Influence of the Poole-Frenkel Effect on Programming and Erasing in Charge Trapping Memories

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Abstract

In this work, we included Poole-Frenkel (P-F) detrapping mechanism to our simulator to calculate programming/erasing characteristics of charge trapping memory, and comprehensively analyze the impacts of temperature, trap depth and parameters of P-F model on program window and erasing speed. Our results reveal that Poole-Frenkel effect could accelerate the erasing operation, but it also could reduce the program window and cause the electric characteristics sensitive to temperature.

1 Introduction

SONOS type charge trapping memory (CTM) becomes a competitive candidate for future non-volatile memory [1]. Poole-Frenkel (P-F) effect is believed to be one of the dominant mechanisms of charge detrapping which is important to CTM [1-2]. However, few works evaluate the influence of P-F effect on the operation of CTM especially during programming and erasing. In this work, we systematically investigate the impacts of P-F effect on operational characteristics of CTM with various temperature and model parameters of P-F effect.

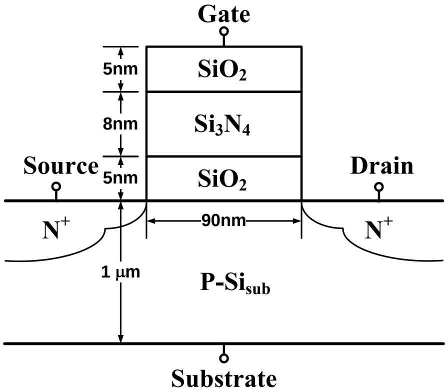

Figure 1: Cross section of a typical SONOS device used in this work.

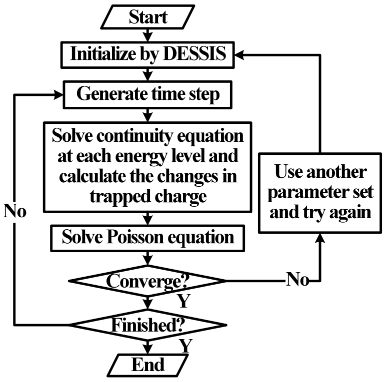

Figure 2: The flowchart for calculating the trapped charge in Si_3N_4

2 Simulation Method

The structure of CTM is shown in Fig. 1. The basic flowchart of the program is shown in Fig.2. After obtaining the initial potential distribution by MESH and DESSIS, the program can simulate programming/erasing operation self-consistently for a 2D SONOS device with arbitrary trap state profile in charge storage layer. Fig. 3 and Fig. 4 show the results obtained from the program.

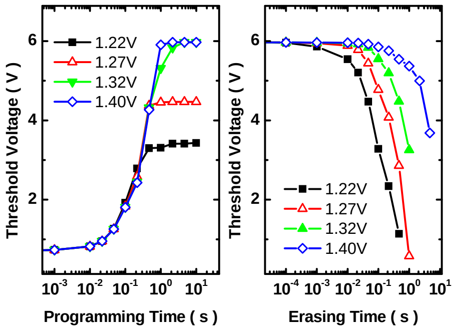

Figure 3: Programming/erasing curves with different trap depth

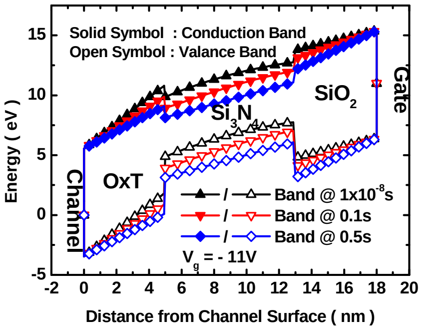

Figure 4: Band diagram of gate stack under different erasing pulse width.

3 Physical Models

For the single-center P-F effect [3] (Fig. 5), the barrier shape is modified (1) by trapped charge, where $E_c(x)$ (dash line in Fig. 5) is the conductive band without P-F effect. The ionization energy $q\Phi_t$ is reduced by applied electric field as (2) predicts. The emissivity of the trapped carriers is given by (3), where ν_0 is referred as the attempt to escape frequency.

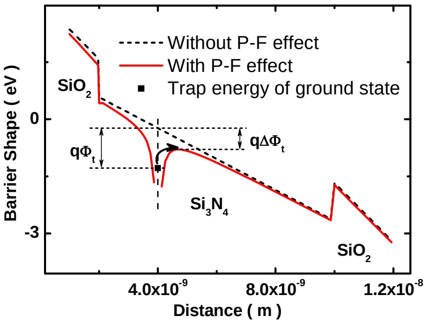

Figure 5: Illustration of the Poole-Frenkel effect.

Parameters	Units	Value
σ_e	cm^2 X	5.0
$\nu_{e,h}$	Hz X	1.0
$q\phi_e$	eV	1.22
$q\phi_h$	eV	1.25
$N_{trap,h,e}$	cm^{-3} X	2.0
$N_{channel}$	cm^{-3} X	1.0
$V_{d,read}$	V	2.0

Table 1: Default parameters used in this work.

$$E_{c.P-F}(x) = E_c(x) - q^2(4\pi\varepsilon_0\varepsilon_{Si_3N_4}|x|)^{-1} \quad (1)$$

$$q\Delta\Phi_t = q^{3/2}(E/\pi\varepsilon_0\varepsilon_{Si_3N_4})^{-1/2} \tag{2}$$

$$e_{P-F} = \nu_0 \exp\left[-(q\Phi_t - q\Delta\Phi_t)/\kappa T\right] \tag{3}$$

The other fundamental models, such as tunneling model and capture/emission models, are the same as those in [4-5]. The default model parameters are listed in Table I.

4 Results And Discussions

P-F effect enhances the possibility of trapped charge to escape from trap. Fig. 6 shows the impact of P-F effect on trapped charge distribution. During the beginning of programming, the influence of P-F effect can be ignored due to low trapped charge density. When trapped charge density goes high, P-F effect plays an important role. Thus the programming speed is not affected by P-F effect, but the programmed V_{th} is reduced (Fig. 7).

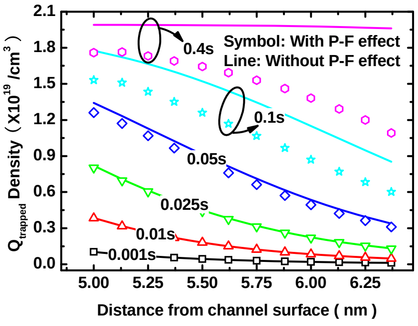

Figure 6: The impact of Poole-Frenkel effect on trapped charge distribution when porgramming.

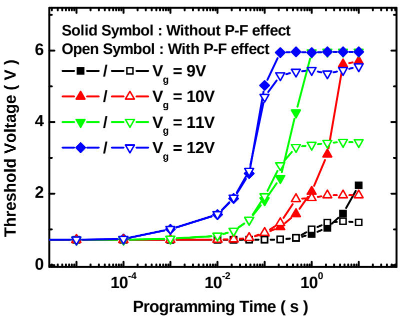

Figure 7: The effects of Poole-Frenkel on programming characteristic.

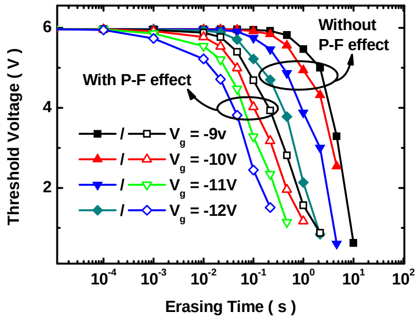

Figure 8: The effects of Poole-Frenkel on erasing characteristic

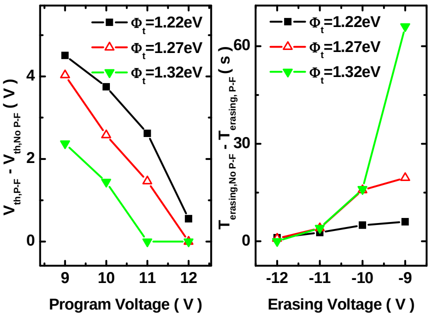

Figure 9: The impact of Poole-Frenkel effect on Vth and erasing time reduction.

When erasing, P-F effect dramatically accelerates the erasing operation (Fig. 8). From Fig. 9 we could see that high program voltage weakens the impact of P-F effect on

ΔV_{th}, and so do large $q\Phi_t$. The extent of P-F effect improvement in erasing speed depends on both program voltage and trap depth (Fig. 9). Smaller program voltage and trap depth yield larger improvement in erasing speed.

Fig. 10 shows the impacts of temperature and attempt to escape frequency on ΔV_{th}. The relationship between ΔV_{th} and temperature is almost linear and ΔV_{th} is more sensitive to ν_0 in the range of $1x10^{10}$~$5x10^{10}$ Hz than in $1x10^{11}$~$1.5x10^{11}$ Hz. Larger ν_0 and higher temperature means larger emissivity, so larger ν_0 and higher T are corresponding to shorter erasing time (Fig. 11).

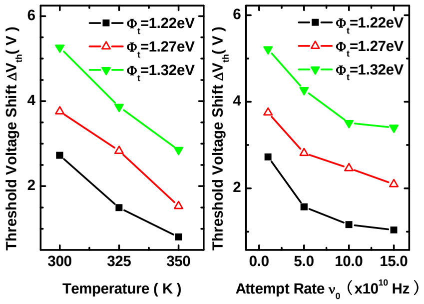

Figure 10: The effect of temperature and attempt to escape rate on Vth shift.

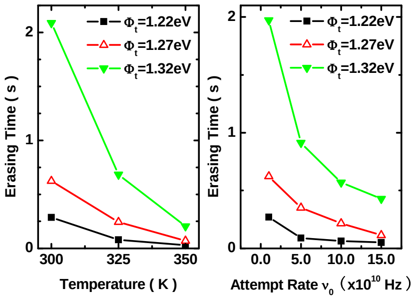

Figure 11: The effect of temperature and attempt to escape rate on erasing time.

5 Conclusion

Poole-Frenkel detrapping mechanism could largely reduce the program window, accelerate the erasing operation and induce strong dependence on temperature to the device. Higher program/erase voltage could weaken the impact of P-F effect. Erasing speed could benefit most from P-F effect with deeper trap depth.

Acknowledgement

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References

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