TEM investigations of gyrotropic vortex motion on structured magnetic specimens

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Transmission electron microscopy (TEM) can be used to investigate magnetic material in the nano- and micrometer range. Understanding magnetic structures and properties of patterned magnetic films at low dimensions is an area of immense technological and fundamental scientific importance. Recently, magnetic devices became extremely interesting for commercial application. Magnetic functional devices are already widely used as sensors, so-called MRAM`s (magnetic random access memories) are being developed with great financial and personal effort, many research groups worldwide race for the "spin transistor", and ferromagnetic disks and squares with vortex configuration have the potential to work as 2 bit data storage elements or four-state logic elements. Dense arrays of microstructured magnets with vortex configuration have been investigated [1] and can form a basis for new applications of the future.

Lorentz microscopy (LTEM), a special operating mode with switched-off objective lens, using a long focal length instead, yields information about domain wall structures and/or vortex core position of magnetic specimens. By Lorentz TEM the position of the magnetic vortex core can be precisely localized. A magnetic disk has a circular in-plane magnetization with two possible chiralities (cw or ccw). The vortex core, being the out-of-plane component of the magnetization, determines the polarity (up or down) of the vortex.

A newly developed RF-specimen-holder (Figure 1) allows us to excite magnetic specimens with an AC-current in the range between 40 tand 700 MHz. Within this range we are able to resonantly excite the gyrotropic Eigenmode of the vortex, a so called low frequency mode. The Eigenmode, e.g. the gyration of the vortex core perpendicular to the plane around its equilibrium position (i.e. the position without excitation) shows a circular trajectory. A possible way to excite the vortex Eigenmode is to drive a spin polarized AC-current through the magnetic specimen. This spin-polarized current will interact with the specimen's magnetization, the electrons will suffer a spin flip from one side of the specimen to the opposite, and the change in the momentum will give rise to a torque on the magnetization distribution. The trajectory of gyrotropic vortex core motion can be directly observed with the LTEM technique and recorded with a charge-coupled-device (CCD) camera. Figure 2a shows a trajectory image of a permalloy disk with a diameter of 2.2 µm and a thickness of 20 nm. We find that the radius of the grotropic motion depends on the amplitude of the injected current and the resonance frequency decreases for increasing currents by several MHz. When, additionally, a static magnetic in-plane field is applied we find that the resonance frequency varies proportional to the applied field. With these two experimentally accessible parameters, current and magnetic field, the resonance frequency of the gyrotropic motion can be adjusted within a range of 20 MHz. The resonance frequency measurements can be used to calculate typical parameters of magnetic specimens in different sizes.

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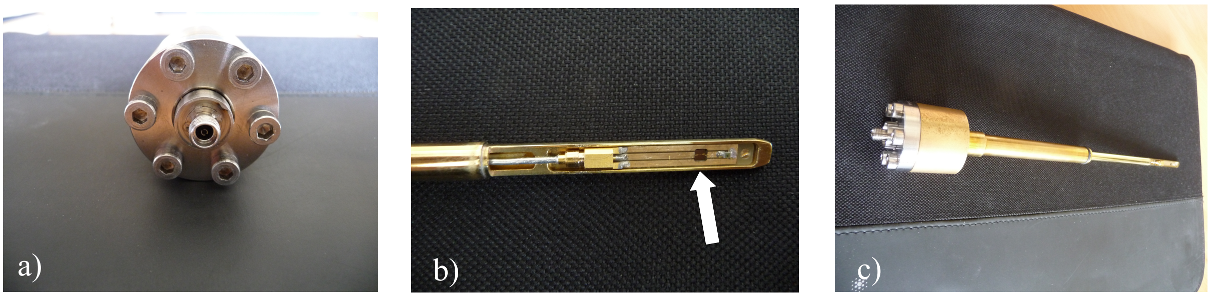

Figure 1. The newly developed RF-holder for the investigation of gyrotropic motion. a) Waveguide connection to the RF-generator which allows us to apply frequencies in the MHz range. b) Tip of the holder, including the circuit board, shaped as a wave guide, with the specimen (see arrow) mounted in place. c) The fully assembled RF-holder.

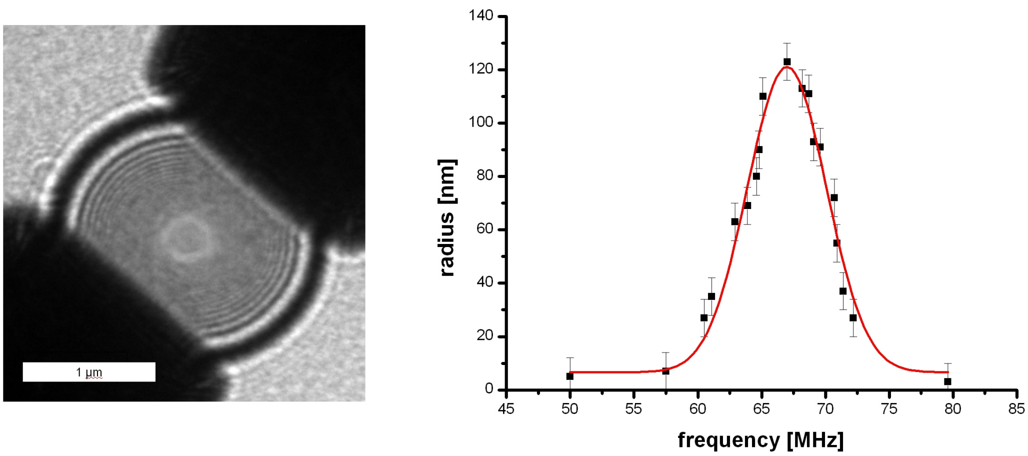

Figure 2. Left) Image from the CCD camera shows the resonantly excite vortex core. In the center of the permalloy specimen one can see the vortex core motion (white circular feature). To excite the specimen with an AC-current, it is contacted by gold leads (dark black regions). Right) Experimental data of a resonance measurement with the fit function from [2].

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