MBE 法により成長した IV-VI 族希薄磁性半導体(Sn,Mn)Te の TEM による構造解析

TEM observation of IV-VI diluted magnetic semiconductor (Sn,Mn)Te grown by MBE

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SnTe has been attracting attention as a typical material of topological crystalline insulator (TCI)[1], in which the topological surface state (TSS) is protected by mirror reflection symmetry, instead of time-reversal symmetry (TRS) in the conventional Z_2 topological insulators (TIs). In the conventional TIs, it has been demonstrated that the onset of magnetism results in the gap opening by breaking of TRS[2]. On the other hand, the effect of magnetism on TSS in TCIs has not been clarified. We have been studying the structural and magnetic properties of a magnetic TCI, (Sn,Mn)Te, in which a transition-metal element Mn is incorporated in SnTe. We grew thin films of (Sn,Mn)Te on a CdTe template deposited on a GaAs substrate by MBE[3] using solid sources of SnTe, Mn and Te. We prepared a series of (Sn,Mn)Te films with a fixed Mn composition of 5.6% and varied hole densities in the range of 10^{20}-10^{21} cm^{-3}.

In our previous presentation[4], we reported the onset of ferromagnetism with the increase of hole density. The hysteretic behavior appears in the magnetic-field dependence of magnetization (*M-H* curve) at a high hole density above 8×10^{20} cm^{-3}, but the hysteresis loop is inverted compared to the ordinary ferromagnetic materials (Fig. 1). This anomalous magnetic behavior, which was already reported in randomly distributed Co nanoparticle system[5], suggests the existence of ferromagnetic clusters in the films. The structural analysis using X-ray absorption fine structure (XAFS) revealed Mn atoms are partially incorporated in another site than the substitutional site in the films exhibiting ferromagnetic behaviors.

In order to clarify the origin of the anomalous magnetic behavior, we have performed cross-sectional transmission electron microscope (TEM) and energy-dispersive X-ray spectroscopy (EDS) analyses on the ferromagnetic film with a high hole density of 1×10^{21} cm^{-3}. As shown in Fig. 2, several small regions of different lattice image from the surrounding matrix were observed near the interface with the CdTe buffer layer. These regions consist of extrinsic precipitates of different structure from the rock-salt (RS) structure or the same RS structure of a different crystallographic orientation from the host matrix. In addition, it was found that Mn segregates near the interface with CdTe layer (Fig. 3), but the local Mn content are not necessarily correlated with the regions of different structure or orientation in the lattice image. As a result, it seems to be difficult to identify which regions observed in TEM are responsible for the anomalous magnetic behavior. Detailed analysis will be presented at the conference.

References [1] T. H. Hsieh *et al.,* Nat. Commun. **3**, 982 (2012). [2] Y. L. Chen *et al.,* Science **329**, 659 (2010). [3] R. Ishikawa *et al.,* J. Cryst. Growth **453**, 124 (2016). [4] R. Ishikawa *et al.,* 65th JSAP Spring meeting 20a-D104-6. [5] J. Y. Yang *et al.,* Phys. Rev. B **78**, 094415 (2008).

Fig.1

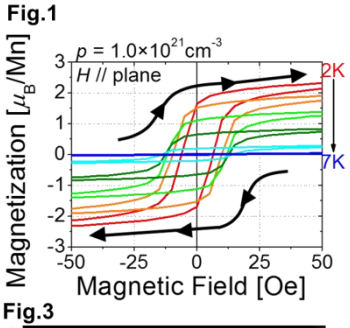

Fig.2

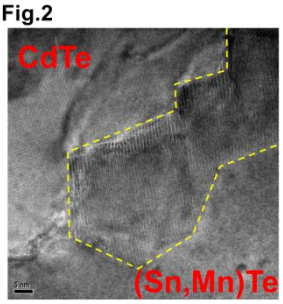

Fig.3

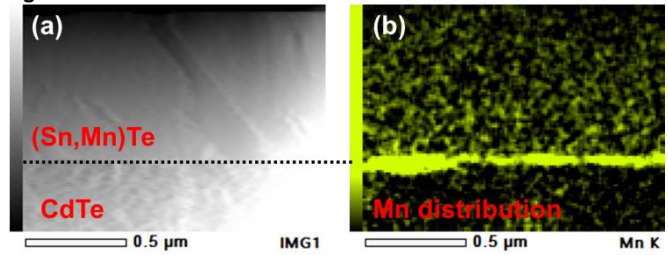

Fig. 1
M-H curves of ferromagnetic (Sn,Mn)Te films measured at temperatures ranging from 2 to 7K

Fig. 2
Cross-sectional TEM image of interfacial area of CdTe and (Sn,Mn)Te. The region of different lattice image from the surrounding matrix is indicated by broken yellow line.

Fig. 3
(a) Cross-sectional bright-field TEM image of (Sn,Mn)Te layer grown on the CdTe buffer layer.
(b) EDS mapping of Mn distribution in the same area as (a).