Magnetic Skyrmions on the Moves

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Magnetic skyrmions are topologically stable magnetic spin textures that have been discovered in materials with Dzyaloshinskii-Moriya interactions. On one hand, the controlled manipulation of magnetic skyrmions in thin films at room temperature is envisioned to enable skyrmion-based spintronics, which would lead to energy-efficient device applications, such as memory for computers. On the other hand, there is the fundamental question as to whether for quasi-particles with a topological charge, like skyrmions, there is a Hall effect, analogous to the ordinary Hall effect of electrically charged particles. In this presentation I will discus our work demonstrating how in thin film heterostructures, inhomogeneous electric charge currents combined with the spin Hall effect in a heavy metal layer can be used to generate and manipulate magnetic skyrmions in an adjacent ferromagnetic layer [1]. Skyrmions, visualized using magneto-optical Kerr effect microscopy, are generated via diverging electric charge currents from stripe domains in a process that appears stunningly similar to droplet formation in surface-tension driven fluid flow. These experiments importantly demonstrate the stabilization of magnetic skyrmions at room temperature, a necessary requirement for any future application. Furthermore, we find that under application of sufficiently large homogeneous currents, the motion of magnetic skyrmions contains both longitudinal and transverse components, evidencing the skyrmion Hall effect [2]. Interestingly, the derived skyrmion Hall angle is shown to first increase with increasing current density, after which it saturates. The behavior indicates pinning due to defects plays a role in determining the dynamics of the skyrmions. The dependence of the sign of the skyrmion Hall angle on the topological charge (+/-1) is demonstrated, illustrating the potential for topological sorting. (*Work at Argonne was supported by the Department of Energy, Office of Science, Basic Energy Science, Materials Sciences and Engineering Division.)*

[1] W. Jiang, P. Upadhyaya, W. Zhang, G. Yu, M. B. Jungfleisch, F. Y. Fradin, J. E. Pearson, O. Heinonen, Y. Tserkovnyak, K. L. Wang, S. G. E. te Velthuis, and A. Hoffmann, *Science* 349, 283 (2015).

[2] Wanjun Jiang, Xichao Zhang, Guoqiang Yu, Wei Zhang, Xiao Wang, M. Benjamin Jungfleisch, John E. Pearson, Xuemei Cheng, Olle Heinonen, Kang L. Wang, Yan Zhou, Axel Hoffmann, Suzanne G. E. te Velthuis, *Nature Physics* 13, 162 (2017).

Bio: Dr. Dr. Suzanne te Velthuis, physicist in the Neutron and X-ray Scattering group in the Materials Science Division, has been studying the physics of magnetic thin films and nanostructures throughout her career, focusing on using techniques such as neutron scattering, nuclear magnetic resonance, X-ray magnetic dichroism, and magneto-optical Kerr microscopy to understand their properties. She was instrument scientist of the POSY1 polarized neutron reflectometer at IPNS from 2001 until the shutdown of that facility in 2009 and is a world recognized expert in polarized neutron scattering, and reflectivity in particular, which is the most commonly used neutron scattering technique for studying magnetic films.

With her work she has contributed to the understanding of exchange bias and exchange coupling, competition of various interactions at the interfaces of complex oxide heterostructures, such as superconducting spin switches and digitally ordered manganites, and magnetic skyrmions.

Dr. te Velthuis came to Argonne in 1999 as a postdoctoral fellow, after obtaining her doctorate degree from Delft University of Technology, which was preceded by a Masters degree in Applied Physics from the Eindhoven University of Technology, both in the Netherlands. In 2014 the American Physical Society elected her as a Fellow for contributions to the understanding of magnetic heterostructures utilizing polarized neutron reflectivity.