Ultrafast dynamics of spatial magnetic fluctuations in Co/Pt multilayers studied at European XFEL

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Abstract — One of the intriguing problems of modern magnetism is unravelling the non-equilibrium spin dynamics following laser excitation on the nanometer length scale. In this work the ultrafast magnetic behavior of thin Co/Pt multilayers is studied by resonant magnetic SAXS in transmission geometry. We have for the first time observed a very bright transient scattering from nanometer scale magnetic fluctuations.

Keywords— XFEL, SAXS, Co/Pt multilayers, ultrafast spin dynamics, nanometer scale magnetic fluctuations

I. Introduction

Optical probing at the femtosecond time scale allows the investigation of ultrafast magnetization dynamics, including fundamental interactions between spins, electrons, and lattice degrees of freedom far from equilibrium. Particularly important is unravelling the non-equilibrium spin dynamics following laser excitation on the nanometer length scale where magnetic order emerges. Access to the nanometer length scale during the ultrafast processes has only recently been achieved thanks to the development of XFEL's and new detectors of scattered X-rays. So far, this opportunity has been implemented only in study of ultrafast dynamics of spatial magnetic fluctuations in ferrimagnets with perpendicular magnetic anisotropy [1]. In the present work, we used XFEL to study spatially resolved ultrafast magnetic dynamics in ferromagnet that arises after femtosecond laser pumping.

II. Results and discussion

The experiment was carried out at the SCS beamline of EuXFEL by resonant magnetic SAXS in transmission geometry with the use of DSSC detector. The photon energy was tuned to the L-edge of cobalt at 779 eV. A femtosecond IR laser with a wavelength of 800 nm was used for pumping. The main results were obtained on a $(1.0\ \mathrm{nm\ Co}/1.2\ \mathrm{nm\ Pt})_6$ multilayered sample. The static SAXS pattern of the non-magnetized sample was dominated by the low-q third order scattering ring at $q \approx 0.08\ \mathrm{nm}^{-1}$ corresponding to the maze-like multi-domain structure with domain size of about 120 nm. A sufficiently strong IR laser pulse was shown to cause an instant femtosecond-fast decrease of the low-q scattering followed by a picosecond-fast recovery. This is a known fingerprint of the ultrafast demagnetization by IR radiation. Remarkably, for the IR fluences above 3.3 mJ/cm^2, another bright feature of the ultrafast magnetization dynamics has been discovered. Namely an additional scattering ring was shown to appear few ps after the IR pulse at $q > 0.8\ \mathrm{nm}^{-1}$, shrinking in diameter over the delay time with a velocity in the km/s range. Importantly, the sample did not completely relax during 1.8 µs between the subsequent FEL pulses. This is an evidence of the quasi-static pulse-by-pulse increase of base temperature on the µs-timescale. As a consequence, the transient magnetic signal at large q being the highest during the first pumped frame, faded away as the system was heated and vanished after several FEL bunches. The number of IR pulses required to erase the transient magnetic signal was shown to decrease with IR fluence. The full relaxation occurred during the 100 ms break between the trains of X-ray pulses. The impact of the magnetic field on demagnetization dynamics was also studied. When a strong saturating field of 350 mT was applied, both static and transient low-q magnetic scattering completely vanished while the high-q transient magnetic scattering got much suppressed. This proves the magnetic nature of the observed effects. Besides, no ultrafast transient scattering was observed for the off-resonant conditions.

To conclude, we have for the first time observed a very bright transient magnetic scattering taking place in thin Co/Pt multilayers upon femtosecond IR excitation. This transient scattering is coupled to the destruction of magnetic domain order occurring at the same time scale.

References

[1] E. Iacocca et al., "On Spin-current-mediated rapid magnon localisation and coalescence after ultrafast optical pumping of ferrimagnetic alloys," Nat. Comm. 10:1756, April 2019.