Dual-pulse laser excitation and MFM probing of a Pt/Co/Pt trilayer

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Abstract

Recent studies have shown that manipulating out-of-equilibrium matter with light is more efficient than controlling equilibrium states. For example, dual-optical pumping, with a preparational pump pulse getting matter out of equilibrium followed by a switching pump pulse, is more energy-efficient for optical switching between insulator-to-metal states [1]. Similarly, manipulating non-equilibrium spin systems leads to new energy-efficient ways to control magnetic states. A recent study demonstrated that a preparational laser pulse could switch an antiferromagnet to a transient nonequilibrium ferromagnetic state, which could be controlled with a second excitation pulse [2]. The dual-pulse optical technique has also been shown to lead to very efficient switching of ferromagnetic Pt/Co/Pt trilayers. [3]. However, the mechanism behind the switching of this ferromagnetic material is still under discussion.

Here, we use a scanning probe magnetic force microscope (MFM) with dual-pulse laser excitation (see Fig. 1a) to study a Pt/Co/Pt trilayer. The laser beam is adjusted to the scanning area of the microscope to conduct in situ measurements following nucleation. By scanning the excitation area for various delays between two pump laser pulses, we can discern magnetic nanopatterns and monitor the switching area of nucleated magnetic domains as function of delay time. When the delay between the two pumps is zero, the nucleated magnetic pattern exhibits the highest switched area (Fig. 1b, lower panel). Introducing a delay between the pulses results in a lower switched area value for the nucleated pattern. The switched area as a function of the delay between the two pulses is plotted in Fig. 1b. The switched area is approximately 120 μm^2 at Δt=±5ps and approximately 250 μm^2 in the overlap. We fitted the relaxation of the switched area with an exponential fit with a time constant of 1.4±0.8 ps. According to the 3-temperature model, this dynamics corresponds to the time of the relaxation of the spin system in the Pt/Co/Pt trilayer. [4].

To conclude, we demonstrate that combining MFM with dual-pulse excitation, offers a new approach to study All-optical switching in ferromagnetic Pt/Co/Pt with high temporal and spatial resolution.

References

[1] A. S. Johnson et al., *All-Optical Seeding of a Light-Induced Phase Transition with Correlated Disorder*, Nat. Phys. **20**, 970 (2024).

[2] T. G. H. Blank, K. A. Grishunin, B. A. Ivanov, E. A. Mashkovich, D. Afanasiev, and A. V. Kimel, *Empowering Control of Antiferromagnets by THz-Induced Spin Coherence*, Phys. Rev. Lett. **131**, 096701 (2023).

[3] K. T. Yamada, A. V. Kimel, K. H. Prabhakara, S. Ruta, T. Li, F. Ando, S. Semin, T. Ono, A. Kirilyuk, and T. Rasing, *Efficient All-Optical Helicity Dependent Switching of Spins in a Pt/Co/Pt Film by a Dual-Pulse Excitation*, Front. Nanotechnol. **4**, (2022).

[4] G. Kichin, M. Hehn, J. Gorchon, G. Malinowski, J. Hohlfeld, and S. Mangin, *From Multiple- to Single-Pulse All-Optical Helicity-Dependent Switching in Ferromagnetic Co/Pt Multilayers*, Phys. Rev. Appl. **12**, 024019 (2019).

Figures

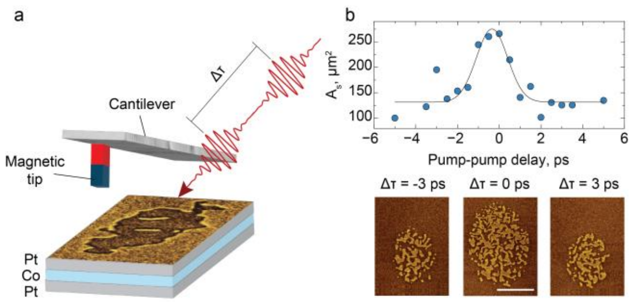

Figure 1. Dual-pulse excitation and MFM probing of Pt/Co/Pt. a) Schematics of the experimental setup of dual-pulse excitation and MFM probing. b) Switched area as a function of pump-pump delay. The lower panel shows MFM images of the nucleated patterns after dual-pulse excitation. The scale bar is 20 μm.