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SPIN ENGINEERING OF FERROMAGNETIC FILMS VIA INVERSE PIEZOELECTRIC EFFECT

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I. INTRODUCTION

One of the current goals in memory device developments is to realize a nonvolatile memory, i.e., the stored information maintains even when the power is turned off. The representative candidates for nonvolatile memories are magnetic random access memory (MRAM) and ferroelectric random access memory (FRAM). In order to achieve a high density memory in MRAM device, the external magnetic field should be localized in a tiny cell to control the direction of spontaneous magnetization. As the magnetic cell size is shrunken, it is more difficult to localize a magnetic filed. In this study, we report a voltage-controlled spin engineering in ferromagnetic (FM) films without applying magnetic field for future ultrahigh density MRAM devices. The key idea is to control the spontaneous magnetization direction of FM/piezoelectric hybrid system utilizing the inverse piezoelectric effect which is the lattice elongation under an applied voltage. To demonstrate this idea for a new MRAM architecture, we deposited CoPd alloy film on lead zirconate titanate (PZT) substrate as described in Fig. 1. This vertical structure allows one to control the magnetization switching of the CoPd alloy film on PZT substrate with low voltage, since it has large magnetostriction constant and therefore, magnetization direction can be easily engineered via magnetoelastic coupling.

II. EXPERIMENTAL PROCEDURE

The PZT film was fabricated on Pt(111)/Ti/SiO_2/Si substrate by multiple spin coating with PZT solution (Zr/Ti = 52/48). The thickness of each layer was 120 ~ 200 nm, and the final film thickness was 1 μm. 30-Å Co_xPd_{1-x} alloy films were grown on PZT film by e-beam evaporation in an ultrahigh vacuum chamber. A 30-Å Pd layer was deposited at the bottom (top) of the CoPd alloys as a buffer (capping) layer. These trilayer films were deposited through a shadow mask with a hole of 3 mm diameter at a rate of 1.65 Å/min and 1.24 Å/min for alloy films and Pd layers, respectively, under a base pressure of 5×10^{-8} Torr. The top Pd layer and bottom Pt layer under PZT film were used as electrodes to apply electric field vertically to the film plane by wiring to a function generator and/or a power supply. The polar magneto-optical Kerr effect measurements were carried out with 45^0 incident laser beam, where the magnetic field was applied perpendicular to the film plane as shown in the figure. The piezoelectric coefficient (d_{33}) is an important parameter in the hybrid system of FM/piezoelectric layers, because the inverse piezoelectric effect of the ferroelectric layer gives an actual strain to the FM layer. The composition of the PZT sample used in this study is $Pb(Zr_{0.52}Ti_{0.48})O_3$. The choice of this composition has been dictated by the fact that this composition has high piezoelectric properties. The d_{33} of this sample is about 270 pm/V, which is sufficient for our application.

III. RESULTS AND DISCUSSION

The ultimate object of this work is to control the spontaneous magnetization direction in FM layer, which has a large remanence at zero applied voltage for nonvolatile memory application, by inverse piezoelectric effect of PZT film. To investigate the magnetization orientation with respect to an applied voltage, we measured the polar Kerr rotation (θ_K) hysteresis loops at each fixed voltage for the $Co_{0.25}Pd_{0.75}$ alloy sample. The representative hysteresis loops for $Co_{0.25}Pd_{0.75}$ alloy sample are shown in the insets of Fig. 2 at (i) +10 V, (ii) 0 V, (iii) -10 V, and (iv) 0 V. From the hysteresis data, we determined the squareness ($\theta^{rem}_K/\theta^{sat}_K$) as a function of an applied voltage as demonstrated in Fig. 2. The squareness at the positive saturation field is 0.6 and it changes to 0.9 at the negative saturation field, which implies the reorientation of the spontaneous magnetization to take place from canted to nearly perpendicular direction. Note that this spin reorientation transition originates from the strain effect of the PZT film via voltage control. It should be emphasized that this FM/piezoelectric hybrid system with vertical structure can be applicable to nonvolatile memory device, since the magnetization orientation nearly remains after removing applied voltage. The asymmetry in $\theta^{rem}_K/\theta^{sat}_K$ hysteresis with respect to an applied voltage might come from the non-180^0 domain switching which is typically found in PZT films. It is very important to find out a proper composition of the FM alloy films for which magnetic properties are easily controllable with external strain effect as well as a suitable actuator such as PZT film maintaining a large remanent strain. Our results open a new perspective for a possibility of application of FM/piezoelectric hybrid system for nonvolatile memory devices.

IV. ACKNOWLEDGEMENT

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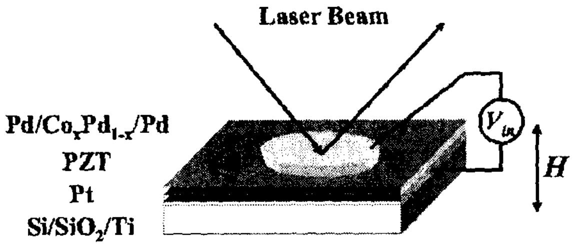

Fig. 1

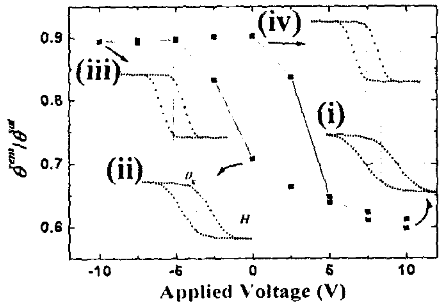

Fig. 2