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Structural and magnetic properties of binary compound CrTe grown by MBE

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1. Introduction

Binary compound CrTe, the stable phase of which is NiAs type structure, have been extensively studied because of their interesting magnetic properties [1]. A hexagonal (hex-) CrTe derived from the NiAs type structure is ferromagnet with Curie temperatures ranging from 170 ~ 340K, depending on the amount of Cr deficiency. Recently, theoretical studies predict that CrTe have half-metallic properties in the metastable phase of zinc-blende (ZB) structure [2]. Half-metal ferromagnets, which have only one electronic spin channel at the Fermi energy, attract much attention due to its potential for application to spintronics devices e.g. source materials for spin injection. Moreover, from the viewpoint of the structural compatibilities with conventional III-V and II-VI semiconductors, the realization of half-metallic ZB-CrTe is highly desirable. The successful growths of ZB-CrTe films were reported by Sreenivasan *et al.* [3,4]. According to their reports, CrTe thin films were grown on ZnTe (001) buffer layers by molecular beam epitaxy (MBE). However, the growth conditions of ZB-CrTe are different between their two reports. Furthermore, the thickness of ZB-CrTe film is ~ 5nm, which is not enough for the applications. Therefore, we need more exploration about the optimum conditions for the growth of the metastable ZB-CrTe. In this study, we investigate the structural and magnetic properties of CrTe films grown on ZnTe or CdTe buffer layers which are grown on GaAs (001) substrates. We grow CrTe films by MBE under various growth conditions (substrate temperature T_S, ratios between Cr and Te fluxes) and investigate the structural and magnetic properties of CrTe films in order to clarify the effect of growth conditions of CrTe.

2. Experimental

The growth of CrTe thin films were performed by MBE using solid sources of Zn, Cd, Te and Cr. A piece of GaAs (001) wafer (a_{GaAs} = 5.65Å) was used as a substrate. Firstly a thick buffer layer (~700nm) of ZnTe (a_{ZnTe} = 6.10Å) or CdTe (a_{CdTe} = 6.48Å) was grown on the substrate in order to relax a large lattice constant mismatch between CrTe and the substrate. Then a CrTe layer (20 ~ 100nm) was grown on it. In order to realize the growth of metastable ZB-CrTe, we focused on three growth parameters; ratios between Cr and Te fluxes (Cr/Te), substrate temperature (T_S) during the growth and lattice constant of the buffer layers. A surface during the growth was monitoring in situ using reflection high-energy electron diffraction (RHEED). RHEED patterns of CrTe layers grown under Te-rich condition were streak patterns, indicating flat surface of the layer. On the other hand, spotty patterns were observed in case of samples grown under Cr-rich or stoichiometric conditions, indicating the formation of Cr metals. The crystal structure analyses of the grown films were performed using X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM). The composition of constituent elements was estimated by energy-dispersive X-ray spectroscopy (EDS). The magnetic properties of CrTe films were investigated in detail using superconducting quantum interference device (SQUID) magnetometer with magnetic fields applied perpendicular to the film plane. The Curie temperature T_C was deduced from the Arrott-plot analysis of the magnetization curve.

3. Results and discussions

We prepared a series of CrTe films with varying three growth parameters (Cr/Te, T_S, lattice constant of buffer layer). As a result, we found that the Cr/Te flux ratio is a key parameter which determines the structural phase of CrTe layer on the both buffer layers; bcc-Cr metal formed under Cr-rich or stoichiometric conditions, while hex-$Cr_{1-\delta}Te$ is grown under Te-rich conditions. However, under the Te-rich conditions, the orientation of the hex-$Cr_{1-\delta}Te$ differs depending on the three growth parameters.

Fig. 1 shows the cross-sectional TEM images of the CrTe layers grown on ZnTe (001) and CdTe (001) in the Te-rich conditions (Cr/Te = 0.5) at T_S = 250ºC. Arrows in

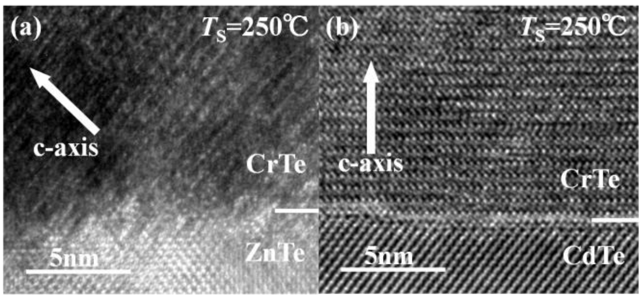

Fig. 1 Cross-sectional TEM images of (a) CrTe/ZnTe and (b) CrTe/CdTe samples. A direction of incident beam is perpendicular to the [110] of GaAs substrate.

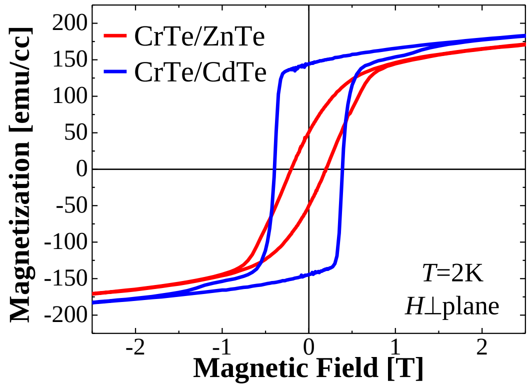

Fig. 2 *M-H* curves of CrTe/ZnTe and CrTe/CdTe samples measured at 2K. The magnetic fields are applied perpendicular to the film plane.

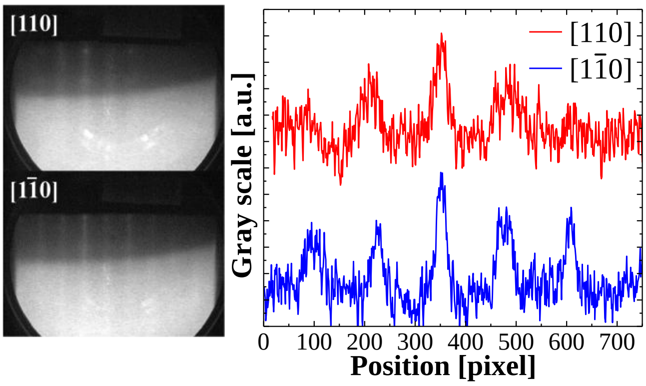

Fig. 3 Left; RHEED patterns of CrTe/CdTe sample grown at Cr/Te = 0.03 and T_S = 250ºC. Right; horizontal line profiles of the RHEED patterns.

the images indicate the direction of the c-axis of the hex-$Cr_{1-\delta}Te$. The c-plane of the hex- $Cr_{1-\delta}Te$ layer grown on ZnTe is inclined against the growth plane by ~ 47 degree, while the c-plane of the layer grown on CdTe is parallel to the growth plane. In the θ-2θ scan of XRD measurement, the diffraction peaks from c-planes of the CrTe layer are observed for the CrTe/CdTe sample, and diffraction peaks from (1$\bar{1}$02) and (2$\bar{2}$03) of hex-$Cr_{1-\delta}Te$ are observed for the CrTe/ZnTe sample, consistent with the TEM observations. The difference of the growth orientation by the buffer layer materials can be explained qualitatively by the commensuration of atomic distance at the interface between hex-$Cr_{1-\delta}Te$ and the buffer layer materials.

We also found that not only buffer layer materials but also Cr/Te flux ratio and substrate temperature T_S effect the growth orientation of hex-$Cr_{1-\delta}Te$. Further Te-rich condition or higher T_S lead to the growth of hex-$Cr_{1-\delta}Te$ whose c-plane is parallel to the growth plane. When a CrTe layer is grown under the further Te-rich condition (Cr/Te = 0.03) at T_S = 250ºC, c-plane of the hex-$Cr_{1-\delta}Te$ is parallel to the growth plane even on the ZnTe buffer layer.

The magnetic property of a CrTe film differs depending on the orientation of the crystal structure. Typical examples of *M-H* curves measured by SQUID at 2K are shown in Fig. 2. The growth condition of CrTe layers is T_S = 250ºC and Cr/Te = 0.5. A square-shaped hysteresis curve with high coercive force was observed for the CrTe/CdTe sample whose c-plane of hex-$Cr_{1-\delta}Te$ was parallel to the growth plane, while a round-shaped hysteresis curve was observed for the CrTe/ZnTe sample whose c-plane of hex-$Cr_{1-\delta}Te$ was inclined against the growth plane. These differences are corresponding to the magnetic anisotropy of hex-$Cr_{1-\delta}Te$; the easy axis of magnetization of hex-$Cr_{1-\delta}Te$ is parallel to the c-axis. Therefore growth orientation of hex-$Cr_{1-\delta}Te$ leads to the different shape of hysteresis curves.

In order to realize the growth of metastable phase of CrTe, we tried to grow CrTe layers at lower temperature (150 ~ 200ºC). It is difficult to grow crystal epitaxially in such low temperature, so we decreased Cr flux to make growth rate of CrTe layer slower. Fig. 3 shows RHEED patterns of CrTe layers grown under Cr/Te = 0.03 at T_S = 200ºC and its horizontal line profile of each streak patterns. Lattice spacing deduced from the RHEED patterns are [110]; 3.65Å and [1$\bar{1}$0]; 3.94Å respectively. A ratio of these values is 1:1.08, completely different from hexagonal and nearly equal to the cubic or tetragonal, indicating the growth of CrTe with a metastable structure.

4. Conclusions

We investigated the structural and magnetic properties of CrTe films grown by MBE. Hex-$Cr_{1-\delta}Te$ films were grown under Te-rich condition while films with bcc-Cr metal were formed under Cr-rich or stoichiometric condition. In Te-rich condition, the growth orientation of hex- $Cr_{1-\delta}Te$ differs depending on the three growth parameters (Cr/Te, T_S, buffer layer). The differences are caused by commensuration of atomic distance at the interface or the degree of atomic migration at the surface of CrTe layer. With controlling these values, we could grow CrTe film which has metastable crystal structure.

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