Growth and Characterization of Sb−doped $Cd_x Mn_{1-x} Te$ grown by MOVPE

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1. Introduction

The Mn−doped CdTe is one of the Diluted Magnetic Semiconductors(DMSs), which atracts much interest in new fuctional devices where the combination of the electrical properties of CdTe and the magnetic one of Mn atom plays an important role. As a result of the combination, the magnetic properties such as the giant magneto−resistance, ferromagnetism, and/or Faraday rotation are expected. There are many reports on the growth and properties of them.[1.2)] The ferromagnetism of the heavy p−type DMS under low temperature was also reported. The (s)p−d interaction between the transition metal and the host crystal is known as the important phenomena to arise the magnetic properties. The hole is also known to act a very important role to arise the magnetic properties in DMSs. The high hole concentration is thought to be nescessary to observe the magnetism in DMSs. The valence band of CdTe consists of the p−state of the tellurium. The acceptor state of the group V element replaced to the tellurium in CdTe originates from the p−state, suggesting that a hole trapped to the acceptor which surrounded by a couple of Mn plays a same role as a free hole. The clusters of the transition metal and the acceptor in DMSs are expected to show a magnetism. The CdTe doped with Mn and Sb is one of the promising materials to investigate such a phenomena, because Sb acts as the acceptor in CdTe.

$Cd_x Mn_{1-x} Te$:Sb (CMTS) was grown well on (001)GaAs substrate by MOVPE. The properties of the CMTS are also presented.

2.Experimental

CMTS was grown on (001)GaAs substrate by MOVPE under the atmospheric pressure. DMCd, $CH_3 C_5 H_4 Mn(CO)_3$, DETe and TESb were used as the source gases cadmium, manganese, tellurium, and antimony, respectively. H_2 was used as the carrer gas. The substrate was heated on the graphite susceptor induced by the RF irradiation. Prior to the growth of CMTS, the GaAs substrate was heated in H_2 including with TESb at 650°C for 15 minutes to remove the oxidized layer. CMTS was grown for 2hours. The typical growth conditions are as follows. The substrate temperature was varied from 450°C to 600°C. The DMCd supply rate was 30μmol/min, the DETe 30μmol/min, and the $CH_3C_5H_4Mn(CO)_3$ from 0.5μmol/min to 1.8μmol/min. The molar fraction of manganese and the crystal quality are discussed with X−ray diffraction. The doping effect of antimony is investigated by the photoluminescence spectra. The focussed 325nm line of He−Cd laser of 15mW was used as the excitation source of the photoluminescence. The magnetic properties are also discussed with the vibrating sample magnetometer(VSM).

3.Results and Discussion

The film thickness was varied from 2.5μm to 5.7μm. The rough surface with many cracks are observed in the film grown at the temperature lower than 500°C, but the smooth surface with few cracks are observed in the sample grown at 550°C. The manganese molar fraction of CMTS grown under the conditions mensioned above was varied from 0.4% to 4%, which was evaluated from the X−ray diffraction peak assuming the Vegard's law. The FWHM of the X−ray diffraction shows the minimum value of 800seconds at 550°C, where raising or lowering of the substrate temperature increases the FWHM sensitively. To increase the molar fraction of manganese, the source gas supply rate of DMCd and DETe were lowered down to 10μmol/min. The substrate temperature was also lowered down to 520°C. The supply rate of $CH_3 C_5 H_4 Mn(CO)_3$ was varied from 0.8 to 1.8μmol/min and the one of TESb were varied from 0.6 to 1.6μmol/min under such conditions. The film thickness of CMTS grown under such conditions was 5.7μmol/min, which is independent of the TESb supply rate. CMTS with a smooth surface was obtained. As is mensioned above, the pre−treatment of the GaAs substrate with H_2 including with TESb at 650°C was necessary to get a thick epitaxial layer with a smooth surface. CMTS was grown little on the GaAs substrate which was treated with H_2 without TESb, suggesting that the antimonized layer of the GaAs surface plays an important role, i.e., relaxes the lattice constant difference between CMTS and GaAs. As shown in Fig.(a), the manganese molar fraction increases gently up to 3%, where the $CH_3C_5H_4Mn(CO)_3$ supply rate is 1.2μmol/min. Then, the manganese molar fraction increases rapidly up to 10%, where the $CH_3C_5H_4Mn(CO)_3$ supply rate is 1.6μmol/min. The manganese molar fraction was independent of antimony supply rate. As is shown in Fig.1(b), the FWHM of the X−ray diffraction was 1100seconds, which is independent of the manganese molar fraction. On the other hand, the FWHM of the X−ray diffraction decreases gently by the increase of TESb supply rate that is 720seconds at 0.8μmol/min of the TESb supply rate and 560seconds at 1.6μmol/min. The antimoy introduced into Cd_x Mn_{1-x} Te (CMT) plays to relax the deformation of the CMT lattice which is caused by the large difference of the lattice constant (14%) between the CMTS and the GaAs substrate.

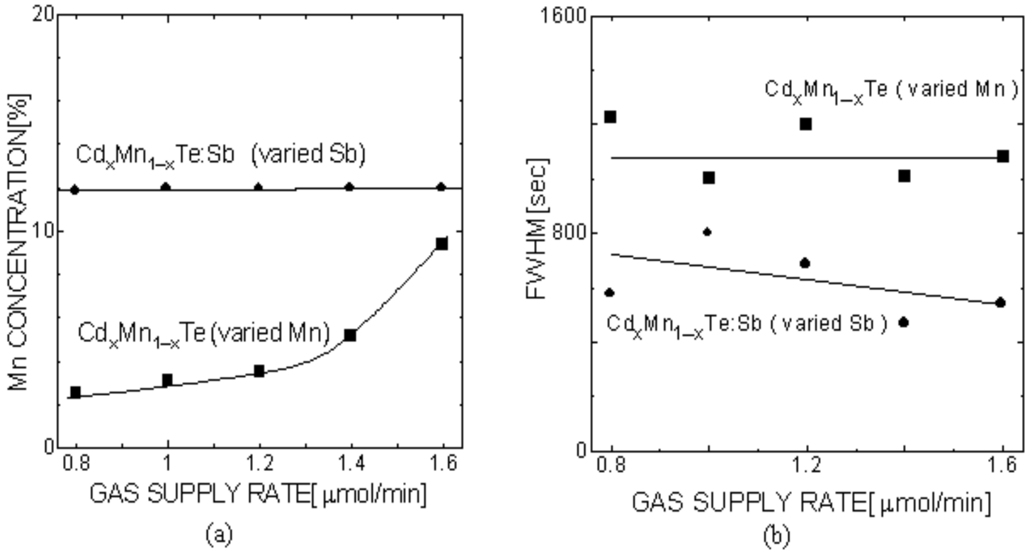

Fig.1 X−ray diffraction measurement of CdXMn1-XTe and CdXMn1-XTe:Sb
(a) Mn concentration dependence on the source gas supply rate.
(b) FWHM of the X−ray diffraction of CdXMn1-XTe and CdXMn1-XTe:Sb
CH3C5H4Mn(CO)3 supply rate was varied on the growth of CMT.
TESb supply rate was varied on the growth of CMTS(x=0.1).

The antimony supply rate dependence of the photoluminescence spectra of $Cd_{0.9}Mn_{0.1}$Te:Sb measeured at 6K are shown in Fig.2(a). The temperature dependence of the photoluminescnece spectra of $Cd_{0.9}Mn_{0.1}$Te:Sb where the antimony supply rate is 1.6μmol/min are shown in Fig.2(b). The photoluminescence spectra of $Cd_{0.9}Mn_{0.1}$Te:Sb measured at 6K shows four peaks peaking at 730nm, 750nm, 830nm and 920nm, where the manganese supply rate was 1.6μmol/min and the manganese molar fraction was 10%, as shown in Fig.2. The emission bands peaking at 730nm and 750nm corresponds with the energy of the band gap of $Cd_{0.9}Mn_{0.1}$Te:Sb. The intensity of these emission bands increases by the increase of the antimony concentration as shown in Fig,2(a). The intensity of these emission bands increase by lowering the temperature as shown in Fig.2(b). These emission cannot be observed at 160K. These emission bands are related to the antimony. Similar photoluminescence spectra are reported by J. Nakahara et al..[3] They suggested that the emission band peaking at 750nm is due to the impurity state and the emission band peaking at 730nm is due to the exciton. The antimony concentration and the hole concentration increase by the increase of the antimony supply rate, resulting in the enhance of the intensity of the exciton emission and the impurity emission. The weak emission band peaking at 830nm can be observed in the sample grown with the lower TESb supply rate than 1.0μmol/min. This emission band appears exclusively to the emission bands peaking at 730nm and 750nm. The X−ray diffraction suggests that the increase of the antimony supply rate improves the crystal quality. The emission band peaking at 830nm is thought to be due to a kind of the lattice defect. The broad emission band peaking at 920nm shows the blue shift by raising the temperature as shown in Fig.2(b), suggesting that this emission is due to the SA emission.

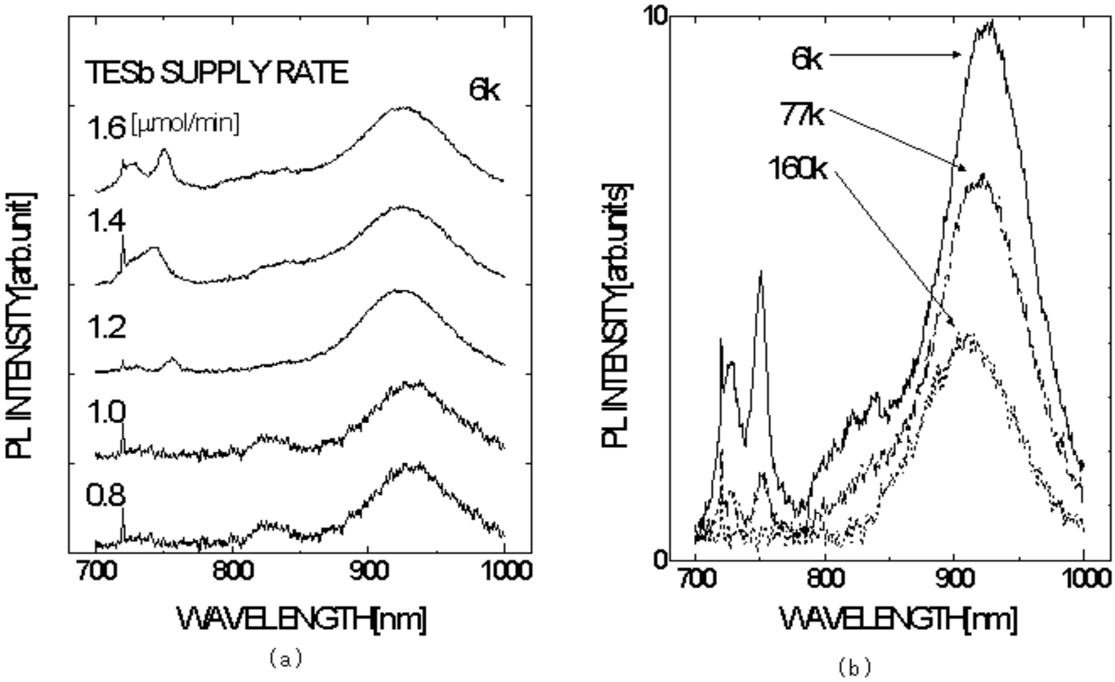

Fig.2 Photoluminescnece spectra of the CdxMn1-xTe:Sb
Samples were excited by 325nm line of He-Cd laser.
(a) TESb supply rate dependence of the PL spectra at 6K.
(b) Temperature dependence of the PL spectra.
Sb supply rate was 1.6 μmol/min.

4.Summary

$Cd_x Mn_{1-x}$ Te:Sb (CMTS) was grown well on (001)GaAs substrate by MOVPE, where the substrate was heated at 650°C with H_2 including TESb prior to the growth. The FWHM of the X−ray diffration of CMTS decreases with the increase of the TESb supply rate, but independent of the $CH_3 C_5 H_4 Mn(CO)_3$ supply rate. The near−band edge emission of CMTS was enhanced by the increase of the TESb supply rate.

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