GaMnAs 薄膜における真性反射磁気円二色性スペクトル

Intrinsic spectrum of reflection magnetic circular dichroism of GaMnAs thin films

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The band structure of ferromagnetic semiconductor GaMnAs has been studied and discussed with magnetic circular dichroism (MCD) spectroscopy. It is known that blue shifts of E_0 peak, which corresponds to the band gap, are observed in the reflection MCD spectra of GaMnAs [1]. These results seem to imply that GaMnAs is degenerated; however, in the recent studies of resonant tunneling spectroscopy, it has been revealed that the Fermi level of GaMnAs stays in the band gap even when Mn is heavily doped [2]. In this study, we successfully calculate the intrinsic MCD spectra of GaMnAs, which is not influenced by optical interference, by using the experimentally estimated off-diagonal element ε_{xy} of the dielectric tensor of GaMnAs. We find that the MCD spectra can be strongly influenced by optical interference and that the experimental spectra of thin films even with 10 - 20 nm thicknesses can be different from the intrinsic MCD spectra.

We have grown GaMnAs thin-film samples composed of $Ga_{0.98}Mn_{0.02}As$ (d nm)/ GaAs (100 nm) on semi-insulating GaAs (001) substrates by low temperature molecular beam epitaxy (inset of Fig. 1(a)). The main panel of Fig. 1(a) shows the experimental MCD spectra measured at 5 K for the GaMnAs thin films with various thicknesses d with the external magnetic field μ_0H = 1 T applied perpendicular to the sample plane. The black vertical broken lines represent the energies of the critical points of GaAs at 4.2 K. As shown in Fig. 1(a), the MCD spectra are strongly dependent on d; the peaks' position and sign of the MCD spectra intricately vary with d. We have successfully estimated ε_{xy} of GaMnAs that can explain the d dependence of MCD spectra of GaMnAs in the previous study [3]. Figure 1(b) shows the MCD spectra of GaMnAs calculated by using the estimated ε_{xy}, and Fig. 1(c) shows the real and imaginary parts of the estimated ε_{xy}. For better fitting, the values of d are slightly changed from nominal d in the calculation. As shown in Fig. 1(a) and (b), the MCD spectra are quantitatively reproduced for all the d values by using the same ε_{xy} shown in Fig. 1(c). The calculated MCD spectrum that is free from interference is shown in Fig. 1(b) with the black curve. In the calculation of intrinsic MCD spectra, we took the limit of MCD as d approaches infinity. We see that the calculated intrinsic MCD spectrum is largely different from the experimental MCD spectra of the GaMnAs thin films. Even though the E_0 peak in the experimental MCD spectra of GaMnAs shown in Fig. 1 with arrows shifts from the band gap energy of GaAs (= 1.5 eV), it is not the case in the intrinsic MCD spectrum. This means that the band structure should be discussed with intrinsic MCD spectra, but not with experimental raw spectra.

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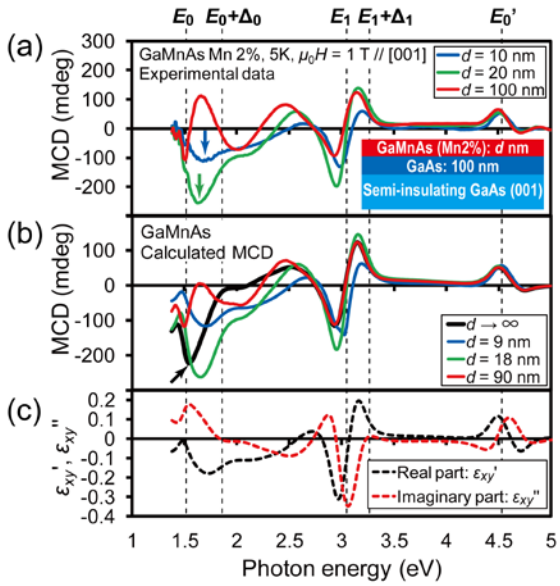

Fig. 1 (a) Experimental MCD spectra of the $Ga_{0.98}Mn_{0.02}As$ films with d = 10 (blue curve), 20 (green curve), and 100 nm (red curve) at 5 K with μ_0H = 1 T applied perpendicular to the film plane. The inset shows the schematic sample structure of our $Ga_{0.98}Mn_{0.02}As$ samples. (b) Calculated MCD spectra of the $Ga_{0.98}Mn_{0.02}As$ films with d = 9 (blue curve), 18 (green curve), 90 nm (red curve), and the calculated intrinsic MCD spectrum (black curve). (c) The real (black) and imaginary (red) parts of ε_{xy} experimentally estimated for $Ga_{0.98}Mn_{0.02}As$.