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Visualization of Magnetization in CoFe Nanofibers by Lorentz TEM and Electron Holography

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It is necessary to understand the magnetic domain configuration of the solid metallic nanofibers as well as that of the core-shell multiferroic nanofibers and correlate it with the microstructure to enable control of their behavior for various applications. Lorentz transmission electron microscopy (LTEM) provides a unique combination to characterize not only the microstructure but also the magnetic domain structure of such nanofibers at a high spatial resolution. The fabrication of magnetic nanofibers or nanotubes was done by a patent-pending integrated electrospinning system with controlled nanofiber deposition orientation, fast IR heating and pneumatic collection of nanofiber/nanotubes. It not only makes the production scalable, but also provides precise morphology control of the nanofiber/nanotubes. It can be easily switched between configurations to produce high quality nanofiber or nanotubes. Atomic layer deposition of CoFe was accomplished using Fe and Co acetamidinate organometallic precursors reacted with hydrogen gas at relatively low temperatures (~250°C). By performing the ALD process in an oxygen-free environment, good, oxide-free metallic deposition was achieved. Figure 1 shows a TEM image of the core-shell nanofiber with CoFe shell and PZT ($Pb[Zr_xTi_{1-x}]O_3$) core along with EF-TEM maps showing distribution of Fe and Ti.

In this talk, we will present visualization and domain behavior in CoFe and PZT/CoFe core-shell nanofibers. This was performed using a dedicated JEOL 2100F TEM with a Lorentz pole piece and equipped with a spherical aberration corrector [1], which enables imaging of magnetic structure at a spatial resolution of a few nanometers. The out-of-focus Fresnel imaging mode was used to observe the magnetization of the nanofibers similar to our previous work on imaging magnetic domains in Co nanospirals [2]. Magnetization color maps were then reconstructed from a through-focus series of images using a phase-retrieval method based on the transport-of-intensity equation (TIE) to determine the magnetization configuration. Figure 2 top panels show a CoFe nanofiber of about 30 nm wide. The phase reconstructed color map indicates that the magnetization in this nanofiber is mostly parallel along its length direction, which indicates that it is dominated by the shape anisotropy. But surprisingly, the magnetization is seen to be separated into segments with head-to-head and tail-to-tail transition domain walls. We will present further detailed analysis of such domain walls as well as domains formed in the core-shell nanofibers. Finally, we will also present high resolution data obtained using off-axis electron holography to map the stray fields as well as magnetization of such nanofibers. Figure 2 bottom panels show one such hologram image and its phase image amplified by 10 × (cos(10*ϕ)), indicating the stray field lines from the nanofiber. [3]

References:

[1] A. K. Petford-Long and J. N. Chapman, Characterization of Materials (Wiley Online Library).
[2] C. Phatak, *et. al*, Nano Letters, **14**(2), 759 (2014).
[3] This work was supported by U.S. Department of Energy (DOE), Office of Science, Materials Sciences and Engineering Division.

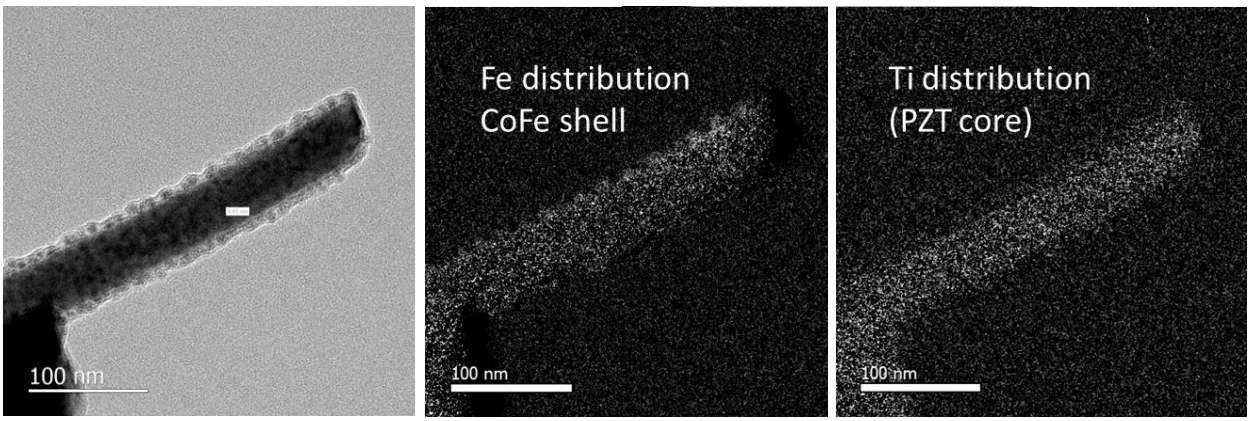

Figure 1. TEM image of CoFe shell and PZT core nanofiber with EF-TEM maps showing distribution of Fe and Ti.

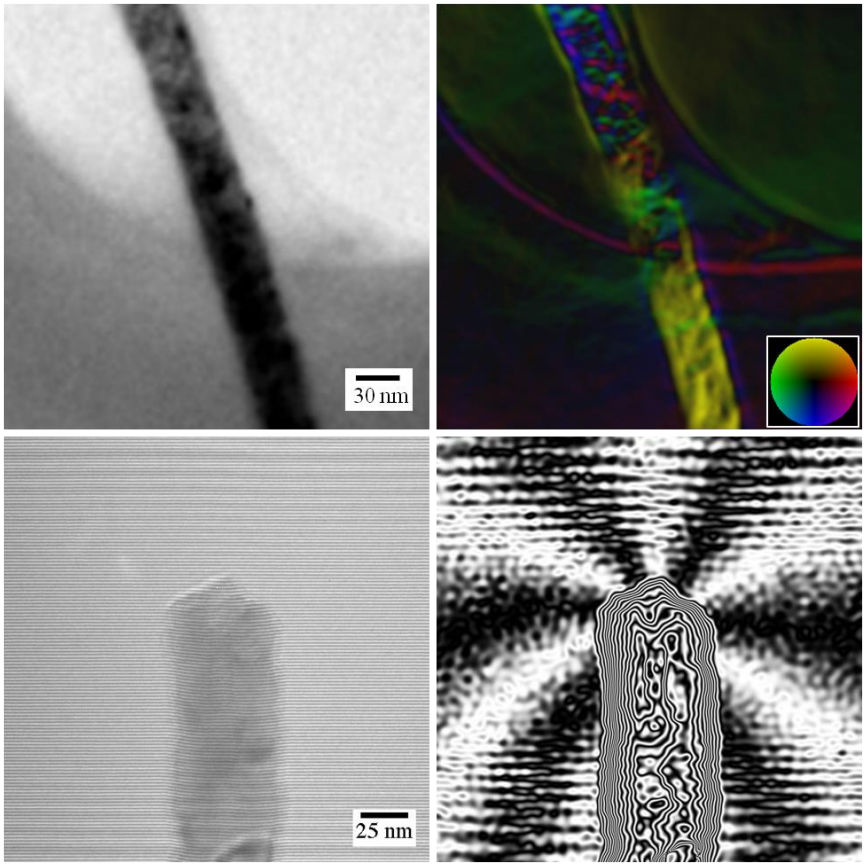

Figure 2. TEM image (top left) and phase reconstructed magnetization map (top right) at one domain wall of a CoFe nanofiber. The magnetization direction is indicated by the color wheel. Hologram image (bottom left) and amplified phase image (bottom right) at the end of a CoFe nanofiber by off-axis holography.

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