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A Method of Predicting Retention Lifetime of EEPROM by Voltage Acceleration

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1. Introduction

Increasing charge retention lifetime is one of the most important issues in the operation of EEPROM and it is required to be guaranteed for long time more than ten years. In general, the charge retention lifetime is measured at high temperatures,[1)] typically raging from 200°C to 300°C, and the lifetime in the practical temperature is predicted by using activation energy extracted from its temperature dependence. Although this conventional method is often used, it requires very long time for the measurement. Furthermore, the obtained activation energy often shows difference depending on the measurement temperature so that the lifetimes predicted from the activation energy in the high temperature range are frequently overestimated.[2)] On the other hand, it has been reported that the retention characteristics can be evaluated by the voltage acceleration method,[3)] in which the voltage is applied to the control gate or drain of EEPROM.

In this work, we developed a novel characterization method which allows us to predict the charge retention lifetime of EEPROM more easily and in shorter time, compared to the previous method. The parameters are carefully extracted from the accelerated voltage dependence of the charge retention time.

2. Charge Retention Model

During the operation of EEPROM, charges stored in the floating gate decreases due to small leakage currents which flow in the tunnel oxide. Thus the time-dependent floating gate voltage $V_{FG}(t)$ can be expressed by the following equations[4)].

$$V_{FG}(t) = V_{FG0} - \frac{\alpha}{C_{FG}} \int_0^t J_L(t)dt \cdots (1a)$$

,

$$V_{FG0} = \alpha \cdot \left(V_{CG} - \frac{Q_0}{C_{FG}} \right) \cdots (1b)$$

where $J_L(t)$ is the time-dependent leakage current, V_{CG} is the control gate voltage, C_{FG} is the capacitance between the control gate and the floating gate, Q_0 is the charges stored in the floating gate, and α is the coupling coefficient.

By solving the equation (1a), we obtained the threshold voltage as a function of time by the following equation.

$$V_T(t) = V_{T0} - P1 \cdot \ln\left(1 + \frac{t}{P2}\right) \cdots (2),$$

where P1 and P2 ($=P1 \cdot C_{FG}/J_{L0}$) are fitting parameters and V_{T0} and J_{L0} is respectively the initial threshold voltage and leakage current. Since the charge retention lifetime (time to failure; TTF) is defined as the duration in which a certain amount of the threshold voltage shift ΔV_T is observed, it is expressed as

$$TTF = P2 \cdot \left[\exp\left(\frac{\Delta VT}{P1}\right) - 1 \right] \cdots (3).$$

3. Experiment

The devices used in this experiment were made by 0.65-μm-rule CMOS technology with 10×12 arrays EEPROM. A negative voltage was applied to the control gate after 100,000 times erase/write cycle, and the threshold voltage as a function of time was measured. The voltage applied to the control gate ranged from −4V to −8V. The parameters were extracted by fitting data using the equation (2). TTF at each applied voltage was calculated from the extracted parameters and then the applied voltage dependence of TTF was obtained.

4. Result & Discussion

Figure 1 shows the measured threshold voltages (V_T) depending on the retention time at various control gate voltages (V_{CG}).

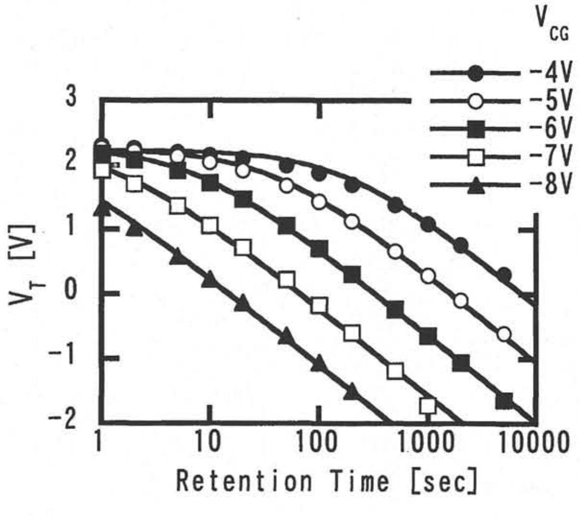

Fig. 1. Threshold voltages (V_T) depending on the retention time at various control gate voltages (V_{CG}).

The data at each V_{CG} were fitted by the solid curves derived from the equation (2). From this fitting, the parameters P1 and P2 are extracted and, as a result, TTFs calculated from the equation (3) using P1 and P2 as a function of V_{CG} are shown in Fig. 2.

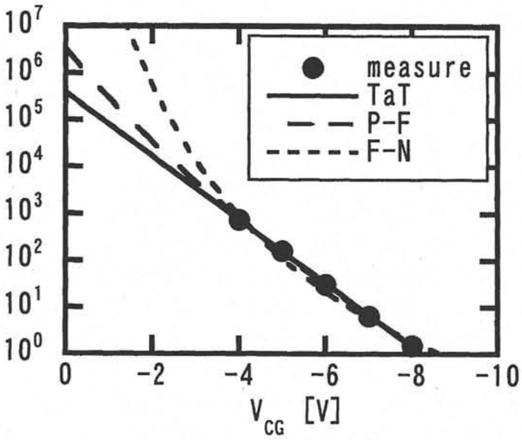

Fig. 2. Charge retention lifetime (TTF) as a function of V_{CG}. Fitting curves derived from the calculations based on three charge conduction models are also shown in the figure.

Since the actual lifetime can be obtained by extrapolating the data points to a V_{CG} value of 0 V, it critically depends on the function exhibiting the relationship between the TTF and V_{CG}. In this analysis, we employed the following three charge conduction models[5] in the tunnel oxide to explain the V_{CG} dependence of TTF: trap assist tunnel (TaT), Poole-Frenkel (P-F), and Fowler-Nordheim (F-N). These are expressed as the following equations.

$$\text{TaT: TTF} = M1\cdot\exp\left[-B1\cdot\alpha\cdot\left(\left|V_{CG}\right| + \Delta V_{T0}\right)\right]\cdots(4),$$

$$\text{P-F: TTF} = M2\cdot\exp\left[-B2\cdot\sqrt{\alpha\cdot\left(\left|V_{CG}\right| + \Delta V_{T0}\right)}\right]\cdots(5),$$

$$\text{F-N: TTF} = M3\cdot\exp\left[\frac{B3}{\alpha\cdot\left(\left|V_{CG}\right| + \Delta V_{T0}\right)}\right]\cdots(6),$$

where M1, M2, M3, B1, B2, and B3 are fitting parameters and α and $\Delta V_{T0}(=Q_0/C_{FG})$ are constants.

The results of fitting are also shown in Fig. 2. It can be clearly seen that both the TaT and the P-F models explains well the measured V_{CG} dependence of TTF. However, the difference between these two models is not so clearly found by the curve fitting. Therefore, in order to confirm which model well-explains the TTF behavior, we measured the charge retention characteristics under the actual condition, i.e., V_{CG}=0 V. Figure 3 shows the measured threshold voltage shift depending on the retention time. Calculated curves are also shown for the aforementioned three models. From this result, it is found that only the P-F model accounts for the observed charge retention characteristics. Furthermore, the obtained value of the lifetime for the P-F model is observed to be that for the TaT model.

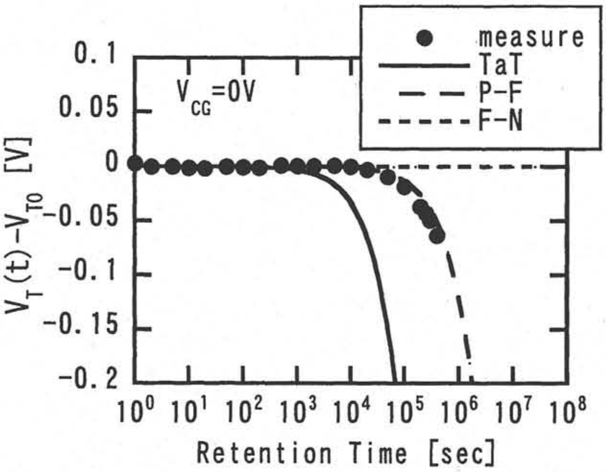

Fig. 3. Threshold voltage shift (ΔV_{CG}) measured under an actual condition of V_{CG}=0 V. Fitting curves derived from the calculations based on three charge conduction models are also shown in the figure.

As shown in Fig. 2, there was ambiguity to determine the value of TTF at V_{CG}=0 V by using fitting curves derived from the TaT and the P-F models. However, since the value for the TaT model is approximately 10 times shorter than that for the P-F model, the estimation using the TaT model always gives us the lowest value of TTF. This means that our method can avoid effectively the overestimation which is one of the problems in the previous method.

4. Conclusions

We have developed a simple characterization method of the charge retention lifetime of EEPROM. The method is based on the voltage acceleration to the devices and the model fitting of the experimentally obtained data to evaluate the retention lifetime. It has been demonstrated that our method can greatly shorten the measurement time compared to the previous temperature acceleration method.

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References

[1] S. Aritome *et al.*, IECE Trans. Electron., E77-C (8), 1994, p.1287

[2] C. Papadas *et al.*, IEEE Trans. Electron Devices, 42 (4), 1995, p.678

[3] S. Satoh *et al.*, IEEE Trans. Electron Devices,45 (2), 1998, p.482

[4] S. T. Wang IEEE Trans. Electron Devices, ED-27 (1), 1980, p.297

[5] P. J. Kuhn et al., IEEE Proc. IRPS, 2001, p266