Precessional all optical switching and deterministic switching outlook

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In the pursuit of faster, more efficient memory, all-optical switching (AOS) technology seeks to achieve magnetization reversal through energy-efficient ultrafast writing with single-femtosecond laser pulses. This work addresses the objective of merging helicity-independent HI-AOS and MRAM devices. The materials investigated are rare-earth transition metal multilayer systems, with a particular focus on Tb/Co-based structures. Through a combination of experimental investigations and numerical simulations, we unveiled the intricate dynamics and precessional character of AOS in these multilayer systems, using them to develop laser pulse switchable nanometer-sized AOS magnetic tunnel junctions (AOS-MTJs). These results provide an understanding of the AOS reversal process and explore its applications in nonvolatile data storage and energy-efficient computation at the nanoscale.

Exploring HI-AOS in thin films of rare-earth transition-metal multilayer systems allows for reliable magnetization toggle reversal, relying on the response to different pulse duration and fluence. Key new findings include the observation of concentric rings with opposite magnetic orientations and the independence of fluence on pulse duration, challenging previous understanding. A hypothesis emphasizing the role of local anisotropy decrease favoring a precessional type of helicity-independent AOS is introduced. The development of a macrospin model, incorporating principles of a two-temperature model (2TM), explains the precession-driven switching mechanism observed in the Tb/Co-based multilayer system. In this framework our investigations, allowing simulating the rapid response of our system to ultrafast laser pulses and gain valuable insights into the underlying physics. One of the central findings of the study is the remarkable independence of HI-AOS from the pulse duration, a characteristic that was consistently observed experimentally and can be attributed to the unique dynamics of the system. This independence implies that the core mechanisms driving the reversal process occurs over longer timescales than the laser pulse duration, primarily influenced by the absorbed laser fluence and the subsequent cooling of the system to its thermal equilibrium. The model considered various parameters such as temperature-dependent uniaxial anisotropy and the tilted anisotropy axis, shedding light on the intricacies of the reversal mechanisms within the system. Our simulations have demonstrated how parameters like damping, anisotropy angles, and the Q factor at equilibrium influence the threshold fluences necessary for HI-AOS. While the 2TM provided the foundational knowledge, it is clear that the full complexity of HI-AOS requires further investigation.

Similar to our initial research [1-3], the AOS behavior appears exclusively in the cobalt-rich region. It is important to note that the regions ‘rich’ in terbium and cobalt are temperature dependent. When the cobalt-rich region, is usually referred in relation to room-temperature conditions (300 K). Put differently, our system allows for ultra-fast reversal only when the initial temperature (usually RT) is slightly above the compensation temperature (T_{Comp}). In such cases, the total magnetization increases as the temperature increases.

The implementation of a stable hard reference layer and optimization of the MgO natural oxidation has allowed for tunnel magnetoresistance (TMR) values, reaching a maximum value of 74%, representing a significant improvement over previous realizations [4]. The main achievement was the demonstration of field-free HI-AOS on 100 nm diameter patterned [Tb/Co]x5 p-MTJ devices, using 50 fs laser pulses with an estimated absorbed energy of approximately 68.6 fJ per bit reversal. These findings hopefully pave the way toward nanoscale devices for optospintronic embedded memories combining nonvolatility, ultrafast and energy-efficient writing.

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Figures

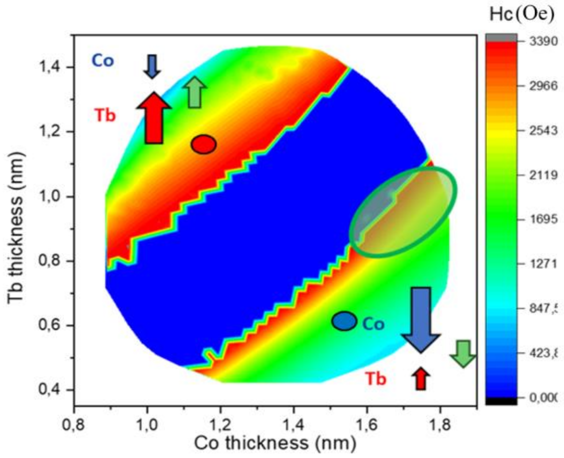

Figure 1. Multilayer thickness of $[Tb/Co]_5$ showing helicity independent switching in cobalt rich highlighted green region under 3.8mJ/cm² 50fs laser pulse.

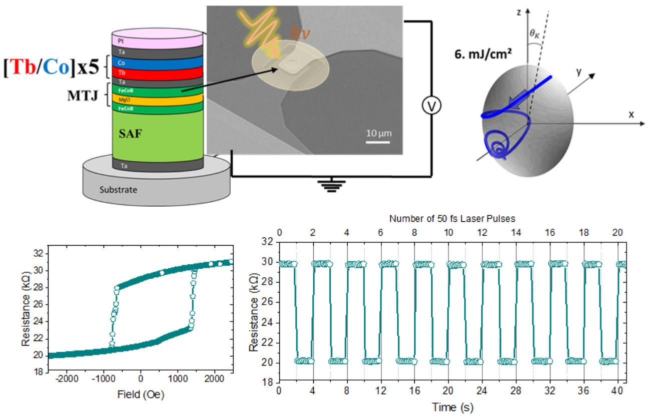

Figure 2. Illustration of the all-optical writing and electrical reading of an AOS MTJ stack showing SEM image of a 100-nm diameter pillar. Out of plane field hysteresis loop and resistance measurement after application of laser-pulse demonstrating toggle switching.