Available online at SciVerse ScienceDirect
SciVerse ScienceDirect
J. Mater. Sci. Technol., 2014, 30(2), 103–106
ELSEVIER
JMST
www.JMST.org

Magnetic and Transport Properties of $Mn_{0.98}Cr_{0.02}Te$ Epitaxial Films Grown on Al_2O_3 Substrates

Z.H. Wang[1)*], *D.Y. Geng*[1)], *J. Li*[1)], *Y.B. Li*[2)], *Z.D. Zhang*[1)]

1) Shenyang National Laboratory for Materials Science, Institute of Metal Research, and International Centre for Materials Physics, Chinese Academy of Sciences, Shenyang 110016, China

2) Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Jilin 130033, China

[Manuscript received September 5, 2012, in revised form November 13, 2012, Available online 18 July 2013]

The epitaxial $Mn_{0.98}Cr_{0.02}Te$ films on single crystal Al_2O_3 (0001) substrates were prepared by pulsed laser deposition. The X-ray diffraction and scanning electron microscopy results showed that the good continuous epitaxial film was obtained with substrate temperature of 500 °C. When the substrate temperature reached 700 °C, the film was island growth and the manganese oxides phase appeared. The temperature dependence of both the magnetization and electrical resistance showed a sharp rise at around 60 K due to the magneto-elastic coupling. The temperature dependence of the electrical resistance of $Mn_{0.98}Cr_{0.02}Te$ provided evidence for a transition from the metallic to semiconducting state at 305 K due to the spin disorder scattering with a large contribution from the influence of magnon drag.

KEY WORDS: Magnetic properties; $Mn_{0.98}Cr_{0.02}Te$ films; X-ray diffraction; Epitaxial film

1. Introduction

MnTe is a particularly interesting material because of its markedly magnetic and electronic behavior among the 3d transition-metal binary compounds[1−3]. MnTe is an example of a crossroads material between NaCl-type insulating manganese chalcogenides (MnS, MnSe) and NiAs-type metallic transition-metal compounds (MnAs, MnSb)[4]. NiAs-type bulk MnTe is a p-type semiconductor, which also shows antiferromagnetic (AF) properties with its Néel temperature of 310 K[5]. The magnetic order of MnTe could be viewed as Mn moments aligned ferromagnetically in the basal plane of the hexagonal lattice, and these planes are antiferromagnetically stacked along the axis[6]. However, pure MnTe semiconducting thin films with ferromagnetic properties has been observed, and the origin of ferromagnetism may be due to the breaking of superexchange AF correlations between Mn spin moments arising from Tellurium vacancies[7]. The observed anomalies below 100 K in the resistivity and susceptibility measurements are due to a magneto-elastic coupling[8]. Recently, MnTe-based diluted magnetic semiconductor such as $Mn_{1-x}Cr_xTe$, $Cd_{1-x}Mn_xTe$, $Be_{1-x}Mn_xTe$, and $Mn_xSi_{1-x}Te$ are of great interest for spintronics application[9−12]. In bulk $Mn_{1-x}Cr_xTe$ system, the ferromagnetic behavior was observed[9]. One possible mechanism for the origin of ferromagnetism in the $Mn_{1-x}Cr_xTe$ compounds is the carrier mediated spin−spin interaction[13]. Another possibility is the change of the magnetic structure from AF to canted spin structure[14]. Al_2O_3 has been most widely used for MnTe thin-film growth because it is inexpensive and has a smaller lattice mismatch with MnTe. Al_2O_3 wafers with three different crystallographic orientations are commercially available, such as C-plane, A-plane, and R-plane. C-plane Al_2O_3 has been most widely used in growing epitaxial MnTe thin films, and it provides fairly good results. In our case, the epitaxial $Mn_{0.98}Cr_{0.02}Te$ films were prepared by pulsed laser deposition (PLD) with single crystal Al_2O_3 (0001) substrates. The temperature dependence of both the magnetization and electrical resistance shows a sharp rise at around 60 K due to the magneto-elastic coupling. The temperature dependence of the electrical resistance of $Mn_{0.98}Cr_{0.02}Te$ provides evidence for a transition from the metallic to semiconducting state at 305 K.

2. Experimental

$Mn_{0.98}Cr_{0.02}Te$ targets were prepared by annealing at 725 °C for 72 h in Ar with Mn (99.9%), Cr (99.9%) and Te (99.9%) elements as sources. $Mn_{0.98}Cr_{0.02}Te$ films were synthesized by PLD (laser wavelength is 248 nm, LPX 305i, Lambda Physik), grown on Al_2O_3 (0001) substrate with laser pulse frequency of 2 Hz and energy density on the surface of about 550 mJ for

* Corresponding author. Assoc. Prof., Ph.D.; Tel.: +86 24 83978846; Fax: +86 24 23891320; E-mail address: zhwang@imr.ac.cn (Z.H. Wang).

http://dx.doi.org/10.1016/j.jmst.2013.07.009

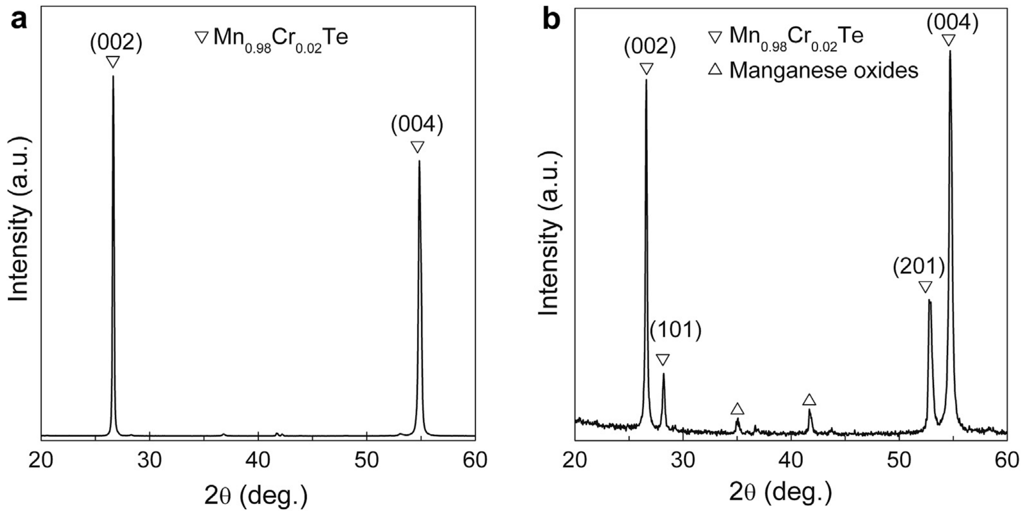

Fig. 1 XRD patterns of $Mn_{0.98}Cr_{0.02}Te$ films obtained at substrate temperature of 500 °C (a) and 700 °C (b).

30 min. During the deposition, the temperature of Al_2O_3 substrate was held at 500 and 700 °C, respectively. The distance between the target and substrate was 4 cm. The crystal structure and quality of grown films were examined by X-ray diffraction (XRD) in a D/max-γA diffractometer with Cu*Kα* radiation. The scanning electron microscopy (SEM) observations were carried out in SSX-550 instrument, operating at 15 kV. The magnetic and transport properties of $Mn_{0.98}Cr_{0.02}Te$ films were investigated with a superconducting quantum interference device (SQUID) magnetometer (Quantum Design, MPMS-7).

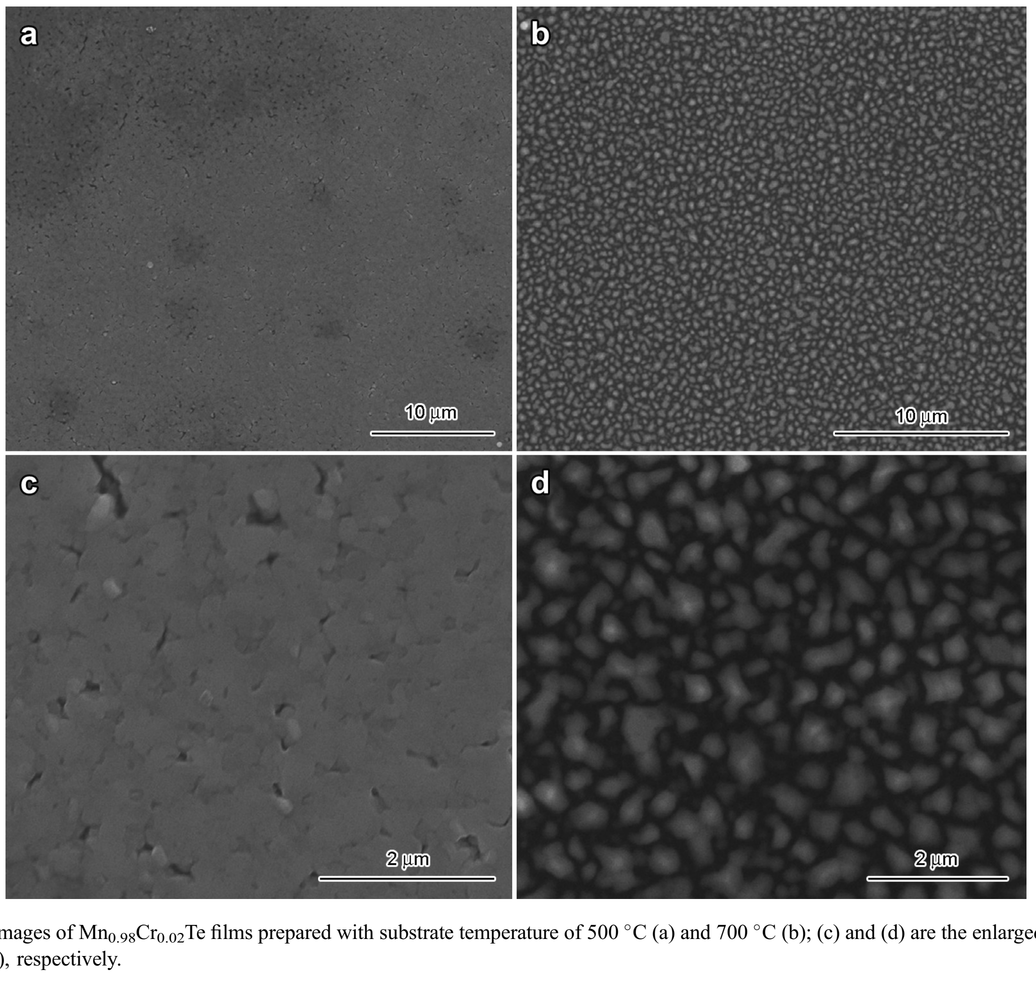

Fig. 2 SEM images of $Mn_{0.98}Cr_{0.02}Te$ films prepared with substrate temperature of 500 °C (a) and 700 °C (b); (c) and (d) are the enlarged images of (a) and (b), respectively.

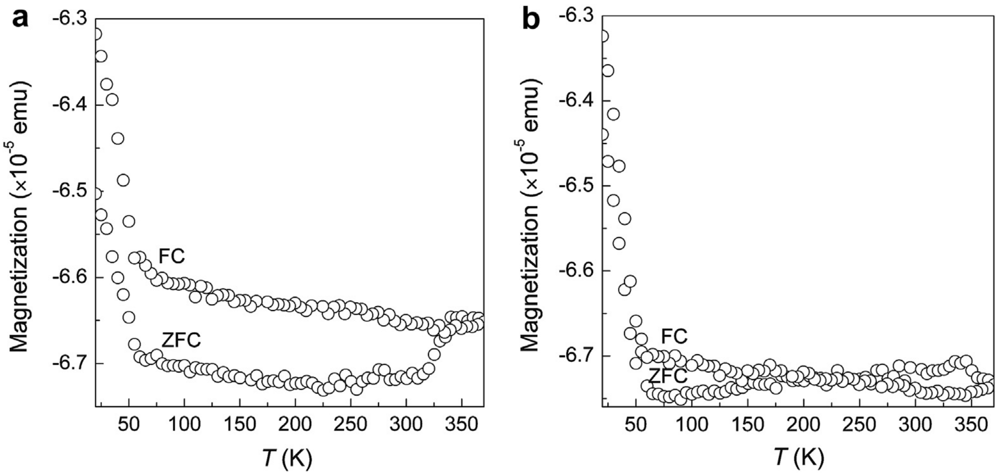

Fig. 3 Temperature dependence of magnetization of $Mn_{0.98}Cr_{0.02}Te$ films prepared with substrate temperature of 500 °C (a) and 700 °C (b).

3. Results and Discussion

Fig. 1 shows XRD patterns for $Mn_{0.98}Cr_{0.02}Te$ films. Characterization of $Mn_{0.98}Cr_{0.02}Te$ film prepared with substrate temperature of 500 °C reveals a good crystal quality of the hexagonal, NiAs-type structure (α-phase) with (0001) crystallographic planes parallel to the growth plane, as shown in Fig. 1(a). Fig. 1(b) shows the XRD pattern of $Mn_{0.98}Cr_{0.02}Te$ film prepared with substrate temperature of 700 °C. In the latter case, the impurity phase of manganese oxides appears, because the high substrate temperature results in the reaction of manganese with oxygen. The XRD pattern also reveals that a small fraction of the film material has grown with the (101) and (201) crystallographic planes parallel to the growth plane. It indicates a way to optimize the single orientation growth by careful adjustment of the temperature of substrate. Fig. 2(a−d) represents the SEM images of $Mn_{0.98}Cr_{0.02}Te$ thin films grown with the substrate temperature of 500 and 700 °C. The SEM images with low magnifications (Fig. 2(a) and (b)) clearly denote that all the films have pinholes. From the enlarged images (Fig. 2(c) and (d)), it is clearly seen that the particles are connected with each other without clear boundary for film prepared at low temperature. However, the film obtained at high substrate temperature has island growth; and the island size is about 500 nm. The thickness of sample obtained with similar synthesized parameters was calculated to be about 150 nm[15].

The magnetic behavior of $Mn_{0.98}Cr_{0.02}Te$ film was investigated with SQUID magnetometer. In our case, the precise value for the magnetic moment could not be obtained from the magnetic data, because the mass of $Mn_{0.98}Cr_{0.02}Te$ film cannot be estimated precisely. The overwhelming diamagnetic contribution from the substrate is not removed from the measured data. Fig. 3 shows the temperature dependence of zero-field-cooling (ZFC) and field-cooling (FC) magnetization. From the temperature dependence of the ZFC and FC magnetization near 315 K (T_N of MnTe), we conclude that the $Mn_{0.98}Cr_{0.02}Te$ film prepared with substrate temperature of 500 °C shows different antiferromagnetic ordering, compared to the bulk NiAs-type MnTe[9]. The similar properties were observed in MnTe and $Mn_{1-x}Cr_xTe$ films grown on Si/SiO_2 substrates[15]. In the meantime, a rise in magnetization around 60 K shows a ferromagnetic-like order due to a magneto-elastic coupling, which strengthens intraplanar ferromagnetic interactions relative to interplanar AF interaction in the MnTe lattice[8,9,15]. It is noticed that almost no temperature hysteresis was observed in $Mn_{0.98}Cr_{0.02}Te$ film prepared with substrate temperature 700 °C. It is known that the lattice mismatch exists between the Al_2O_3 substrate and MnTe film, although the mismatch is small compared with other substrate. And the high temperature is propitious to decrease the mismatch. So the difference in hysteresis may be due to the fact that the different lattice mismatch and different thermal expansion coefficient between epitaxial film and substrate affect the film structure and induce some different magnetic properties.

The temperature dependence of the electrical resistance of $Mn_{0.98}Cr_{0.02}Te$ was measured. From the SEM image, it is known that the film prepared with substrate temperature of 700 °C is formed by island growth, and the particles are not connected with each other, so the resistance is too large to be measured. The film prepared with substrate temperature of 500 °C provides evidence for a transition from the metallic to semiconducting state. Fig. 4 reveals a maximum in the electrical resistance at 305 K near T_N (315 K) and a sharp change at about 60 K[16]. $Mn_{0.98}Cr_{0.02}Te$ should be a semiconductor at room temperature and it is expected that the resistance increases with decreasing temperature. However, $Mn_{0.98}Cr_{0.02}Te$ shows the metallic properties from the magnetic-ordering temperature $T_N = 315$ to

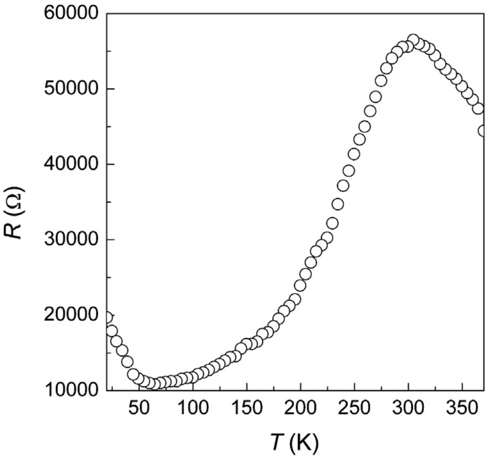

Fig. 4 Temperature dependence of electrical resistance of $Mn_{0.98}Cr_{0.02}Te$ film prepared with substrate temperature of 500 °C.

60 K, and the decrease of resistance is due to the spin disorder scattering with a large contribution from the influence of magnon drag[8,17]. As the temperature is further lowered, a rise in resistance is observed below 60 K. In the low-temperature region, our results are in agreement with the data reported in literature[8,16], assigned to the formation magneto-elastic coupling, as shown in ZFC and FC magnetization curves.

4. Conclusion

The epitaxial $Mn_{0.98}Cr_{0.02}Te$ films were prepared by PLD on single crystal Al_2O_3 (0001) substrates. The high quality epitaxial film was obtained with substrate temperature of 500 °C. When the substrate temperature reached 700 °C, the film was discontinuous and the manganese oxides phase appeared. A small fraction of the film prepared with high temperature had grown with the (101) and (201) crystallographic planes. The temperature dependence of both the magnetization and electrical resistance showed a sharp rise at around 60 K due to the magnetoelastic coupling. The temperature dependence of the electrical resistance of $Mn_{0.98}Cr_{0.02}Te$ showed a transition from the semiconducting to metallic state at 315 K due to the spin disorder scattering with a large contribution from the influence of magnon drag and a transition from the metallic to semiconducting state at 60 K assigned to the formation magneto-elastic coupling.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 50902128), Project of Shenyang Natural Science and Technology Support Program (No. F10205154), Project of Jilin Provincial Natural Science Foundation (No. 20101534).

REFERENCES

[1] K. Nakamura, Y. Kato, T. Akiyama, T. Ito, Phys. Rev. Lett. 96 (2006) 047206.
[2] R.K. Sharma, G. Singh, Y.G. Shul, H. Kim, Physica B 390 (2007) 314−319.
[3] W. Szuszkiewicz, E. Dynowska, B. Witkowska, B. Hennion, Phys. Rev. B 73 (2006) 104403.
[4] J.W. Allen, G. Lukowsky, J.C. Mikkelsen Jr., Solid State Commun. 24 (1977) 367−370.
[5] J.J. Banewicz, R.F. Heidelberg, A.H. Luxem, J. Phys. Chem. 65 (1961) 615−617.
[6] M. Podgòrny, J. Oleszkiewicz, J. Phys. C: Solid State Phys. 16 (1983) 2547−2557.
[7] W. Kim, I.J. Park, H.J. Kim, W. Lee, S.J. Kim, C.S. Kim, IEEE Trans. Mag. 45 (6) (2009) 2424−2427.
[8] J.B.C. Efrem D'Sa, P.A. Bhobe, K.R. Priolkar, A. Das, S.K. Paranjpe, R.B. Prabhu, P.R. Sarode, J. Magn. Magn. Mater. 285 (2005) 267−271.
[9] Y.B. Li, Y.Q. Zhang, N.K. Sun, Q. Zhang, D. Li, J. Li, Z.D. Zhang, Phys. Rev. B 72 (2005) 193308.
[10] I. Sänger, B. Kaminski, D.R. Yakovlev, R.V. Pisarev, M. Bayer, G. Karczewski, T. Wojtowicz, J. Kossut, Phys. Rev. B 74 (2006) 235217.
[11] D. Seger, S. Wei, Phys. Rev. B 70 (2004) 184401.
[12] S.H. Kim, H.C. Kim, J.W. Park, J.W. Kim, J. Magn. 13 (2008) 23−29.
[13] T. Dietl, J. Magn. Magn. Mater. 290−291 (2005) 14−19.
[14] G.I. Makovetskii, A.I. Galyas, K.I. Yanushkevich, Phys. Solid State 39 (1997) 280−283.
[15] Z.H. Wang, D.Y. Geng, W.J. Gong, J. Li, Y.B. Li, Z.D. Zhang, Thin Solid Films 522 (2012) 175−179.
[16] S.S. Aplesnin, L.I. Ryabinkina, O.B. Romanova, D.A. Balaev, O.F. Demidenko, K.I. Yanushkevich, N.S. Miroshnichenko, Phys. Solid State 49 (2007) 2080−2085.
[17] C. Hass, Phys. Rev. 168 (1968) 531−538.