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# Coherent polarization rotation of TeraHertz spintronic emitters with in-plane uni-axial magnetic anisotropy

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**Abstract:** Spintronic TeraHertz emitters using uni-axial anisotropic FeCo/TbCo<sub>2</sub>/FeCo ferromagnetic layers allow the polarization control of the THz emitted wave thanks to the Stoner-Wohlfarth coherent rotation of magnetization when submitted to a magnetic field along hard axis. © 2020 The Author(s)

## 1. Introduction

The TeraHertz (THz) frequency band (extending from 0.1 to 30 THz) presents a large number of potential applications in a wide variety of fields, from non-invasive control to spectroscopy, imaging or telecommunication. In this framework, THz time-domain spectroscopy (TDS) methods are powerful phase sensitive tools. However, the current THz generation technologies based on semiconductors are limited in their applications due to the narrow THz bandwidth or gaps due to phonon absorption. Typical TDS spectra are cut-off maximally at 6THz. THz spintronic emitters, introduced by Kampfrath et al. [1,2], offer a new approach to break this limit. Exciting a 5d/3d nonmagnetic (NM) /ferromagnetic (FM) multilayer by IR fs-pulses generates a spin-polarized current that upon diffusion in the NM metal undergoes strong spin-orbit coupling. The action of the inverse spin-Hall effect transforms the spin-current into a charge current dipole transversely oriented to the spin direction. The ultrafast relaxation times and absence of phonon absorption bands typical of metals allow the generation of THz pulses Fourier-limited by the IR pulse. Gapless spectra up to 30 THz have been reported. The polarization state is intrinsically linked to the magnetization direction in the FM layer. While optimizations of the THz power have been reported, little work has been done on the control of the THz polarization state, other than by rotating the applied field [3]. Here, we demonstrate for the first time coherent control of the magnetization state of a spintronic emitter and thereby a controlled generation of an arbitrary linear THz polarization.

## 2. Results

In order to be able to control the polarization direction, our proposed solution is to use a strongly uni-axial magnetically anisotropic ferromagnetic layer in the emitter to replace the classic ferromagnetic layer used in spintronics THz experiments. As is known from magnetics, perfect uniaxial anisotropy allows to coherently rotate the magnetization by varying the applied field ONLY along the hard axis between its saturation values. This is known as Stoner-Wohlfarth rotation. Thus, the considered emitter is a W(2nm)/ FeCo(0.5nm)/ TbCo<sub>2</sub>(0.8nm)/ FeCo(0.5nm)/ Pt(2nm) stack deposited on a c-cut Sapphire substrate by RF sputtering in a LEYBOLD Z550 equipment. During the growth, a magnetic field is applied in the plane of the substrate. Thanks to the exchange coupling between the layers, the result is a magnetically anisotropic and soft material with low saturation field around 100Oe, as it is clearly shown by the Vibrating Sample Magnetometer (VSM) measurements on fig. 1a (dotted lines).

The spintronic emitter was then investigated under a normal incidence transmission configuration of a time domain spectroscopy (TDS) setup, exposed by a 100 fs infrared pulse with a central wavelength of 820nm. The longitudinal and transverse component of the THz emission were measured by combining two polarizers placed between the emitter and a dipole photoconductive antenna. By setting up the delay line of the TDS setup at the point of maximum THz emission, it was possible to measure it as a function of the applied field. Both THz components are shown on fig. 1a (full lines) and are perfectly consistent with the VSM measurements. Moreover, the 3D plot on fig 1b also shows that magnetization clearly rotates in a Stoner-Wohlfarth fashion. The visible jumps are caused by the small angle between hard axis and applied magnetic field.

In a second step, TDS spectra of both THz components were recorded for various values of the magnetic field,

starting from saturation at 200 to -6 Oersted. As seen of fig. 2, the polarization clearly rotates from vertical to horizontal. As it is possible to control the rotation of magnetization over  $360^\circ$ , so is the polarization angle span.

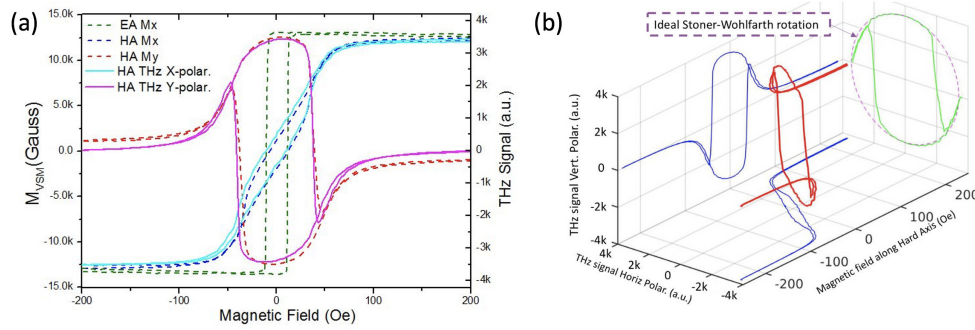


Fig. 1. (a) Comparison between VSM measured magnetic loops (dashed lines) and THz-TDS measurement (full lines) on the maximal peak position. The hysteresis loop with the field applied along the easy axis for the longitudinal component (green) is also presented. (b) 3D representation of the longitudinal and transversal components of the THz emission vs. magnetic field.

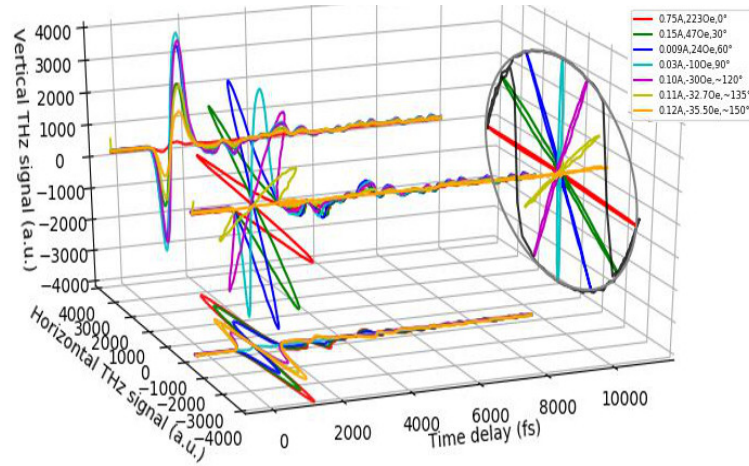


Fig. 2. 3D representation of THz-TDS scan under different magnetic fields to show the rotation of the polarization of the emitted radiation.

### 3. Summary

We present an improved scheme to achieve coherent polarization rotation without multipolar or rotating external magnetic bias nor complex cascaded emitters. This is achieved by exploiting recent progress in artificially engineered strong uniaxial anisotropy in intermetallic heterostructures of rare-earth and transition metals. By replacing the FM layer of the spintronic emitter with a carefully designed FeCo/TbCo<sub>2</sub>/FeCo heterostructure, we experimentally demonstrated Stoner-Wohlfarth-like coherent rotation of the THz polarization only by a unipolar variation of the strength of the hard axis field. These results improve greatly the feasibility of fast polarization switchable integrated THz sources impacting practical applications such as ultrabroadband THz spectroscopic ellipsometry without rotating elements, or polarization modulated high speed wireless data communications, but also fundamental physical studies into ultrafast terahertz optospintronics. This works also opens paths toward new THz high speed modulation schemes via the control of magnetization.

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