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# Lorentz Transmission Electron Microscopy Imaging of Magnetic Textures in MnBi

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MnBi has attracted much attention as a potential replacement for rare-earth magnets in engineering applications [1], as well as a system for exploration of exotic transport phenomena [2,3]. This ferromagnetic metal has a Curie temperature of ~630K and is a hard magnet at room temperature with the magnetic moments oriented along the c-axis of its NiAs-type hexagonal structure [2]. The magnetic moments rotate away from the c-axis below the initial spin reorientation temperature $T_{SR1}$=140K and are oriented completely within the ab-plane below $T_{SR2}$=90K [2]. Recent reports suggest that intriguing magnetic textures such as striped domains and skyrmion bubbles form in thin MnBi lamellae under certain temperature and magnetic field conditions [3].

In this contribution we present the results of an *in-situ* Lorentz transmission electron microscopy (TEM) study of magnetic textures in MnBi. This contributes to a larger study exploring the influence of such textures on the thermal transport properties of MnBi. For the TEM study, thin lamellae were extracted from MnBi single crystals along the ab-plane (with c-axis perpendicular to the long direction of the foil) using a focused ion beam (FIB) instrument. Since MnBi is sensitive to oxidation [2], the foils were transferred rapidly from the FIB to the TEM to minimise air exposure.

Initially, we performed annular dark field (ADF) imaging, energy dispersive x-ray (EDS) spectral mapping, and electron energy-loss (EELS) spectrum images of the thin lamellae. ADF images presented in Figure 1 show the hexagonal lattice observed with the c-axis out of the image (left image) as well as Moiré fringes consistent with the presence of oxidation products on the surface of the thin foil (right image).

The microscope was switched into Lorentz TEM mode, decreasing the *in situ* magnetic field applied to the foil from ~2T to 0T (with ~10mT remnant field). The Lorentz TEM was performed using Fresnel imaging by collecting through-focal image series to observe the magnetic contrast. Using a double tilt cryogenic TEM specimen-holder enabled us to vary the sample temperature from 300K to 90K. This temperature range was sufficient to track the same region of interest in the Lorentz TEM images through the spin re-orientation transition temperatures.

Under zero field cooling conditions, we observed spontaneous formation of stripe domains around 170K, which remained unchanged down to 90K. Surprisingly, these stripe domains were not present in the thinner regions of the lamellae. In contrast, imaging of a field cooled (~2T) sample revealed at 90K, when the field was removed,  coexistence of stripe domains and magnetic bubbles, with the latter most abundant in the thick regions of the foil. The dependence of the magnetic textures in MnBi lamellae on temperature, applied field, and specimen thickness are currently under further investigation to establish the correlation with thermal transport properties in this system.

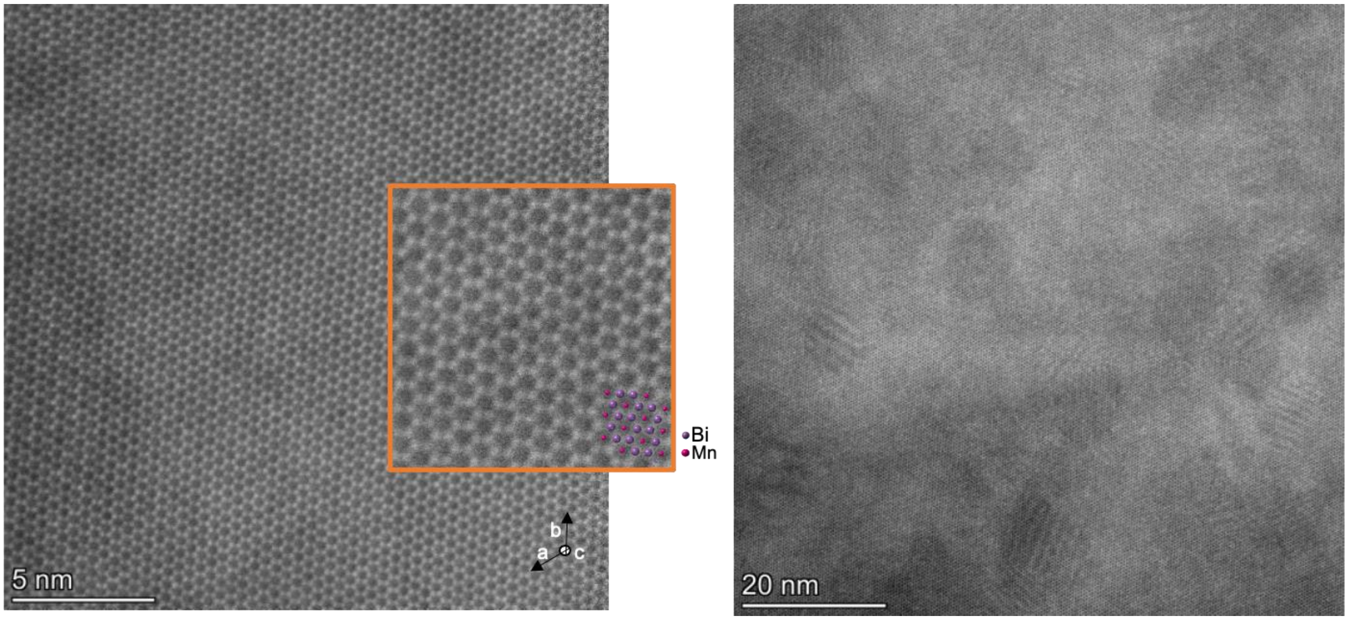


**Figure 1.** Figure 1. ADF images viewed along the c-axis of the MnBi. Left, high resolution image showing the hexagonal lattice. Right, low magnifications image showing the dark areas and Moiré fringes due to the presence of oxides on the surface of lamellae.

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