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Strutural and Magnetic Properties of Ternary Transition-metal Chalcogenide CrFeTe Grown by MBE

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Abstract

We fabricated thin films of a ternary compound CrFeTe by molecular beam epitaxy (MBE). By investigating the magnetic properties of the films grown under various flux ratios of Fe to Cr (Fe/Cr), we found that the film grown at Fe/Cr~1 exhibited room-temperature ferromagnetic properties. This result suggests that the coexistence of Fe and Cr enhances the ferromagnetic interaction between magnetic atoms.

1. Introduction

Binary compound CrTe has been expected as one of the promising materials for realization of future semiconductor spintronics devices, such as spin injections into semiconductors, due to its ferromagnetic property and structural compatibility with III-V and II-VI conventional semiconductor materials. In our previous study[1], we fabricated CrTe thin films on II-VI semiconductor ZnTe(001) and CdTe(001) surfaces by MBE under various conditions and found that an epitaxial film grown under Te-rich condition was formed as $Cr_{1-\delta}Te$ of the hexagonal crystal structure (hex-$Cr_{1-\delta}Te$), which is derived from NiAs-type CrTe by incorporating a Cr deficiency. Furthermore, the growth orientation of the hex-$Cr_{1-\delta}Te$ crystal differed depending on the growth parameters such as ratio of flux between Cr and Te, substrate temperature T_S during the growth, and the material of the buffer layer. In addition, the magnetic property of the CrTe film also varied depending on the orientation of the crystal structure; a square-shaped hysteresis curve with a large coercive force was observed for the CrTe/CdTe(001) 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(001) sample, whose *c*-plane of hex-$Cr_{1-\delta}Te$ was 47° inclined against the growth plane[1]. Though the square-shaped hysteresis curve in the former case is considered to be useful for application to spintronics devices, Curie temperature (T_C) of hex-$Cr_{1-\delta}Te$ grown with its *c*-plane parallel to the growth plane is much lower than room temperature. In this study, we investigate the magnetic properties of a ternary transition-metal chalcogenide CrFeTe. It is expected that ferromagnetic behavior should be changed by incorporating another kind of magnetic elements due to the effect of magnetic interaction between different kinds of magnetic ions. It is theoretically predicted that strong antiferromagnetic interaction will work between Fe and Cr in a chalcogenide compound [2]. Therefore, we investigate how the magnetic properties of binary compound CrTe are changed by incorporating Fe in order to clarify the magnetic interaction between Cr and Fe.

2. Experimental

The growth of CrFeTe thin films were performed by MBE using solid sources of Cd, Te, Cr, and Fe. A piece of GaAs(001) wafer was used as a substrate. Firstly a buffer layer (~600nm) of CdTe was grown on a substrate, then a CrFeTe or FeTe layer was grown on it at T_S = 250 ºC. After that, we grew a CdTe cap layer (~20nm) to prevent the deterioration. We prepared three CrFeTe films grown under different Fe/Cr flux ratios of 0.1, 0.2 and 1 with keeping Cr/Te = 0.1. We also grew a CrTe film under a flux ratio of Cr/Te = 0.1 and a FeTe film under a flux ratio of Fe/Te = 0.1.

The surface during the growth was monitoring *in situ* using reflection high-energy electron diffraction (RHEED) to estimate flatness and symmetry of surface of the layer. The crystal structure analyses of the grown films were performed using X-ray diffraction (XRD). The magnetic properties of the films were investigated using superconducting quantum interference device (SQUID) magnetometer with magnetic fields applied perpendicular to the film plane. The T_C was deduced from the Arrott-plot analysis of the magnetization curves.

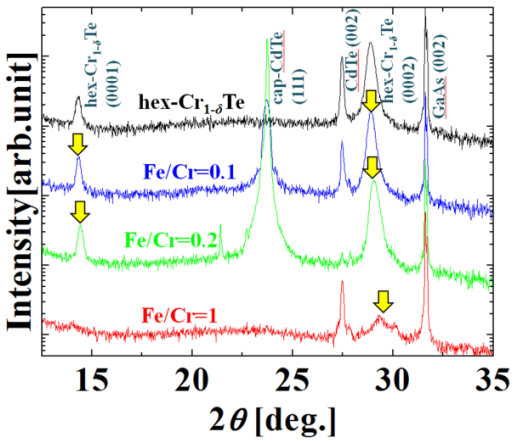

Fig.1 The profiles of XRD $2\theta/\theta$ scans for CrTe and CrFeTe films grown at various Fe/Cr flux ratios. Yellow arrows indicate peaks assigned as diffractions from the (000*n*) planes of hexagonal structure.

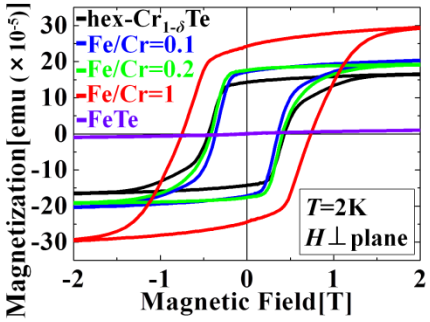

Fig.2 Magnetic-field dependence of magnetization (*M-H* curves) at 2K of the CrTe, FeTe, and CrFeTe films grown at various Fe/Cr flux ratios. A magnetic field is applied perpendicular to the film plane.

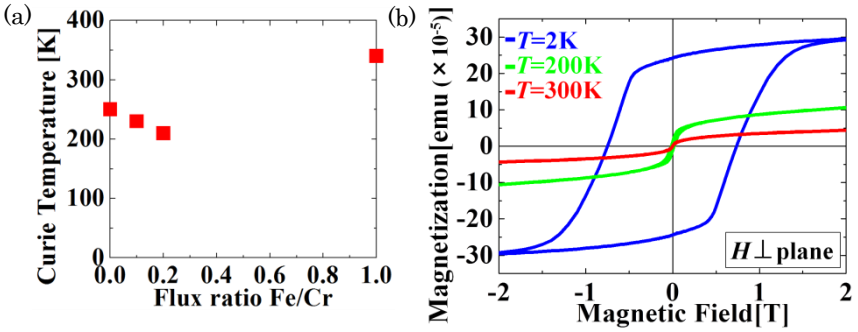

Fig.3 (a) Curie temperature T_C deduced from the Arrott plot analysis against Fe/Cr flux ratio. (b) Magnetic-field dependence of magnetization (*M-H* curves) of the film grown at Fe/Cr ~ 1 at 2K, 200K and 300K. A magnetic field is applied perpendicular to the film plane.

3. Results and Discussion

Firstly, we describe the results of the RHEED observation during the growth of CrFeTe thin films. At low Fe/Cr flux ratios of 0.1~0.2, the result of RHEED observation is very similar to that observed in the growth of CrTe; the RHEED image exhibited six-fold in-plane rotational symmetry and clear streaky images were observed both at the GaAs[110] and [1$\bar{1}$0] azimuths. In addition, the spacing between the observed streaks was almost same as that in the growth of CrTe. On the other hand, at a high Fe/Cr flux ratio around 1, we obtained a completely different result in the RHEED observation; the RHEED image exhibited two-fold in-plane rotational symmetry and the image at the GaAs[110] azimuth was streaky while the image at the GaAs[1$\bar{1}$0] azimuth was halo.

Figure 1 shows the profiles of XRD $2\theta/\theta$ scan for CrTe and CrFeTe films. As shown in the figure, the profiles of CrFeTe grown at low Fe/Cr flux ratio of 0.1~0.2 are very similar to that of CrTe. This result, together with that of the RHEED observation, suggests that the CrFeTe layer is formed as the same crystal structure of hex-$Cr_{1-\delta}Te$ with its *c*-axis perpendicular to the growth plane. On the other hand, at a high Fe/Cr flux ratio around 1, the peak intensity at 29°, which is assigned as the diffraction from the (0002) plane of the hexagonal structure, was much reduced as compared to the results at low Fe/Cr flux ratios and CrTe. These results suggest that CrFeTe films grown at Fe/Cr~1 has a different crystal structure from that of hex-$Cr_{1-\delta}Te$.

In the growth of FeTe, the result of the RHEED and XRD measurements revealed that FeTe of the tetragonal structure was formed with its *c*-axis perpendicular to the growth plane.

In order to investigate the magnetic property of CrFeTe films grown under different Fe/Cr flux ratios, we performed SQUID measurements. Figure 2 shows *M-H* curves at 2 K for CrTe, CrFeTe, and FeTe films. A square-shaped hysteresis curve was observed at 2K for all the CrFeTe films, similarly to the CrTe films. In particular, the coercivity of ~ 0.4T is almost same as that of CrTe. This suggests the magnetic properties of the CrFeTe films grown under low Fe/Cr flux ratios are similar to that of the hex-$Cr_{1-\delta}Te$ film with its *c*-plane parallel to the growth plane. For a high Fe/Cr flux ratio around 1, the ferromagnetism is enhanced with a larger coercivity of ~0.75 T. On the other hand, the magnetization of the FeTe film was much smaller and did not show any ferromagnetic behaviors such as hysteresis. Figure 3(a) plots the Curie temperature T_C deduced from the Arrott-plot analysis as a function of Fe/Cr flux ratio. As shown in the figure, T_C first decreases gradually with the increase of Fe/Cr, but T_C increases abruptly up to 340 K at Fe/Cr ~ 1. Figure 3(b) shows *M-H* curves of the CrFeTe film grown at Fe/Cr ~ 1 at respective temperatures. The room-temperature ferromagnetism is clearly confirmed from the shape of *M-H* curve at 300K. The apparent enhancement of ferromagnetism by incorporating a large amount of Fe into CrTe suggests that the interaction between Cr and Fe may contribute to the stabilization of ferromagnetism.

4. Conclusions

We grew CrFeTe thin films by MBE under various Fe/Cr flux ratios and investigated the structural and magnetic properties. The films grown at low Fe/Cr flux ratios of 0.1~0.2 have the same crystal structure as hex-$Cr_{1-\delta}Te$ and the magnetic properties are also similar to that of hex-$Cr_{1-\delta}Te$. On the other hand, the film grown at a high Fe/Cr flux ratio around 1 have a different crystal structure and the ferromagnetic properties are enhanced with a larger coercivity and an increase of T_C up to 340K. These results suggest a possible contribution of the interaction between Cr and Fe to the apparent enhancement of ferromagnetism.

References

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[2] M. Nakao, Phys. Rev. B **74**, 172404 (2006)