Skyrmion Diffusion and Lattices: From Observation to Application

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Ferromagnetic skyrmions, whirls of magnetization with topological charge, are efficiently displaced using spin-transfer torques[1] and spin-orbit torques[2]. Thermally induced motion of skyrmions has been predicted by theory and was initially been deemed negligible compared to the current induced motion[3]. Recently, we have uncovered thermal diffusive skyrmion dynamics in a multilayer material with engineered ultra-low pinning[4]. At low skyrmion densities, the motion of skyrmions observed was following the diffusive motion assuming rigid particles with no correlation, having the mean-squared displacement linearly proportional to the time (Fig. 1). Investigating the temperature dependence, we observed that skyrmions in the prepared system move in a non-flat energy landscape, revealing an exponential dependence of the diffusion coefficient on temperature. For the application of the diffusive motion, we develop a reshuffler device[5] that can be used for probabilistic computing. A key problem for probabilistic computing is that cascading gates propagate undesired correlations and thus vitiate the functionality of the logic device. Therefore, in order to implement probabilistic computing, one needs to reshuffle the signals to keep them uncorrelated for further calculations. While for many non-conventional computing approaches non-magnetic implementations have been identified as promising, for building a reshuffler device, skyrmions might be ideally suited due to the low footprint and low power compared to e.g. CMOS implementations.

At low densities, the diffusion of individual skyrmions is observed. However, at higher densities, skyrmion lattices emerge in the material (Fig. 2). While from previous measurements it is established that the skyrmions tend to move and diffuse throughout the material[4], the ordering of the lattice is highly dependent on the skyrmion-skyrmion interactions. We investigate the structure of the system in the temperature range 280-350 K as a function of the skyrmion radius that can be tuned by external magnetic fields. By determining the pair-correlation function we study the lattice formation process and the phases of the two-dimensional system.

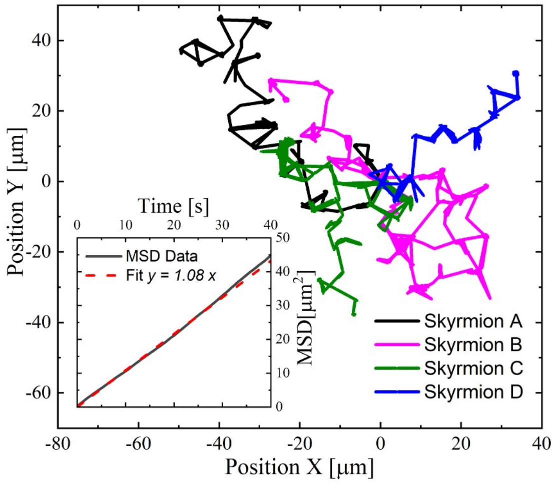

Fig. 1. Trajectories of selected skyrmions at 296 K. The reference position was taken from the first frame in the measurement. All the skyrmions are set to start at position (0,0). The timescale of the observation is in the range of seconds to minutes. The inset shows the time-averaged MSD (black line) and the linear fit of the data. Image taken form Ref. 4.

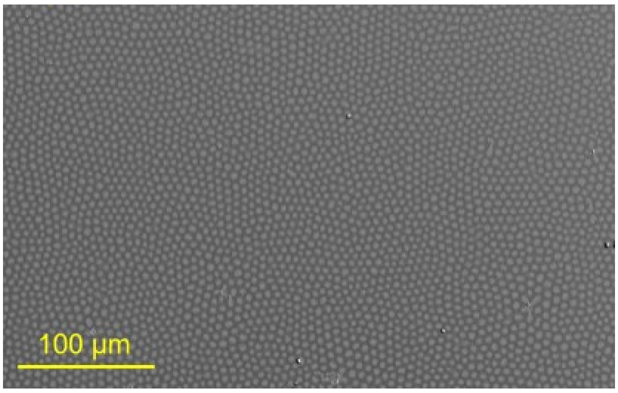

Fig. 2. Skyrmion lattice in a semi-steady state and hexatic order parameter. Kerr image of a skyrmion lattice at 335 K with μm sized skyrmions.

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