Anomalous Nernst Imaging of Uncompensated Moments in Antiferromagnetic FeRh Thin Films

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Abstract:

We use anomalous Nernst microscopy to image uncompensated magnetic moments in Pt/FeRh <001> bilayers as a function of temperature and magnetic field. Uncompensated moments (UMs) in antiferromagnets (AFM) have been extensively studied in ferromagnetic (FM)/antiferromagnetic (AF) bilayers, where they are responsible for exchange bias, but their structure in a single antiferromagnetic layer is less well characterized. We image the emergence of the ferromagnetic phase in the 1st-order magnetic phase transition in FeRh. Below T_N we resolve µm-scale FM domains with large, spatially inhomogeneous vertical shifts to the $M(H)$ loop. This so-called vertical exchange bias signals the presence of bulk UMs with varying degrees of exchange-coupling to the local Néel order. Our measurements provide new insight into the structure of uncompensated moments within a single antiferromagnetic thin film.

Summary of Research:

In a simplified picture of a collinear Néel antiferromagnet, each spin is compensated by an oppositely-pointing spin on an adjacent lattice site, and therefore there is no net magnetic moment. In reality, uncompensated moments (UMs) form both in the bulk and at interfaces [1]. These UMs are of great practical importance because they are directly responsible for exchange bias in antiferromagnet /ferromagnet (FM) bilayers [2]; however, they are difficult to probe directly. In this work we use anomalous Nernst microscopy to image uncompensated moments in FeRh, which undergoes a 1st-order AFM/FM phase transition near T_N = 100°C [3] and therefore provides an ideal platform to study the interaction of ferromagnetism and antiferromagnetism in the same material.

We study 10 nm Pt/20 nm FeRh bilayers patterned into 3 µm × 30 µm Hall crosses. We first characterize the phase transition with anomalous Nernst imaging [4], shown in Figure 1. In agreement with previous imaging studies [5] we observe that FM domains first nucleate on defects and sample edges near 80°C, then percolate through the sample, and finally grow in size until the FM phase is uniform above 100°C.

At 25°C, we image µm-scale magnetic contrast, shown in Figure 2, which exhibits a ferromagnetic hysteresis loop averaged over the whole sample but unlike conventional FM samples does not saturate uniformly with field. Imaging at positive and negative field, we resolve signal from both unpinned domains, which switch with field, and pinned domains, which do not switch.

Plotting the average signal within adjacent ..m-scale pinned domains as a function of field in Figure 3, we obtain hysteretic $M(H)$ loops characteristic of a ferromagnet, but with unusual large vertical offsets signifying spatially inhomogeneous vertical exchange bias [6]. We explain these results in terms of bulk uncompensated moments exchange-coupled to the Néel order: large (> 1 µm) regions of UMs are strongly exchange-coupled and do not switch, while small (< 500 nm) regions of UMs are weakly exchange-coupled and can be reoriented with 1 kG field.

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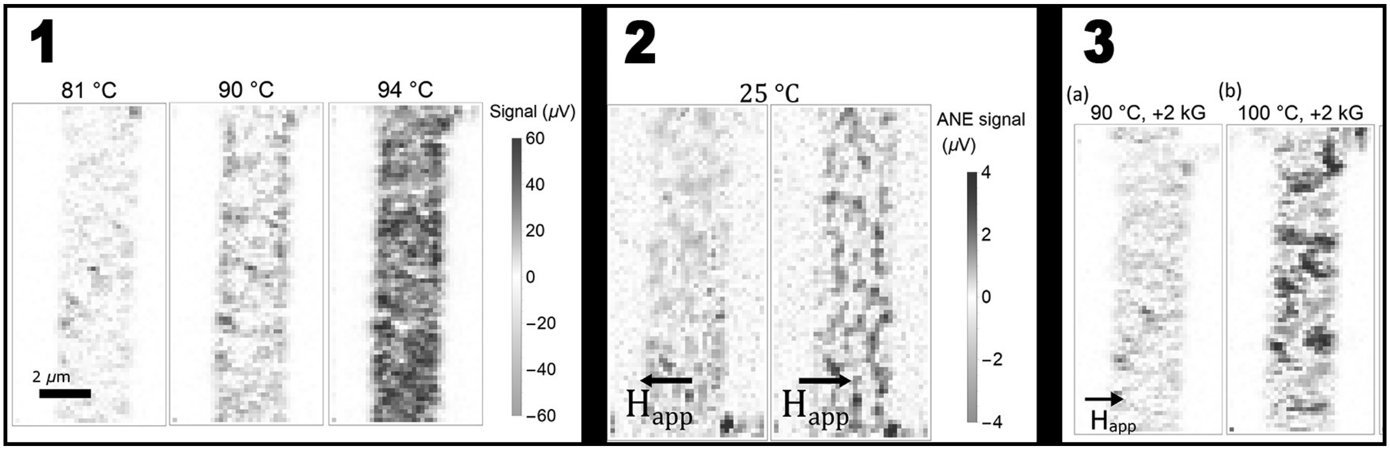

Figure 1, left: *Anomalous Nernst imaging of the 1st-order magnetic phase transition in FeRh. We observe the FM phase nucleating at sample edges and defects at 81°C, percolating through the sample at 90°C, and nearly uniform at 94°C.* ***Figure 2, middle:*** *Imaging FM contrast at 25°C, nominally in the antiferromagnetic phase, at positive and negative 1.3 kG field. The signal contains both unpinned FM domains, which reverse with field, and spatially inhomogeneous pinned domains, which do not reverse up to 5 kG field.* ***Figure 3, right:*** *Average signal from adjacent pinned domains as a function of field, yielding ferromagnetic* M(H) *loops with giant vertical shifts (vertical exchange bias). Pinned and unpinned domains correspond to strong and weak exchange-coupling between uncompensated moments and the bulk antiferromagnetic order.*

In conclusion, we image uncompensated moments in FeRh which exchange-couple to the bulk antiferromagnetic order in a complex, spatially inhomogeneous pattern. Our results establish anomalous Nernst microscopy as a powerful technique for imaging UMs in antiferromagnetic metals and provide insight into the interaction of coexisting AF and FM order in a single material.

References:

[1] J. Nogués and I. K. Schuller, J. Magn. Magn. Mater 192, 203-232 (1999).

[2] I. K. Schuller et al, J. Magn. Magn. Mater 416, 2-9 (2016).

[3] J. B. McKinnon et al, J. Phys. C: Solid State Phys. 3, S46 (1970).

[4] J. M. Bartell et al, Nat Comm. 6, 8640 (2015).

[5] C. Baldasseroni et al, Appl. Phys. Lett. 100, 262401 (2012).

[6] P.-H. Huang et al, Appl. Phys. Lett. 90, 062509 (2007).