Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 608-609

P10-1

Erratic bits in Flash Memories under Fowler-Nordheim programming

Andrea Chimenton Paolo Pellati Piero Olivo

Dipartimento di Ingegneria, Universita' di Ferrara, Italy
phone: +39 0532 29.38.29, fax: +39 0532 76.86.02, Email: achimenton@ing.unife.it

I. Introduction

Erratic bits are one of the most important single bit failures in Flash memories [1, 2]. The erased threshold voltage of some cells, called erratic, may change unpredictably cycle by cycle (Fig. 1) and there is a considerable risk that some of them become depleted giving rise to leaky columns and, therefore, to reading errors.

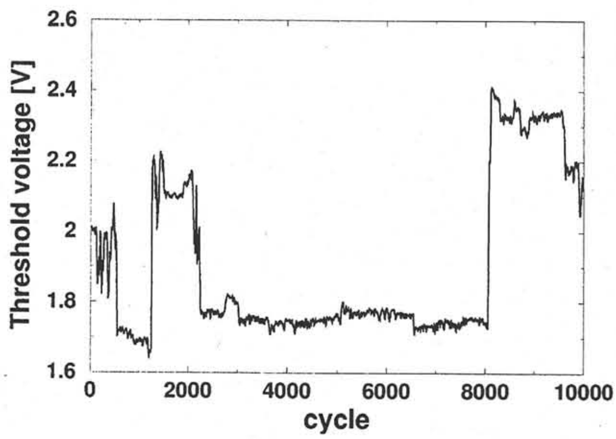

Fig. 1. Example of an erratic cell featuring both negative and positive jumps during cycling.

Since erratic bits have been observed only after erasing in conventional Flash programmed via CHE injection, their nature was related to physical phenomena occurring during erasing [1, 3]. On the other hand, the impulse towards low power Flash applications focuses a new attention over the Fowler-Nordheim (FN) tunneling mechanism for programming and it is important to fully exploit the performances of the standard Flash cell in such conditions.

The purpose of this work is to show the existence of erratic bits (hereafter denoted as PE) also after FN programming in standard cells, where electrons are injected into the floating gate from the channel. This result has a relevant impact on the study of the physical nature of erratic bits, since some possible causes can now be ruled out. A full set of statistics about the PE generation and a comparison with erratic bits during erasing (denoted as EE) will be presented.

II. Experimental Results

Experiments were performed on sectors of 512k cells of Flash memories featuring a 7nm oxide. Erasing and programming have been performed by applying a single pulse between control gate and substrate of all cells of the array simultaneously: V_G = 10V, $V_B = V_S = V_D$ = 0V, t = 10 s for programming; V_G = −3 V, $V_S = V_B$ = 8 V, V_D floating, t = 10 ms, for erasing.

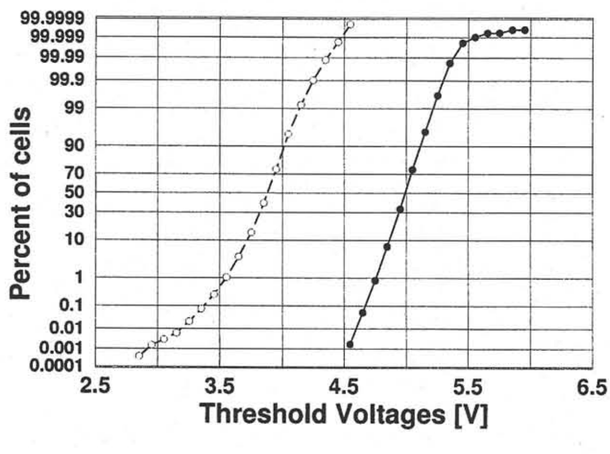

Fig. 2. Distributions of erased (dashed line) and programmed (solid line) thresholds.

Fig. 2 shows the two distributions after both programming and erasing.

EE and PE events have been measured whenever, for a single cell, the variation of the erased (programmed) threshold voltage with respect to the value measured at the previous cycle was larger than ± 350 mV. A cell was marked as erratic during erasing (programming) when it exhibited its first EE (PE) event.

As shown in Fig. 3, erratic events are observed also during FN programming. Nevertheless their occurrence is significantly lower (5%) than that observed during erasing. Fig. 4 shows that both erratic bit failure distributions do no saturate within 5,000 cycles. Therefore, in both cases, after a huge number of cycles, all cells in the array are expected to exhibit almost one erratic event. The distribution of threshold shifts reported in Fig. 5, show an almost perfect symmetry with respect to the vertical axis indicating that positive (increasing threshold) and negative (decreasing threshold) jumps of the same entity occur with the same probability. Moreover, even if PE are countless with respect to EE, their jumps may be much larger.

The ratio of the number of erratic events exhibited by each cell to 5,000 cycles may be considered as the average

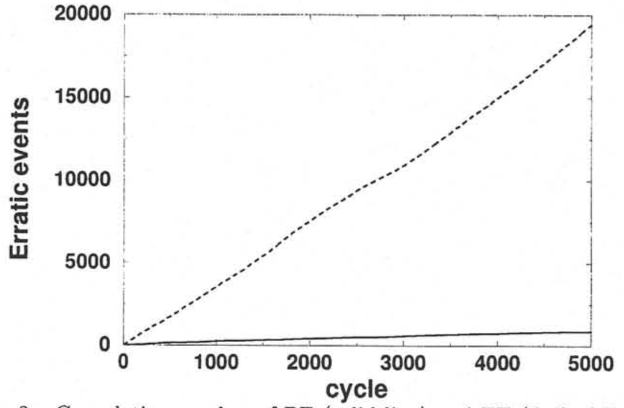

Fig. 3. Cumulative number of PE (solid line) and EE (dashed line) events as a function of the cycle number.

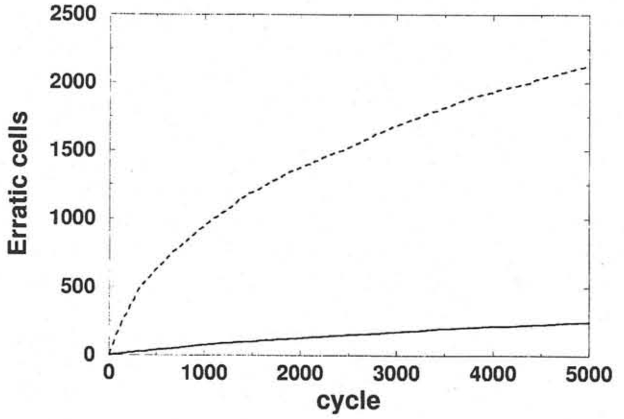

Fig. 4. Cumulative number of erratic bits during programming (PE - solid line) and erasing (EE - dashed line).

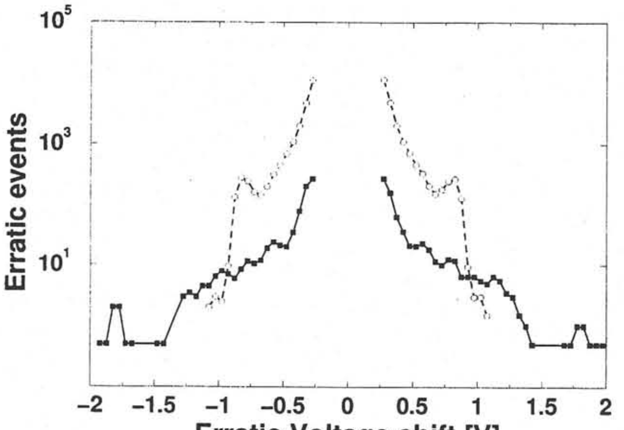

Fig. 5. Distribution of PE (solid line) and EE (dashed line) erratic threshold voltage shifts.

erratic event probability of the considered cell (EEP) at a generic cycle. Fig.6 shows the distribution of EEPs of all cells of the sector. In both cases only few cells have high EEP while the majority shows a lower occurrence.

It has been also experimentally verified that EE and PE cells are uniformly scattered throughout the entire sector and this implies that both, PE and EE phenomena, are

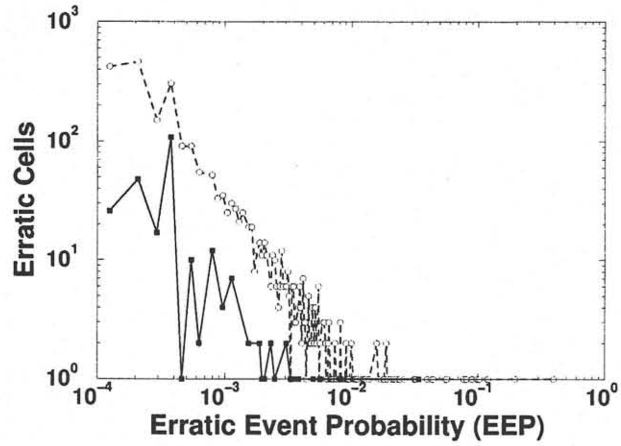

Fig. 6. Distributions of Erratic Event Probability (EEP) for PE (solid line) and EE (dashed line).

related to cell 'intrinsic' defects.

The oxide defects responsible for the erratic erase may be present in all cells yet from the virgin condition or/and they may be created by the FN erasure stress during cycling. The analysis of the physical map of all erratic bits excludes a dependence on both architectural defects (leaky columns and/or rows) and external contaminations.

Moreover, the importance of the oxide quality near the injecting interface rather than in the bulk oxide, i.e. at $t_{ox}/2$, is also evident considering that only 1% of PE cells were also marked as EE: in fact, assuming that erratic phenomena is caused by oxide-bulk defects, it is expected that, thanks to symmetry, PE and EE cells were the same.

III. Conclusions

We observed that the erratic erase phenomena were present for both FN injection polarities but with a significantly different occurrence probability. Any physical mechanism responsible for the erratic erase induced by Channel Hot Electron may now be ruled out.

We suggest that the actual causes of the erratic threshold shifts have probably the nature of broken/strained Si-O bonds generating electron and/or hole traps near the injecting interface. The density of these defects close to an interface may be conditioned by its roughness and/or by the doping diffusion in the oxide, that, in some cases, have yet been used to explain and limit the over-erase problem related to tail bits [4]. The experimental observation that EE events have a higher occurrence with respect to PE events, is therefore due to the higher density of oxide defects close to the Si_{poly}/SiO_2 interface.

References

[1] T.C. Ong et al., VLSI Symp. on Tech., 83, (1993)
[2] P. Cappelletti et al., in Flash Memories, 399, Kluwer (1999)
[3] C. Dunn et al., Int. Rel. Phys. Symp., 299 (1994)
[4] S. Muramatsu et al., IEDM, 847 (1994)