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INVESTIGATION OF PHONONS IN HgCdMnTe USING FAR-INFRARED REFLECTIVITY

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The first reflectivity spectra of $Hg_{1-x-y}Cd_xMn_yTe$ with $0.03 < x < 0.1$ and $0 < y < 0.05$ were measured in the spectral region 700–30 cm^{-1} at 300 K and 90 K. The quaternary alloys measured show three mode behaviour. The experimental results are interpreted by using a classical dynamic dielectric function model.

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1. Introduction

The quaternary alloy $Hg_{1-x-y}Cd_xMn_yTd$ is an interesting diluted magnetic semiconductor because of possibility of additional control of its material parameters. Important physical properties such as band gap, lattice constant, magnetization can be changed independently of each other by proper choosing its molar compositions x and y [1]. HgCdMnTe is a competitive material to the widely used HgCdTe semiconductor for infrared detectors [2].

2. Experiment

HgCdMnTe samples (of sizes about 8 × 8 mm^2) used in experiment were the epitaxial layers (about 200 μm thick) grown by isothermal vapour phase epitaxy in the way similar to that described in [3]. Single crystals of CdMnTe with 5–30% MnTe molar content were used as a substrate. The molar compositions were measured by electron microprobe. Four samples with molar compositions ($0.03 < x < 0.1$ and $0 < y < 0.05$) were used in the experiment.

Reflectivity measurements at 300 K and 90 K were made with Bruker IF-88 Fourier transform spectrometer in the spectral region 700–30 cm^{-1}. The pyroelectric TGS and Si bolometer working at 4.2 K were used as detectors in different spectral regions.

3. Results and discussion

The far-infrared reflectivity spectra measured on exemplary sample are presented in Fig. 1. Only the most interesting spectral range of the lattice resonance 250–30 cm^{-1} is shown. It is clearly seen that quaternary HgCdMnTe mixed crystals are characterized by three well resolved reststrahlen bands near the HgTe-, CdTe- and MnTe-like TO-phonon modes. There is an additional peak or bump (called Ω_2 mode in [7]) below the HgTe-like mode. This additional band was observed in HgTe [4, 5] and in other Hg compounds and Hg-rich mixed crystals, i.e. [6–12]. We performed a standard Kramers–Kronig analysis which yields the dielectric function $\varepsilon(\omega)$ and mode frequencies without presupposing any model for response function. The spectra of $\mathrm{Im}\varepsilon$ and $\mathrm{Im}(-1/\varepsilon)$ were calculated and in this way the frequencies of transverse optical-phonon modes and frequencies of longitudinal excitations (coupled plasmon–longitudinal phonon modes ω_{LO}–ω_{p}) determined. These data were the start points in the fitting procedure. We used the dynamical dielectric function model applied in [4, 6] to describe the reflectivity spectra. In this model the

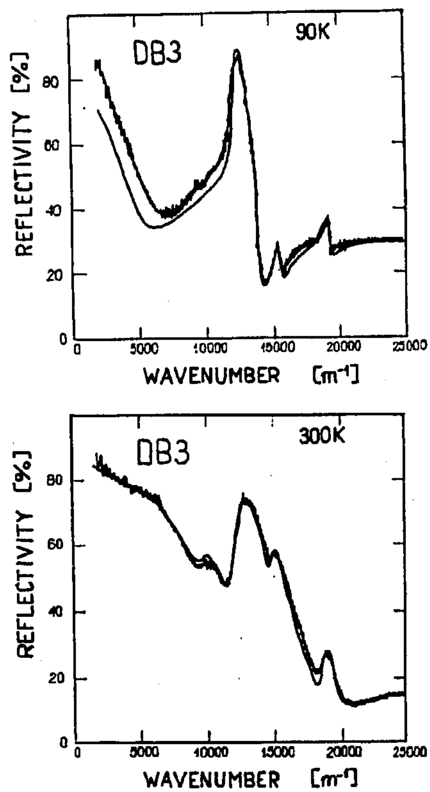

Fig. 1. Far-infrared reflectivity spectra for $Hg_{1-x-y}Cd_xMn_yTe$ with $x = 0.067$ and $y = 0.03$ at 90 K and 300 K (noisy line — experimental, smooth line — calculated).

TABLE

Sample	MnTe			CdTe			HgTe		
	ω_{TO} [cm^{-1}]	Γ [cm^{-1}]	S	ω_{TO} [cm^{-1}]	Γ [cm^{-1}]	S	ω_{TO} [cm^{-1}]	Γ [cm^{-1}]	S
DB3:									
300 K	187	7.9	0.11	148	6.7	0.10	122	12	4.3
90 K	191	4.5	0.175	153	3.35	0.10	121	2.0	4.5
DA3:									
300 K	188	11	0.2	149	6.7	0.15	120	7	3.8
90 K	190	7	0.25	151	4.1	0.12	119	1.5	3.9

Sample	Ω_2			Plasmon	
	ω_{TO} [cm^{-1}]	Γ [cm^{-1}]	S	$Ne^2/\varepsilon_0 m^*$ [$\times 10^5$ cm^{-2}]	Γ_p [cm^{-1}]
DB3:					
300 K	98	15	2.9	2.56	65
90 K	105	25.5	2.0	0.54	40
DA3:					
300 K	98	25	3.5	3.24	250
90 K	100	50	2.5	7.94	400

dielectric function is of the form

$$\varepsilon(\omega) = \varepsilon'_\infty + \Delta\varepsilon_{\text{inter}}(\omega) - \frac{Ne^2}{\varepsilon_0 m^*}\frac{1}{\omega^2 + \mathrm{i}\Gamma_\mathrm{p}\omega} + \sum_{j=1}^{4} \frac{S_j \omega_{\mathrm{TO},j}^2}{\omega_{\mathrm{TO},j}^2 - \omega^2 - \mathrm{i}\Gamma_j \omega}. \quad (1)$$

The third and fourth terms in (1) represent the free-carrier and phonon contributions described by the classical plasmon and phonon oscillators. In Eq. (1) the following notations are used: N — free carrier concentration, ε_0 — permittivity of free space, m^* — effective mass of free carriers, Γ_p — damping constant of plasma oscillation, $\omega_{\mathrm{TO},j}$, Γ_j are the frequencies and damping constants of phonon oscillators, S_j is the strength of the j-th phonon oscillator. The summation contains three phonon modes of the three alloy constituents and the additional Ω_2 mode. The first and second terms in (1) are the interband contribution to $\varepsilon(\omega)$: ε'_∞ is the contribution due to all interband transitions except $\Gamma_8^\mathrm{v} \to \Gamma_8^\mathrm{c}$ (being real and frequency independent) and $\Delta\varepsilon_{\text{inter}}(\omega)$ is the contribution due to $\Gamma_8^\mathrm{v} \to \Gamma_8^\mathrm{c}$ transitions and is described in [4, 6]. The calculated reflectivity curves fit relatively well to the experimental reflectivity spectra (Fig. 1). The fitting parameters, given in Table, are reasonably comparable, in the sense of virtual crystal approximation with literature data for HgTe and its ternary alloys [4–15].

The quaternary HgCdMnTe alloy gives the opportunity to compare the strength of phonon modes of the constituents in respect to their molar concentrations. The relatively high strength of MnTe-like mode is noticeable. The Ω_2

mode is similar to that in HgTe and HgTe-rich HgCdTe but slightly broader. Its strength is strongly temperature dependent; at 90 K it manifests as a bend point. The energy of the longitudinal optical phonon of HgTe-like mode agrees well with the results obtained from phonon assisted interband magnetoabsorption in our previous measurements of HgTe-rich HgCdTe samples [16].

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