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Preparation of Terfenol-D/PZT heterostructuresfor the study of voltage-control of magnetization easy axis

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To facilitate ultra-high density integration in a magnetic random access memory (MRAM), suitable data recording and retrieval methods have to be determined. In the conventional data recording method using a magnetic field produced bya current carrying conductor, it is difficult to obtain ultra-high density integration due to the fact that there are severe limitations in localizing the magnetic field in the vicinity of the nano-sized data bitsnecessary for ultra-high density memories. Hence, there is a need to explore alternate data recording methods. Recently, a method of controlling the direction of the magnetization easy axis using voltage has been reported in the $Pd/Co_{1-x}Pd_x/PZT/Pt/MgO$ heterostructures [1]. This is a promising method for data recording in an ultra-high density MRAM since it uses a voltage applied locally to the bit under consideration. However, since this method depends on the coupling of the magnetostrictive and piezoelectric property, it is believed that the ability to control the direction of magnetization easy axis using an applied voltage could be enhanced in heterostructures of Terfenol-D and PZT, as Terfenol-D is a well known giant magnetostriction material. Recently, electric field - induced magnetization was reported in bulk composite structures of PZT with Terfenol-D [2], but there has been no such report in thin film heterostructures. In the present work, an attempt has been made to study the feasibility of this method in Pt/Terfenol-D/PZT /Pt/MgO heterostructures.

PZT (1 μm) films were deposited on Pt(111)/MgO(100) substrates at 100 °C by rf magnetron sputtering method followed by annealing in 10%O_2 in N_2 atmosphere at 725°C for 15mins. The PZT films were then slowly cooled down to room temperature. Terfenol-D films were then deposited using a shadow mask containing an array of circular holes each 0.5mm in diameter at room temperature. The Terfenol-D films in the form of an array of dots were then capped using a platinum layer 3 nm thick. The crystal structure of the films was determined using X-ray diffraction (XRD) measurements. The ferroelectric property of the heterostructures was measured using a Precision LC (Radiant Technologies Inc.) measuring system. The magnetic properties were measured using a home-made magneto-optic microscope magnetometer (MOMM).

PZT films deposited using the above given conditions are polycrystalline with a preferred (111) orientation as confirmed by XRD measurements. These PZT films show good ferroelectric characteristics with a remanent polarization of 70 $\mu C/cm^2$ and a coercive electric field of 38.5 KV/cm. Fig. 1 shows the magnetic hysteresis of Terfenol-D films deposited at 300 °C and annealed for 15 mins in a magnetic field applied perpendicular to the plane of the substrate. It is seen that that films deposited and annealed at these conditions show perpendicular magnetic

anisotropy (PMA). However, at these conditions, the P-V loop of the PZT film shows poor ferroelectric switching characteristics. On the other hand when Terfenol-D films are deposited at room temperature and subjected to rapid thermal annealing at 300 °C, the ferroelectric properties are well preserved as shown in Fig.2.

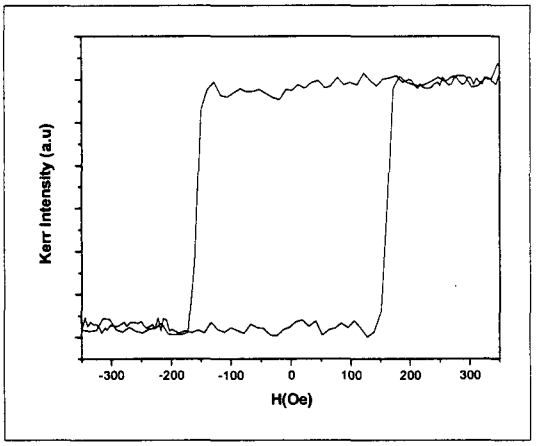

Fig.1

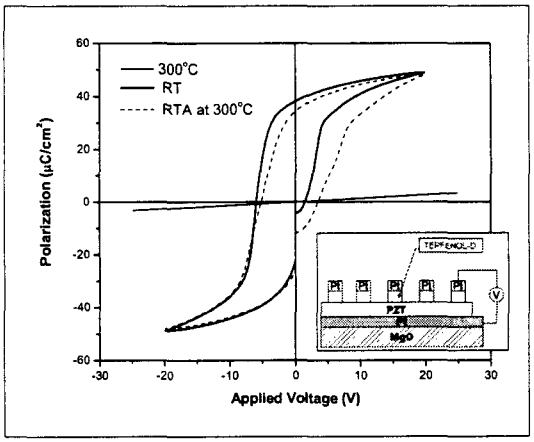

Fig.2

In order to observe voltage-control of magnetization easy axis in Terfenol-D films grown on PZT with the geometry as shown in inset to Fig.2, it necessary to obtain films with perpendicular magnetic anisotropy. This is because in the presence of an applied uniaxial stress, the magnetization direction in positive magnetostriction materials such as Terfenol-Drotates in to the direction of the applied stress when it is tensile and perpendicular to the direction of a compressive stress.In this case since the stress is in the in-plane direction, the magnetization easy axis has to be perpendicular to the direction of stress in order to obtain any observable effect. However, the deposition and annealing conditions of Terfenol-D films have to be optimized to preserve the switching characterisitics of the PZT film.

We have fabricated Pt/Terfenol-D/PZT/Pt/MgO heterostructures for the study of voltage control of magnetization easy axis. We find Terfenol-D films deposited directly on PZT at 300 °C degrade the switching characteristics of the PZT film. However, films deposited at RT and subjected to RTA at 300 °C preserve the ferroelectric properties of the PZT film. Further work is in progress to obtain Terfenol-D films with PMA.

References

[1] Jeong-Won Lee, Sang-Koog Kim and Sung-Chul Shin, *Appl. Phys. Lett.* **82** (2003), p. 2458.

[2] J. G. Wan, J. M. Liu, G. H. Wang, and C. W. Nan, *Appl. Phys. Lett.* **88** (2006), p.182502.