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Magnetic properties of quaternary magnetic semiconductor (Cd,Mn,Cr)Te grown by MBE

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1. Introduction

For the application in spintronics, novel semiconducting materials exhibiting high-temperature ferromagnetism are desired. Until now, a broad class of diluted magnetic semiconductors (DMSs) consisting of various combinations of host semiconductors and magnetic elements have been studied as possible candidates of room-temperature ferromagnetic semiconductors. Among various DMSs, ternary compounds containing only one kind of magnetic element have been studied intensively and extensively, but quaternary compounds containing two kinds of magnetic element have rarely been studied. As a result, little has been known about the interaction between different kinds of magnetic elements in semiconductors. Recently, the room-temperature ferromagnetism of a quaternary compound (Cd,Mn,Cr)Te in bulk form has been reported[1], but neither the origin of ferromagnetism in this quaternary DMS nor the interaction between Mn and Cr have been clarified. In the present study, we have grown thin films of quaternary DMS (Cd,Mn,Cr)Te by molecular beam epitaxy (MBE) and have investigated the magnetic properties.

2. Experimental methods

Thin films of (Cd,Mn,Cr)Te have been grown by solid-source MBE. A CdTe buffer layer (thickness ~ 700nm) was firstly grown on a GaAs(001) substrate and then a (Cd,Mn,Cr)Te layer (~ 300nm) was successively grown on it. The Mn content x and the Cr content y in $Cd_{1-x-y}Mn_xCr_yTe$ were estimated using electron probe microanalyzer (EPMA). In this study, we prepared a series of $Cd_{1-x-y}Mn_xCr_yTe$ films with a fixed Mn content $x \sim 0.2$ and varied Cr contents in the range of $y = 0 \sim 0.07$. The crystal structure was investigated using x-ray diffraction (XRD). The magnetization of the grown films was measured using superconducting quantum interference device (SQUID) magnetometer with magnetic fields applied perpendicular to the film plane.

3. Experimental results and discussions

The θ-2θ scan of XRD revealed that $Cd_{1-x-y}Mn_xCr_yTe$ layers of zinc-blende crystal structure were grown epitaxially in the (001) direction. With the increase of Cr content y at a fixed Mn content $x \sim 0.2$, the diffraction peak of the $Cd_{1-x-y}Mn_xCr_yTe$ layer was shifted to a higher angle and became broader, indicating the shrink of the lattice constant and the increase of structural disorder with the increase of Cr content. In the magnetization measurements using SQUID, the dependences of magnetization on magnetic fields and temperature were measured. Figure 1 shows the magnetic-field dependence of magnetization (M-H curve) for the series of the samples measured at 2K. The M-H curves of $Cd_{1-x-y}Mn_xCr_yTe$ films with Cr content $y = 0.0046$

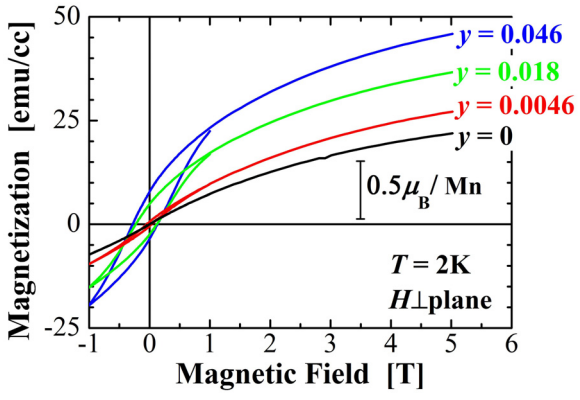

Fig.1 M-H curves of a series of $Cd_{1-x-y}Mn_xCr_yTe$ films with a fixed Mn content $x \sim 0.2$ and varied Cr contents $y = 0 \sim 0.046$. The measurement was performed with magnetic fields applied perpendicular to the film plane at 2K.

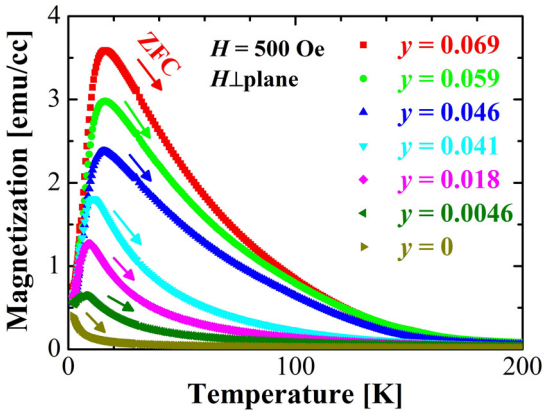

Fig. 2 M-T curves of a series of $Cd_{1-x-y}Mn_xCr_yTe$ films with a fixed Mn content $x \sim 0.2$ and varied Cr contents $y = 0 \sim 0.069$. The measurement was performed in the zero-field-cooled (ZFC) process with the application of a perpendicular magnetic field of 500 Oe.

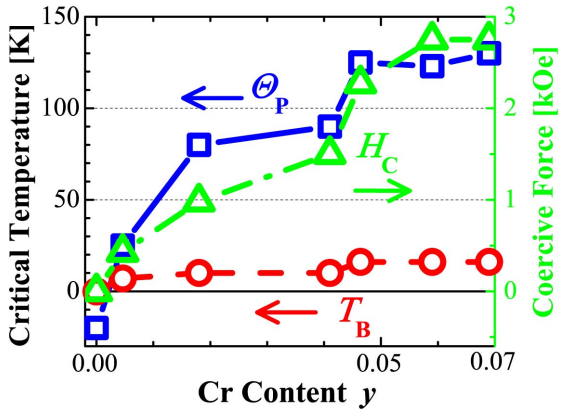

Fig.3 The plot of the two characteristic temperatures Θ_P and T_B and the coercive force H_C in the *M-H* curves measured at 2K as a function of Cr content y in $Cd_{1-x-y}Mn_xCr_yTe$ (Mn content $x \sim 0.2$)

~ 0.046 exhibit a hysteretic loop, in contrast to a paramagnetic behavior without hysteresis in $Cd_{1-x}Mn_xTe$ without Cr. Figure 2 shows the temperature dependence of magnetization (*M-T* curve) measured in the zero-field-cooled (ZFC) process with the application of a perpendicular magnetic field of 500 Oe. In the $Cd_{1-x-y}Mn_xCr_yTe$ films with Cr content $y = 0.0046 \sim 0.069$, a cusp appears in the *M-T* curve; with lowing temperature, the magnetization takes a maximum and then decreases. This is considered to be the blocking phenomenon which is typical for superparamagnetic system. In order to extract features of the magnetic properties, the two characteristic temperatures representing critical behaviors of magnetization are deduced from the temperature dependence of magnetization; the paramagnetic Curie-Weiss temperature Θ_P, obtained from the linear fitting of the temperature dependence of the inverse susceptibility χ^{-1}–T, and the blocking temperature T_B, determined as the position of a magnetization maximum in the *M–T* curve in the ZFC process. In Fig. 3, these two critical temperatures are plotted as a function of the Cr content y, together with the coercive force H_C in the *M-H* curve measured at 2K (shown in Fig. 1). Θ_P is negative in $Cd_{1-x}Mn_xTe$ without Cr, but it becomes positive with the incorporation of a small amount of Cr with a content of $y = 0.0046$. Since the Cr content in this film is very small, it is considered that the observed magnetization mainly originates from Mn spins. Therefore the change in sign of Θ_P suggests that the magnetic interaction between Mn spins turns to be ferromagnetic due to the presence of Cr, in contrast to the antiferromagnetic interaction in $Cd_{1-x}Mn_xTe$ without Cr. With the further increase of Cr content y, the values of Θ_P, T_B, H_C increase at first, and then exhibit a tendency to be saturated. This indicates the ferromagnetic properties, which are turned on due to the incorporation of a small amount of Cr, are enhanced by the increase of Cr content. It is considered that the observed change of the interaction between Mn from antiferromagnetic to ferromagnetic due to the presence of a small amount of Cr is caused by the interaction between Mn and Cr. A possible origin of the interaction between different magnetic species will be discussed at the conference.

4. Summary

The magnetic properties of a quaternary DMS compound (Cd,Mn,Cr)Te were investigated. Thin films of $Cd_{1-x-y}Mn_xCr_yTe$ with a fixed Mn content $x \sim 0.2$ and varied Cr contents in the range of $y = 0 \sim 0.07$ were epitaxially grown on a GaAs (001) substrate by MBE. In the magnetization measurements, a ferromagnetic behavior, such as hysteretic loops in the *M-H* curves, as well as superparamagnetic features such as the blocking phenomenon in the *M-T* curves, were observed in $Cd_{1-x-y}Mn_xCr_yTe$ containing Cr content less than 1%. The paramagnetic Curie temperature Θ_P changes its sign from negative to positive with the incorporation of Cr. These results suggest that the interaction between Mn spins becomes ferromagnetic due to the presence of a small amount of Cr.

References

[1] S. Shen, X. Liu, Y. J. Cho, J. K. Furdyna, M. Dobrowolska, Y. H. Hwang, and Y. H. Um, Appl. Phys. Lett. **94**, 142507 (2009).