Imaging the magnetic stray field of an artificial chiral spin ice system

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We use a scanning nanometer-scale superconducting quantum interference device (nanoSQUID) [1] to image the magnetic stray field of a chiral artificial spin ice system in a series of in- and out-of-plane applied magnetic fields at 4.2 K. The spin ice system is composed of a 500 μm x 500 μm array of individual nanomagnets spaced by a 1.5 μm lattice constant (center-to-center distance of neighboring elements). Each magnetic element is a 7-nm-thick permalloy ($Ni_{83}Fe_{17}$) nanoisland with a length of 1.55 μm and a width of 0.56 μm. The small thickness of the nanomagnets compared to their in-plane dimensions produces a strong shape anisotropy that favors uniform, i.e. single-domain, magnetization patterns [2]. The measured stray field maps are largely consistent with micromagnetic simulations of the expected patterns. For large in-plane applied fields, however, we observe a distorted pattern, shown in Figure 1 (a), indicating a bending of the local magnetization at the edge of each island and therefore a breakdown of the single-spin approximation [3]. At low applied fields, complex stray field patterns emerge likely due to the breakup of the magnetization into multiple domains. This first application of scanning nanoSQUID to spin ice, which can achieve lateral resolutions and sensitivities better than 50 nm and 10 nT/$\sqrt{\text{Hz}}$, respectively, is particularly promising for these systems. Unlike magnetic force microscopy, which measures magnetic force and from which precise stray fields values are often difficult to extract, scanning nanoSQUID produces quantitative maps of magnetic flux. These flux distributions provide insight into the behavior of the system and therefore provide a better picture of its state compared to maps of magnetization, as measured in techniques such as x-ray photoemission electron microscopy.

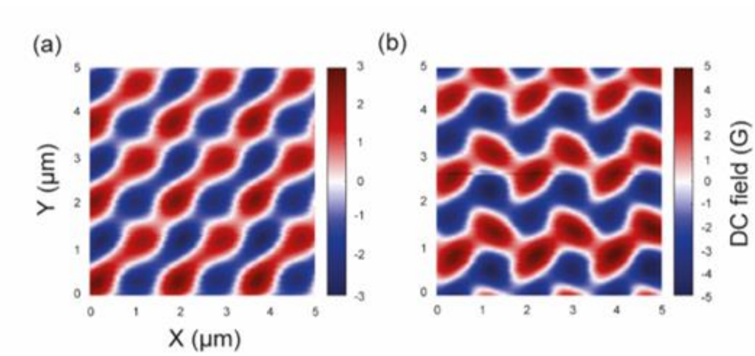

Figure 1. Imaged stray field pattern of the chiral spin ice system at an applied magnetic field strength in-plane of B_x = 0.250T in a), and out-of-plane of B_z= 0.708T in b).

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