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CYCLOTRON AND OTHER RESONANCES IN HgSe AND $Hg_{1-x}Mn_xSe$

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We report a far-infrared (FIR) magneto-optical investigation of HgSe and $Hg_{1-x}Mn_xSe$ carried out using an optically pumped FIR laser. From the positions of observed resonances we determined the band parameters of HgSe as well as the parameters describing the exchange interaction between the free carriers and the Mn ions in $Hg_{1-x}Mn_xSe$.

I. Introduction

Nearly all recently reported experiments performed on mercury selenide and HgSe-based ternary compounds showed the presence of an electron plasma with an estimated carrier concentration $n \gtrsim 10^{17}$ cm^{-3}. In our experiment we used samples grown by the Bridgman method with estimated (from the position of the plasma edge) carrier concentrations of $4 \cdot 10^{16}$ cm^{-3} (HgSe) and $6 \cdot 10^{16}$ - $2 \cdot 10^{17}$ cm^{-3} (for $Hg_{1-x}Mn_xSe$). The samples were annealed after crystallization in a dynamic vacuum for 2 days at 200°C and stored in a refrigerator. These samples were suitable for direct magneto-optical transmission measurements in the FIR region ($\hbar\omega \gtrsim$ 7.5 meV). A superconducting magnet with a maximum field around 14 T has been used. A FIR laser pumped by a 30 W c.w. CO_2 laser was utilized as a light source. Several wavelengths from the region 251 μm - 96.5 μm were produced by two lasing media: CH_3OH and CH_3OD. The major feature of the experiment described below is the observation of plasma shifted resonances. All our measurements were done in either the $E \parallel B$ or $E \perp B$ polarization of the Voigt geometry.

II. Experimental Results and Discussion

Figure (1) is an example of a transmission curve obtained for HgSe for λ = 119 μm. The dashed line is for $E \perp B$. The broad minimum around 2 T is the plasma-shifted cyclotron resonance with the arrow indicating the minimum transmission. The shifting of the cyclotron resonance (CR) line in the Voigt geometry can be easily understood on the basis of the Drude model for plasma [1]. The resonance

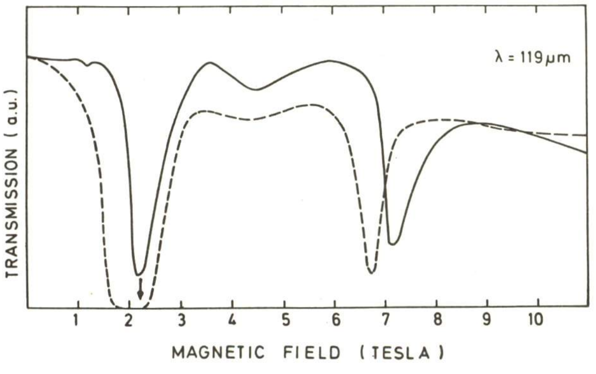

Figure 1

The experimental magneto-transmission curves of HgSe for λ = 119 μm in the Voigt geometry: The solid line is for $E \parallel B$ and the dashed line is for $E \perp B$

occurs not for $\omega = \omega_c$ but for $\omega = (\omega_c^2 + \omega_p^2)^{\frac{1}{2}}$, where ω_c and ω_p are cyclotron and plasma frequencies respectively. In the case of the HgSe used $\hbar\omega_p \approx 7.3$ meV so the shifting of the CR line observed in 119 μm is really significant (~ 1 T). The line observed at 2.12 T for the E||B geometry has been assigned to the combined resonance (CBn), in the Luttinger notation $\epsilon_1^-(n) \to \epsilon_2^-(n+1)$, where the integer n refers to the initial Landau sublevel. The combined resonance is allowed in the Γ_8 band for E||B; in that geometry no coupling between the plasma and electromagnetic radiation occurs and no shifting of the resonances could be observed. The other line in the E||B curve is probably the spin resonance (SR) allowed in Γ_8 band in both the E⊥B and E||B polarizations through the inversion asymmetry of the band. It must be pointed out here that the origin of the spin resonance in HgSe differs substantially from the one responsible for the resonance in InSb [2], therefore, the selection rules are different. The most important result is the shifting of the SR line excited in the E⊥B polarization in the same direction as the cyclotron resonance (but the shift is smaller due to weaker absorption). The same resonance observed in the E||B polarization remains unshifted reflecting the real structure of the Γ_8 band in HgSe. Having the three lines identified, we were able to determine the band parameters using the spherical Pidgeon-Brown model. The parameters obtained are: $\gamma_1 = 0.1$, $\gamma_2 = \gamma_3 = \bar{\gamma} = 0.0$, $\kappa = -1.4$, and $E_p = 12.9$ eV ($P = 7.0 \cdot 10^{-8}$ eV-cm). The energy gap Eg = -273.3 meV and Δ = 387 meV were taken from the literature [3]. The structure of the Γ_8 band in a magnetic field is shown in Fig. (2). Note that the nonparabolicity is small and the Luttinger model is sufficient to describe the band accurately.

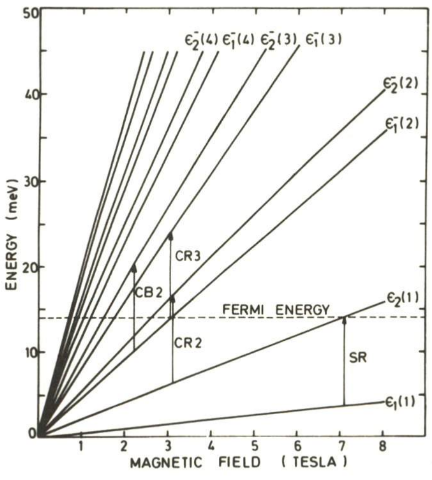

Figure 2 The band structure of the Γ_8 band of HgSe in a magnetic field with the transitions observed for λ = 119 μm indicated

Similar measurements were carried out also for several different samples of the mixed system HgSe-MnSe in a standard electromagnet with a maximum field of 2.5 T. Therefore the spin resonance has not been detected and the only source of information about the system was the other spin-flip resonance, namely the combined resonance. The plasma-shifted cyclotron resonance could not be used for determining band structure or the exchange interaction because the samples had different concentrations. The exchange interaction strongly modifies the spin splitting in the conduction band in semimagnetic semiconductors and the observation of spin-flip resonances provides detailed information on the interaction.

In Fig. (3) there are theoretical predictions of the magnetic field at which the combined resonance takes place. The theory is the Pidgeon-Brown model modified by the exchange interaction [4], using the parameters reported above. Circles denote the measured positions of the combined resonance for several different samples. The agreement is very good providing that the parameters Nα and Nβ are those reported in [5], namely Nα = -0.9 eV and Nβ = 1.4 eV. Other parameters, specifically those similar to the ones obtained for $Hg_{1-x}Mn_xTe$ [6], make the agreement between the theory and the experimental data much worse.

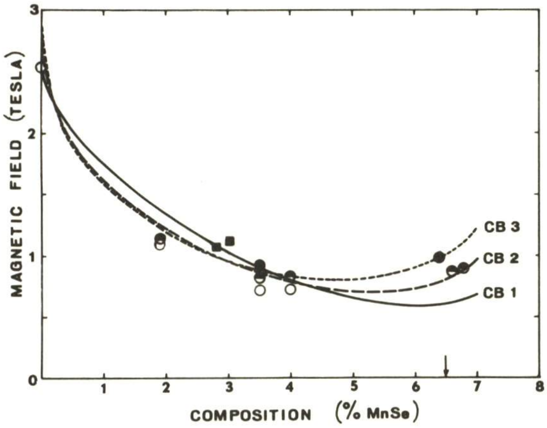

Figure 3

Comparison between the theoretical and observed positions of the combined resonance lines in several different samples of $Hg_{1-x}Mn_xSe$: The results for samples with estimated carrier concentration 6-7 · 10^{16} cm^{-3} are denoted by open circles (○), 10^{17} cm^{-3} by half black circles (◓), 2 · 10^{17} cm^{-3} by black circles (●), and higher concentration by squares (■)

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