Towards imaging magnetisation dynamics with high spatial and temporal resolution in a transmission electron microscope

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The importance of magnetic fields in modern technology is exemplified by the use of the giant magnetoresistance effect in current data storage applications. In the future, a wide range of new possibilities may be provided by magnetisation dynamics. For example, magnonic applications that make use of spin waves promise a route towards the minimisation of electronic circuits operating at GHz frequencies. It is therefore important to be able to investigate the dynamic properties of magnetic fields in materials with high temporal resolution and nm spatial resolution. Here, we report on progress towards the dynamic measurement of magnetic fields in a transmission electron microscope (TEM).

In order to image in-plane magnetic fields in a TEM, a magnetic-field-free environment at the sample position is required. This requirement can be met by using a non-immersion Lorentz lens instead of the conventional microscope objective lens. Phase contrast techniques, such as Fresnel imaging and off-axis electron holography, can then be used to record image that are sensitive to the in-plane magnetic induction within and around the sample. Fresnel imaging is most often used to provide real-time measurements of the switching of magnetic domain walls in continuous or patterned thin films, while off-axis electron holography is better suited for studying the magnetic properties of deep-submicron nanocrystals and devices. However, when applying these techniques, standard TEM specimen holders are not optimised for studying the dynamics of high frequency magnetic switching processes.

We have developed a magnetising TEM specimen holder that allows in-plane radio frequency (RF) magnetic fields to be introduced at the sample position at frequencies of up to 10 GHz, in order to excite magnons. Strip lines for RF currents are contacted by pressing the sample onto coplanar waveguides, which are connected to a power supply using a coaxial cable, with the RF circuitry designed to result in minimal losses. The waveguides are terminated by a 50 Ohm resistor and are fabricated on an exchangeable silicon/silicon nitride chip. The holder is designed to support standard 3-mm-diameter samples, which are compatible with standard TEM specimen holders. Before studying magnon excitations, the holder is being characterised to ensure that the electron beam is not deflected by the RF magnetic field. The first samples are investigated at low frequencies. Lithographically patterned ferromagnetic disks are used as a test system, since they support magnetic vortices, whose core gyrations can be studied at frequencies of approximately 200 MHz. Disks consisting of thin permalloy or cobalt layers are prepared on silicon nitride membranes together with the strip lines that are needed for excitation by spin coating, electron beam lithography and lift-off. It is planned to excite magnons at frequencies of up to 10 GHz using antennas that have been fabricated directly onto lithographically patterned samples.

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