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Proposal of New Non-Volatile Memory with Magnetic Nano-Dots

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1. Introduction

Demand to a high density and high performance nonvolatile memory has rapidly grown as the market for mobile information devices has expanded. Flash memory is the nonvolatile memory most widely used in current mobile information devices. However, there is a big concern in Flash memory that the programming and erasing speed is very low. Meanwhile, MRAM has recently attracted considerable attention due to its non-volatility and high programming speed. However, there is a concern in MRAM that a memory cell size is large. In order to overcome these problems in Flash memory and MRAM, we propose a new non-volatile memory with magnetic nano-dots (MND) dispersed in an insulating film as a charge retention layer. We call this new non-volatile memory MND memory. In this paper, fundamental characteristics of MND memory are presented.

2. Basic Structure of MND Memory

Fig.1 shows a cross-sectional structure of MND memory. As is obvious in the figure, MND film is inserted between control gate and Si substrate in MND memory. Extremely high density of magnetic nano-dots are dispersed in the MND film. Each magnetic nano-dot acts as a small floating gate (floating dot gate). A very thin tunnel oxide is inserted between the control gate and MND film and a block oxide is inserted between MND film and Si substrate. The charge injection into MND and emission from it are performed between the control gate and MNDs. The control gate acts as a free layer for magnetic writing that consists of a ferromagnetic material while MND acts as a magnetic pinned electrode because the magnetic switching field for MND is very high due to its extremely small size. The electron tunneling probability between the free layer and pinned MND electrode changes depending on the relative magnetic polarization, parallel or anti-parallel, of the free layer with respect to the pinned MND electrode. The tunneling probability is high for parallel polarization and low for anti-parallel polarization. The polarity of magnetic polarization in the free layer can be changed by the superimposed magnetic field that is produced by both currents flowing through the word line and bit line. The bit line is formed underneath the buried oxide as shown in Fig.1. This structure can be formed by using SOLK (Silicon-On-Low K substrate) technology that we proposed before [1]. Electrons can be injected from the free layer to MNDs by applying a high voltage to the source line or drain line maintaining the word line at the relatively low voltage when the magnetic polarization is parallel (Writing or Programming). After writing, the magnetic polarization is changed back to anti-parallel for the charge retention. On the other hand, electrons trapped in MNDs are emitted to the free layer by applying a high voltage to the word line maintaining the source line or drain line at 0V (Erasing).

In MND memory, we can use a thin tunnel oxide since the electron tunneling between the free layer and MNDs is switched by the magnetic filed. Therefore, very high speed for writing, programming and erasing can be achieved although reading speed is similar to that of Flash memory. In addition, the charge retention characteristics can be improved in MND memory since it does not need to reduce the thickness of block oxide and the work function of MND material is large. The charge storage in MNDs also improves the retention characteristics since only a small part of charges stored in the MND film is lost even if a charge leakage path exists between the small floating gate and the substrate or the control gate. It is also possible to simultaneously change the magnetic polarization in several memory cells, which belong to one block, using the block word line and block bit line as shown in Fig.2. In this case, the writing operation becomes “enable” by the magnetic field produced by the block word line and block bit line. The several memory cells within a block are electrically programmed by applying the signal voltages to the word line and the source line or drain line. In this memory, the density of current to produce the magnetic field can be reduced.

3. Results and Discussions

We proposed a new sputtering method to deposit the Co MND film [2]. First of all, we evaluated the structural properties of such MND film by TEM. Fig.3 shows a TEM cross section of the Co MND film. It is clearly demonstrated that the self-organized Co MNDs with a diameter of a few nano meters are densely incorporated in a thin insulating film with the thickness of 10 nm. It was estimated from the diameter of Co MNDs and the content ratio of Co MNDs to the film material obtained by EDS analysis that the density of Co MNDs is about 10 times higher than that of the conventional Si quantum nano-dots. The dot size and density of Co MNDs are controlled by changing the sputtering conditions as shown in Fig.4. The crystallographic properties before and after high temperature annealing were studied by using X-ray diffraction method (XRD) in order to evaluate the thermal stability of MND film. It was confirmed that the basic crystallographic properties of Co MND film do not change by high temperature annealing as shown in Fig.5 and hence MND film is very stable. Next, fundamental electrical characteristics of MND memory were evaluated using Co MND MOS structures with NiFe electrode for a control gate and a free layer. Fig.6 shows the C-V characteristics of the Co MND MOS structure with NiFe control gate. As is clear in the figures, hysteresis caused by the charging and discharging of electrons in the MND film was observed in the C-V curve. It is noted in the figures that the charging and discharging of electrons are carried out between the control gate and Co MNDs when the tunnel oxide is thin and the block oxide is thick while the charging and discharging occur between Co MNDs and Si substrate when the tunnel oxide is thicker and the block oxide is thinner. The work function of NiFe was 4.51eV. Fig.7 shows the MFM pictures of NiFe control gate that acts as a free layer. NiFe control gate electrode represented the multi-domain magnetic behaviors. In addition, the brightness in MFM picture was inverted by applying the magnetic field as is obvious in Fig.7. This means that the magnetic polarization of NiFe control gate changed by applying the magnetic field. Fig.8 shows the I-V characteristics of Co MND MOS structure with NiFe control gate. Negative voltage is applied to the NiFe control gate in order to inject the electrons from the NiFe control gate to Co MNDs. As is clear in Fig.8, the current changes depending on the polarity of applied magnetic field. Thus, it was confirmed for the first time that the injected current from the control gate to MNDs can be switched by the applied magnetic field.

4. Summary

We proposed a new MND nonvolatile memory with extremely high density of magnetic nano-dots. Fundamental characteristics as a nonvolatile memory were evaluated.

Acknowledgement

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References

[1]Y.Yamada, H.Kurino, M.Koyanagi et al., Extended Abstr. of Intern. Conf. on Solid State Devices and Materials, 794 −795 (2002) [2]M. Takata, H. Kurino, M. Koyanagi, Abstr. of Intern. Semiconductor Technology Conference , 40 (2002)

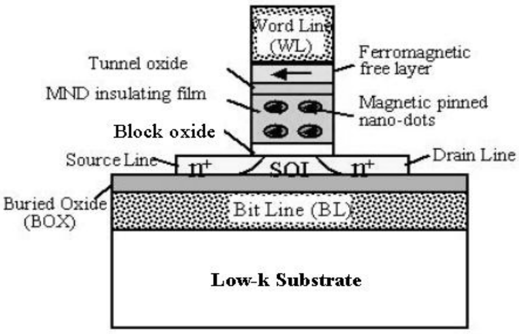


Fig. 1 Cross-sectional structure of MND memory.

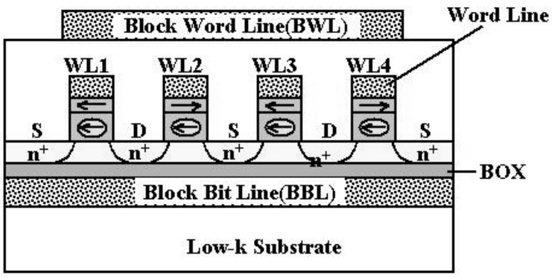


Fig. 2 Cross-sectional structure of MND memory with block writing function.

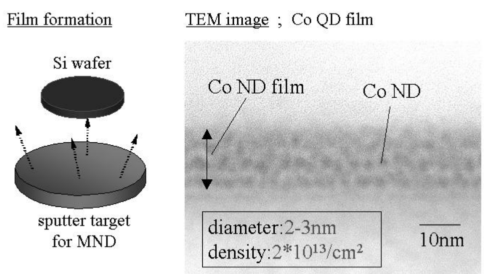


Fig. 3 Formation of Co MND film and TEM cross section of deposited film.

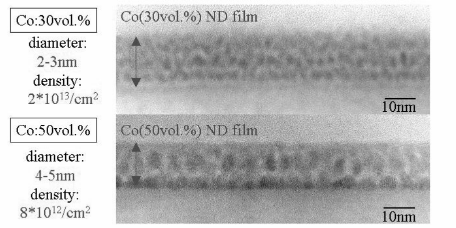


Fig.4 TEM cross section of Co MND with different Co composition at sputter target.

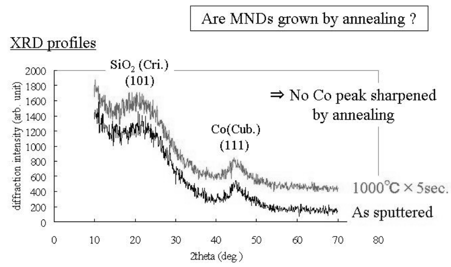
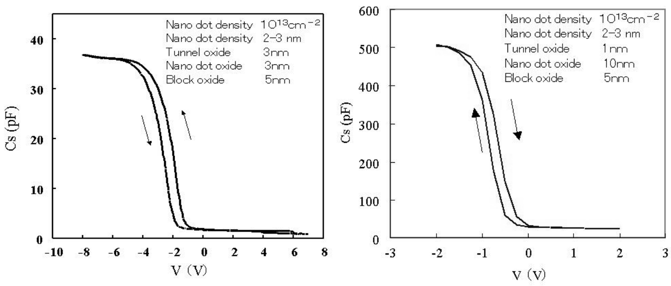
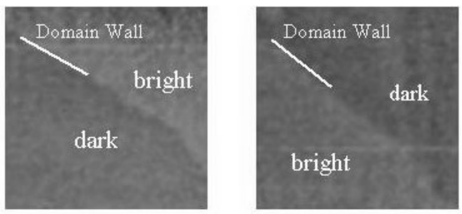


Fig.5 XRD profiles of MND film before and after annealing.



(a) (b)

Fig.6 C-V characteristics of MOS structure with MND film.



(a) Magnetic field N →S (b) Magnetic field S →N

Fig.7 MFM pictures of NiFe control gate in MND memory.

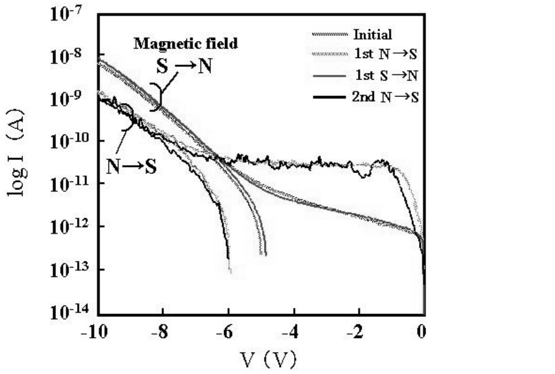


Fig.8 I-V characteristics of MOS structure with MND film.