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CONCENTRATION DEPENDENCE OF PHOTO-INDUCED MAGNETIZATION IN DILUTED MAGNETIC SEMICONDUCTOR $Cd_{1-x}Mn_xTe$

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The photo-induced decrease in magnetization ΔM_{photo} was observed in $Cd_{1-x}Mn_xTe$ ($0.25 < x < 0.42$) under unpolarized light illumination whose photon energy is smaller than the band gap of the sample. The photo-induced magnetization decreases with increasing Mn content through Mn^{2+}–Mn^{2+} antiferromagnetic interaction, which supports our idea for origin of it based on the flipping of Mn spins in the bound magnetic polarons accompanied by the spin-flip Raman scattering.

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1. Introduction

$Cd_{1-x}Mn_xTe$ belongs to a class of semiconductor materials called diluted magnetic semiconductor (DMS). The presence of magnetic ion of Mn^{2+} in $Cd_{1-x}Mn_xTe$ results in the Mn^{2+}–Mn^{2+} antiferromagnetic interaction and the *sp–d* exchange interaction which lead to the interesting magnetic behavior such as the formation of the spin-glass (SG) order and the bound magnetic polaron (BMP). Such magnetic behavior has been investigated based on the magnetic and optical methods. On the other hand, several investigations have paid attention to the change in magnetization of DMS under the light illumination. The photo-induced magnetization of $Cd_{0.8}Mn_{0.2}Te$ was detected in zero magnetic field at optical excitation with circularly polarized light [1]. Changes in the relaxation of the thermo-remanent magnetization (TRM) and isothermal-remanent magnetization (IRM) were observed under the unpolarized light illumination [2]. In spite of the intensive investigations, there has been only insufficient understanding about the correlation between the photo-induced magnetization and the magnetic interactions in DMS. We have investigated the photo-induced change in the magnetization in some samples of $Cd_{1-x}Mn_xTe$ under the unpolarized light illumination, and derived a picture that photo-induced magnetization originates from the flipping of Mn spins in the BMP [3]. In this report, we investigate the concentration dependence of the photo-induced magnetization to evaluate the validity of our picture.

2. Experimental procedure

Single crystal samples of $Cd_{1-x}Mn_xTe$ ($x = 0.25, 0.28, 0.40, 0.42$) were prepared using the Bridgman method. The changes in the magnetization of the samples by the light irradiation were measured using a superconducting quantum interference device (SQUID) magnetometer. The light was guided to a sample through an optical fiber parallel to the external magnetic field using He–Ne laser ($\lambda = 632.8$ nm) whose photon energy is smaller than the band gaps of the samples. The light irradiation was chopped at frequency of 700 Hz to suppress a temperature rise of the sample. We detected the increase in temperature smaller than 110 mK at 5 K under the light illumination using the thermocouple fixed on the sample when the laser output was 5.6 mW. The light intensity (I) was controlled by attenuating the laser output using a set of neutral density filters.

3. Results and discussion

First, we show the photo-induced change in magnetization of $Cd_{0.60}Mn_{0.40}Te$ measured at several light intensities at 5 K under the field cooled (FC) condition (Fig. 1). The magnetization decreases under light illumination and the decrement increases with increasing light intensity. The photo-induced decrement at 5 K attains to about 1% of the net magnetization for the laser output of 5.6 mW. The present photo-induced magnetization is much larger than that in $Cd_{0.80}Mn_{0.20}Te$ for circularly polarized light with $h\nu > Eg$ in zero magnetic field [1].

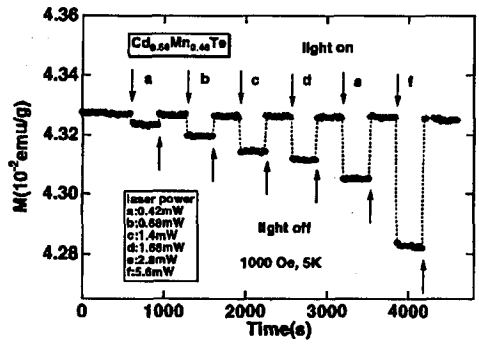

Fig. 1. Photo-induced change in magnetization of $Cd_{0.60}Mn_{0.40}Te$ measured at several light intensities under the field cooled condition.

Figure 2 shows the photo-induced magnetization ΔM_{photo} of $Cd_{1-x}Mn_xTe$ as a function of magnetic field. In case that a desired temperature was higher than a spin-glass transition temperature (Tg), the data were measured on decreasing field after cooling of the sample down to a desired temperature in a field of 50 kOe. The measurements at a temperature below Tg were performed after the sample was cooled in each desired magnetic field from a temperature several times higher than Tg to avoid the effect of the long time relaxation of magnetization. We can deduce the following characteristics from Fig. 2: (1) ΔM_{photo} linearly increases with increasing field in the low field region and shows the tendency of saturation in the high field region in all the samples. (2) The magnitude of ΔM_{photo}

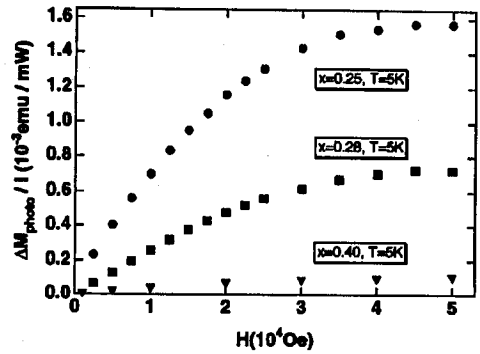

Fig. 2. Magnetic field dependence of ΔM_{photo} of $Cd_{1-x}Mn_xTe$ at 5 K. I stands for the light intensity of the laser.

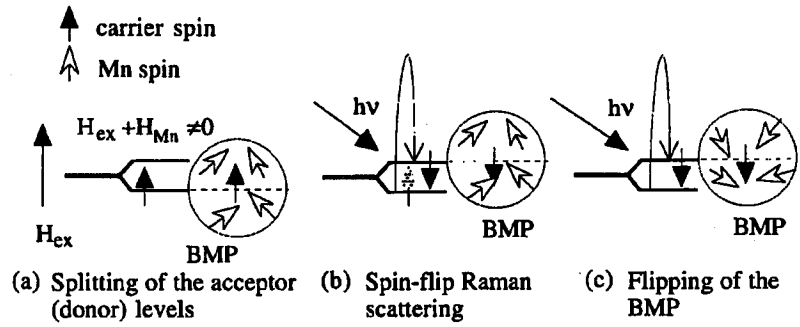

Fig. 3. Mechanism of the photo-induced magnetization. H_{Mn} stands for the internal field caused by Mn spins.

of $Cd_{0.75}Mn_{0.25}Te$ is largest among the present samples. (3) The remanence of ΔM_{photo} observed at zero field decreases as the Mn concentration increases. We discuss these characteristics based on picture that ΔM_{photo} originates from the flipping of the BMP accompanied by the spin-flip Raman scattering as illustrated in Fig. 3 [3].

First, the field dependence of the photo-induced magnetization is interpreted on the lines of that of the spin-flip Raman shift of $Cd_{1-x}Mn_xTe$ [4], i.e., the field dependent difference between the Stokes and anti-Stokes components brings about the polarization of the polaron magnetic moments dependent on the Mn content. This idea well explains the saturation of ΔM_{photo} at high fields. Next, to discuss the Mn concentration dependence of photo-induced decrease in magnetization, we compare ΔM_{photo} at 50 kOe, measured at a temperature which is determined so as to identify the normalized temperature T/Tg (≈ 0.8) among the samples, with the effective number of Mn spins belonging to one bound magnetic polaron N_{Mneff} as shown in Fig. 4, where the value of N_{Mneff} is evaluated based on the information about the polaron size and the contribution from the Mn^{2+}–Mn^{2+} antiferromagnetic interaction evaluated based on the Raman scattering data [4]. We note that the characteristic changes in ΔM_{photo} and N_{Mneff} occur around

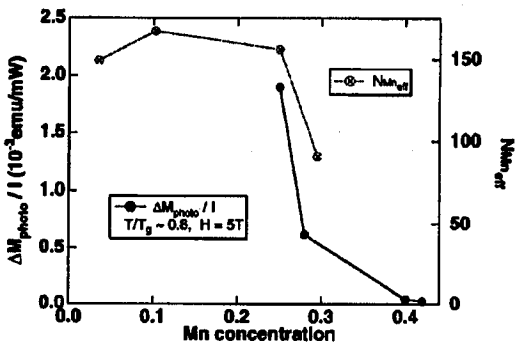

Fig. 4. Mn concentration dependence of $\Delta M_{\mathrm{photo}}$ of $Cd_{1-x}Mn_xTe$ ($T/Tg \approx 0.8$, $H = 5$ T) and N_{Mneff}. I stands for the light intensity of the laser.

$x \approx 0.3$ in common. Such correlation between them should be related to the fact that the antiferromagnetic interaction becomes significant around the same Mn concentration which strongly supports our model for the origin of photo-induced magnetization. Finally, we can interpret the Mn concentration dependence of the remanence of $\Delta M_{\mathrm{photo}}$ on the same lines. This should be interpreted based on the degree of effective field originating from the polarized Mn moments in BMP since the remanence should be attributed to the splitting of the acceptor (donor) levels due to the s–d interaction at zero magnetic field. We naturally deduced an idea that the effective field is weakened with increasing the Mn^{2+}–Mn^{2+} antiferromagnetic interaction, then, the remanence of $\Delta M_{\mathrm{photo}}$ must decrease with increasing Mn content. Thus, the Mn concentration dependent behavior of the photo-induced magnetization is comprehensively interpreted based on the model relevant to the spin-flip Raman scattering accompanied by the Mn^{2+}–Mn^{2+} antiferromagnetic interaction.

4. Conclusions

The photo-induced magnetization decreases with increasing Mn content through Mn^{2+}–Mn^{2+} antiferromagnetic interaction, which supports our idea for origin of it based on the flipping of Mn spins in the bound magnetic polarons accompanied by the spin-flip Raman scattering.

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