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A Simple Model for the Switching Behavior of a SONOS EEPROM Device

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A simulation program, which shows an excellent accuracy to predict the device programming operation, has been developed. The carrier transport model was incorporated with a field dependent tunneling probability, which is deduced from WKB approximation, and used the Fermi-dirac statistics. Using the J-E and accompanying with the Arnett's trapping model, the switching behavior can be predicted with an accuracy of 5 % tolerance in a very wide range of writing time from 1 us to 0.1 s.

1.INTRODUCTION

Due to the simple fabrication process and excellent reliability, the SONOS (polySilicon - Oxide - Nitride - Oxide - Silicon) EEPROM has taken much attention recently. Composing of a conventional structure with ONO layer as a storage site, the SONOS EEPROM possesses a good performance including rapid write and erase speed. The data retention and endurance are also good.

As a memory cell, the programming behavior is very important. There are numerous reports on the switching behaviors of the MNOS devices. D. Forhman and M. Lenglinger proposed [1)] that the charge is stored in oxide/nitride interface and solved numerically the continuity equation to explain the switching characteristics of MNOS devices with a thick bottom oxide (>5.0nm). J. J. Chang used the charge centroid concept and calculated the injection current by the modified Fowler-Nordheim tunneling. [2)] Chang's model gave a good comment on charge transfer mechanism of MNOS devices. But it is only a mathematical formulation and never verified. In our study we developed a simple model and have been shown that it can describe the experimental results accurately.

2. FABRICATION PROCESS

The main difference between a SONOS device and a conventional CMOS device is the composition of gate dielectrics. SONOS devices apply triple insulating layers of bottom oxide, nitride, and top oxide to the gate insulator. In this study, the thickness of bottom oxide was about 2.2 nm, which was grown thermally at 750 $^{\circ}C$ with 1 % dry O_2 diluted in N_2 ambient for 35 minutes. Nitride was deposited by LPCVD with an ammonia (NH_3) : dichloro - silane (SiH_2Cl_2) of ratio 5:1 for 16 minutes at 800$^{\circ}C$. After nitride deposition, wafers were thermally oxidized in steam at 950$^{\circ}C$ for 60 minutes, and the top oxide of 4.0 nm was obtained in final. Nitride was consumed during thermal reoxidation and the thickness of nitride was reduced to 17.8 nm.

3. Model

The model is based on a rectangular potential barrier approximation for electron tunneling probability calculation, which is deduced by Ross and wallmark. [3)] It was used by Chang for modified Fowler-Nordheim tunneling calculation. However, in the high field, as the programming operation range in SONOS devices, it is no longer valid. From WKB approximation we can calculate the tunneling probability. As a result of secondary approximation, a field dependent tunneling formula was derived. It may be written as

$$P(W,E) = \exp(A*E)*\exp(\frac{W}{\lambda})$$

where $A = \frac{\sqrt{2mq}\ W^2}{2\bar{h}\ \sqrt{\varphi}}$,

$\lambda = \frac{\bar{h}}{\sqrt{8mq\varphi}}$,

and $m, q, \varphi, \bar{h}$, are the electron mass, charge , potential barrier height, Planck's constant, respectively. W is the effective barrier width, which is determined by barrier shape. There is a additional item in this equatilon, exp(A*E), when compared with rectangular barrier approximation. Accompanied with Fermi-Dirac statistics the J-E can be derived as

$$J = B * P$$

where $B = \frac{4\pi m}{h^3} \left(\frac{2\varphi}{AE + \frac{W}{\lambda}} \right)^2$.

In order to characterize the switching behavior of the SONOS EEPROM device, the Arnett's charge trapping model [4], was used. The trapped charge density can be written as

$$N(x,t) = \frac{Nt}{1 + \frac{\exp(\sigma Q)}{\exp(x/x_o) - 1}}$$

where

x: distance from injecting electrode;

Nt: total traps density;

σ: trapping cross section;

Q: total injection carrier density, which is a function of time;

and $x_o = \frac{1}{Nt\ \sigma}$.

4. Results and discussion

Using the above method, the J-E can be solved. As described by Chang , there are four different tunneling mechanisms: modified Fowler-Nordheim , direct, Fowler-Nordheim tunneling, and hot carrier emission, each responding to different potential levels. It had been calculated with different tunneling oxide thicknesses as parameters, and the results were plotted in Fig.1 and Fig.2. Due to the barrier width is still a constant in direct tunneling dominate region, the current density, which calculated by rectangular barrier approximation, in Fig.1 show a saturation trend in higher field region. Fig.2 shows the J-E curves calculated by using Modified rectangular barrier approximation. It can be seen that the current density is no longer a constant, which is more accurate. Thus the J-E was used to calculation according to applied voltage. Then the Q, N(x,t), and Vfb are calculated, and repeat until the write time is reached. There are four simulation parameters: A, B, Nt, σ. With adequate simulation values (as shown in table 1), the simulation results are very consistent to experimental data as shown in Fig.3. Also shown is the simulation results which used rectangular potential barrier approximation. There is a large deviation to experimental data especially in shorter write time. Fig.4 shows the simulated and measured data of Vth shift versus write time under different pulse heights. As we can see, the simulation results are well consistent with experimental data. It should be emphasised that the simulation parameters are reasonable and A is compatible to theoretical calculation. It implied that the switching model is simple and accurate.

5. Summary

We have successfully fabricated a low voltage operation EEPROM by using the SONOS structure. Simple process, low cost, large window, and compatible with CMOS process are the advantages of SONOS devices. In order to characterize the programming behavior, we have introduced a modified rectangular potential barrier approximation to build a charge transfer model of SONOS devices. We have shown this model is more adequate for interpreting the carrier transportation than rectangular potential approximation. The programming simulation results of this model reveal an reasonable accuracy with experimental data. This model is usable to design and optimize a scaled SONOS device.

6. References

1) Forhman-Bentchkowsky and M. Lenglin ger, J. Appl. Phys., vol. 40, pp. 3307-3319, July 1969.
2) J.J. Chang, IEEE Trans. Electron Devices, vol. ED-24, pp.511-518, May 1977.
3) E.C. Ross and J.T. Wallmark, RCA Rev. vol.30, pp.366-381, June 1969.
4) P.C. Arnett, J. Appl. Phys., vol.46 pp. 5236-5243, Dec. 1975.

Nt	σ	A	B
$7.3*10^{18}$	$8.*10^{-13}$	$1.1*10^{-6}$	$5.0*10^{4}$

Table 1. The simulation parameters used in this study.

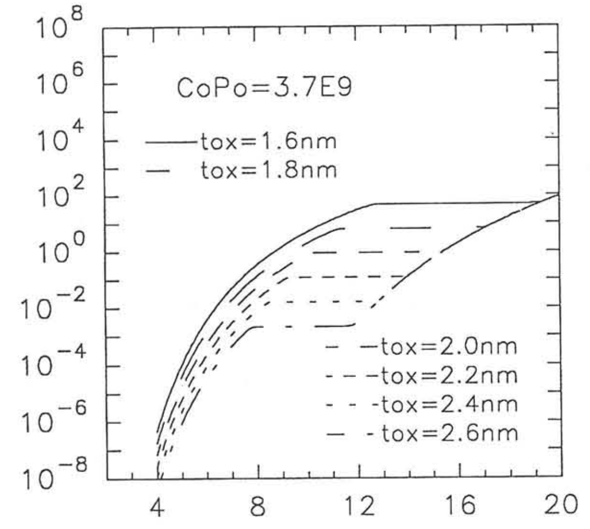


Fig.1 The J−E curves calculated by rectangular potential barrier approximation. CoPo is prefactor in Chang's model.

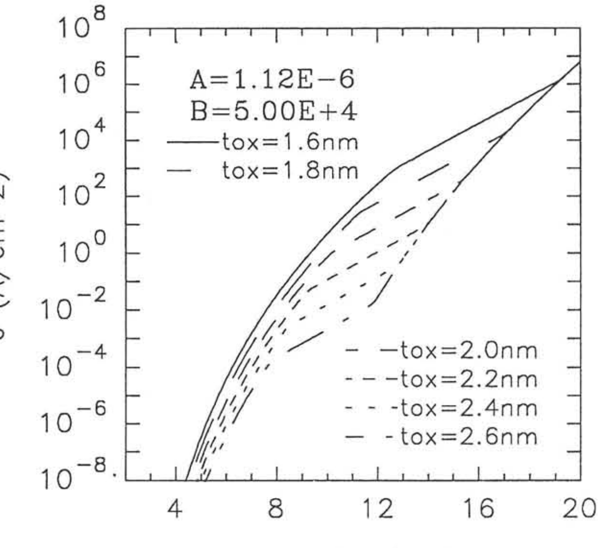
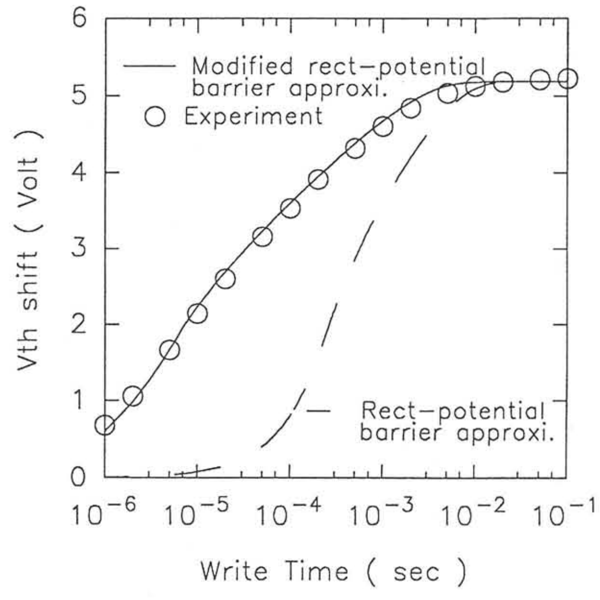


Fig.2 The J−E curves calculated by modified rectangular potential approximation.



Fif.3 The experimental and calculated programming characteristics.

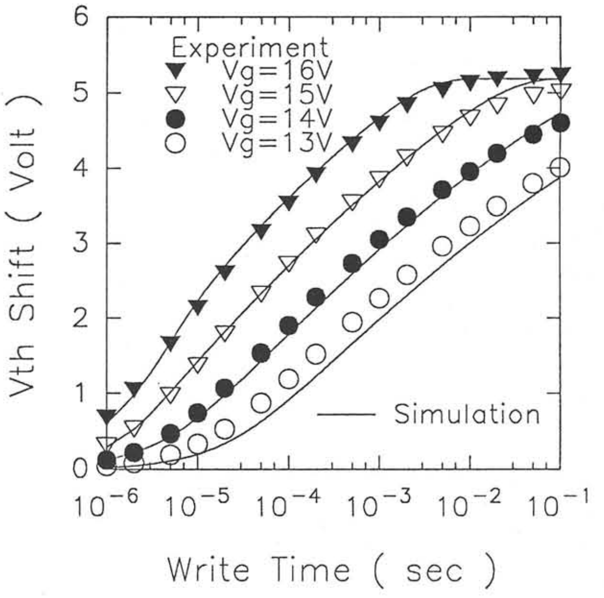


Fig.4 Vth shift versus write time under different pulse heights.