Optical generation of magnetic skyrmions via a fluctuation driven, topology-sensitive mechanism

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Magnetic skyrmions in thin films are topologically non-trivial spin structures with soliton character. They have attracted interest for applications as units of information storage due to their potentially small size, room temperature stability and the ability to be manipulated via current pulse. In contrast, the optical generation of skyrmion structures via femtosecond laser pulses is less well explored and not understood. From a fundamental point of view, it is interesting to consider the mechanisms of topological switching in materials which can host topologically non-trivial structures in their ground state. Here, we study topological switching in spin textures induced by single or multiple sub-picosecond laser pulses.[1]

We experimentally explore skyrmion formation and annilihation via laser pulses in the presence of a magnetic field in Pt/CoFeB/MgO-type multilayers with built-in Dzyaloshinskii-Moriya interaction. We are able to controllably generate or annilihate single skyrmions as well as short-range ordered skyrmion lattices and observe that the process is not defect-driven in our multilayer samples. We observe the final state skyrmion density to be only controlled by the magnetic field and not by the cooling rate. This is in contrast to the formation of topological defects during symmetry-breaking non-adiabatic phase transitions, such as the crystallization of a liquid. Mapping out the the switching threshold as a function of laser fluence and pulse duration via x-ray holography imaging, a sharp fluence threshold at about 15 mJ/cm^2 is observed for skyrmion generation with a single femtosecond laser pulse, indicating the presence of a phase transition. Our observations are in contrast to earlier models of a thermally activated process over a (topological) energy barrier separating a metastable region from the ground state. Further theoretical analysis suggests that the optically deposited energy promotes the system into a transient phase with strong fluctuation of the topological charge, followed by an asymmetric evolution of the skyrmions depending on the sign of their topological charge upon cool-down.

We are able to follow the temporal development of skyrmion ensembles generated by a single laser pulse via pump-probe experiments at the European XFEL. In this reciprocal space experiment, we observe the initial nucleation of skyrmions and their subsequent lateral growth on a sub-nanosecond time scale. The experimental results are in line with a fluctuation-driven, topology-sensitive mechanism of optical skyrmion generation.

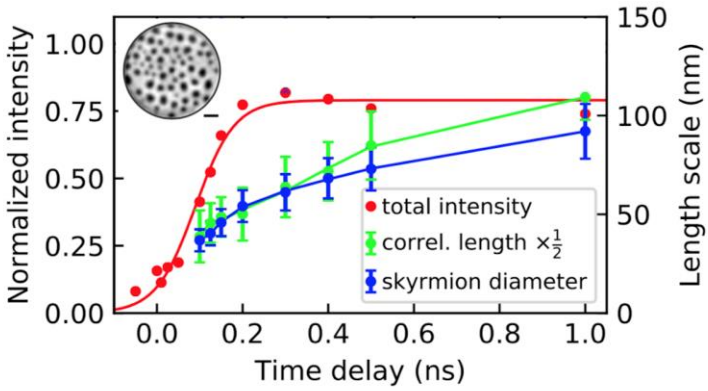

Figure 1: Circles: Experimental x-ray scattering intensity and inferred length scales of optical skyrmion formation as a function of pump-probe time delay. Inset: Representative real space image of the final skyrmion state. Scale bar 200 nm.

References:

[1] F. Büttner, B. Pfau, M. Böttcher, M. Schneider, G. Mercurio, C. M. Günther, P. Hessing, C. Klose, A. Wittmann, K. Gerlinger, L.-M. Kern, C. Strüber., C. von Korff Schmising, J. Fuchs , D. Engel, A. Churikova, S. Huang, D. Suzuki, I. Lemesh, M. Huang, L. Caretta, D. Weder, S. Zayko, K. Bagschik, R. Carley, L. Mercadier, J. Schlappa, A. Yaroslavtsev, L. Le Guyarder, N. Gerasimova , A. Scherz, C. Deiter, R. Gort, D. Hickin, J. Zhu, M. Turcato, D. Lomidze, F. Erdinger, A. Castoldi, S. Maffessanti, M. Porro, A. Samartsev, C. Ropers, J. Sinova, J. H. Mentink, B. Dupé, G. S. D. Beach, and S. Eisebitt (unpublished).