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journal or publication title	AIP Conference Proceedings 19th International Conference on NOISE AND FLUCTUATIONS-ICNF2007
volume	922
page range	115-118
year	2007
URL	http://hdl.handle.net/10097/51830

doi: 10.1063/1.2759648

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Abstract. In this paper, we developed an advanced Test Element Group (TEG) which can measure Random Telegraph Signal (RTS) noise in over 10^6 nMOSFETs including various gate sizes with high accuracy in a very short time. We measured and analyzed these noises statistically, as the result, we confirmed that appearance probabilities in the TEG and noise intensities of RTS are dependent on gate sizes.

Keywords: MOSFET, RTS noise, Test Element Group, Statistical Analysis
PACS: 73.50.Td, 72.20.Jv

INTRODUCTION

Random Telegraph Signal (RTS) noise and low frequency noise caused by RTS have become serious issues in electronic circuit design with downscaling of CMOS device [1-3]. They induce a degradation of signal-to-noise ratio in overall analog circuits, such as an increase of phase noise in oscillators for wireless applications. Recent years, it has been reported that an image quality degradation in a CMOS image sensor from random noise caused by RTS, which is difficult to eliminate by established noise reduction circuitry [2]. Then statistical analysis of RTS noise is indispensable for theoretical elucidation of the physical origin of RTS and its noise reduction. However, we can not find the MOSFET showing RTS behavior frequently and the statistical analysis of the noise characteristics has been difficult actually until today because the measurement system becomes so complex and it needs very long time to measure a sufficient number of samples which are element device forms.

In this work, we developed a new Test Element Group (TEG) which can measure both variation of stationary electrical characteristics [4] and noise characteristics in a large number of MOSFETs. Using this TEG, we have measured and analyzed statistically noise characteristics of the total of 10^6 MOSFETs. We first measure entire noise characteristics of the MOSFETs in a short time (about 4 minutes), and

CP922, *Noise and Fluctuations, 19th International Conference,* edited by M. Tacano, Y. Yamamoto, and M. Nakao

then we can find easily and analyze a specific MOSFET having anomalous noise behavior individually. In the result, we discuss the dependences of appearance probabilities of RTS and amplitudes of RTS in the TEG on the gate size.

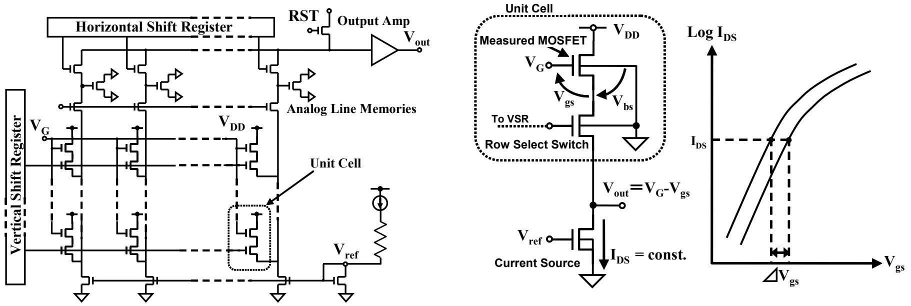
TEG STRUCTURE AND MEASUREMENT METHOD

The circuit schematic of the TEG is shown in Fig. 1 (a). Values of applied bias voltage to the measured MOSFETs (V_G, V_{DD}) are fixed and the voltages are forced simultaneously. The operating points of the MOSFETs are controlled by I_{DS} given by the current sources which are placed at every column. Electrical characteristics of the MOSFETs can be observed as the V_{gs} included in the output voltage V_{out} (Fig. 1 (b)). When a particular cell has a RTS behavior, we can specify and observe them as V_{gs} fluctuation in time-scale by the result of continuous sampling with adequately small sampling rate. The key point for fast read-out is that the output signal from a cell is not the "current" but the "voltage" signal and they are converted to digital data by Analog / Digital converter near the TEG. Therefore, we can easily measure noise characteristics of 10^6 MOSFETs in a short time (0.7 s per 1 scan) by use of the horizontal and the vertical shift registers. We can also sample the value of V_{gs} of a specified MOSFET every 0.33 μs continuously.

We designed the TEG that includes 15 gate sizes of nMOSFETs as shown in Table 1 and manufactured the TEG by 0.18μm, 1 Poly 2 Metal standard CMOS technology.

TABLE 1. Gate sizes and the number of MOSFETs in the TEG.

Gate Length (μm)	0.22	0.22	0.24	0.24	0.4	0.24	0.4	1.2	1.2	4	4	1.2	4	10	
Gate Width (μm)	0.28	0.3	0.3	1.5	1.5	15	15	0.3	1.5	0.3	1.5	15	15	15	total
No. of nMOSFETs	131,072	131,072	131,072	131,072	131,072	32,768	32,768	65,536	65,536	65,536	65,536	16,384	16,384	16,384	1,032,192



(a) (b)

FIGURE 1. (a) Circuit schematic of the proposed TEG and (b) Measurement method of V_{gs} fluctuation of a MOSFET in the TEG.

RESULTS AND DISCUSSION

To examine the random noise from RTS distribution of the TEG, we use the standard deviations of the continuous 300-time outputs from each MOSFET (σ_R) as the random noise indicator. The distribution of σ_R in Fig. 2 shows a NOT gaussian distribution and a specific tail in high σ_R region. Figure 2 also shows time-domain plots of V_{gs} for particular cells on the random noise distribution. V_{gs} behaviors for the

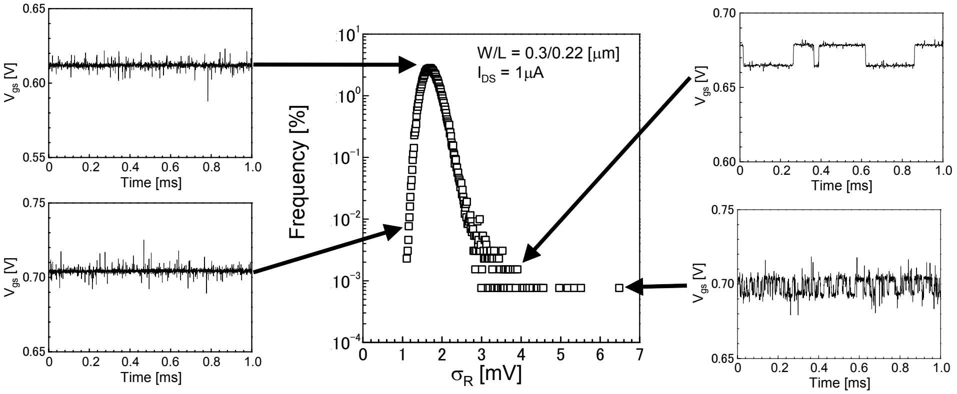


FIGURE 2. Distribution of the standard deviation of V_{gs} fluctuation for one MOSFET in time-scale (σ_R) with W/L=0.3/0.22 [μm] and time-domain V_{gs} behaviors for particular cells.

cells having large σ_R become two-level quantum change randomly. These phenomena indicate the RTS noise, which is caused by capturing and emitting a carrier on a trap near the Si/SiO_2 interface. We measured various MOSFETs which show RTS behaviors in the TEG and extracted their RTS parameters including amplitudes (ΔV_{gs}), mean time to capture ($<\tau_c>$) and to emission ($<\tau_e>$). Then, signal transition probability is defined by the following equation [5]

$$T = \frac{<\tau_e><\tau_c>}{\left(<\tau_e>+<\tau_c>\right)^2}\,. \tag{1}$$

Here, $\Delta V_{gs}*T$ is considered as a factor to characterize RTS noise intensity of a MOSFET. Figure 3 shows correlation diagram between σ_R and $\Delta V_{gs}*T$. There is strong correlation clearly. Therefore the origin of increasing σ_R is regarded as RTS noise and σ_R is available to find cells having RTS noise easily. And then, values of $\Delta V_{gs}*T$ vary widely under same gate area and same bias condition. It indicates that the energy level of traps and the distance from Si/SiO_2 interface are distributed.

The distributions of σ_R for several gate sizes are shown in Fig. 4 (a). The tails

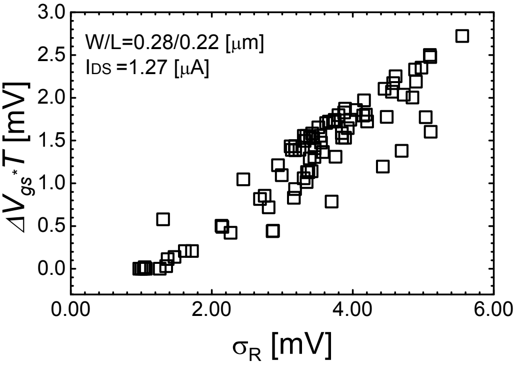
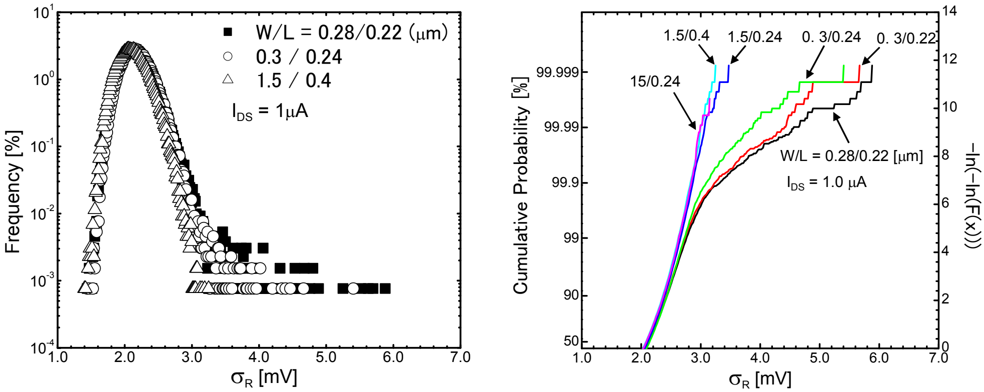


FIGURE 3. Correlation diagram between σ_R and $\Delta V_{gs}*T$ when sampling rate = 3 MHz (sampling cycle = 0.33 μs).



(a) (b)

FIGURE 4. (a) Distributions of σ_R and (b) Gumbel distributions of σ_R with several gate sizes.

appear prominently as gate area becomes smaller. This tendency becomes clear by representing same distributions as Gumbel distributions, which is used in the extreme statistics (Fig. 4 (b)) [3]. The distributions for small gate MOSFETs are fit into straight lines in the range of $\sigma_R > 3$ mV. This means that the appearance probability of MOSFETs having critical RTS noise for circuit operations could be described by the theory of Gumbel distribution statistically and we may be able to predict and control RTS noise in ULSI to avoid the harmful effect of the noise.

CONCLUSION

In this work, we developed an advanced TEG for statistical analysis of RTS and we can easily find the cells having large RTS noise in over 10^6 nMOSFETs from the distribution of σ_R, which is supposed an indicator to show RTS noise intensity briefly and shortly. From the result, we found that appearance probabilities of RTS become larger as shrinking of the gate size. The quantitative information given by the TEG is very useful for understanding the physical origin of RTS and circuit-level RTS noise behaviors in the process and the device development or electronic circuit design

REFERENCES

1. M. J. Kirton and M. J. Uren, "Noise in Solid-State Microstructures: A New Perspective on Individual Defects, Interface States, and Low-Frequency Noise," *Adv. in Phys.,* **38**, 367-468, 1989.
2. X. Wang, P. R. Rao, A. Mierp, Albert J. P. Theuwissen, "Random Telegraph Signal in CMOS Image Sensor Pixels," Tech. Dig. of IEDM '06, IEEE, 2006, pp. 115-118.
3. N. Tega, H. Miki, T. Osabe, A. Kotabe, K. Otsuga, H. Kurata, S. Kamohara, K. Tokami, Y. Ikeda, R. Yamada, "Anomalously Large Threshold Voltage Fluctuation by Complex Random Telegraph Signal in Floating Gate Flash Memory," Tech. Dig. of IEDM '06, IEEE, 2006, pp. 491-494.
4. S. Watabe, S. Sugawa, A. Teramoto, T. Ohmi, *Jpn. J. Appl. Phys*., **46**, 4B, 2054-2057 (2007).
5. C. Leyris, F. Martinez, M. Valenza, A. Hoffmann, J.C. Vildeuil, F. Roy, "Impact of Random Telegraph Signal in CMOS Image Sensors for Low-Light Levels," Proceedings of the 32nd European Solid-State Circuits Conference ESSCIRC 2006, IEEE, 2006, pp. 376-379.