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Magneto-electric control of polarization in spintronic terahertz emitters

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Abstract— Magnetolectric control of the emitted polarization of THz waves was demonstrated for the first time in spintronic emitters thanks to the use of a magnetostrictive ferromagnetic layer in an emitter deposited on top of a ferroelectric relaxor substrate.

I. INTRODUCTION

POLARIZATION control of THz light is of paramount interest for the numerous applications offered in this frequency range. Recent developments in THz spintronic emitters allow for a very efficient broadband emission, and especially unique is their ability of THz polarization switching through magnetization control of the ferromagnetic layer[1]. So far, such a control has only been achieved using an external magnetic field. For the first time, we present here a scheme to achieve a voltage controlled coherent polarization rotation using a strain mediated magnetoelectric effect in spintronic emitters.

II. SAMPLE PREPARATION AND MEASUREMENT SETUP

The considered emitter is a W(2nm)/ CoFe(0.5nm)/ TbCo₂(0.8nm)/ CoFe(0.5nm)/ Pt(2nm) stack deposited by RF sputtering in a LEYBOLD Z550 equipment on a 300 μm thick <011> cut PMN-PT ferroelectric relaxor (figure 1a). During the growth, a magnetic field was applied in the plane of the substrate in order to induce a well-defined uni-axial anisotropy that allows for a stoner-wohlfarth coherent rotation of the magnetization in the ferromagnetic layer. The CoFe/TbCo₂/CoFe tri-layer acts as an exchange-coupled multilayer and the 5d metals Pt and W provide the ISHE with opposite signs for their spin-Hall angles.

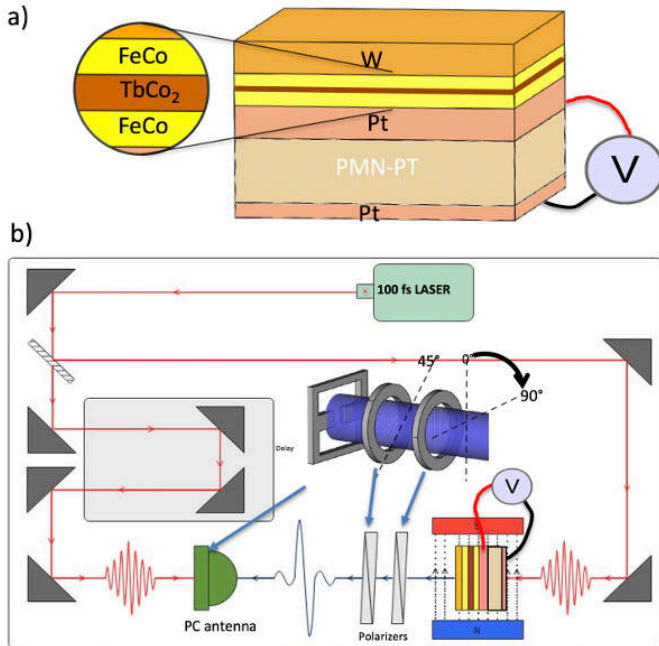


Fig. 1. a): schematic representation of the deposited magnetolectric spintronic emitter on <011> PMN-PT substrate with an additional electrode for voltage application. b) TDS setup for polarization measurements of the emitted THz signal.

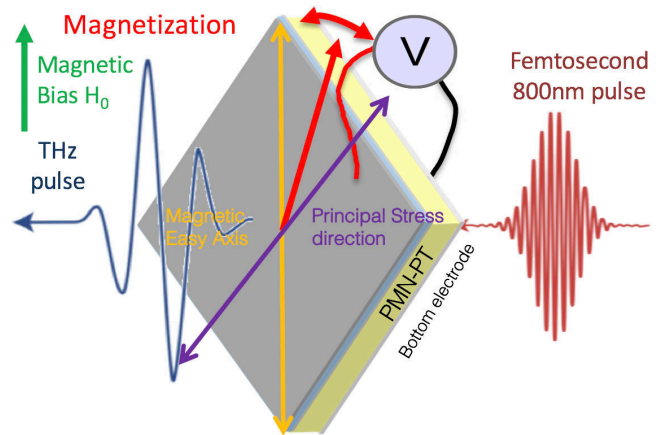


Fig. 2. Magnetolectric configuration: at rest, magnetization lies vertically along the magnetic easy axis. A 60 Oe magnetic bias ensures that there are no domains. Upon application of a voltage, a mechanical stress is created at 45 degrees in the plane of the PMN-PT.

The THz emission was characterized on a customized existing terahertz time-domain spectroscopy (TDS) setup as seen of figure 1b. The ISHE-mediated terahertz emission is generated by pumping the sample with femtosecond pulses from a Ti:sapphire laser oscillator (80MHz repetition rate, center wavelength 800nm and 100fs pulse duration). The E-field of the emitted terahertz pulse is measured by sampling the response of a photo-conductive Auston switch that is probed by a split-off fraction of the femtosecond infrared pulse by a delay line. In order to measure the horizontal and vertical components of the E-field and deduce the polarization angle, two wire-grid polarizers were inserted in the THz path. Figure 2 shows the magnetic and elastic configuration of the sample.

At first, temporal traces of the emitted electric field are measured for various values of the applied voltage. As it can be seen of figure 3, the polarization of the emitted THz signal clearly rotates from its horizontal direction upon application of the voltage.

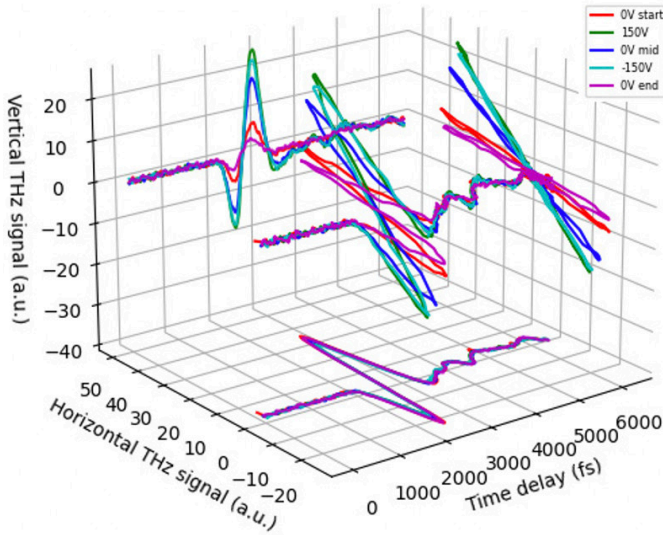


Fig. 3. 3D representation of the TDS temporal traces for horizontal and vertical components of the emitted THz wave, for several values of applied voltage.

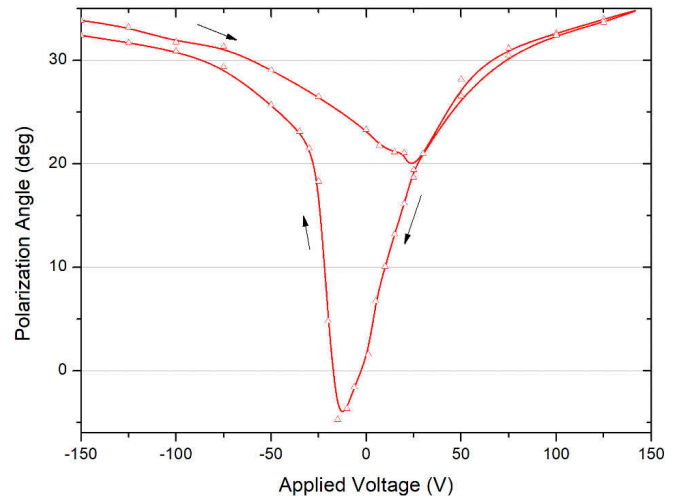


Fig. 4. Polarization angle (red) as a function of the applied voltage.

In a second step, the TDS setup delay line was set to obtain the maximum signal amplitude and E-field components were measured while cycling the applied voltage on the PMN-PT substrate. The deduced polarization angle shown on figure 4 clearly shows its controlled rotation over a span of nearly 40 degrees. Figure 5 shows a polar representation of the polarization direction. It can be seen that the emission behaves as expected: (i) at rest, the emitted signal has a horizontal polarization since magnetization lies vertically along the easy axis. (ii) Thanks to the magnetostrictive properties of the ferromagnetic tri-layer, and upon voltage application, the 011 PMN-PT substrate generates a stress in the 45 degrees direction, which induces a large change in magnetic anisotropy [2]. The magnetization thus rotates to its new equilibrium position resulting from the competition between the original anisotropy, the stress induced magnetoelastic anisotropy, and the Zeeman interaction due to the magnetic bias H_0 . In the present case, magnetization and thus the emitted polarization rotates by 35 degrees. At some point in the cycle, the rotation goes to the negative side, since between 0 and 15V (on the upward direction) and 0 and -15V (on the downward direction), the generated stress is negative. But then after 15V (and -15V), the ferroelectric polarization reverses in the PMN-PT, thus leading to an abrupt inversion of stress. This explains that the stress is equal and positive for 150 and -150 Volts, and that the hysteresis behavior of the polarization direction simply reflects the hysteresis of the ferroelectric relaxor response. Details of the experiments and discussion of the results will be given during the conference.

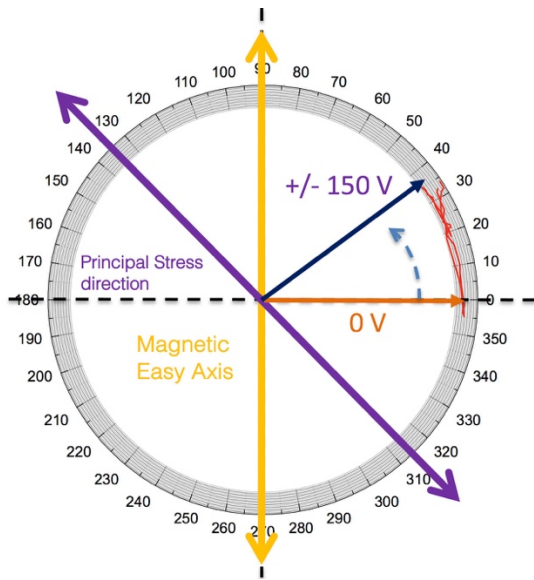


Fig. 5. Polar representation of the Polarization angle as a function of the applied voltage.

III. SUMMARY

This first demonstration of a magnetoelectric control of THz polarization paves the way to a new class of voltage-controlled THz devices. The authors thank the RENATECH network as well as the EU funded s-nebula project (Grant No. 863155).

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