Ordering of manganese spins in photoconducting $Zn_{1-x}Mn_xTe$

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Abstract

Single crystals of $Zn_{1-x}Mn_xTe$ with x=0.3 - 0.6 were prepared by the standard Bridgeman method. Diffuse neutron diffraction intensities due to the short range magnetic ordering is found in the vicinities of 1 1/2 0 reciprocal point and its equivalent points, indicating that the magnetic correlation of the clusters is the type III antiferromangetic one of the F-type Bravais class crystals, being identical with that of $Cd_{1-x}Mn_xTe$.Neutron inelastic scattering measurement has been performed for $Zn_{0.6}Mn_{0.4}Te$ sample using the cold neutron spectrometer, AGNES. High resolution measurement with the energy resolution of $\Delta E=\pm 0.1meV$ was carried out in the temperature range from 10K to the ambient. Critical scattering, closely related with the spin glass transition, has been observed for the first time in this semimagnetic semiconductor. The critical scattering is observed at temperatures in the vicinity of the spin glass transition temperature, 17K. The scattering is observed as a kind of quasielastic scattering in the reciprocal range where the elastic magnetic diffuse scattering has been observed ,e.g., 1 1/2 0 reciprocal point, indicating the spin fluctuation has dynamic components in this material. Photoconductivity has been discovered below 150K in $Zn_{0.4}Mn_{0.6}Te$. The electric AC conductivity has been increased dramatically under the laser light with the wave lengths of λ =6328, 5145 and 4880Å, respectively. After the light was darkened, the conductivity was reduced to the original level after about 2000 seconds at 50K , being above the spin glass transition temperature. This phenomenon is the typical persistent photoconductivity; PPC which was similarly found in $Cd_{1-x}Mn_xTe$.

Introduction

$Zn_{1-x}Mn_xTe$ with 0<x<0.8 is a doped semimagnetic semiconductor, while ZnTe is a typical II-VI group wide gap semiconductor. Increase of g-factor[1] and Zeeman splitting[2] of the energy levels by the pulsed Laser beam are known and the phenomena are understood in terms of photo-induced giant magnetic polarons[3]. The $Zn_{1-x}Mn_xTe$ with 0<x<0.6 exhibits spin glass transition below 50K[4]. But the crystal with 0.6<x<0.8 becomes antiferromagnetic below 60K , the Neel temperature increasing with manganese content.

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The lattice parameter, a , of the Zincblende type crystal[5] and the band gap, E_g[6], of $Zn_{1-x}Mn_xTe$ almost linearly change with manganese content. These linear properties have close similarity with the $Cd_{1-x}Mn_xTe$ system[5,7]. Figure 1 shows magnetic phase diagrams of $Zn_{1-x}Mn_xTe$ and $Cd_{1-x}Mn_xTe$ systems determined by Samarth and Furdyna[7]. The magnetic structure of the antiferromagnetic phase of the $Cd_{1-x}Mn_xTe$ with 0.6<x<0.8 was determined from the neutron diffraction data by Giebultowicz et al [8] to be the type-III of the F- Bravais class lattice (full face centered). Manganese atoms occupy cadmium site statistically and form psudo-fcc lattice. Temperature dependent photoconductivity of the heavy doped semiconductors, semimagnetic sometimes, are quite non-linear[9], increasing sharply below the quenching temperature. This photo-induced conductivity has relatively long lifetime, being more than 2000 seconds sometime, and is called as persistent photoconductivity (PPC). The PPC has been explained theoretically in terms of the photo-induced excitations of DX^- centers existing in the II-VI and III-V group semiconductors by Chadi and Chang [10].

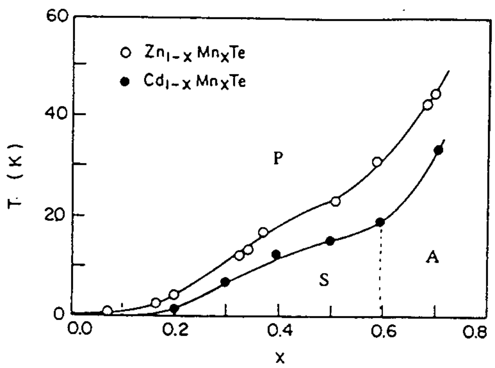

Fig.1 Magnetic phase diagrams of $Zn_{1-x}Mn_xTe$ and $Cd_{1-x}Mn_xTe$ [7].

The aim of the present work is to study magnetic ordering of manganese moment in the doped II-VI goup semiconductor. $Zn_{1-x}Mn_xTe$ with x=0.3 - 0.6 was prepared for the purpose. Neutron diffraction measurement and neutron inelastic scattering measurement were carried out to know the static and dynamic magnetic correlations , respectively, in the low temperature range including the spin glass transition temperature. Photoconductivity measurement was also conducted at low temperatures.

Experimental Procedures

$Zn_{1-x}Mn_xTe$ with x = 0.3 - 0.6 single crystals were grown by the Bridgman method by T.Sato, one of the present authors. The maximum size of the grown samples was about 8 ϕ × 30 mm. The magnetic susceptibility of the samples was measured with SQUID magnetometer (Quantum Design Co.). The neutron diffraction measurement was performed for $Zn_{0.57}Mn_{0.43}Te$ sample at temperatures in the range from 10K to 250K using high resolution and high efficiency powder neutron diffractometers, HRPD [10] and HERMES [11], installed in the JAERI-JRR3M reactor hall and the thermal guide hall, respectively. High efficiency neutron single crytal diffraction measurement becomes available using the multiple detector-type diffractometers like HRPD (64 neutron counters) and HERMES (150 neutron counters) which have mainly been designed for the high efficiency powder diffraction measurements. Using above apparatuses, single crystal diffraction intensities in a given reciprocal lattice plane (zero Laue zone) can be measured effectively. Two dimensional diffraction intensities in the (001) reciprocal lattice plane were measured rotating the single crystal choosing [001] direction pallarel to the rotation axis. High magnetic field, 5 Tesla, was applied from the direction vertical to the (001) plane at 10K to observe magnetic field dependent variations in the diffraction intensities. The measurement was performed with the monochromatized neutron radiation of λ =1.8232 Å (HRPD) and 1.8196 Å (HERMES). Neutron inelastic scattering intensities were also measured at several reciprocal points situated in the vicinity of the 1 1/2 0 reciprocal point , being the W-point on the 1st Brillouin zone boundary, by the use of a cold neutron (λ =4.19 Å for the present measurement) scattering spectrometer, AGNES [13]. Photoconductivity under the gas Laser beam with λ = 4885、5145 and 6328 Å was observed at temperatures in the range from 10K to the ambient.

Results and Discussions

Figure 2 shows χ vs. temperature dependency of $Zn_{0.568}Mn_{0.432}Te$ measured in the heating process in a relatively high field at H=3000Oe. FC and ZFC represent the field cooled and zerofield cooled states, respectively. The spinglass temperature, T_G=18K, was determined from the point where the χ becomes different in the either processes. The χ - T curve becomes complicated in the case of low field measurements. Figure 3 shows the χ -T curves observed in the weak field at H=100Oe showing that the χ of the field cooled case becomes anomalously high in the range well above the T_G ≒ 17K. This phenomenon is originated from the frustrated spin ordering below 100K.

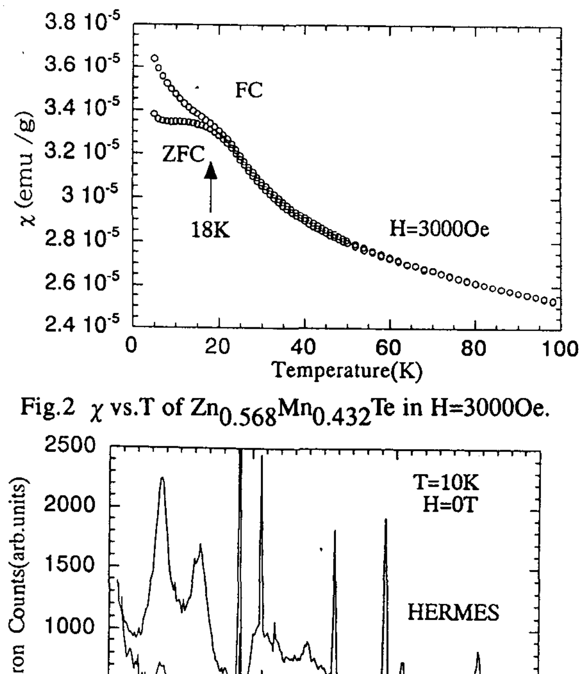

Fig.2 χ vs.T of $Zn_{0.568}Mn_{0.432}Te$ in H=3000Oe.

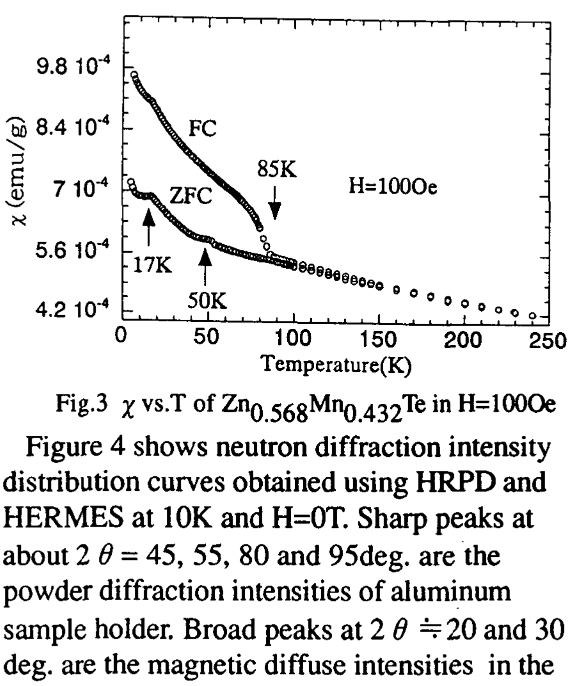

Fig.3 χ vs.T of $Zn_{0.568}Mn_{0.432}Te$ in H=100Oe

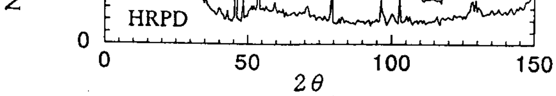

Fig.4 Neutron single crystal diffraction intensities of $Zn_{0.568}Mn_{0.432}Te$ at 10K.

Figure 4 shows neutron diffraction intensity distribution curves obtained using HRPD and HERMES at 10K and H=0T. Sharp peaks at about 2 θ = 45, 55, 80 and 95deg. are the powder diffraction intensities of aluminum sample holder. Broad peaks at 2 θ ≒20 and 30 deg. are the magnetic diffuse intensities in the vicinities of 1 1/2 0 and 3/2 1 0 reciprocal lattice points, respectively. Broad intensities at 2 θ ≒ 55 and 70 deg. are also the magnetic diffuse intensities in the equivalent reciprocal lattice areas. Each pattern was obtained in about 90 minutes. Two dimensional intensity distribution in the (001) reciprocal plane, zero Laue zone, were measured rotating a single crystal sample for 11 times with 5 deg. step. Figure 5 represents obtained 2D map at 10K. The h and k axes correspond to the a* and b* axes, respectively. 111 and 200 Debye-Scherrer rings of Al sample holder can be seen in the upper right corner. Diffuse intensities are observed in the vicinities of 1/2 1 0, 1 1/2 0 and their equivalent reciprocal points, being the W-points of the 1st Brillouin zone boundary of fcc metal (Zn,Mn) lattice. Since the W-points are unique reciprocal points for the type III

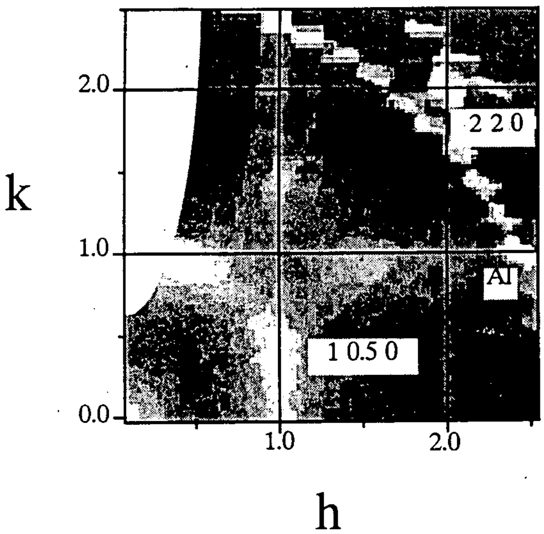

Fig.5 2D-representation of diffraction intensities in the (001) plane at 10K.

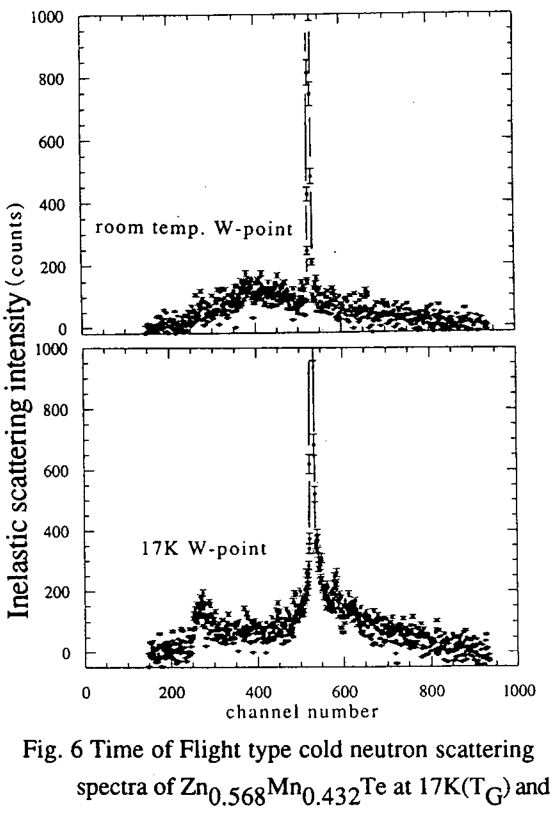

Fig. 6 Time of Flight type cold neutron scattering spectra of $Zn_{0.568}Mn_{0.432}Te$ at 17K(T_G) and the ambient.

antiferromagnetic spin ordering, it is indicated that major part of the manganese spins are antiferromagnetically ordered in the spin glass phase. However, the magnetic correlation is extended only in the limited range, i.e., about 10 unit cell size. Some diffuse intensities are extended toward 1 0 0 and its equivalent points which are the unique points for the type I antiferromagnetic ordering, indication of frustrating spin ordering between the type III and type I antiferromagnetic spin ordering at low temperatures. These diffuse intensities were observed at temperatures well above T_G,e.g., 100K. Figure 6 shows temperature dependent change in the cold neutron scattering intensities observed at 1 1/2 0 reciprocal point by the use of time of flight (TOF) type cold neutron spectrometer, AGNES at room temperature and 17K(T_G). Central peaks correspond to the elastic scattering. The energy transfer, gain or loss, of the incident cold neutron can be calculated from the difference in the TOF of the scattered neutrons from the elastic peak. Broad intensity distribution due to a dynamic spin fluctuation can be seen in the vicinity of the central elastic peak at 17K. This broad inelastic intensity becomes weak with the increase as well as decrease of temperature.

Figure 7 shows AC conductivity vs. temperature dependency of $Zn_{0.431}Mn_{0.569}Te$ observed at 1kHz in the dark and under the irradiation of continuous laser light with $\lambda = 5145$ Å. The intensity of the laser light was about 100mW. The sample size was $1.9\times3.8\times4.9mm^3$. The electric field was applied parallel to [110] direction. The laser light was irradiated from [111] direction, normal to the surface. The electric conductivity increased by about one or two order magnitude higher in the range below 157K. Increased conductivity was maintained after the shut off of the laser light for more than 1000 seconds at 50K. This phenomenon may be discussed in terms of the persistent photoconductivity [9,10] as similarly observed in Cd_{1-x}-Mn_xTe system. Details of above results will be presented in the symposium.

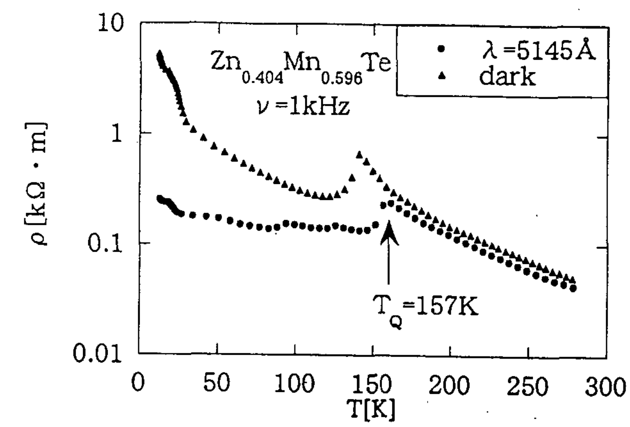

Fig. 7 AC conductivity of $Zn_{0.404}Mn_{0.596}Te$ observed in the dark and under the irradiation of laser.

Acknowledgement

Present work was supported in part by the Grant-in-Aid for the Scientific Research from the Ministry of Education, Science and Culture of Japan.

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