Micromagnetics Of All-Optical Switching Dynamics In A Tb/Co Bilayer

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Ultra-fast heating alone drives helicity independent, all-optical switching (HI-AOS), predominantly in Gd-based ferrimagnetic alloys and multi-layers [1-3]. Governed by the inter-sublattice exchange coupling, this mechanism requires a careful adjustment of the laser fluence in relation to the pulse length, thus undermining its technological potential. A different HI-AOS mechanism was recently shown to govern laser-induced magnetisation switching in Tb and Dy-based ferrimagnetic multilayers, bilayers or trilayer systems [4]. Several of its characteristics remain theoretically unexplained: (a) the energy threshold to switching is independent of the pulse duration up to several ps; (b) the excitation area presents a concentric ring domain pattern; (c) the magnetisation exhibits a slow recovery process [4,5]. The switching is believed to occur due to an in-plane reorientation of the magnetisation under a temperature induced reduction of the perpendicular anisotropy at the interface and the presence of a local distribution of easy-axes directions arising from the granular thin film texture which could favour the slow, in-plane precession dynamics [4,5]. Here we provide a high temperature micromagnetic model which captures in full detail this behavior.

We examine this problem in the framework of the Landau-Lifshitz-Bloch (LLB) micromagnetic model [6] considering a Tb(1nm)/Co(1nm) bilayer as reference system. The key ingredient enabling the AOS is the assumption of a distribution of easy-axes (EAs) directions perpendicular to the thin film. We assume that it follows a Gaussian distribution within a cone with an average value set to 0^0 and a standard deviation of 2.5^0 for the polar angle θ_{EA} − see Fig. 1(a). The laser heating is described via a two-temperature model which includes a laser power source with a Gaussian profile in time as well as in space, inside the Oxy plane. The EAs distribution has the advantage of preserving an out-of-plane perpendicular magnetisation at room temperature whilst providing a torque on magnetisation favouring the precession during the ultra-fast laser excitation. Our model indicates that a 50-fs pulse induces a rapid heating of the sample along with an initial fast switching on a timescale of several ps, followed by a subsequent slow recovery in the ps-ns time domain as seen in subplot (c) of Fig. 1. During the laser pulse heating, the maximum electron temperatures corresponding to the squared regions in (b) satisfy the relationship: $T_1 > T_2$ due to the Gaussian spatial profile. This leads to a slower reversal in region 1 due to a competition between transverse and longitudinal relaxation mechanisms where a strong demagnetization followed by a slow precession can be observed, in comparison to the faster dynamics in region 2. Our model recovers the characteristic, ring domain-like pattern − shown for the Co m_z component in subplot (b) 1.5 ns after exposure to the laser pulse. We explore this switching mechanism closely following the results presented in Refs. [4,5]. Thus, we investigate the role of the θ_{EA} maximum tilting, the exchange coupling between the Co and Tb layers as well as the cooling rate in fitting the experimental switching curves. Although the results of Fig. 1 are obtained in zero applied field, we separately assess the role of in-plane and out-of-plane Zeeman contributions in the switching process. Our results contribute towards the fundamental understanding of recent advancements in the ultrafast magnetism community which so far lacked a supporting, theoretical picture.

References

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Figures

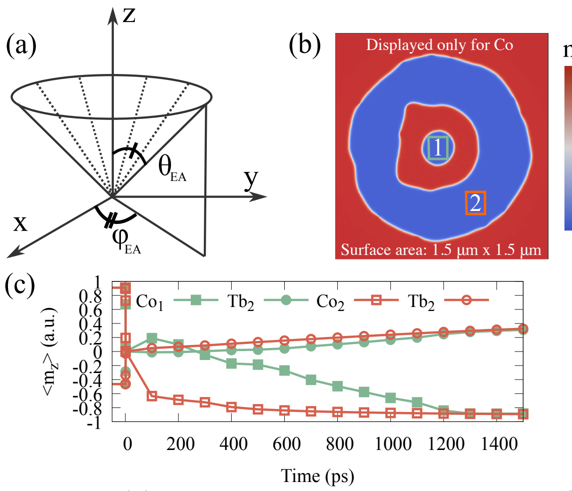

Figure 1. (a) EA anisotropy distribution: average θ_{EA} is zero with standard deviation of 2.5^0 and φ_{EA} varies uniformly in the range [0^0: 360^0]. (b) Concentric ring domain pattern in the Co sublattice along Oz, 1.5 ns after exposure to a 50-fs laser-pulse. (c) Average $\langle m_z \rangle$dynamics extracted for Co and Tb from the two squared spatial regions in (b).