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Laser-driven resonant soft-X-ray scattering for probing picosecond dynamics of nanometre-scale order

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Magnetic domains are fingerprints of the complex interactions within magnetic materials. In addition to a local magnetic order, these emergent textures exhibit lateral periodicities on the nanoscale with a specific orientation and distribution. Statically, the relevant magnetic interactions can be tailored by growing heterostructures of magnetic nanolayers and by applying external stimuli such as magnetic fields and temperature changes. However, the laser-driven dynamics of magnetic domains result from an intricate interplay of local and non-local processes in the depth and in the plane of the sample.

Here, we investigate the ultrafast dynamics of magnetic maze domains in a ferrimagnetic [Fe(0.4nm)/Gd(0.5nm)]116 multilayer sample by time-resolved resonant magnetic small-angle-X-ray scattering (SAXS). This technique is an ideal tool to probe the local and lateral magnetic order element selectively on the relevant femto- to picosecond time and nanometer length scale - but so far the use of this approach has been exclusive to installations at X-ray free-electron lasers. We utilize a novel, laboratory-based setup for transient SAXS experiments at the Fe L (707 eV) and Gd M (1189 eV) absorption edges with 9-ps-temporal resolution [1-4] to benefit from the strong magnetic contrast and large penetration depths at such high photon energies.

Upon photoexcitation, we observe distinctively different time scales for the quenching and recovery of the local magnetization compared to the changes in the domain periodicity. In contrast to previous work [5-7], we find both a transient decrease and increase in the domain periodicity for different pump-probe delays. Based on a detailed analysis of the time-resolved SAXS signal in reciprocal space and heat diffusion simulations [8], we understand these results as indicators for a strongly inhomogeneous magnetic order along the depth of the 100-nm-thick sample.

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