The technique involving manipulation of magnetic order and the subsequent control of its final state both using ultrashort laser pulses without the aid of external magnetic field, is known as all-optical switching (AOS) [1]. This type of switching has been observed for a broad range of materials [2], including ferrimagnetic alloys, multilayers, heterostructures as well as ferromagnetic films and granular recording media [3]. Until now two types of mechanisms have been reported: laser helicity-dependent and helicity-dependent. The latter has gained much attention due to the deterministic controllability over the final state of magnetic order, especially, in ferromagnetic thin films. Recently, it was demonstrated that the helicity-dependent all-optical switching (HD-AOS) in both Co/Pt ferromagnetic continuous and FePt granular thin films recording is multi-pulse induced [4-6]. Especially, the HD-AOS dynamics in Co/Pt media occurs by two stages: laser-induced stochastic nucleation, and deterministic displacement of domain walls [6]. In this paper, we highlight these stages for the deterministic magnetization reversal between $M^f$ and $M^r$, and vice-versa, only by changing the helicity of the pump laser pulses between left (σ) and right circularly (σ$^*$) polarized, or vice-versa.

We first obtained the magnetization reversal of a ~15 μm magnetic domain via HD-AOS, in 3 repeats of Co(0.4 nm)/Pt(0.7 nm) thin film multilayer system, by pumping a $M^f$ region with σ-pulses as we reported earlier in Ref.6. This was achieved when a sequence of 660 σ-pulses each at a fluence of 0.5 mJ/cm$^2$, and a repetition rate of 1 Hz was used to pump the sample region. The obtained reversed magnetic domain (along $M^f$) is shown in the left most image in Fig.1a. Note that the dark and bright regions in the magneto-optical images correspond to sample regions fully saturated towards $M^f$ and $M^r$, respectively. We then reversed the helicity of the laser to σ and pumped until the initial state $M^f$ was achieved. The remaining images in Fig.1a correspond to those recorded at various CCD camera exposure times (t). We also performed similar experiment for the reversal from $M^r$ state to $M^f$ state, and the result is shown in the bottom panel of Fig.1a. Clearly, the first visible changes in the laser exposed regime, due to nucleation of reversed magnetic domains, occur at different time intervals. One can clearly see the formation of nucleations of reversed magnetic domains occur at various t values and at different sample regions. Once the nuclei are formed the switching to $M^r$ or $M^f$, or vice-versa proceeds via displacement of domain walls separating the $M^f$ and $M^r$-regions at the nucleation sites. To demonstrate the directionality of the displacement of domain walls, we prepared a domain wall separating $M^f$ and $M^r$-regions as shown in the top image of Fig.1b. First, we pumped the domain with 100 σ-pulses until it displaced about 5 μm to its left (see center image in Fig.1b). Further, without moving the sample region, we changed the helicity of the laser to σ$^*$ and continued to pump with another 100 pulses. Clearly, the displacement of the domain wall takes place towards the right side (see bottom image in Fig.1b). In both the cases, the resulting displacement of the domain wall is about 50 nm/pulse, for a given fluence of 0.4 mJ/cm$^2$, and is in good agreement with our previous study [6].

In summary, we demonstrate the control of magnetization reversal between its two ground states just by changing the helicity of the pump laser pulses. The process of stochastic nucleation is dominant in both switching cases. Further pumping of laser pulses initiates the process of deterministic displacement of the domain walls at the reversed nucleation sites. This type of magnetization reversal process can enable breakthroughs for numerous applications since it exploits materials that are currently used in magnetic data storage and memory technologies.

REFERENCES


Review Editor’s Comments | The paper by Medapalli et al. provides new insight into the competitive mechanisms underlying the helicity dependent all-optical magnetization switching, an intriguing scientific topic with interesting application potential.