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Mechanical, electrical and optical control of magnetization reversals and spin dynamics in extrinsic multiferroics

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Galfenol thin films have attracted a large amount of interest in the last two decades. Indeed, it is of interest to understand the fundamental mechanisms driving the strain and magnetic coupling in thin films. This study focuses on thin Fe_{0.81}Ga_{0.19} (FeGa) films of thickness 5, 10, 20, and 60 nm deposited by sputtering onto glass substrates, PMN-PZT substrates and Aluminium foils. FeGa magnetostrictive properties were characterized using optical deflectometry. This first study reveals a remarkable thickness dependence, with an effective magnetoelastic coefficient decrease with an a thickness increase. A 10 nm Fe-Ga thin film was grown on Al kitchen foil and then mechanically strained under an isotropic configuration using spherical optical lenses. The FeGa MR properties under such a mechanical strain were determined. The results indicate the development of a random anisotropy character due to the bending. Under an electric field, a large converse magneto-electric effect for the Fe-Ga/PMN-PZT layered structure is observed. This effect is shown to be angular dependent. Finally, light control of static and dynamic magnetic properties in the Blue region is demonstrated. It is achieved with a CW laser or a LED.

Index Terms—FeGa magnetostriction, magnetization reversals and spin dynamics, multiferroics, photostriction.

I. INTRODUCTION

MAGNETOSTRICTIVE thin films have attracted a large amount of interest in the last few decades. Indeed, it is of interest to understand the fundamental mechanisms driving the strain and magnetic coupling in thin films. Also, the magnetostrictive properties are key properties used in different applied issues and devices such as actuators, energy-harvesters spintronic devices. Among the different magnetostrictive alloys, Fe-Ga discovered in 2000 by Clark has received a particular attention as it exhibits remarkable properties such as low hysteresis, large magnetostriction, and good tensile strength [1]. Due to the interest of magnetostrictive systems and the remarkable properties of Fe-Ga, the strain mediated control of Fe-Ga magnetization reversals is of importance. However as the strain mediated control may be realized by different ways, understanding the mechanisms at play is a huge task. In this regard, our study focuses on the strain mediated control of Fe-Ga magnetization reversals (MR) for thin films grown by RF sputtering under a 300 Oe magnetic field, onto different substrates. First, Fe-Ga thin films with composition Fe₈₁Ga₁₉ were grown on glass to probe the magnetostriction thickness dependence [2]. Second, Fe-Ga thin films were grown on PMN-PZT to probe the strain-mediated electric-field control of magnetization reversals [3]. Third, a 10 nm Fe-Ga film was grown on flexible kitchen aluminum foil and a strain mediated mechanical control magnetization reversals was achieved through the use of spherical optical lenses [4]. Finally, light control of magnetization reversals and spin

dynamics is demonstrated in the Blue region, for FeGa thin films grown on Glass and PMN-PZT [5].

II. MAGNETOSTRICTION AND MECHANICAL CONTROL

A. Inverse magnetostriction

Azimuthal dependencies (external field applied at different angles ϕ , see Fig. 1-c) of Fe-Ga magnetization reversals were probed using a VSM. A thickness dependence of the coercive field azimuthal shape was observed. The thicker film exhibiting a quasi-circular shape was observed for the thicker films whereas a more complex behavior with local extrema positions was obtained. These different behaviors as a function of the Fe-Ga thickness were found to be driven by the Fe-Ga crystallographic texture [2]. Magnetostriction of Fe-Ga was characterized using optical deflectometry under an applied magnetic field, the cantilever (made of glass substrate with Fe-Ga deposited onto it) deformation is recorded through laser beam reflection at the free tip. —beff—, the effective magnetoelastic coefficient is shown to be thickness dependent, since —beff— decreases from 1.5 to 0.7 MPa (the corresponding magnetostrictive coefficient λ_{eff} decreases from 20 to 9 ppm) when the thickness increases from 5 to 60 nm. Values obtained in the present study for the magnetostriction are in good agreement with previous ones reported in the literature [2].

B. Direct magnetostriction : Mechanical control

It is well known that a strain mediated control of MR can be obtained through a macroscopic mechanical deformation of a

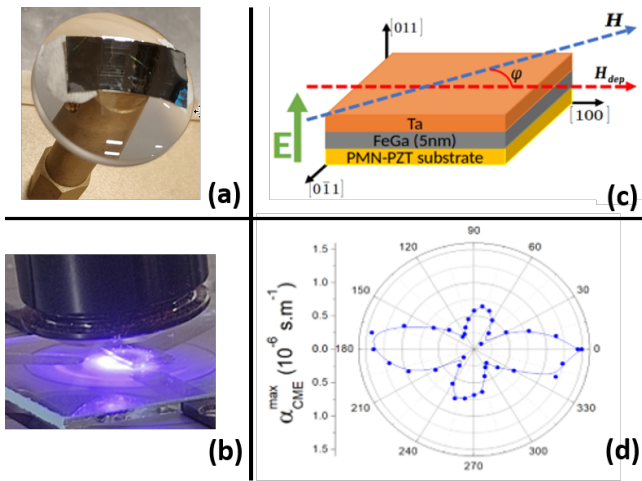


Fig. 1. (a) Photography of the FeGa/Al on top of a convex optical lens (b) Photography of the FeGa/PMN-PZT under the LED illumination (c) Schematic drawing of a ME composite consisting of magnetostrictive $\text{Fe}_{81}\text{Ga}_{19}$ and a (011)-oriented PMN-PZT beam. ϕ is the angle between the magnetic field H and the deposition field H_{dep} . E is the applied electric field. (d) Angular dependence of the α_{CME}^{\max} ($E=6.2$ kV/cm), for the 5 nm $\text{Fe}_{81}\text{Ga}_{19}$ film on PMN-PZT.

given magnetostrictive film grown on a flexible substrate. The growth of magnetostrictive thin films on flexible substrates is therefore relevant for the field of flexible electronics including logic, sensor, and memory devices. In these flexible systems, one of the key properties to understand and to tailor is the magnetic anisotropy. Indeed, this property drives the magnetic moment direction, the working frequency, as well as the power consumption of devices. In this regard, the anisotropic properties of FeGa thin films grown on flexible substrates were previously studied under an anisotropic mechanical stress (tensile or compressive). These studies revealed large modification of the anisotropic properties due to the anisotropic bending of the flexible substrate. Thus, study focusing on isotropic bending would further contribute to the understanding of the anisotropic properties of flexible Fe-Ga systems. In the study presented here, the 10 nm Fe-Ga thin film was grown on Al kitchen foil and then mechanically strained under an isotropic configuration using spherical optical lenses. The MR properties under such a mechanical strain were determined. The results indicate the development of a random anisotropy character due to the bending. To further understand the isotropic bending effect, the results obtained on the single Fe-Ga film were compared with a 10nm NiFe film and an hybrid NiFe(10 nm)/Fe-Ga(10 nm) bilayer submitted to the same isotropic mechanical strain [4].

III. ELECTRICAL CONTROL

Strain-mediated electrical manipulations in extrinsic multiferroics (EMF) which consist of stacked Fe-Ga and piezoelectric phases is attracting a huge amount of attention, as EMF are remarkable tools to achieve large magneto-electric coupling response at room temperature. In such EMF, the material properties of each layer are combined : magnetization can be controlled by an electric field through a transferred strain from the piezoelectric material to the magnetostrictive

one. This is the converse magnetoelectric effect (CME) which can be schematically written as $\text{CME} = (\text{electric/mechanical}) \times (\text{mechanical/magnetic})$. If a magnetic field H is applied to provide a CME, then the CME efficiency, characterized by a coefficient named α_{CME} , may depend on the strength and the direction of H . However, the dependence over the H field direction is overlooked in most studies. In the study presented here, we obtain a large CME for the Fe-Ga/PMN-PZT layered structure [3]. The angular dependence of α_{CME} is probed as shown in Fig.1-d. Firstly, the results presented here indicate that the angular dependence should be performed in such a system. Secondly, the results presented here will provide valuable information when compared to previous findings on Fe-Ga of different thicknesses.

IV. OPTICAL CONTROL

Finally, light control of static and dynamic magnetic properties is demonstrated. This control is performed in the Blue region with a CW laser and a LED, as shown in Fig. 1-b. Angular dependent magnetization reversals properties are shown to be largely enhanced or reduced under a converse magneto-photostrictive effect (CMPE) [5]. The CMPE strength is analysed with a novel physical coefficient named the converse magneto-photostrictive coupling coefficient. This coefficient is proposed as a general approach to analyse and to compare different extrinsic multiferroics under the converse magneto-photostrictive effect. Furthermore, experimental evidence for a control of dynamic magnetic properties under CMPE is then revealed by ferromagnetic resonance measurements and will be presented at the conference.

REFERENCES

- [1] A. E. Clark, J. B. Restorff, M. Wun-Fogle, T. A. Lograsso, and D. L. Schlagel, "Magnetostrictive properties of body-centered cubic fe-ga and fe-ga-al alloys," *IEEE Transactions on Magnetics*, vol. 36, no. 5, pp. 3238–3240, Sep. 2000.
- [2] W. Jahjah, R. Manach, Y. L. Grand, A. Fessant, B. Warot-Fonrose, A. R. E. Prinsloo, C. J. Sheppard, D. T. Dekadjevi, D. Spenato, and J.-Ph. Jay, "Thickness dependence of magnetization reversal and magnetostriction in FeGa thin films," *Physical Review Applied*, vol. 12, no. 2, p. 024020, Aug. 2019.
- [3] W. Jahjah, J.-Ph. Jay, Y. Le Grand, A. Fessant, A. Prinsloo, C. Sheppard, D. Dekadjevi, and D. Spenato, "Electrical manipulation of magnetic anisotropy in a $\text{Fe}_{81}\text{Ga}_{19}/\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-Pb}(\text{Zr}_x\text{Ti}_{1-x})\text{O}_3$ magnetoelectric multiferroic composite," *Phys. Rev. Applied*, vol. 13, p. 034015, Mar 2020. [Online]. Available: <https://link.aps.org/doi/10.1103/PhysRevApplied.13.034015>
- [4] F. Legall, C. Morice, W. Jahjah, A. Bivic, N. Ryon, J. Richy, A. Prinsloo, C. Sheppard, A. Fessant, J.-Ph. Jay, D. Spenato, and D. Dekadjevi, "Magnetization reversals of $\text{fe}_{81}\text{ga}_{19}$ -based flexible thin films under multiaxial mechanical stress," *Phys. Rev. Applied*, vol. 15, p. 044028, Apr 2021. [Online]. Available: <https://link.aps.org/doi/10.1103/PhysRevApplied.15.044028>
- [5] M. Liparo, J.-P. Jay, M. Dubreuil, G. Simon, A. Fessant, W. Jahjah, Y. L. Grand, C. Sheppard, A. R. E. Prinsloo, V. Vlamincq, V. Castel, L. Temdie-Kom, G. Bourcin, D. Spenato, and D. T. Dekadjevi, "Static and dynamic magnetization control of extrinsic multiferroics by the converse magneto-photostrictive effect," 2022. [Online]. Available: <https://arxiv.org/abs/2206.12703>