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Meeting-report

Defects in Pyrochlore $Dy_2Ti_2O_7$ Thin Film

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There has been a vast and strong interest in magnetic behavior of pyrochlore oxides of the crystal structure of $A_2^{+3}B_2^{+4}O_7$, where *A* is a rare-earth ion and *B* is usually a transition metal. Both A and B site atoms form a corner-sharing tetrahedron network, where the magnetic rare-earth ion sits on the corners of tetrahedron resulting in a geometrically frustrated magnets. These systems have a large degree of degeneracy with different spin lattice configurations leading to exotic ground states, such as spin glasses, spin ices, and spin liquids [1]. For $Dy_2Ti_2O_7$, a spin ice with analogous strings and magnetic monopoles has been observed [2]. Growing thin film form of these exotic system is a way to further explore their properties and expand their novel electronic behaviors.

It has been shown that magnetic frustrated magnetic system is prone to defects and its associated strains leading to perturbed magnetic ground states [3]. It was observed that $Dy_2Ti_2O_7$ thin film depart from spin ice behavior at lower temperature than 2 K and zero field, where it was speculated that strains was the origin at this energy scale [4]. So in this work, we look into the most common defects inside the $Dy_2Ti_2O_7$ thin film grown on yttrium stabilized zirconia (YSZ) substrate by pulsed layer deposition. The YSZ substrate is commercially available from CrysTec company. A KrF excimer laser ($\lambda = 248$ nm) is used at a repetition rate of 2 Hz and the laser beam fluency is 1.7 J/cm2. The $Dy_2Ti_2O_7$ film was first deposited at 800 °C and 0.0133 mbar of oxygen pressure on YSZ substrate. After deposition, the films were cooled down in 0.0667 mbar oxygen pressure.

The TEM lamellar is prepared by focused ion beam in a ThermoFisher Scientific Helios G4 UC DualBeam SEM. The TEM results are acquired on a cold-field-emission probe-aberration corrected JEOL JEM-ARM200cF at 200kV. High-angle-annular-dark-field scanning electron microscopy (HAADF-STEM) imaging were acquired on a JEOL annular detector with a probe size of 0.078 nm and a camera length of 8cm.

The HAADF-STEM image of the $Dy_2Ti_2O_7$/YSZ thin film along [110] is shown in Fig.1a. The anti-phase boundary (APBs) are revealed by doing inverse FFT of g = ±(-11-1) (Fig.1b). It's easy to identify the three perfect $Dy_2Ti_2O_7$ regions with the APBs in between, where the atom intensity profile of the {111} planes are different from the perfect lattice as shown in Fig.1c and 1d. Yb atomic column has a Z number of 70 while Yb/Ti column has an average atomic number of 46. The perfect lattice planes shows the alternating stronger and weaker atomic column intensity of Yb and Yb/Ti, but at the APB, because of two perfect crystals shifted 1/8<112>, the atomic columns have comparable number of Yb and Ti atoms, therefore, showing similar intensity.

By using GPA 4.12.1 plugin in Gatan DigitalMicrograph software, the strain maps of the region in thin film are shown in Fig.2. Generally speaking, the APB has negative strain, i.e. compressive strain within the {111} planes and positive strain, i.e. tensile strain along the {111} normal. This is consistent with the APBs observed in another pyrochlore $Yb_2Ti_2O_7$ oxide [3]. These defects in thin films would generate more complexed strain maps because they are not isolated, but connected. As shown in this region, three APBs intersect, where additional strains are evident at the junction. Because of the varied local strains, the Dy^{3+} magnetic ions on the four corners of the tetrahedron are distorted off the balanced positions, so the magnetic balance of the two-in and two out of the Dy^{3+} magnetic ions of the tetrahedron in this spin ice system could be disturbed, resulting in a different magnetic ground states. The strain of these defects disrupt the long range magnetic interactions [5].

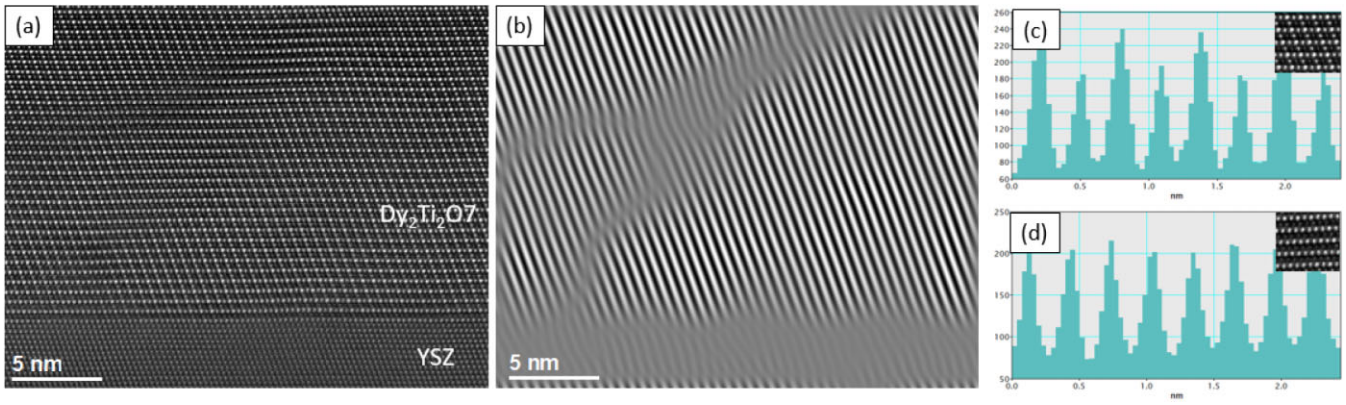

Fig. 1. (a) HAADF-STEM image of $Dy_2Ti_2O_7$ thin film on YSZ substrate along [110]. (b) Inverse FFT image using g = ±(-11-1) showing the APBs. (c) Yb and Yb/Ti atomic column intensity profile of perfect region. inset: HAADF-STEM image of perfect $Dy_2Ti_2O_7$ (d) Atomic column intensity profile of APB region. inset: HAADF-STEM image of the APB region.

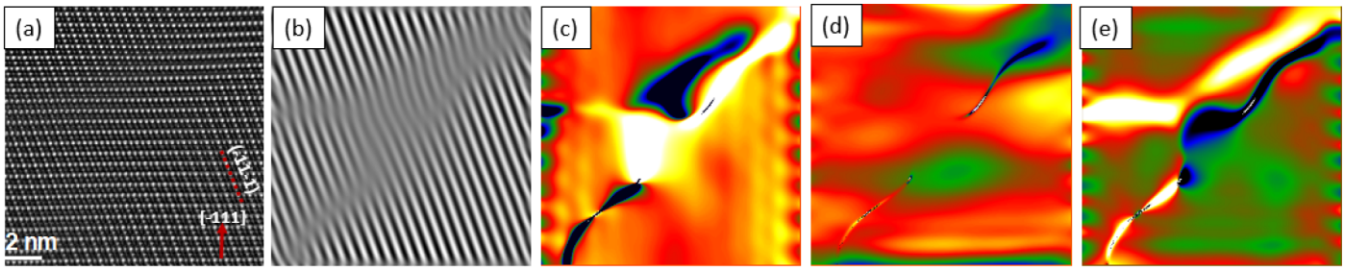

Fig. 2. (a) Region with APBs in $Dy_2Ti_2O_7$ thin film. (b) Inverse FFT image using g = ±(-11-1). (c-e) strain maps of ε_{xx} along [-11-2], ε_{yy} along [-111], and ε_{xy}.

References

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