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Retention Behaviour of MNOS Memory Devices with Embedded Si or Ge Nanocrystals – Computer Simulation

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The charge retention behaviour of MNOS structures with embedded Si or Ge nanocrystals are studied by computer simulation. It is obtained that the oxide thickness and the location of nanocrystlas affect the retention behaviour very strongly. The retention time changes from a few ms to several years.

Keywords: Non-volatile memory, MNOS, Tunneling, Retention.

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1. INTRODUCTION

The two basic types of memory elements used in non-volatile (EEPROM and flash) memories are the floating gate and the SONOS (silicon-oxide-nitride-oxide-silicon) field effect transistors (FETs). Floating gate memory arrays face difficulties with technology scale-down. The main problem is that through defects or weak points of tunnel oxide with reduced thickness the whole amount of stored charge carrying the information can be lost. One of the possible solutions is to replace floating gate with separated semiconductor nanocrystals (NCs), which are electrically isolated [1].

But, in SONOS and MNOS (metal-nitride-oxide-silicon) devices (the latter were the first realized memory structures [2]) the charge is stored in traps located in the Si_3N_4 layer close to the Si_3N_4 / SiO_2 interface. In these structures traps are isolated a'priori. However, formation of semiconductor NCs in silicon nitride based structures can enhance their charging and / or retention behaviour, as it was demonstrated first in SONOS structures by Rao and co-workers [3]. Nevertheless, only very few works are devoted to silicon nitride based memory structures with embedded NCs, although it seems obvious to merge the advantages of nanocrystal and silicon nitride based memory devices.

We have studied both MNS (metal-nitride-silicon) and MNOS structures with Si NCs, and compared their memory behaviour with similar reference memory structures without NCs. MNOS structures with embedded Ge NCs has also been studied. For proper locations of NCs in MNOS structures enhanced charge injection and retention properties were obtained [4, 5]. But, in the case of MNS structures the effect of NCs on charge injection properties was just opposite, than it was expected: the memory window shrinked with increasing duration of NC deposition [4, 5].

For the optimization of the memory properties of MNOS structures, an additional thin nitride layer was grown between the oxide layer and the sheet of embedded Ge or Si nanocrytals [5]. Indeed, for these SiO_2 / Si_3N_4 / NC / Si_3N_4 structures much wider memory window was obtained than for the SiO_2 / NC / Si_3N_4 structures with NCs grown at the oxide / nitride interface, prepared by similar way. However, the retention behaviour changed in opposite way. For structures with embedded Si NCs a very short retention time (few seconds) was obtained, while for those with Ge NCs the retention time was close to 4000 years [5].

To understand the origin of these opposite behaviour the charge injection and retention behaviour of SiO_2 / Si_3N_4 / NC / Si_3N_4 and SiO_2 / NC / Si_3N_4 structures were studied by calculation of tunneling probability of electrons and holes to the structure for the case of charge injection (charging voltage pulse applied) [6, 7], and for the case of retention (no bias applied). The results of these simple calculations are in cotradiction with most of the experimental results: both the injection probability and the probability of escape of captured electrons or holes decreases, if NCs are deeper in the nitride layer. In this paper the results of simulation of retention behaviour are presented.

2. RESULTS AND DISCUSSION

The band structure used for simualtions is presented in Fig. 1. The probability of electron (or hole) escape from nanocrystals equals the tunneling probability via the potential barrier determined by the actual electric field, to the substrate or to the nitride conduction (or valence) band. The tunneling probabilities have been calculated by WKB approximation [6, 7].

The probabilities were calculated to both directions, namely towards the metal and towards the silicon substrate. These tunneling probabilities are different due to different electric fields and different potential barriers.

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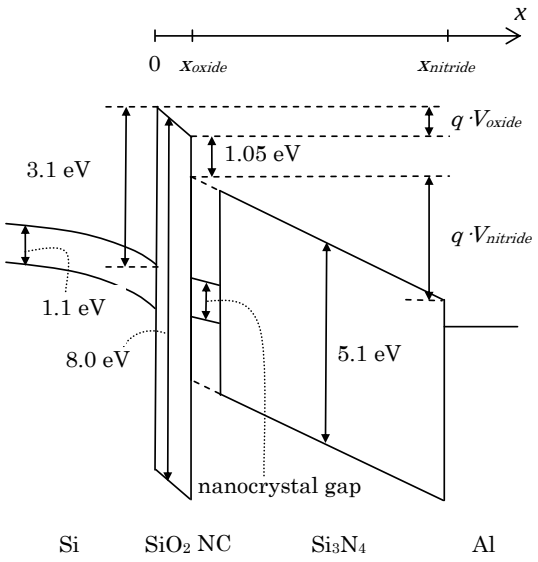

Fig. 1 – Band diagram of MNOS structures with semiconductor nanocrystals used for the calculations

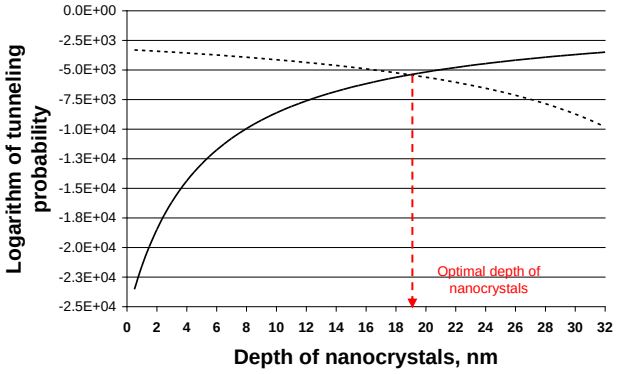

Fig. 2 – The logarithm of electron tunneling probability towards the substrate (dashed line) and towards the metal (solid line) during the escape of electrons from Si nanocrystals as a function of depth of nanocrystals from the oxide / nitride interface. The oxide thickness is 2.5 nm, the nitride thickness is 48 nm

If nanocrystals are close to the oxide / nitride interface, the tunneling probability is much higher towards the substrate, than towards the metal. However, getting nanocrystals deeper into the nitride layer, the probability towards the substrate decreases, while that towards the metal increases, as it can be seen in Fig. 2 for MNOS structures containing Si nanocrystals (the oxide thickness is 2.5 nm, the nitride thickness is 48 nm). The optimal depth of nanocrystals for retention behaviour can be considered as the depth where the tunneling probabilities towards the two directions equal.

But, it was obtained by our earlier calculations that the optimal location of nanocrystals for charge injection is at the oxide / nitride interface. The effect of injected charge on the threshold voltage is decreasing either with deeper location of nanocrystals. So, a compromise has to be made between these two opposite requirements.

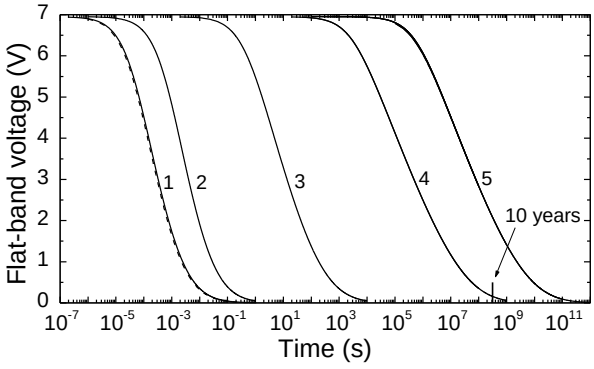

Fig. 3 – The change of flat-band voltage (absolute value) due to charge escape from the nanocrystals. The initial charge is $\pm 10^{13}$ q/cm^2 ($\pm 1.6 \times 10^{-6}$ C/cm^2) for holes and electrons, respectively. 1 – nanocrystals located at the oxide / nitride interface, oxide thickness 2 nm, electron escape from Si or Ge, hole escape from Si (three dependences very close to each other), 2 – nanocrystals located at the oxide / nitride interface, oxide thickness 2 nm, hole escape from Ge, 3 and 4 – nanocrystals located at the oxide / nitride interface, oxide thickness 3 nm or 4 nm, respectively, electron escape from Si, 5 – nanocrystals located at a depth of 3 nm from the oxide / nitride interface, oxide thickness 2 nm, electron escape from Si

The representative results of simulation of retention behaviour are presented in Fig. 3. The depth of potential well, i.e. the material of nanocrystal (Si vs. Ge) does not influence the retention time very much, but the oxide thickness and location of nanocrystals exhibit a great effect. The retention time for electron escape varies about 10 orders of magnitude from several hundred microseconds to several months, while the oxide thickness changes from 2 nm to 4 nm, if nanocrystals are located at the nitride/oxide interface. Even higher effect is obtained for the same oxide thickness, but different depth of nanocrystals in the nitride layer (compare curves 1 and 5). So, there is a very sharp dependence of retention behaviour on the oxide thickness and location of nanocrystals.

Another issue is the escape of charge carriers during reading of the information. As the electric fields are higher during reading, the tunneling probabilities are much higher yielding much faster loss of charge holding the information. Therefore, the reading process has to be as short as possible.

3. RESULTS AND DISCUSSION

The retention behaviour of MNOS structures with embedded Si or Ge nanocrystals have been studied by computer simulation. It has been obtained that the oxide thickness and the location of nanocrystals affect the retention behaviour very strongly. The retention time changes from a few ms to several years. The deeper the location of nanocrystals the longer the retention time.

REFERENCES

1. Zs.J. Horváth, P. Basa, T. Jászi, A.E. Pap, L. Dobos, B. Pécz, L. Tóth, P. Szöllősi, K. Nagy, *J. Nanosci. Nanotechnol.* **8**, 812 (2008).
2. D. Frohman-Bentchkowsky, M. Lenzlinger, *J. Appl. Phys.* **40**, 3307 (1969).
3. R.A. Rao , R.F. Steimle, M. Sadd, C.T. Swift, B. Hradsky, S. Straub, T. Merchant, M. Stoker, S.G.H. Anderson, M. Rossow, J. Yater, B. Acred, K. Harber, E.J. Prinz, B.E. White Jr., R. Muralidhar, *Solid-State Electron.* **48**, 1463 (2004).
4. Zs.J. Horváth, P. Basa, *Mater. Sci. Forum* **609**, 1 (2009).
5. Zs.J. Horváth, P. Basa, *Nanocrystals and Quantum Dots of Group IV Semiconductors*, (Eds. T.V. Torchynska, Yu.V. Vorobiev), (American Scientific Publishers: 2010).
6. Zs.J. Horváth, K.Z. Molnár, Gy. Molnár, P. Basa, T. Jászi, A.E. Pap, R. Lovassy, P. Turmezei, *phys. status solidi c* **9**, 1370 (2012).
7. Zs.J. Horváth, P. Basa, T. Jászi, K.Z. Molnár, A.E. Pap, Gy. Molnár, *Appl. Surf. Sci.* **269**, 23 (2013).