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Optical properties of $Hg_{1-x}Mn_xTe_{1-y}Se_y$

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Abstract

Far-infrared reflectivity spectra of $Hg_{1-x}Mn_xTe_{1-y}Se_y$ ($0.01 \leqslant x \leqslant 0.14$, $0.01 \leqslant y \leqslant 0.1$) single crystals were measured in the 80–420 cm^{-1} range at room temperature. The analysis of the far-infrared spectra was made by a fitting procedure based on the model of coupled oscillators. The dependence of plasma frequency and phonon modes on composition was determined. A model for phonon behavior in quaternary mixed crystals of the type $A_{1-x}B_xC_{1-y}D_y$ was developed, too. This model was tested for $Hg_{1-x}Mn_xTe_{1-y}Se_y$.

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1. Introduction

$Hg_{1-x}Mn_xTe_{1-y}Se_y$ is a semimagnetic semiconductor made from two three-component diluted magnetic narrow-gap semiconductors—$Hg_{1-x}Mn_xTe$ and $Hg_{1-x}Mn_xSe$, which have been studied before [1,2]. It has been found that $Hg_{1-x}Mn_xTe$ has a p-type conductivity [3], while $Hg_{1-x}Mn_xSe$ always has an n-type conductivity with a high electron density [4]. The type of conductivity is connected with charge defects appearing in the crystals: Vacancies in the mercury sublattice are acceptors in $Hg_{1-x}Mn_xTe$, while mercury atoms at interstitials and vacancies in the selenium sublattice are donors in $Hg_{1-x}Mn_xSe$. It may be assumed that varying the selenium concentration will produce a particular kind of compensation of the various defects.

$Hg_{1-x}Mn_xTe_{1-y}Se_y$ solid solutions have revealed interesting electronic and magnetic properties different from those of the constituent systems

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[5–7]. Even though the band structure is essentially the same as those of the hosts, the Mn-induced acceptor impurity band is enhanced in energy, the electron concentration is increased and the hole concentration in the impurity band remains almost unchanged, but second type holes appear additionally in the solid solutions [7]. These three types of conduction carriers are found to be responsible for the temperature and magnetic field dependences of the observed Hall coefficients, in contrast to the two-carrier model valid for the host $Hg_{1-x}Mn_xTe$ [3] or a single-carrier model for $Hg_{1-x}Mn_xSe$ [4].

Far-infrared reflection spectra were previously measured [8] but only for one concentration of Se ($y = 0.01$). No qualitative analysis was done and as a consequence of that and of the high concentration of free carriers (plasmons), the phonons registered were wrongly assigned. Also, the measured phonons were not discussed in the frame of any model. We examined eight samples with different compositions ($0.01 \leqslant x \leqslant 0.14$, $0.01 \leqslant y \leqslant 0.1$). For reflectivity spectra analysis we applied a model that includes plasmon–phonon interaction [9] and determined phonon frequencies precisely. To analyze the phonons we used the models [10–12], which, with various modifications, were used to analyze phonons in three component mixed crystals. We introduced the necessary modifications to apply this model to four-component mixed crystals.

In this work the far-infrared reflection spectra were measured at room temperature. The analysis of these spectra is done and the plasma frequency (ω_p) and optical modes (TO and LO) are determined.

2. Samples and experiment

Single crystals of $Hg_{1-x}Mn_xTe_{1-y}Se_y$ were grown by the Bridgman technique from chemically pure components. The value of Mn concentration x was determined with an error of ±0.005 from the magnetic susceptibility at room temperature measured by a Faraday method at $H = 1000\,Oe$, where the diamagnetic contribution of the host HgTe ($\chi_d = -(2.3 - 3.6) \times 10^{-7}\,emu\,g^{-1}$) [1] was neglected; even if χ_d is taken into account, the x value is increased by 0.01 at most. Also, the manganese content was determined (more precisely) with the aid of an X-ray microprobe. Both methods give identical results within the limits of measurement error. The selenium content in the samples was inferred from these data. From the X-ray [13] and microprobe analyses and also the magnetic measurements it was determined that there were no foreign phase inclusions in the samples and that the samples were homogenous. The homogeneity of the samples was also monitored from measurements of the Hall coefficient R_H and did not exceed a few percent.

Table 1
List of $Hg_{1-x}Mn_xTe_{1-y}Se_y$ samples

No.	1	2	3	4	5	6	7	8
x	0.01	0.03	0.05	0.14	0.14	0.05	0.14	0.14
y	0.01	0.01	0.01	0.01	0.075	0.1	0.1	0.05

It is known that the optical, electrical and galvanomagnetic properties of HgTe-based semiconductor solid solutions are significantly affected by the surface region (skin layer) [13]. To eliminate this effect, the samples were etched immediately before measurement.

Samples with different composition were investigated (Table 1). Far-infrared reflection spectra were measured at room temperature in spectral range of 80–420 cm^{-1}, on a BOMEM spectrometer.

3. Results and discussion

The far-infrared reflection spectra of the $Hg_{1-x}Mn_xTe_{1-y}Se_y$ single crystal samples are shown in Fig. 1. The experimental data are represented by circles. The solid lines were obtained using a modified factored dielectric function model of coupled plasmon–LO phonon modes [9] (Eq. (1)).

From Fig. 1 we can see that these spectra are very different for various compositions. For some spectra the plasma minimum is on the low wave numbers and then phonon modes are clearly observable. For some other spectra the plasma minimum is on the higher wave number side and