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# Distributed-cycling Effects for Data Retention Characteristics of Flash Memories

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**Abstract**

The dependence of the distributed-cycling effects on data retention characteristics of flash memories with NAND type operation on the cycling temperature and interval was investigated. The slope of Vt shift curves in the logarithm of bake time changes with the cycling temperature regardless of the cycling interval. On the other hand, the time offset of Vt shift curves changes with the cycling interval regardless of the cycling number. These phenomena are qualitatively explained by the tunneling front model. Using these results, data retention time with a long cycling interval can be predicted from a very short time cycling test in low temperature.

## Introduction

Recently, the distributed-cycling effect on data retention characteristics of NOR type flash memories was reported [1]. It assumes that Vt shifts logarithmically with bake time and the cycling rate, or the cycling interval, only affects to the x-intercept of the Vt shift curve in the logarithm of bake time, which is named a time offset in this paper. The same slope is also assumed independent of cycling conditions, the cycling temperature and interval, and slope changes are not considered in data analysis. It assumes the slope changes only by the cycling number.

The tunneling front model (TFM) [2] is widely accepted to explain MOSFET's Vt shift due to charge de-trapping from the gate oxide. According to the model, in case of uniform charge density, Vt shifts logarithmically with bake time and its slope is proportional to the trapped charge density. The gate oxides under different degraded conditions shows different slopes of Vt shift curves. We observed this phenomenon in the NAND flash memory cells with the different cycling temperatures even with the same cycling number. Fig.1 shows Vt shifts of cycled memory cells in the different temperatures with the same cycling interval of 2 minutes and cycling number of 3.6K. A high temperature cycling condition induce a steeper slope, which means a higher temperature cycling generates a higher charge density. This difference of the slopes is very important to decide the data retention lifetime. And this change is not expressed by single activation energy, since temperature acceleration changes with Vt shift value. This is one of the main subjects of this paper. Fig.1 also shows the cycling temperature much affects the horizontal positions, or the time offsets, of Vt shift curves. The time offset dependence on the cycling temperature and interval is another subject of this paper.

## Experimental

Experiments were performed on a giga-bit class memory array with NAND type operation. One cycling and bake condition is applied to a part (2G cells unit) of large array. 3.6k cycling were performed in temperature ranging from 25$^{o}$C to 85$^{o}$C with the cycling interval ranging from 0.5 minutes to30 minutes. In order to investigate a cycling number effect, 1.2k cycling was also performed. Retention bake was performed at 85$^{o}$C. Vt shift was measured at the Vt distribution edge, which was defined by Vt of 10000$^{th}$ cell from the lowest Vt cell. For longer cycling interval conditions, so called final 10% method [1] was applied.

## Results and analysis

### *A. Experimental results and tunneling front model (TFM)*

Fig.2 shows representative experimental results of Vt shift with the cycling intervals of 2 minutes and 30 minutes. Each pair of Vt shift curves, which composed of 1.2k cycling and 3.6k cycling with the same cycling temperature and interval, crosses around Y=2 - 3 (in a.u.), except 85$^{o}$C. A higher temperature cycling moves the crossing to longer time and increases the slope. Of course a higher cycling number also increases the slope. In this paper we defined the time offset as the time of extrapolated Vt shift curve have a value of Y=2.5.

These phenomena are qualitatively explained by TFM as shown in Fig.3. According to TMF, charge de-trapping occurs from oxide surface and the de-trapping of charges in deep region takes long time. On the other hand in FN tunneling stress, it is known that electrons are trapped uniformly in the gate oxide. Then after the distributed-cycling stress, the electron density near the surface is low and that of deep region, where electrons are only accumulated without de-trapping, is high. It is also known that high temperature accelerates both electron de-trapping from surface and trapping in deep region. Schematic profiles of the trapped electron density after different temperature cycling are shown in Fig.3(a). An electron density profile after high temperature cycling has deeper low-density region and higher density in the deeper region. Corresponding Vt shift curves are shown in Fig.3(b). After higher temperature cycling Vt shift starts after a longer time offset and has a steeper slope. A higher cycling number only increases electron densities in deeper region and results in the steeper slope of Vt shift curve with the same time offset, which is illustrated with dotted lines in the Fig.3(b). .

### *B. Slope analysis*

Fig.4 shows the Vt shift slope dependence on the cycling interval. The slope seems to be independent of the cycling interval and decided only by the cycling temperature and number. Then average slopes on intervals are used for the slope analysis.

Fig.5 shows Arrhenius plots of slopes of the Vt shift curves. The temperature dependence of slope is small and Ea is between 0.03-0.05eV. The pre-exponential factor for 3.6k cycling is two times bigger than that of 1.2k cycling. It may means that a saturation tendency appears after 1.2k cycles.

### *C. Time offset analysis*

Fig.6 shows the time offset dependence on the cycling interval. The cycling interval dependence of the time offset is almost the same at the temperature lower than 60$^{o}$C, which is m= 0.4. The time offset is independent of the cycling number, except 85$^{o}$C. Temperature acceleration of the time offset is almost the same at the temperature lower than 60$^{o}$C, irrespective of the cycling interval. The temperature dependence has an activation energy of about Ea= 0.5eV. The Ea seems to be larger at the temperature higher than 85$^{o}$C and this tendency becomes larger at the higher cycling number.

## Conclusions

The distributed-cycling experiments were performed including the conditions of a long time interval and low temperature. The dependence of the slope and the time offset of Vt shift curve on the cycling temperature and interval is fully explained by the tunneling front model (TFM). As predicted by TFM, the slope becomes steeper in higher temperature cycling regardless of the cycling interval. The time offset changes with the cycling interval and temperature regardless of the cycling number. Using the parameters which are obtained in this paper, the result of a certain cycling condition can be converted to that of other cycling condition in the temperature range lower than 60$^{o}$C. You do not have to do a long time cycling test to estimate data retention lifetimes with long cycling interval applications.

**Acknowledgement**

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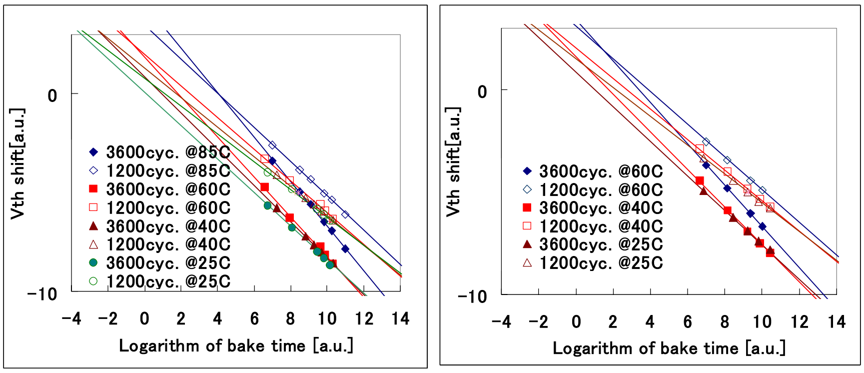
**References;**[1] N. Mielke et.al.,IRPS.,29(2006), [2] S. Manzini et.al., "Ins. films on semic.",112(1983).




(a) (b)

Fig.2 The dependence of Vt shift curve on the cycling numbers and temperature. The cycling intervals are 2min.(a) and 30min.(b).

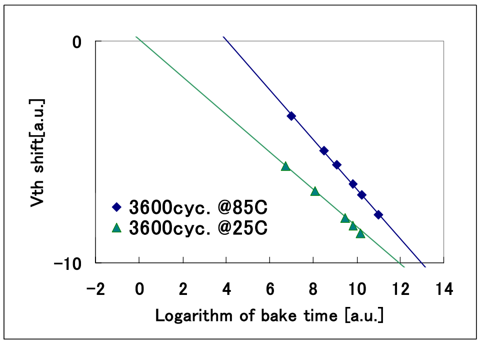



Fig.1 The cycling temperature dependence of Vt shift curve

In higher cycling temperature, the slope is steeper. This phenomenon cannot be expressed by single activation energy.

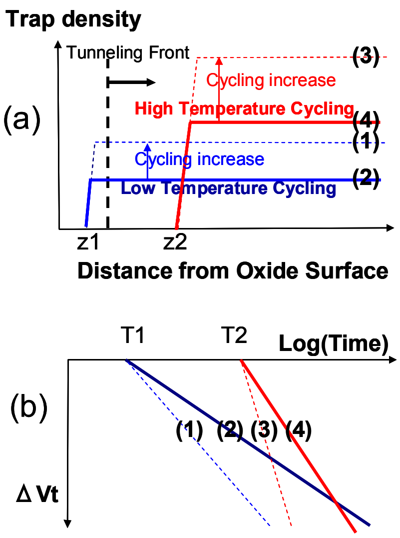



Fig.3 The tunneling Front Model

(a) Profiles of electron trap density.

(b) Vt shift curves corresponding to the profiles of (a). Numbers on the Vt shift curves indicate the corresponding profile curve of the same number. Higher temperature cycling increases the low electron density region (z1 to z2) and the density in deeper area((2) to (4) in (a)), which induces the longer time offset (T1 to T2) and steeper slope((2) to (4) in (b)). More cycling numbers also induce higher trap density and the steeper slope (solid line to dotted line).

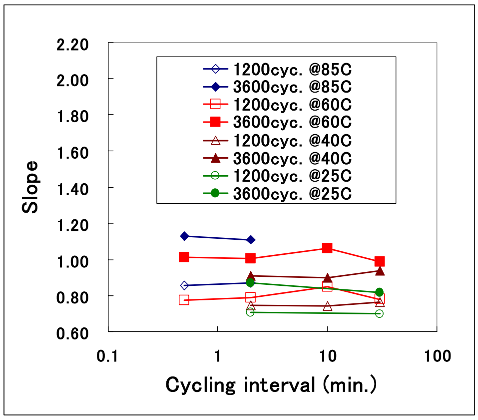



Fig.4 The cycling interval dependence of the slope

The slopes of Vt shift curves has little dependence on the cycling interval.

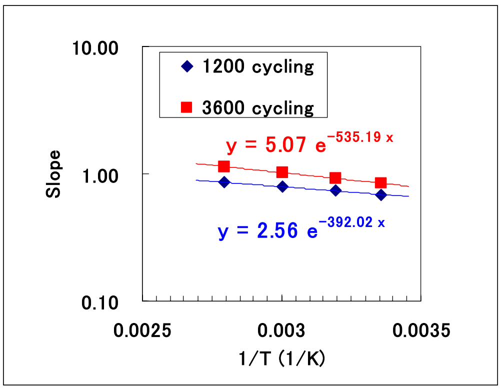



Fig.5 The temperature dependence of the slope

The slope of Vt shift curve has a little dependence on temperature. Ea=0.03eV for 1.2k cycling and Ea=0.05eV for 3.6k cycling. Pre-exponential factor of 3.6k cycling is twice of that of 1.2k cycling..

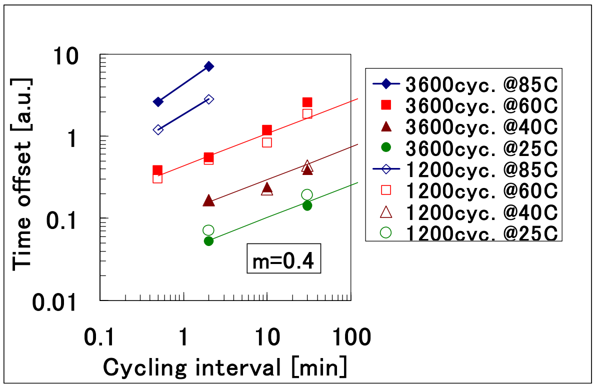



Fig.6 The time offset dependence on the cycling interval and temperature

The time offset dependence on the cycling interval is m=0.4, and is independent of the cycling number when temperature is lower than 60°C. At 85°C, the dependence on the cycling interval is larger than that of lower temperature and the dependence on the cycling number can be seen. The temperature dependence has an activation energy of Ea=0.5eV in temperature range lower than 60°C regardless of the cycling interval. The Ea seems to be larger at higher temperature of 85°C. This tendency is larger at the cycling numbers of 3.6k than that of 1.2k.