to enlarge the time range is necessary, because it is considered the limits of $<\tau_c>/<\tau_e>$ are determined by measurement system, for example sampling period and sampling time.

4. Conclusion

The numerous MOSFETs were measured accurately for wide time range by the array test circuit. The time constants ranging from 5 μsec to 6 sec were extracted. It was found that $<\tau_c>/<\tau_e>$ is distributed over nine orders of magnitude. It was also found that the distribution of the time constants were random and correlation was not observed. Therefore, the extraction and investigation of $<\tau_e>$, $<\tau_c>$, $<\tau_c>/<\tau_e>$ for a wide time range are necessary for understanding RTN in MOSFETs

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Reference

[1] M. J. Kirton et al., Adv. Phys, 38, p. 367, 1989. [2] H. Kurata et al., VLSI Circuit symp, p. 112, 2006. [3] X. Wang et al., IEDM Tech, p. 115, 2006. [4] N. Ashraf et al., IEEE Trans. Electron Devices, 10, P. 1394,2011.[5] K. Abe et al., IRPS, 2011. [6] Y. Kumagai et al., Jpn J Appl phys., 50, p. 106701, 2011. [7] S. Watabe et al., Jpn. J Appl phys., 46, p. 2054, 2007. [8] K. Abe et al., VLSI Technol symp, p. 210, 2007. [9] A. yonezawa et al., IRPS, XT-11, 2013. [10] T. Fujisawa et al., ICMTS 2009, P. 19.[11] K. Abe et al., Jpn. J Appl phys., 48, p. 04C044, 2009.

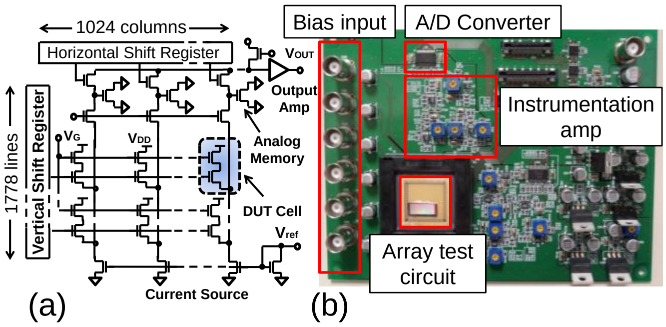

Fig. 1 Schematic of the array test circuit chip (a) and measurement board (b) to evaluate and to analyze RTN. About one million MOSFETs can be measured accurately in very short time (0.7 sec/frame).

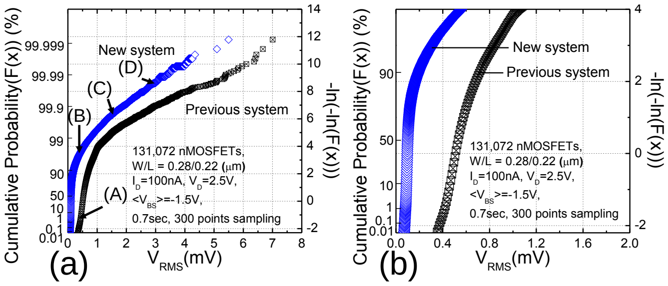

Fig. 2 Distribution of RTN V_{RMS} in output voltage in Gumbel plot (a), and Fig. 2 (b) is enlarged view of distribution. It is clear that the background noise level was reduced from 400 to 59 μV_{RMS} by the improving the measurement system.

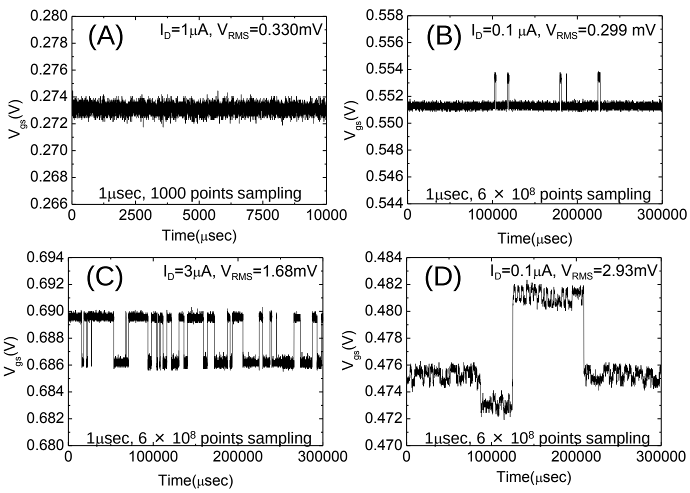

Fig. 3 Typical RTN waveforms picked up by V_{RMS} value.
(A) RTN which is buried in background noise level of previous measurement system (V_{RMS}=0.330 mV).
(B) RTN with low V_{RMS} value (V_{RMS}=0.299 mV).
(C) RTN with middle V_{RMS} value (V_{RMS}=1.68 mV).
(D) Multi states RTN waveform (six states and V_{RMS}=2.93 mV).

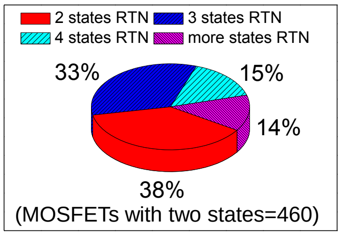

Fig. 4 Ratio of two states type RTN and the others. Two states type RTN account for 38 % of all appeared RTN. The total number of transistors is 1211.

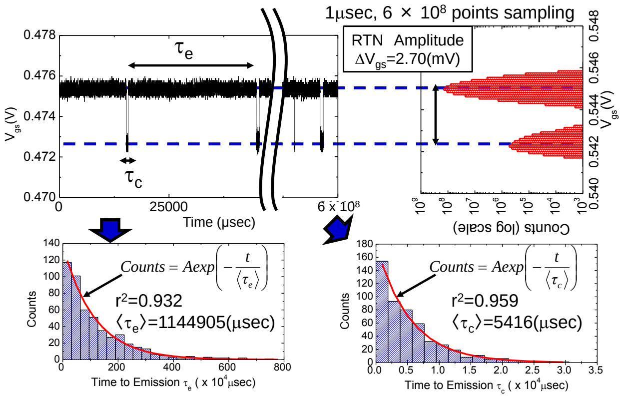

Fig. 5 extraction method of two time constants (time to emission $<\tau_e>$ and time to capture $<\tau_c>$) and amplitude (ΔV_{gs}) from RTN waveform.

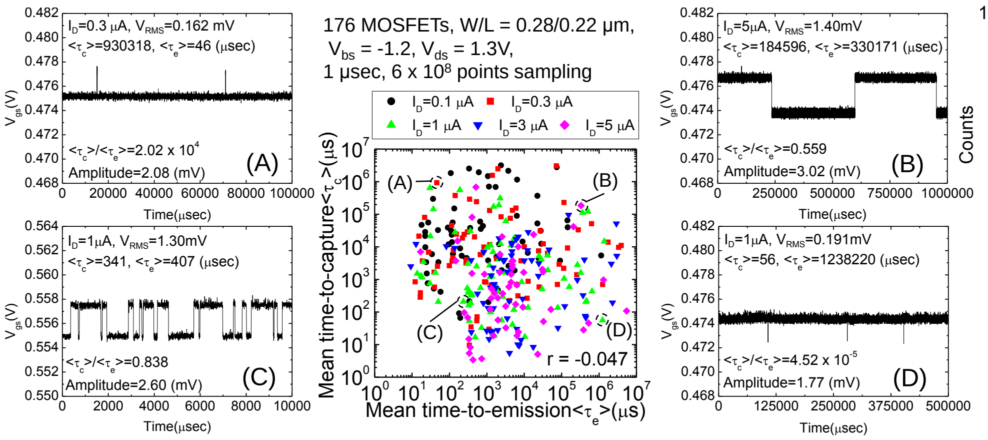

Fig. 6 Distribution of the extracted $<\tau_e>$ and $<\tau_c>$ and waveforms. The time constants were extracted for over six orders of magnitude. The center graph shows the $<\tau_e>$ and $<\tau_c>$ were randomly distributed and the correlation was not observed (coefficient of correlation r = -0.047). By enlarging the measurement time range, the pairs of long τ_e/short τ_c and short τ_e/long τ_c can be observed.

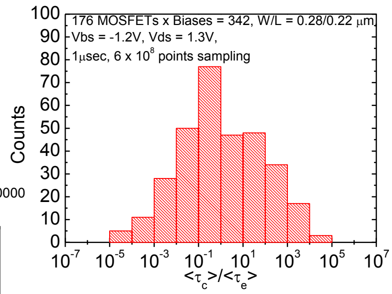

Fig. 7 The histogram of time constant ratio $<\tau_c>/<\tau_e>$. The values were distributed for over nine orders of magnitude. This result implies the broad distribution of traps by means of energy and position.