Proceedings of the 12th International Symposium UFPS, Vilnius, Lithuania 2004

Optical Properties of $Cd_{1-x}Mn_xTe$ Crystals near Fundamental Absorption Edge in Transverse Magnetic Fields

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A simple and convenient model is proposed to elucidate the optical characteristics of $Cd_{1-x}Mn_xTe$ crystals using experimental data on light reflection in magnetic field. The model is based on the quasi-oscillator concept accounting both for the exciton and fundamental absorption edge contributions. The energy dependencies of refraction index and absorption coefficient are presented for Mn mole fraction $x = 20\%$ at the magnetic field values up to 5 T.

PACS numbers: 75.50.Pp, 78.20.Ci, 78.20.Ls

1. Introduction

Diluted magnetic semiconductors (DMS) as well as various structures based on these materials are very promising for optoelectronic applications in the visible light region due to the wide direct band gaps, strong exciton effects, and the possibility of effective tuning by the external magnetic fields. Optical constants are needed when using such materials to design required structures. Especially important is the vicinity of the fundamental absorption band edge where photon interaction with excitons is particularly efficient. The model of photon–exciton interaction including the fundamental dielectric constant dispersion [1, 2] does not refer to DMS. Ellipsometric studies of the dielectric function of $Cd_{1-x}Mn_xTe$ crystals [3] have been performed in the absence of magnetic field and in the region above the band gap energy. We propose a simple and convenient model describing experimental data on light reflection enabling to determine optical characteristics of DMS crystals in transverse magnetic fields.

2. Experiment

Experiment was performed on $Cd_{1-x}Mn_xTe$ single crystals with the Mn molar fraction of 20% at the temperature of 2 K. Material quality was proved by photoluminescence and magnetoreflection measurements [4]. p-polarized light was directed at the angle of 45 degrees to the sample surface. Steady external magnetic field up to 5 T was applied in the direction transverse to the plane of incidence.

3. Modeling

The dielectric function used for the modeling of the experimental results is supposed to be additive

$$\varepsilon_{\pm}(E) = \varepsilon_{\mathrm{b}} + \varepsilon_{\mathrm{f}}(E) + \varepsilon_{\mathrm{e}\pm}(E). \tag{1}$$

Here ε_{b} is the background dielectric constant, ε_{f} is the contribution related to the fundamental absorption edge, and ε_{e} accounts for the excitonic transitions. In the transparency region, ε_{b} corresponds to the real part of the dielectric function and can be approximated by the sum of rational fractions in the square photon energy E^2 [3]. In the relatively narrow energy range of interest, we assume ε_{b} to be a constant.

The contribution of the interband transitions is expressed by the sum of quasi-oscillator terms

$$\varepsilon_{\mathrm{f}} = \sum_{i=1}^{n} \frac{F_{\mathrm{f}i}^2}{E_{\mathrm{f}i}^2 - E^2 + \mathrm{i}E\Gamma_{\mathrm{f}i}}, \tag{2}$$

where E_{f} is the oscillator energy, F_{f} is the oscillator strength and Γ_{f} is the associated damping factor. In the most common form, this contribution is rather an integral with n tending to infinity. However, limited number of terms turned out to be sufficient for describing of experimental results.

The exciton contribution is represented by the similar terms as in Eq. (2). In this case the summation accounts for two σ_+ and two σ_- transitions between relevant Zeeman levels [5], $\varepsilon_{\mathrm{e}+}$ and $\varepsilon_{\mathrm{e}-}$. The corresponding eigenvalues of the dielectric tensor ε_+ and ε_- are used to construct the dielectric tensor components and effective dielectric function for the Voight geometry.

The complex reflection coefficient is calculated assuming the surface of the sample to be a flat boundary between two semi-infinite media [6].

4. Results and discussion

The typical reflection spectrum of the crystal in magnetic field (Fig. 1) exhibits three peaks. The lowest-energy peak relates to the excitonic transitions induced by the right-hand photons (σ_+), the central one is created both by σ_+ and σ_- photons, and σ_- photons are responsible for the upper-energy peak and slope. The latter peculiarities are strongly influenced by interband transitions. The fit of the experimental results has been obtained with $\varepsilon_{\mathrm{b}} = 7.0$. This is close to conventionally used optic dielectric constant of CdTe [3, 7]. The slight deviation of the calculated lower-energy slope from the experimental one is most probably due to the energy dependence of ε_{b} neglected in the model.

Eight oscillators were used to account for the interband transitions. They were equidistant in energy, except the lowest one the energy of which increased slightly with the rise of magnetic field B. Oscillator strength had a maximum at

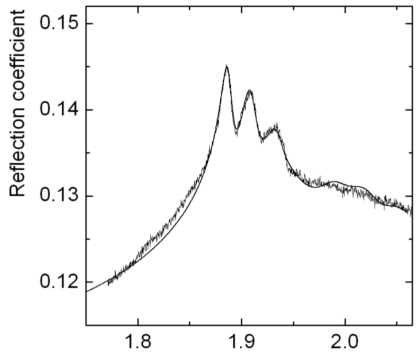

Fig. 1

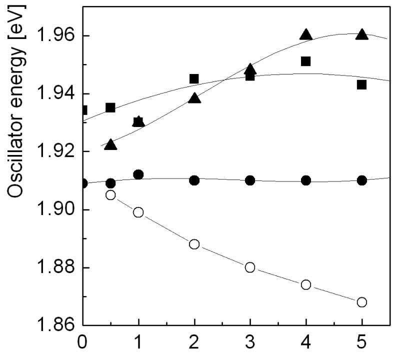

Fig. 2

Fig. 1. Measured p-polarized light reflection spectrum of $Cd_{0.8}Mn_{0.2}Te$ single crystal and the calculated one (smooth line) in transverse magnetic field $B = 2$ T.

Fig. 2. The dependencies of oscillator energy on magnetic field: the energies of σ_+ transitions (circles), the upper σ_- transitions (squares), and lowest-energy interband transitions (triangles). The polynomial fit lines serve as a guide for eye.

the photon energy 2.085 eV independent of magnetic field. The mean value of the interband oscillator strength, practically independent of B, was about 0.32 eV. It turned out to be nearly 1.5 times higher than the strength of oscillators for σ_+ and ≈ 4 times higher than that for σ_- excitonic transitions.

The excitonic transitions were accounted for with the use of 4 oscillators but the contribution of the lower-energy σ_- photons turned out to be small compared to higher energy σ_+ ones. This is confirmed by the fact that the central reflection peak position is practically constant up to 5 T and corresponds to the energy of oscillator representing the σ_+ transitions (Fig. 2). The oscillator strength for the σ_+ transitions exceeds that for the σ_- ones. There exists no strict symmetry of the side peak positions relative to the central one (Fig. 2). It is interesting that in magnetic field above 2.5 T the highest energy exciton transitions (σ_-) seem to merge with the fundamental absorption band ($E_{-1} > E_{f1}$).

The values of the refraction index and absorption coefficient (Figs. 3a, b) are elucidated from the experimental data analysis with the use of the model. Two absorption maxima caused by σ_+ photons are clearly seen at $B > 0.5$ T manifesting the growing contribution of the lowest-energy transitions. Absorption peculiarities related to σ_- photons are not clearly detectable in magnetic fields under consideration. Nevertheless, the corresponding transitions manifest their presence undoubtedly in the refraction index forming the broad maximum and subsequent slope at highest energies.

Early data on the complex dielectric function of $Cd_{0.8}Mn_{0.2}Te$ crystals in zero magnetic field [3] are in good agreement with our results. However, much higher spectral resolution in our experiments enabled us to reveal fine peculiarities related to exciton lines on overall dense background spectrum. The well

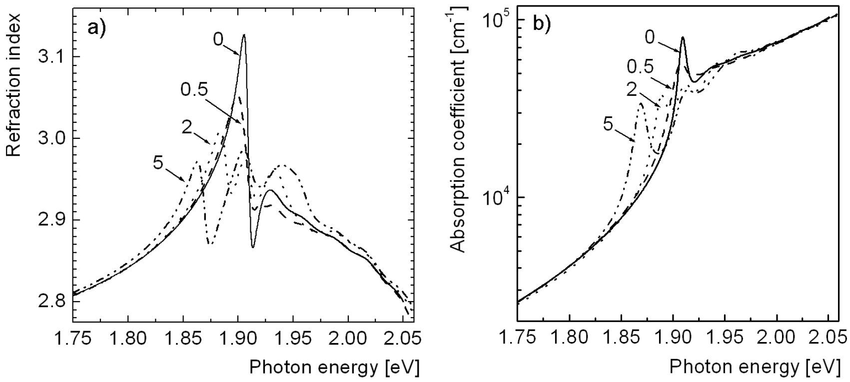

Fig. 3. Calculated energy dependencies of the refraction index (a) and absorption coefficient (b) of $Cd_{0.8}Mn_{0.2}Te$ crystal for different magnetic fields (in tesla).

determined changes of refraction index and absorption coefficient dispersion in magnetic field present an additional advantage for the material applications in tunable optical device design.

Acknowledgments

The authors are greatly indebted to Prof. M. Godlewski (Institute of Physics, Polish Academy of Sciences) for providing the measuring facilities.

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