Excitons Diffusion in (Cd, Mn)Te-Based Two-Dimensional Electron System under Magnetic Fields

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The in-plane motion of *neutral* exciton (X) and *negatively-charged* exciton (X^-) in CdTe and GaAs-based two-dimensional electron system (2DES) under magnetic fields or/and electric fields has been reported using scanning near-field optical microscopy (SNOM) [1,2] or spatially resolved photoluminescence (PL) spectroscopy [3-5]. In Ref. 3, Pulizzi *et al*. suggested that the spatial diffusion of X and X^- under magnetic fields can be explained by assuming that only X is mobile and free to move and that it is in local dynamical equilibrium with localized X^- by the Lorentz force. Recently, there have been growing interests in diluted magnetic semiconductors (DMS)-based 2DES; '*magnetic*' 2DES, in which the electronic and magnetic degrees of freedom should be independently controlled and the spin properties of 2D electrons should be exhibited in an enhanced manner due to the exchange interaction with localized magnetic moments. So far as we know, little has been known about the effect of magnetic fields on the in-plane motion of X and X^- in *magnetic* 2DES although extensive studies have been carried out through magneto-PL investigations. In this contribution, we present the results of time and spatially resolved magneto-PL measurements on (Cd,Mn)Te-based 2DES and demonstrate the significant features resulting from the existence of *magnetic* spins.

The structure of samples was as follows; a (Cd,Mn)Te well layer was sandwiched by (Cd,Mg)Te barrier layers and an iodine(I)-doped layer was separated by a 100Å-thick spacer layer from the well. The 2D electron densities of studied samples were 3.0 and 4.6×10^{11} cm^{-2} (sample *A* and *B*, respectively). Mn was uniformly incorporated in the well and the composition is estimated at about 5% in both samples. Time and spatially resolved circular-polarized PL measurements were performed on these samples at 4.2K up to magnetic fields of 0.5T by using a fluorescence microscopy. A semiconductor laser with the wavelength of 659 nm and the pulse width of 62ps was used for carrier excitation. The spatial and time resolutions were 1μm and 300ps, respectively.

The PL spectra from respective samples in the absence of magnetic field are shown in Figure 1. They exhibit typical PL spectra of 2DES with asymmetric form due to the Fermi edge singularity (FES) [6]. Figure 2 shows the CCD images of the laser spot and the spatially resolved PL of the right (σ^+) polarization at the time of 0.1ns (The time of laser excitation is defined as 0ns). The PL spatial extent of both samples exceeded the laser spot. It means that the carriers diffused spatially out of the photo-excitation area. The driving force for the PL spatial extent comes from the non-equilibrium in the density of carriers caused by laser excitation. In zero field, X is created at the excitation area and able to diffuse out to create X^- there [3]. Moreover, under magnetic fields, localized X^- due to the Lorentz force is expected; that is, the PL spatial extent should be restricted by magnetic fields. A reasonable result has been observed in GaAs-based '*non-magnetic*' 2DES

through the same measurement as this work [5], i.e., the PL spatial extent shows a consistent tendency to shrink with the increase of magnetic fields. However, the different features were observed in *magnetic* 2DES as shown in Figure 2; that is, the PL spatial extent got larger with the increase of magnetic fields in sample *A*, although little change was observed in sample *B*.

Now we are considering the *singlet* state as X^- in σ^+ polarization; that is, the combination of electron and hole spin states is (e↓, h↑) + e↑. Under magnetic fields, the redistribution of electrons between the two spin subbands is more enhanced by the gigantic Zeeman splitting due to the *sp-d* exchange interaction (Figure 3). It is considered that the formation of X^- is suppressed by magnetic fields because of the shortage of up-spin electrons, especially in the lower electron density sample *A*. In such a case, the restriction of X diffusion due to the formation of X^- should be relaxed, i.e., the PL spatial extent of sample *A* should be enhanced more than that of sample *B*. These considerations can interpret the difference between sample *A* and *B*. However, the result that the PL spatial extent under magnetic fields exceeded that in zero field cannot be explained only by these considerations.

One candidate for the proper explanation is the suppression effect of a free exciton magnetic polaron (EMP) formation by magnetic fields. EMP is associated with a ferromagnetic orientation of magnetic spins within free-exciton Bohr orbits accompanied by a self-trapping localization process. Therefore, in zero magnetic field, the lateral motion of photo-excited X is expected to be limited by EMP formation. External magnetic fields can arrange also the orientation of magnetic spins outside free-exciton Bohr orbits, i.e., the formation of EMP is suppressed. Therefore, the spatial diffusion of X caused by laser excitation should be more enhanced by magnetic fields.

In summary, we found the strong dependence of the PL spatial extent on the intrinsic carrier density in *magnetic* 2DES under magnetic fields. It can be qualitatively interpreted by considering the competition of mobile X, localized X^- and also the suppression effect of EMP.

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[3] Pulizzi *et al*. Physica B **298**, 397 (2001), [4] Sanvitto *et al*. Science **294**, 837 (2001),
[5] Tokizaki *et al*. in preparation, [6] Huard *et al*. Phys. Rev. Lett. **84**, 187 (2000)

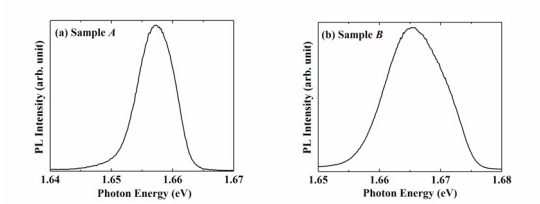


Fig. 1 PL spectra from samples *A* and *B* in the absence of magnetic field. The dependence of the Fermi edge singularity (FES) feature on carrier density was clearly observed.

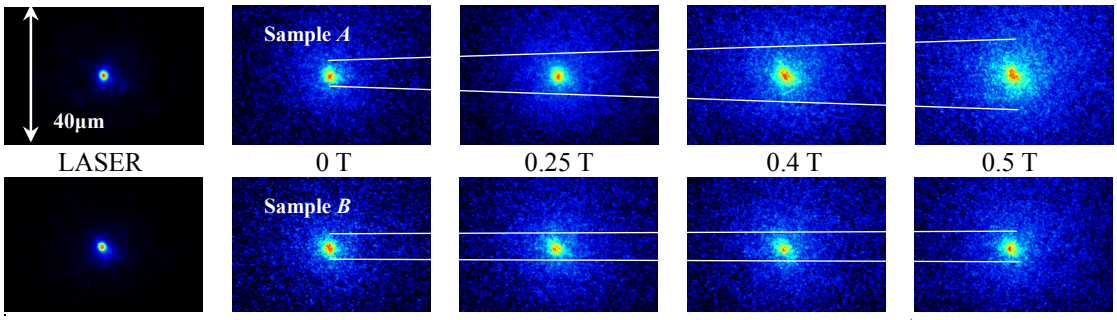
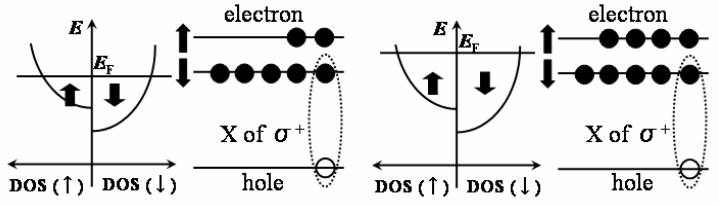


Fig. 2 CCD images of the laser excitation spot and the spatially resolved PL of σ^+ polarization at the time of 0.1ns. Here, the time of laser excitation is defined as 0ns. The PL spatial extent of sample *A* got larger with the increase of magnetic fields. However, little change was observed in sample *B*.



(a) In the case of sample *A* (b) In the case of sample *B*

Fig. 3 Diagrams of the relation between the gigantic Zeeman splitting and the formation of X, X^- under magnetic fields. E_F denotes the Fermi energy. Up and down spin states are represented by ↑ and ↓, respectively.