Flash Memory Cell Diagnosis: High level Model

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Introduction

The evolution of the market of portable devices such as smart card or mobile communication media has a straight impact on the use of Flash. Indeed, Flash have become over the last few years' very relevant choices for any application requiring non-volatile semiconductor memory and represent 50% of the NVM market [1].

The fundamental discussion of this paper is to show the efficiency of a Flash polynomial model that allows to generate the geometric parameters of a cell for a given set of extracted threshold voltages. The paper presents the "*Design of Simulation*" (*DOS*) technique used to generate a polynomial model of threshold voltages for Flash memory cell. Using this high level model, a diagnosis process is presented and the validity of the method is illustrated with simulations performed using ELDO to generate the threshold voltages and our model to generate the geometry of the cell in order to compare the simulated geometry with the generated one.

Flash cell: Polynomial model

Diagnosis of Flash cell geometry implies to be able to link the different measured threshold voltages (V_{Terase}, V_{Twrite} and $V_{Tvirgin}$) to the 5 pertinent geometric parameters (L, Tox, Tono, W, Wpp) of the cell as illustrated Fig.1.

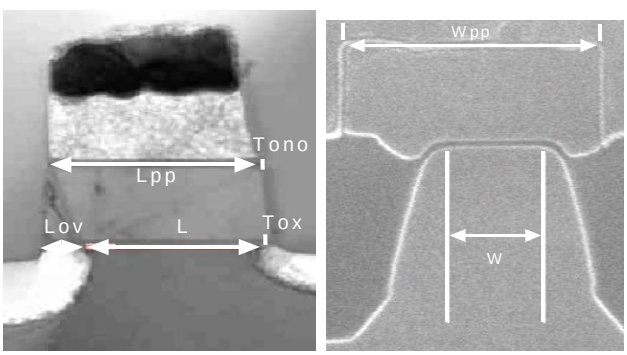

Figure 1: Flash cell memory structure overview

To achieve this goal, a Design Of Experiment (DOE) technique is used, in our case the experiments are Simulations so we speak about DOS. This technique allows obtaining a complete knowledge of the selected answers (Threshold voltages) in the domain of variation of the 5 geometric parameters from a limited number of simulations. This domain of variation is called sphere of knowledge. More concretely, a Doehlert matrix [2] is selected to define all the geometric configurations that have to be simulated. The selected answers are generated from a Surface Response analysis. From this result a multi-linear regression algorithm extracts the polynomial model of each considered threshold voltage (V_{Terase}, V_{Twrite} and $V_{Tvirgin}$). The threshold voltage V_T equation is given in a general form as follows:

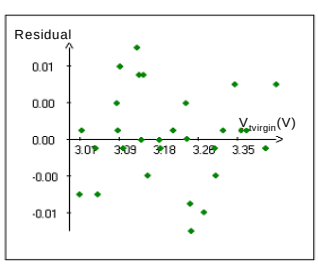

Figure 2: Residual study for the virgin threshold voltage

$$VT = b0 + \sum_i bi \cdot Xi + \sum_i bii \cdot (Xi \cdot Xi) + \sum_{ij} bij \cdot (Xi \cdot Xj)$$

The confidence on the 3 V_T equations is given by the study of the residual as presented Fig.2, i.e. the difference between the value obtained from the equations and the ones obtained from the simulations. The maximal differences are 10mV for a virgin cell, 30mV for an erased cell and 10mV for a written cell. They represent less than respectively 0.3%, 1% and 0.2% of error compared to the simulated values of threshold voltage.

Diagnosis process based on polynomial model

The presented model allows to fast calculating the three threshold voltages of the Flash memory cell, whatever the geometry of the cell in the geometric parameters domains. Surface plots can be generated to have a fast determination of the geometry of a cell and obviously of the potential defects that may affect this given cell. Depending, on the geometry parametric failure scenario, different surface plots are generated in order to debug the geometry defect. The failure scenarios are based on the knowledge of the fabrication process, with the different mask levels and all process operations. Some of these scenarios are mentioned in examples Table 1.

Scenario	Parameters involved
1. Active etching defect	W
2. FG etching defect	Wpp, L
3 Oxide growth defect	Tono, Tox
4. Implant defect	L
Etc …	

Table 1 : Overview of some failure scenarios.

First of all, the three threshold voltages values have to be obtained. In the example given, they are simulated with ELDO for a defective geometry (reduced Tox value) of the cell. This three threshold values are given as follow $V_{Tvirgin}$ = 3.24 V, V_{Terase} = 2.21 V and V_{Twrite} = 6.02 V.

Knowing this three threshold values, the plots corresponding to each defect scenario are generated. The result for the scenarios 2 and 3 are respectively given Fig.3 and 4. In all cases, except the parameters involved in the plot calculation, all the others geometric parameters of the cell remain to the target of the technology. In the Fig.3, a floating gate etching defect is suspected, so the three threshold voltages are calculated versus Wpp and L. And none single values of

this both parameters appears to match with all the three threshold voltages in the same time. In the Fig.4, an oxide growth defect is suspected, so the three threshold voltages values are calculated versus the Tox and Tono parameters values. From this plot, it appears that a small range of Tox and Tono values allows matching with the three threshold voltages. The scenarios results show that the behavior of the cell, i.e. the threshold voltages values, is due to a cell affected by an oxide thickness reduction. This validate our diagnosis approach, because the threshold voltages, where obtained with ELDO simulations of a cell with a low Tox.

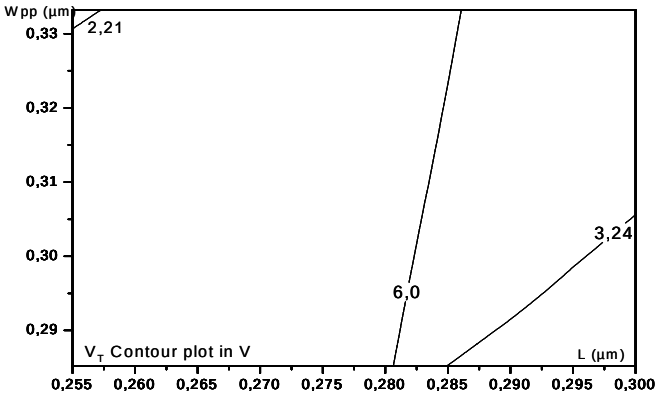

Figure 3: Scenario 2 result (VT vs Wpp & L)

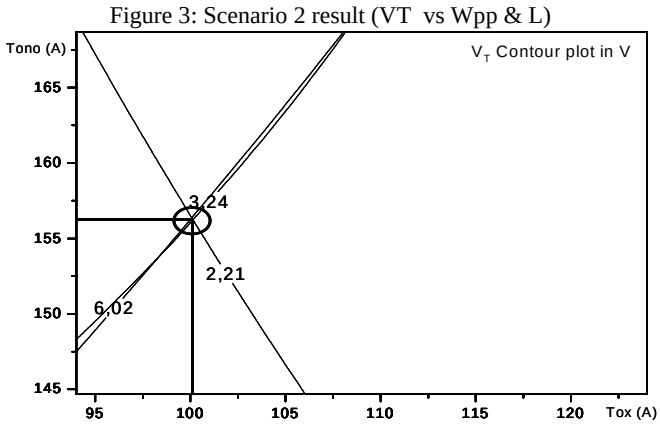

Figure 4: Scenario 3 result (V_T vs Tox & Tono)

Conclusion

Flash Memories are based on analog cells, that leads to critical problems of process control and design. In this paper, a polynomial model of the different threshold voltages of the cell versus its geometry is proposed. This model allows to fast calculate the threshold voltages versus one or two geometric parameters depending on different failure scenarios, in order to have a fast debugging help during the parametric test. The on going perspective of this work, are to finish to validate this approach with silicon data, and to develop a complete diagnosis tool that will take into account any geometric defect avoiding the use of scenario and so speeding up the diagnosis process.

References

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