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Magnetic domain-wall motion study under an electric field in a Finemet® thin film on flexible substrate

Ngo Thi Lan [a], Silvana Mercone [a,*], Johan Moulin [b], Anouar El Bahoui [a], Damien Faurie [a], Fatih Zighem [a], Mohamed Belmeguenai [a], Halim Haddadi [a]

[a] Laboratoire des Sciences des Procédés et des Matériaux, CNRS-Université Paris XIII, 93430 Villetaneuse, France
[b] Institut d'Electronique Fondamentale, UMR 8622 Université Paris Sud/CNRS, Orsay, France

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ABSTRACT

We study the influence of applied in-plane elastic strains on the static magnetic configuration of a 530 nm magnetostrictive FeCuNbSiB (Finemet®) thin film. The in-plane strains are induced via the application of a voltage to a piezoelectric actuator on which the film/substrate system was glued. A quantitative characterization of the voltage dependence of the induced-strain at the surface of the film was performed using a digital image correlation technique. Magnetic Force Microscopy (MFM) images at remanence ($H=0$ Oe and $U=0$ V) clearly reveal the presence of weak stripe domains. The effect of the voltage-induced strain shows the existence of a voltage threshold value for the strike configuration break. For a maximum strain of $\varepsilon_{XX} \sim 0.5 \times 10^{-3}$ we succeed in destabilizing the stripes configuration helping the setting up of a complete homogeneous magnetic pattern.

1. Introduction

During the last decades technological progress has been driven predominantly by the modern information and communication technology. The steadily increasing data output and functionality of devices has required an ongoing miniaturization of their structural elements. In the design and manufacturing of actual microelectronic and microelectromechanical systems (MEMS), thin metallic films play an important role [1,2]. Thin films can show continuous geometry for which lateral dimensions are much higher than thickness (typically less than one micron), or show complex geometry (wires or dots arrays) for which one or two lateral dimensions and thickness are of same order. Usually, thin films are deposited on substrates, which are several ten times thicker. In the case of flexible substrates (generally polymers) used in stretchable electronics, the thin films are usually submitted to mechanical stresses due to the curvature of the whole system. Obviously, these stresses may have an important effect on the magnetic properties, especially on the effective magnetic anisotropy [3,4]. Magnetic devices fabricated on compliant substrates such as polymers are believed to have great potential for applications due to their mechanical flexibility, enhanced durability and lightweight compared with those on a rigid substrate. Moreover, it has been found that the specific nature of polymer substrates has non-negligible consequence on the magnetic properties of deposited films, which leads to a different performance from a film deposited on a rigid substrate. Due to their stress sensitivity, the magnetic properties of magnetostrictive films on flexible substrate can be tailored by the stress [5–9]. In this context, a few dedicated techniques have been developed to study the magnetoelastic behavior of thin films. Concerning magnetic films deposited on flexible substrates, recent papers have reported *in situ* characterizations by FerroMagnetic Resonance (FMR) [10], Magneto-Optical Kerr Effect [7] and Giant MagnetoResistance (GMR) measurements [9,11,12]. The purpose of these studies is especially to demonstrate the feasibility of a magnetostrictive sensor on a polymer substrate. The main advantage of polymer materials is obviously their high flexibility, which cannot be achieved by crystalline materials, and their relative low cost.

In the present paper, the influence of an applied elastic strain on the magnetic domain of a Finemet® film/Kapton® substrate is investigated. The external loading is successfully applied thanks to a piezoactuator [13] on which our system is glued [10,14,15]. A quantitative study of the voltage-induced elastic in-plane strains is performed thanks to a Digital Image Correlation (DIC) technique while the evolution of magnetic domain structures is probed by Magnetic Force Microscopy (MFM).

2. Experimental

The amorphous Finemet® film has been deposited on Kapton® substrate (125 μm) (shown in Fig.1a) by RF sputtering with the following conditions: residual pressure in the range of 10^{-7} mbar,

* Corresponding author.
E-mail address: silvana.mercone@univ-paris13.fr (S. Mercone).

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working Ar pressure of 40 mbar and RF power of 250 W. A thin film of titanium was deposited either on substrate before film deposition in order to increase film adhesion to the Kapton and on the film surface in order to avoid oxidation. The composition of the target was $Fe_{73.5}$ $Cu_1Nb_3Si_{15.5}$ B_7. The film composition has been characterized by EDS and is close to the one of the target. The film thickness (530 nm) has been estimated by Scanning Electron Microscopy equipped with a Field Electron Gun (SEM-FEG) (see the cross-section view in Fig.1b).

After deposition, the flexible film/substrate system was glued onto a piezoelectric actuator. Zighem et al. [10] have already shown that a compliant substrate allows to have a nearly 100% strain transmission in between the piezoelectric actuator and the film. In the present work, a quantitative characterization of the voltage dependence of the induced-strain at the surface of the film was performed using Digital Image Correlation technique [16]. Magnetic Force Microscopy (MFM) measurements are performed by using a standard Veeco D3100 microscope. In order to provide reasonable sensitivity and resolution, standard hard magnetic tips (PPP-MFMR tips) are used. The hard magnetic coating of this tip has approximately 300 Oe coercivity and a 300 emu cm^{-3} remanence magnetization allowing high magnetic contrast. This latter characteristic is mandatory for weak magnetic stray field detection and high lateral resolution domain imaging (*i.e.* around 50 nm). The MFM allows *in situ* probing of the static magnetic domains configuration under the influence of an applied in-plane elastic strains. In order to fully characterize the ground state (U=0 V) of the system, we performed standard contact Atomic Force Microscopy (AFM) for a roughness check of the surface and static magnetization measurements at room temperature for static magnetic behavior.

3. Results and discussion

The sketch of the studied artificial multiferroic system, made by the 530 nm Finemet® ferromagnetic film deposited onto the compliant polyimide substrate (Kapton®) glued on a piezoelectric device, is shown in Fig.2a. This latter allows, via the application of a voltage, to induce in-plane strains (ε_{XX} and ε_{YY}) to the film/substrate, thanks to the choice of the Kapton® substrate which avoids clamping effects leading to low transmission of strains from the actuator to the film/substrate system [15]. The DIC measurements have been performed by varying the external voltage from +50 V to −50 V. The measured in-plane strains (ε_{XX} and ε_{YY}) in this range of voltages are presented in Fig.2b. The reference image for the determination of the in-plane strains has been taken at U=0 V (after applying a voltage of +50 V in order to avoid hysteresis effects due to the piezoelectric material). In these conditions, a maximum (resp. minimum) value of 0.065% (resp. −0.035%) for ε_{XX} (resp. for ε_{YY}) is found at $U=+50$ V. One can note that the values obtained at $U=-50$ V are slightly higher (−0.085% for ε_{XX} and 0.045 for ε_{YY}) than the ones obtained at $U=+50$ V. This behavior is due to the non-linear and hysteretic behavior of the piezoelectric actuator. However, we have verified that no variations of these values are observed after several $U=+50$ V to $U=-50$ V sweeps (note that the sweep $U=-50$ V to $U=+50$ V is not shown here). In addition, one can note that the sketch presented in Fig.2a corresponds to a positive applied voltage where the magnetic film is tensily stressed (when a negative voltage is applied, the film is compressively stressed).

The influence of voltage-induced in-plane elastic strains on the magnetic domain of the film has been probed by MFM. The presence of magnetic domains has been clearly identified at

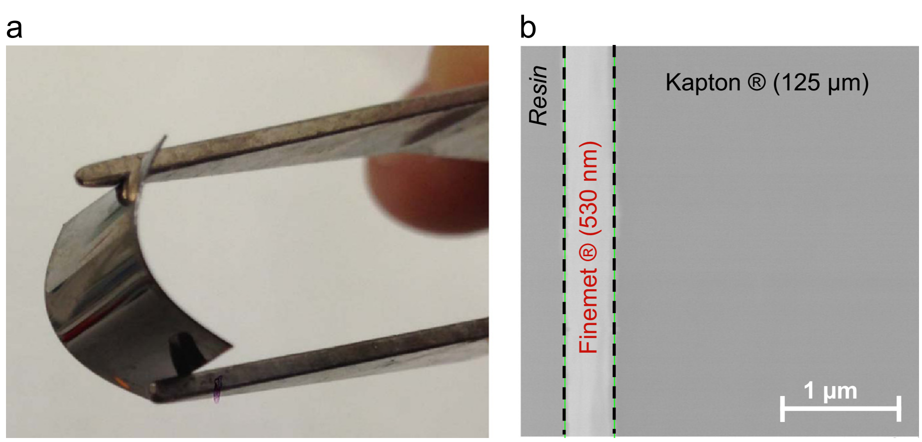

Fig. 1. (a) Image of the flexible Finemet/Kapton® system. (b) Cross-section of the Finemet/Kapton® system obtained by a scanning electron microscope (SEM). A Finemet film thickness of about 530 nm is estimated.

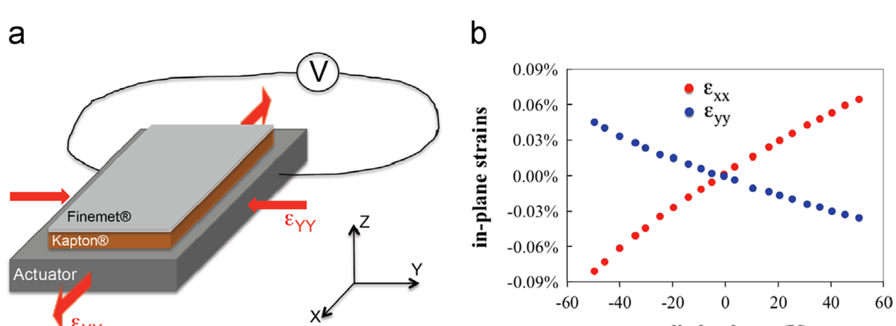

Fig. 2. (a) Sketch of the artificial FeCuNbSiB/piezoelectric heterostructure. (b) Quantitative characterization of the voltage dependence of the induced-strain at the surface of the film performed using a digital image correlation technique.