Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp61-62

Spin Wave and Phonon Excitation by the Magnetoelectric Effect

Davide Tierno[1,2], Tobias Jost[3], Moritz Geilen[3], Thomas Brächer[3], Marc Heyns[1,2], Burkard Hillebrands[3], Iuliana P. Radu[1], Philipp Pirro[3], Florin Ciubotaru[1] and Christoph Adelmann[1]

[1] imec
75 Kapeldreef
Leuven 3001, Belgium
Phone: +32 16 28 83 10 E-mail: davide.tierno@imec.be
[2] Departement Materiaalkunde KU Leuven
44 Kasteelpark Arenberg
Leuven 3000, Belgium
[3] Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern
56 Erwin-Schrödinger-Straße
Kaiserslautern 67663, Germany

Abstract

The microwave behavior of CoFeB-BPZT magnetoelectric bilayers was studied by microfocus BLS with a particular focus on the factors affecting the excitation of spin waves and phonons.

1. Introduction

Among the technologies that could potentially represent a paradigm shift with respect to CMOS technology, spin wave computation presents several advantages to achieve area and power reduction [1-4]; furthermore, the possibility to perform multifrequency processing and the non-volatility of the magnetic materials could provide new functionalities to circuit designers for various applications [5-7]. However, a major limitation for the realization of spin wave-based devices is the lack of a scalable and energy efficient transducer capable of converting voltage signals into spin waves [1,2].

Microwave antennae are typically used to generate spin waves using electric currents [8] but they are not energy efficient when scaled down to the nm range. By contrast, magnetoelectric transducers represent a scalable and low-power alternative [1-3]. They consist of a piezoelectric-magnetostrictive compounds (*e.g.* bilayers), in which the coupling between the electric and the spin domain occurs via strain. The strain induced in the piezoelectric layer by the applied electric field is transferred to the magnetostrictive film that in turn changes its magnetic anisotropy. This can result in a torque exerted on the magnetization and generate spin waves when a microwave excitation signal is applied. However, this excitation regime at GHz frequencies has been scarcely investigated [9] with most of the studies, both theoretical and experimental, addressing the static (DC) coupling mechanism [10].

In this work we investigate the microwave behavior of magnetoelectric bilayers obtained by thin-film technology with the aim to excite spin waves.

2. Experimental Procedure

We have recently investigated the microwave behavior of Ba-doped PZT (BPZT) thin films deposited by Pulsed Laser Deposition (PLD), using concentric capacitors with different dimensions to compensate parasitic effects [11]. We have shown that the thin layers were still ferroelectric up to 30 GHz with no significant relaxation behavior [12].

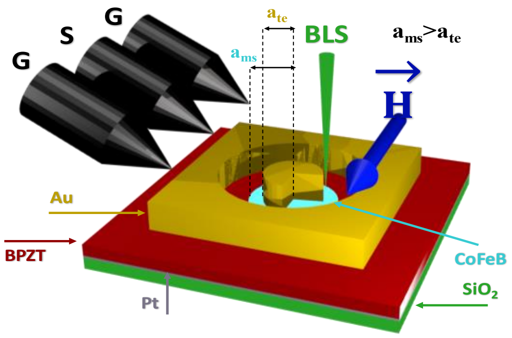

Fig. 1 Schematic of the test structure. The BPZT layer is not patterned and the magnetostrictive layer and Au are patterned in two steps by lift-off technique. The inner electrode has a quarter missing for clarity.

To study magnetoelectric effect in such capacitor structures, a magnetostrictive layer was inserted between the piezoelectric film and the top electrode, as shown in Fig. 1. The magnetostrictive CoFeB element (in light blue) is first patterned onto the piezoelectric layer and subsequently the top electrode (Au) with a smaller area, *i.e.* $a_{ms} > a_{te}$. Such a test vehicle has the major advantage of not requiring any processing of the piezoelectric layer and it allows optical access to the magnetostrictive element.

The optical access to the CoFeB layer was used for the detection of spin waves and phonons by microfocus Brillion Light Scattering (BLS) spectroscopy [13], a well-established technique for studying spin waves generation and propagation, allowing the temporal and spatial mapping of spin waves.

CoFeB layers, either 15-nm- or 30nm-thick, were sputtered onto 400-nm- and 200-nm-thick BPZT films, used as piezoelectric elements. The samples were then annealed at 300 °C for 10 minutes in N_2 environment to improve the magnetic properties prior to the definition of the Ti/Au top electrode. Phonon and spin wave spectra were recorded for different values of the applied in-plane magnetic field and DC bias voltage.

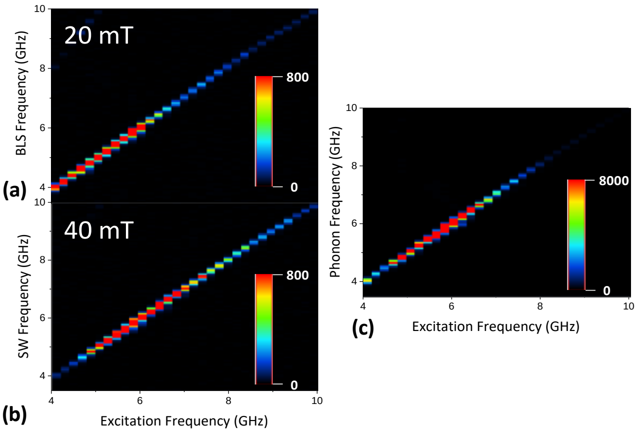

Fig. 2. 2D maps, with color-coded intensity, of spin wave spectra at (a) 20 mT and (b) 40 mT and (c) phonon spectrum recorded for the 30nm-thick CoFeB layer.

3. Experimental Results

The phonon and spin wave spectra recorded for the 30-nm-thick CoFeB layer are shown in the 2D maps in Fig. 2. The magnetic field was applied transversally to the G-S-G probe as shown in Fig. 1. A clear variation of the spin wave intensity was observed as the magnetic field was increased from 20 mT to 40 mT as shown in Fig. 2a and 2b respectively. The plots show that our approach is suitable for studying spin waves and phonons excited by the magnetoelectric transducer in the microwave regime.

Spin waves and phonons were measured also for a 15-nm-thick CoFeB layer. We studied the impact of a DC bias superimposed on the microwave excitation signal and we observed an increase of the intensity of the phonon peak at ~6 GHz when the bias was varied between 0 and +7 V (Fig. 3a). However, an analysis of the normalized intensity suggests that the phonon mode structure was not affected. Finally, the small difference observed between the two spectra recorded at 0 V, during the forward (Fw) and backward (Bw) voltage sweep, was attributed to the hysteretic behavior of the ferroelectric BPZT.

In Fig. 3b the non-normalized spin wave spectra recorded in similar conditions are shown. Beside the peak at ~6 GHz observed also for phonons, a second peak was present at ~4.5 GHz, attributed to backward volume waves, that was not affected by the sweep of the applied bias voltage.

4. Conclusions

We proposed a simple approach for the microwave characterization of magnetoelectric bilayers for the excitation of spin waves and phonons. Their spectra were mapped in CoFeB-BPZT systems by Micro-focus BLS and we observed the effect a superimposed DC bias on the intensity of spin waves and phonons.

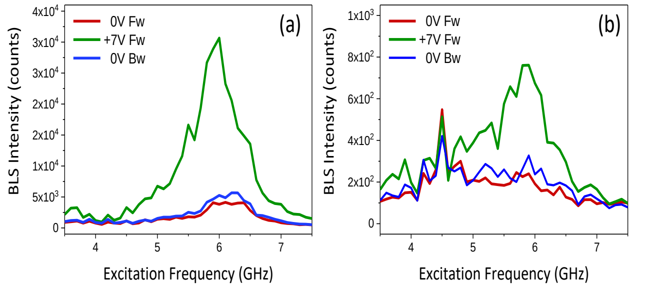

Fig. 3 (a) phonon e (b) spin wave spectra for the CoFeB(15nm)-BPZT bilayer for an applied magnetic field of 20 mT. Spectra are not normalized. A DC bias voltage was superimposed on the microwave excitation signal.

References

[1] A. Khitun and K.L. Wang J. Appl. Phys. 110 (2011) 034306.
[2] A. Khitun, M. Bao and K.L. Wang. IEEE Trans. Magn. 44 (2008) 2141.
[3] S. Manipatruni, D. E. Nikonov and I.A. Young Nat. Phys. 14 (2018) 338.
[4] A.V. Chumak,V.I. Vasyuchka, A.A. Serga and B. Hillebrands Nat. Phys. 11 (2015) 453.
[5] O. Zografos, S. Dutta, M. Manfrini, A. Vaysset, B. Sorée, A. Naeemi, P. Raghavan, R. Lauwereins, I.P. Radu AIP Adv. 7 (2017) 056020.
[6] T. Fischer, M. Kewenig, D.A. Bozhko, A.A. Serga, I.I. Syvorotka, F. Ciubotaru, C. Adelmann, B. Hillebrands and A.V. Chumak Appl. Phys. Lett. 110 (2017) 152401.
[7] G. Csaba, A. Papp and W. Porod Phys. Lett. A 381 (2017) 1471.
[8] F. Ciubotaru, T. Devolder, M. Manfrini, C. Adelmann I.P. Radu Appl. Phys. Lett. 109 (2016) 012403.
[9] S. Cherepov, K. Pedram, J. G. Amiri, W. Kin, M Lewis, Pramey Upadhyaya, Jayshankar Nath et al., Appl. Phys. Lett 104, 8 (2014)
[10] J.M. Hu, C.G. Duan, C.W. Nan and L.Q. Chen, NPJ Comput. Mater. 3 (2017) 18.
[11] Z. Ma, A.J. Becker, P. Polakos, H. Huggins, J. Pastalan, H. Wu, K. Watts, Y.H. Wong and P. Mankiewich IEEE Trans. Electron. Devices 45 (1998) 1811.
[12] D. Tierno, M. Dekkers, P. Wittendorp, X. Sun, S.C. Bayer, S.T. King, S. Van Elshocht, M. Heyns, I.P. Radu and C. Adelmann, IEEE Trans. Ultrason. Ferroelectr. Freq. Control (2018) – *in publication*.
[13] T. Sebastian, K. Schultheiss, B. Obry, B. Hillebrands and H. Schultheiss Front. Phys. 3 (2015) 35.