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RTN Effects in Scaled Flash Memory Arrays

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1. Introduction

Scaling of the Flash technology below the 90 nm node raised issues previously uninfluent from the standpoint of cell reliability. In particular, single-electron trapping/detrapping events in the tunnel oxide modify the cell threshold voltage V_T [1-2], affecting the stability of the programmed levels. We discuss here the main experimental results and issues pertaining to this effect.

2. Experimental data

To characterize RTN effects on Flash arrays, we have measured the drain current of 8 K cells (randomly selected) over time at constant gate bias, and then computed the statistical distribution of $\Delta I_D(t) = I_D(t) - I_D(0)$. In our case the read time is about 50 μs, which allows good sampling of the traps dynamics while still collecting a reasonable statistics of cell. Results for ΔI_D are shown in Fig. 1 for different times: a distribution with nearly exponential tails in the lower and upper parts appears, with the tails slowly drifting with time. From the point of view of device reliability, the I_D (or V_T) instability raises issues concerning the origin of the fluctuations and their magnitude, and requires careful analysis of the basic device physics.

3. RTN features

Tail shape

The origin of the exponential tail has been quantitatively assessed in [2], and related to the overall effect of a statistical distribution of traps over the array cells. A single trap, in fact, can capture and emit an electron (Fig. 2), giving rise to standard RTN behavior (Figs. 3a and b). If more than one trap is present in a cell, their individual contributions can add up, resulting in a larger ΔV_T, as shown in Fig. 3c.

Tail drift

The time drift of the distribution tails can be explained by the activation of slower and slower traps, whose RTN behavior becomes observable only for times comparable with their time constants. An example is shown in Fig. 4, where a trapping event is observed only after hours from the beginning of the experiment. This is explained in Fig. 5, where the oxide region sampled by the RTN experiment of Fig. 1 is shown [2]. Note that more and more traps become involved in the RTN process as time elapses, moving the left boundary of the selected region deeper and deeper in the oxide. A thin oxide region near the substrate surface is excluded as a consequence of the I_D integration performed during the cell sensing, which reduces the possibility to observe very fast traps.

Amplitude

The amplitude of the individual contributions to ΔV_T also affects the shape of the distributions in Fig. 1. Fig. 6 shows the expected electrostatic contribution to ΔV_T, $q/(LWC_{ox}\alpha_G)$, due to the trapping of a single electron at the silicon/oxide interface. The cases of constant $L = 100$ nm and $L = W$ are shown, together with the range of experimental data reported in [1]. Very large RTN values are measured, which cannot be explained with the simple electrostatic theory. It has been suggested [3] that dopant fluctuation effects play an important role, leading to a non-uniform inversion channel over the cell area and to current percolation effects. Under these conditions, a trap "strategically" located over a percolation path can turn it off, resulting in a large ΔV_T. The ΔV_T distribution becomes then related to both the statistics of the number of traps and of their position over the channel. Fig. 7 shows results of Monte Carlo simulations of the effects of a single trap on ΔV_T: note the low tail due to the blockage of percolation paths by the trap.

4. Open issues

Fig. 8 shows results of the RTN characterization performed over a large population of cells. Note that the exponential behavior holds for the entire population observed, with cells experiencing larger and larger fluctuations, though with negligible probabilities. It was argued [4] that dopant fluctuations alone cannot explain the extreme phenomena, and that correlation between the single-trap amplitudes could also give a contribution. This point obviously deserves further investigation, as does the microscopic physics of the traps involved, which presents data still unclear [4].

5. Conclusions

The ΔV_T distribution due to RTN in Flash arrays has an exponential distribution, determined by the statistics of trap number and positions over the cells. RTN is an issue for the cell scaling, but careful optimization dictated by physical understanding can relieve the issue.

Acknowledgments

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References

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[3] A. Asenov *et al.*, *IEEE Trans. Electron Dev.* **50**, 839-845, 2003.
[4] H. Miki *et al.*, *Proc. IRPS*, 29-35, 2007.

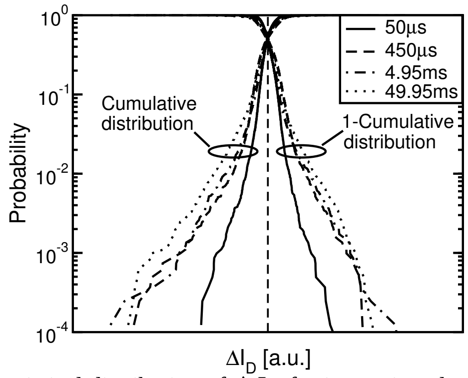

Fig. 1: Statistical distribution of ΔI_D for increasing elapsing time between the two read operations.

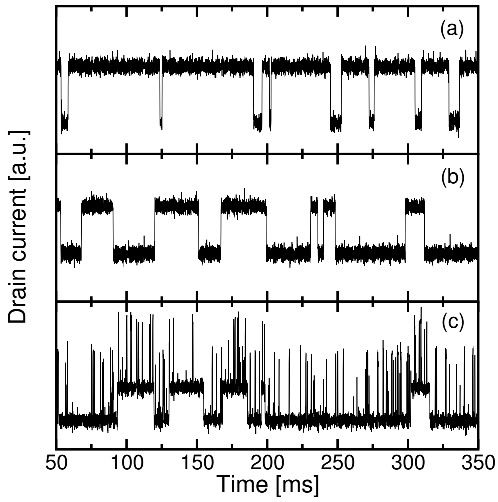

Fig. 3: RTN I_D fluctuations in selected Flash cells.

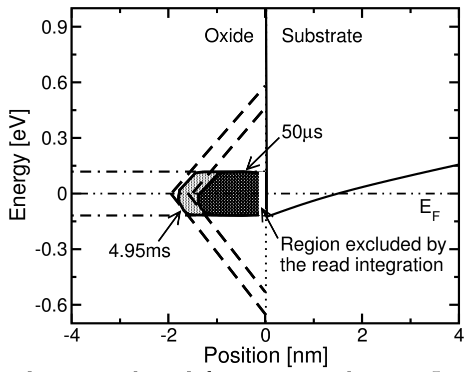

Fig. 5: Oxide region where defects active in the RTN I_D instability are located for stationary initial trap filling.

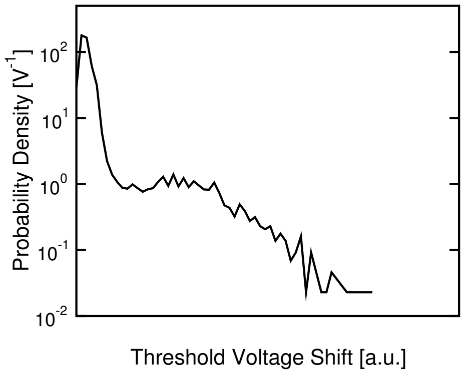

Fig. 7: Numerical simulation of the ΔV_T distribution due to RTN.

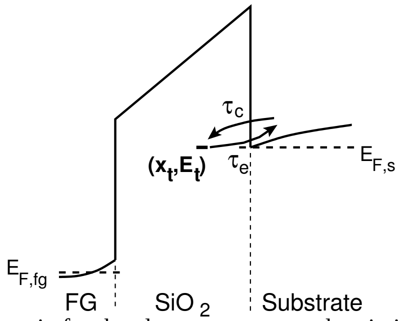

Fig. 2: Schematic for the electron capture and emission processes involved in single-trap RTN fluctuations.

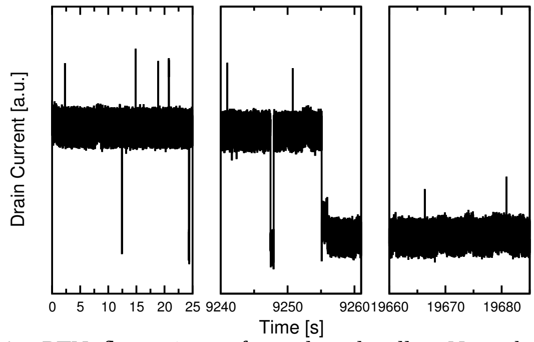

Fig. 4: RTN fluctuations of a selected cell. Note the capture/emission times which can range from ms to s and to several hours, explaining the drift phenomenon.

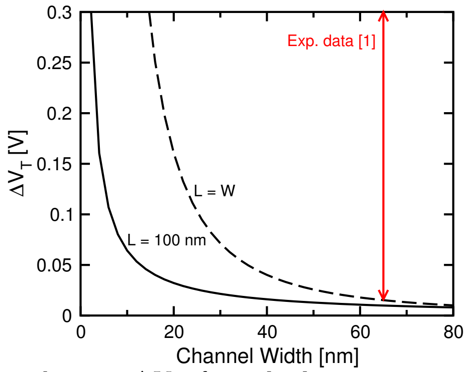

Fig. 6: Contribution to ΔV_T of a single-electron capture event in the tunnel oxide of a Flash memory, assuming $t_{ox} = 9$ nm and $\alpha_G = 0.65$. Experimental data from [1] are also shown for comparison.

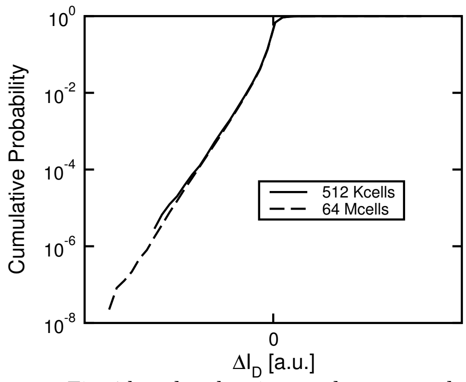

Fig. 8: Same as Fig. 1 but also showing results measured over 64 M cells. Note the prolonged exponential behavior.