Program Trapped-Charge Effect on Random Telegraph-Noise Amplitude in a Planar SONOS Flash Memory Cell

H. C. Ma, Y. L. Chou, J. P. Chiu, Tahui Wang, *Senior Member, IEEE*, S. H. Ku, N. K. Zou, Vincent Chen, W. P. Lu, K. C. Chen, and Chih-Yuan Lu, *Fellow, IEEE*

***Abstract*—Program-charge effects in a SONOS Flash cell on the amplitude of random telegraph noise (RTN) are investigated. We measure RTN in 45 planar SONOS cells and 40 floating-gate (FG) cells in erase state and program state, respectively. We find that a SONOS cell has a wide spread in RTN amplitudes after programming, while an FG cell has identical RTN amplitudes in erase and program states at the same read-current level. A 3-D atomistic simulation is performed to calculate RTN amplitudes. Our result shows that the wide spread of program-state RTN amplitudes in a SONOS cell is attributed to a current-path-percolation effect caused by random discrete nitride charges.**

***Index Terms*—Percolation, program charge, random telegraph noise (RTN), SONOS.**

I. INTRODUCTION

RANDOM telegraph noise (RTN) arising from electron emission and capture at an interface-trap site has been recognized as a new scaling constraint in Flash memories [1]–[4]. V_t fluctuations originating from a large-amplitude RTN tail will cause a read failure and become a prominent issue in designing a multilevel-cell (MLC) Flash memory in a 45-nm technology node and beyond [3], [4]. Recently, a statistical model based on a 3-D Monte Carlo simulation [5], [6] has shown that the amplitudes of RTN and, thus, the V_t fluctuations exhibit an exponential distribution, i.e., $f(\Delta V_t) = \exp(-\Delta V_t/\sigma)/\sigma$ [4]. In a floating-gate (FG) Flash memory, an RTN tail is attributed to a current-path-percolation effect due to random dopants in a substrate, and σ is dependent on a substrate-doping concentration. Unlike an FG Flash cell, where program charges are stored in a conducting poly-silicon and have a continuous distribution, program charges in a SONOS cell are stored in silicon-nitride traps. Because of the nature of random nitride charge trapping, a current percolation path in a SONOS cell is formed by both substrate dopants and program charges. In this letter, we will investigate program-charge effects on RTN amplitudes in an MLC SONOS.

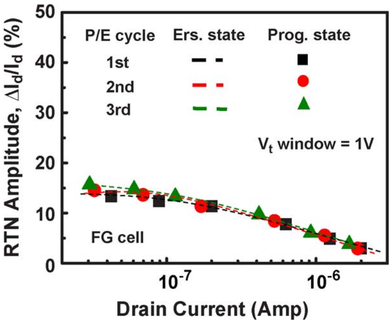

Fig. 1. Measured relative RTN amplitude versus drain–current in an FG flash cell in erase and program states in three P/E cycles. The V_t window is 1 V. The drain voltage measurement is 0.7 V, and the gate voltage varies. The FG cell has $W/L = 0.11\ \mu\text{m}/0.09\ \mu\text{m}$ and an 8-nm tunnel oxide.

Program- and erase-state RTNs are characterized in planar SONOS Flash cells and FG Flash cells. The SONOS cell has a 6-nm top oxide, a 6-nm nitride layer, and a 2.8-nm bottom oxide. The device area is $0.09 \times 0.08\ \mu\text{m}^2$. Uniform FN injection is employed for program and erase. The program V_t window is chosen to be 1 V for MLC application. A 3-D Monte Carlo simulation is performed to calculate an RTN amplitude due to a percolation effect. Our simulation does not consider a local modulation in mobility associated with an interface charge [5]. The drain–current variation due to number fluctuation will be examined.

II. RESULTS AND DISCUSSION

We measured single-trap RTN amplitudes $(\Delta I_d/I_d)$ in an FG Flash cell. The erase- and program-state RTN amplitudes versus the drain–current in three program/erase (P/E) cycles are shown in Fig. 1. The program V_t window is 1 V. In RTN measurement, the drain voltage is 0.7 V, and the gate voltage varies such that the drain–current ranges from 50 nA to 2 μA. In Fig. 2, we

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H. C. Ma, Y. L. Chou, and J. P. Chiu are with the Department of Electronics Engineering, National Chiao Tung University, Hsinchu 300, Taiwan (e-mail: hcma.ee94g@nctu.edu.tw; novicent.ee95g@nctu.edu.tw; clouders.ee96g@nctu.edu.tw).

T. Wang is with the Department of Electronics Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, and also with the Macronix International Company, Ltd., Hsinchu 300, Taiwan (e-mail: twang@cc.nctu.edu.tw).

S. H. Ku, N. K. Zou, V. Chen, W. P. Lu, K. C. Chen, and C.-Y. Lu are with the Macronix International Company, Ltd., Hsinchu 300, Taiwan (e-mail: shku@mxic.com.tw; nkzou@mxic.com.tw; VincentChen@mxic.com.tw; WPLu@mxic.com.tw; kcchen@mxic.com.tw; cylu@mxic.com.tw).

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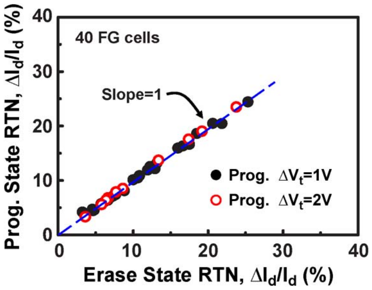

Fig. 2. Program-state RTN amplitude versus erase-state RTN amplitude in 40 FG cells. The RTN is measured at $I_d = 500$ nA, and $V_d = 0.7$ V. The V_t window is 1 or 2 V.

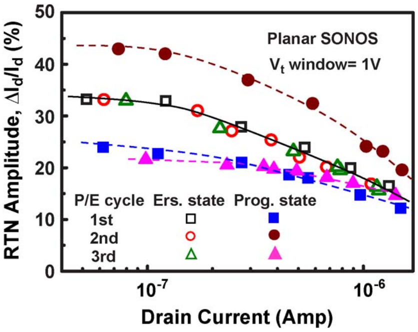

Fig. 3. Measured RTN amplitude versus drain–current in a SONOS Flash memory cell in three P/E cycles. The drain voltage measurement is 0.7 V. The V_t window is 1 V. The cell has $W/L = 0.09\ \mu\text{m}/0.08\ \mu\text{m}$.

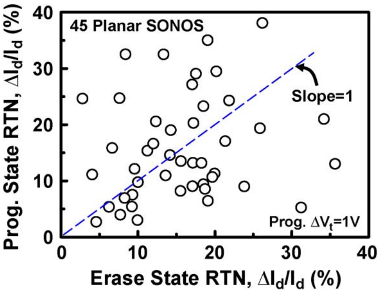

Fig. 4. Program-state RTN amplitude versus erase-state RTN amplitude in 45 planar SONOS cells. The RTN is measured at $I_d = 500$ nA, and $V_d = 0.7$ V. The V_t window is 1 V.

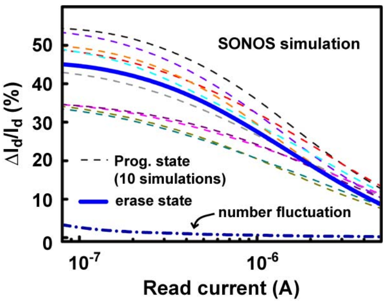

Fig. 5. Simulated RTN amplitude versus read current in a SONOS Flash cell. In simulation, dopants and program charges are randomly placed in the substrate and in the nitride layer, respectively. Ten sets of random nitride charges having a similar program state V_t are simulated with a fixed substrate-dopant placement.

trace the RTN amplitudes from erase state to program state in 40 FG cells. Program- and erase-state RTNs have almost identical amplitudes at the same read-current level. This result implies that program charges in an FG cell do not have an effect on RTN amplitudes. In other words, they do not alter a current percolation path caused by random dopants. We changed the program V_t window from 1 to 2 V, and the result remains the same (Fig. 2). In contrast, a distinctly different feature is obtained in a SONOS Flash cell. Fig. 3 shows measured erase- and program-state RTN amplitudes in a SONOS cell in three consecutive P/E cycles. Two-level current switching is observed, showing that RTN arises from a single interface trap, and no additional traps are created during P/E cycles. The program-state RTN varies from cycle to cycle. Fig. 4 shows program-state RTN amplitude versus erase-state RTN amplitude in 45 SONOS cells. The RTN amplitude exhibits a wide spread after programming and is almost independent of erase-state, suggesting that program charges play a major role in RTN. To calculate a nitride trapped-charge effect on RTN, we performed a 3-D atomistic simulation with random discrete program charges and substrate dopants. In an FG cell simulation, only substrate dopants are randomly placed, and program charges have a continuous distribution. An equipotential condition in an FG is obtained in the simulation. We calculate the change of the drain–current due to trapping/detrapping of an interface charge placed in the center of the device. Our simulation shows that RTN in program and erase states have the same amplitude, which is in agreement with our measured result. The simulated RTN amplitudes in a SONOS cell are shown in Fig. 5. Ten different sets of random nitride charges having a similar program state V_t are simulated. The number of nitride electrons in simulation is 180. In all simulations (program state or erase state), a fixed placement of random substrate dopants is used. The RTN amplitude due to a number-fluctuation effect is simulated by assuming continuous substrate doping and program-charge distributions. The simulated RTN amplitude resulting from number fluctuation is less than 10% in the current device. The program- and erase-state RTN amplitude is much larger than the current variation due to number fluctuation. This suggests that the large-amplitude RTN results from a percolation effect caused by nitride trapped charges. In Fig. 5, we observe a wide spread in program-state RTN amplitudes in a SONOS cell since each set of program charges results in a different current percolation path. The large spread of program-state RTN amplitudes from cycle to cycle in Fig. 3 can be also realized.

III. CONCLUSION

Read failure due to a large-amplitude RTN tail is an urgent issue in Flash-memory scaling. Random program-charge effects in a planar SONOS cell on RTN have been characterized and simulated. In an FG cell, the RTN tail is mainly attributed to random substrate dopants, while in a SONOS cell, the percolation path and, thus, the amplitude of RTN are determined by both substrate dopants and program charges. Our simulation has shown that random program charges have a large effect on RTN. This effect has to be considered in RTN modeling in a program state of an MLC SONOS.

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