ROLE OF MICROSTRUCTURE ON ALL-OPTICAL SWITCHING AND THZ EMMISSION

E. E. FULLERTON[1]
1) Center for Memory and Recording Research, University of California San Diego, La Jolla, CA, 92093-0401, USA, eefullerton@ucsd.edu

I. INTRODUCTION

The possibilities of manipulating magnetization without applied magnetic fields have attracted growing attention over the last fifteen years. The low-power manipulation of magnetization, preferably at ultra-short time scales, has become a fundamental challenge with implications for future magnetic information memory and storage technologies. I will discuss recent experiments on the optical manipulation of magnetic materials and devices using 30-4000 fs optical pulses. We will discuss two related phenomena: (1) all-optical switching and control of magnetization without an external magnetic field (see Fig. 1) [1, 2] and (2) the emission of THz radiation (see Fig. 2) open laser excitation. All-optical switching has been observed for a broad range of materials, including ferrimagnetic alloys, multilayers, heterostructures as well as ferromagnetic films and granular recording media [1-5]. This discovery can enable breakthroughs for numerous applications since it exploits materials that are currently used in magnetic data storage and memory technologies. The observation of THz emission is believed to result from the generation of charge and spin currents generated from ultrafast demagnetization of magnetic materials [6, 7]. Generating and controlling of the spin currents in magnetic nanostructures using ultrashort laser pulses has may be the enabling technology for the spin based electronic devices operating at THz frequencies. In both cases integrating laser excitations with magnetic nanostructures in devices provides additional degrees of freedom in using intrinsic magnetic properties and their ultrafast response to laser pulses.

II. RESULTS

While both all-optical switching and THz emission have been experimentally observed in an increasing number of materials the mechanism or mechanisms involved are still under debate. To provide insight into these phenomena we have combined detailed temporally and spatially resolved measurements of a range of magnetic thin films and heterostructures which have a varying degree of structural disorder. These studies include FePt-based granular media [1, 2, 4, 5], Co/Pt-based thin-film heterostructures [1, 3] and FeRh/Pt bi-layers. Each system shows distinct behavior and dependence on structural disorder that challenge our current theoretical understanding.

For FePt-based magnetic recording media we find that the optical magnetic switching by circularly polarized light is an accumulative effect from multiple optical pulses [2] and can be described by a statistical model considering a small probability of switching magnetic grains for each light pulse, and these probabilities depend on the helicity of the light [2, 3]. It results in a high degree of alignment of FePt grains of approximately 75% achieved only with multiple circularly polarized optical pulses. This magnetic switching is found to be inhomogeneous throughout the material with some individual FePt grains neither switching nor demagnetizing. The origin of this behavior is identified as the near-field modification of the incident laser radiation around FePt nanoparticles [5] and the fraction of not-switching nanoparticles is influenced by the heat flow between FePt and a heat-sink layer. However, deterministic magnetization switching is achievable by the combination of circularly polarized light and modest external magnetic fields demonstrating that the circularly polarized light can aid the writing in a HAMR-like recording process.

For Co/Pt films time-resolved magneto-optical imaging reveals the dynamics of the helicity-dependent all-optical switching occurs on timescales from femtoseconds to seconds. Single femtosecond pulse demagnetizes the sample by 75% and aids the nucleation of a reverse domain. At the second stage circularly

E. E. FULLERTON
E-mail: efullerton@ucsd.eud
tel: +1-858-534-9639

polarized light breaks the degeneracy between the magnetic domains and promotes a preferred direction of domain wall motion. The growth of the reversed magnetic domain from the nucleation site, via deterministic displacement of the domain wall, leads to a full magnetization reversal [3].

Finally we have observed both helicity-dependent [6] and helicity-independent [7] THz emission in both Co/Pt and FeRh structures. By decoupling the horizontal and vertical components of the emitted THz-signals, we reveal the pump laser helicity-dependence in the emitted photocurrents in the ferromagnetic phase. We find the helicity dependent THz emission for Co/Pt structures increases dramatically with Co-Pt interfacial roughness and is strongly suppressed for epitaxial structure. Taking advantage of antiferromagnetic-to-ferromagnetic phase transition temperature in FeRh we distinguish a drastic change in the amplitudes of laser-induced emitted THz-signals upon heating the sample above transition temperature. Also, we can use 30 fs-laser pulses to force the material into its transition region, while the ultrafast magnetization dynamics are probed via THz-emission spectroscopy under the application of moderate external magnetic fields. Our results clearly reveal that the emitted electric fields show strong external magnetic field dependence (see Fig. 2) and the shape of the field dependence curve hints that the phase transition, in FeRh, occurs via super-paramagnetic-like behavior of the nucleated ferromagnetic phase.

III. ACKNOWLEDGEMENTS

This work is supported, in part, by the ONR MURI program and is in collaboration with R. Medapalli, C.-H. Lambert, Y. Quessab, M. Gottwald, R. Tolley, S. Patel, V. Uhlir, M. Menarini, L. Sham, V. Lomakin and Y. Fainman at UCSD, G. Malinowski and S. Mangin at Université de Lorraine, R. Mikhaylovskiy, G. Li, A. Kirilyuk, Th. Rasing, and A. V. Kimel, Radboud University, Nijmegen, The Netherlands and B. Varaprasad, Y.K. Takahashi, and K. Hono, National Institute for Materials Science, Tsukuba, Japan.

REFERENCES

1) Lambert *et al*., *Science* **345,** 1337-1340 (2014).
2) Takahashi *et al. Phys. Rev. Appl.* **6** (5) 054004 (2016).
3) Medapalli *et al.* arXiv: arXiv:1607.02505.
4) M.O.A. Ellis, E. E. Fullerton, R. W Chantrell, *Scientific Reports* **6**, 30522 (2016).
5) P. W. Granitzka et al., *Nano Letters*, **17** (04), 2426-2432 (2017).
6) J. Huisman *et al*., *Nature Nanotechnology* **11**, 455–458 (2016)
7) T. Kampfrath et al., *Nature Nanotechnology* **8**, 256–260 (2013)

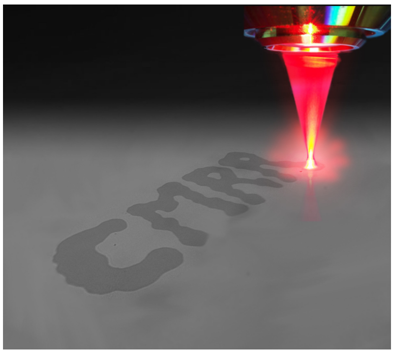

Figure 1: Magneto-optical image of CMRR written in a magnetic film using a circularly polarized 100-fs laser pulses where the orientation of the magnetic domains were controlled by sweeping circular polarized light over the film.

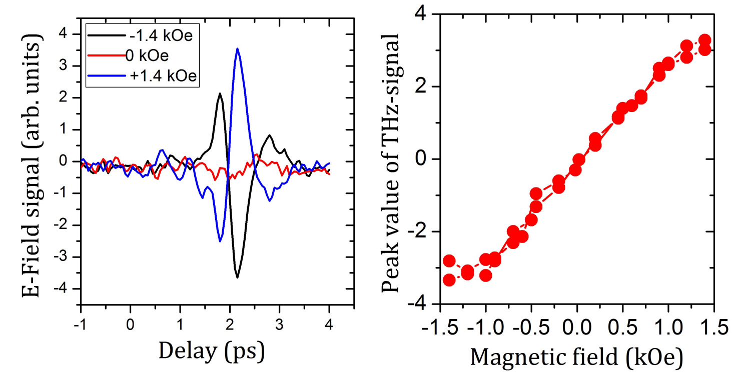

Figure 2: (left) Electric field of the emitted radiation polarized perpendicular to the applied magnetic field is shown for three different external magnetic field strengths. The emitted radiation changes sign with magnetization. (Right) The peak values of the E-field signals are plotted as a function of external magnetic field strengths.