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Edge mode spectroscopy and imaging for film edge properties in magnetic nanostructures

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Lithography is an act of violence. Often, films are almost entirely obliterated by patterning, leaving only nanostructures behind with film edges that have borne the brunt of the damage, edges that carry with them the scars of energetic ion bombardment, reactive ions, liftoff and exposure to ambient conditions. In this talk, I will present a variation on ferromagnetic resonance force microscopy that can provide insight into the magnetic properties of film edges in magnetic nanostructures. The method relies on the non-uniformity of the magnetic field in patterned-film nanostructures that are magnetized in-plane, specifically, the low-field regions that form near where the magnetization is directed normal to the edge. In these regions, localized precession forms as trapped spin wave modes, and the resonance condition of these modes serves as an indicator of the edge properties. I will present modeling and measurements on a 500 nm diameter, 25 nm thick Permalloy disk to illustrate the method. Micromagnetic modeling of this disk predicts a main mode that is nearly uniform across the sample and three localized edge modes with higher resonance fields. The spectra measured with various tip positions and mode imaging are consistent with the modeling results. In addition to a strong center mode, three distinct edge modes are observed when the tip is near the disk edge. For a symmetric disk, the modeling predicts that the edge mode resonances are identical on the two opposite edges. However, the measured edge mode resonances on opposite edges of the disk are detected at different resonance fields, suggesting inhomogeneity of the edge properties. By rotating the applied field, we control the position of the localized edge mode along the edge of the disk and confirm that the edge mode resonance field has a strong angular dependence, showing that edge mode properties can vary significantly in a nominally circular disk.