Phase Diagram of Multi-ferroic $MnWO_4$ determined by Neutron Diffraction in 40 T Pulsed Magnetic Fields

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Multi-ferroic phenomena found in frustrated antiferromagnets have been investigated intensively for their cross-correlation between magnetism and dielectric properties. Various novel phase transitions arise in high magnetic fields and the magnetic structures are highly non-trivial. Thus, it is essential to observe the magnetic structure directly by using neutron diffraction. $MnWO_4$ is one of the most well-known multi-ferroic compounds, which shows the memory effect in high magnetic fields. For the strong spin frustration, three different magnetic phases;AF1(uudd), AF2 (non-collinear, incommensurate cycloidal), AF3 (incommensurate sinusoidal) appear at zero field [1] (Fig. 1). There are at least three phases in high magnetic fields: HF, IV and V. When a magnetic field is applied along the easy-axis, a distinct memory effect is found. Namely, the polarization between the AF2 and IV are always opposite irrespective of the initial polarization. Interestingly, the polarization of the phase IV reverses when it enters into the phase V. These facts show that the memory is kept while the system is passing through the HF and V phases, where no polarization exists. The key experiment to understand the mechanism of the multi-ferroic behavior and the distinct memory effect in $MnWO_4$ is the determination of magnetic structures in the high magnetic field phases HF, IV and V. We have investigated this compound at SNS in Oakridge and at J-PARC in last three years and found following results [2]. (1) At 4.2 K, the reentrant transitions occur in the sequence of AF1-AF2-HF-PhaseIV. (2) HF is close to commensurate, but there is a small splitting in the magnetic Bragg peak showing possible two phases mixture or long-pitch incommensurate magnetic structure. The intensity of two components varies with the magnetic field intensity and with the hysteresis (arrow A in Fig. 1). (3) Phase IV is incommensurate and there is about 1 % change of incommensurate wave vector between AF2 (10 K at zero field) and Phase IV (4.2 K at 40 T) (arrow B in Fig. 1). It is not clear if the change is continuous in temperature or there is a new phase boundary within the phase IV. (4) At the phase boundaries of the reentrant transitions, two successive phases coexist showing that the transitions are 1st order. (5) The magnetic structure of Phase V at 10 K and at 35 T (blue circle in Fig. 1) is incommensurate and the wave vector is nearly identical with that of Phase IV. If one assumes that Phase V persists between 4 and 12 K, the phase V is incommensurate phase without polarization. In another word, the origins of the absence of the polarization are different between phase V and HF phase. Magnetic structure models will be discussed considering the results of neutron diffractions.

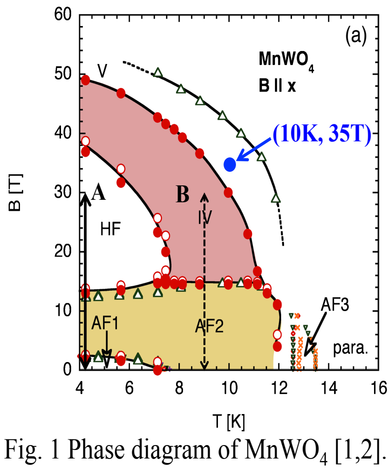

Fig. 1 Phase diagram of $MnWO_4$ [1,2].

[1] H. Mitamura et al., J. Phys. Soc. Jpn. **81** 054705 (2012)

[2] H. Nojiri et al., Phys. Rev. Lett. **106** 237202 (2011)