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PLASMON - PHONON COUPLING IN III-V ALLOY SEMICONDUCTOR CRYSTALS

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ABSTRACT

The influence of plasmon-phonon coupling on the coefficient of reflection R(ω) in far infrared spectra is presented in this paper. The big changes in the reflection coefficient R(ω) curves with respect to the existing results, are found by optical measurements in far infrared spectra on GaAs and InAs singe crystal samples with high concentrations of impurities.

The theoretical, quantum mechanical model of plasmon-phonon interaction is developed and a numerical optimisation programe is used for calculations of optical and electrical parameters of crystals.

I. INTRODUCTION

The work presented here forms a part of a continuous study[1,2,] of the long-wave length optical properties in pseudo binary mixed crystals $A_{1-x}B_xC$.[7] The influence of plasmon-phonon coupling on the reflection coefficient $R(\omega)$ is analysed through the quantum mechanical, and through a newly developed numerical methods. Optical measurements are carried out on GaAs and InAs single crystals. The concentrations of impurities were in samples $n_{GaAs} = 5.10^{17} cm^{-3}$, $n_{InAs} = 4.10^{17} cm^{-3}$. The Fourrier spectrophoto-meter is used for measuring $R(\omega)$ coefficient at the room temperature and at 77K. The numerical optimization of parameters, their fitting is done on IBM 1130 system, by using SIMPLEX programme to minimize the sum of the squares of the deviations. The results, optical and electrical parameters were compared with hitherto obtained results for mixed crystals GaAs and InAs.

II. THEORETICAL MODEL OF PLASMON-PHONON COUPLING IN III-V MIXED CRYSTALS[5,6]

It is useful to take the Hamilton operator of the total system as a sum of three terms for analysing this interaction. The first term reppresents the influence of electron gas free field, the second the lattice vibrations of the crystal and the third the contribution of the interaction to the complete energy of the system. The Hamiltonian of the interaction is assumed as perturbation.

$$H = \sum_{k}\sum_{\lambda} h\omega_{k\lambda}\, b^{+}_{k\lambda} b_{k\lambda} + \sum_{\nu}\sum_{\vec{k}^{\nu}} E(\vec{k}^{\nu})\, a^{+}_{\vec{k}^{\nu}} a_{\vec{k}^{\nu}} +$$

$$+ i \sum_{\nu}\sum_{\vec{k}}\sum_{\lambda}\sum_{\vec{k}^{\nu}} \left(\frac{h}{2\rho v \omega_{\vec{k}\lambda}}\right)^{1/2} Q_{\lambda}^{(\nu)}(\vec{k}) \cdot \{a^{+}_{\vec{k}^{\nu}+\vec{k}}\, a_{\vec{k}^{\nu}}\, b_{\vec{k}\lambda} - a_{\vec{k}^{\nu}-\vec{k}}\, a_{\vec{k}^{\nu}}\, b^{+}_{\vec{k}\lambda}\}$$

where $b^{+}_{\vec{k}\lambda}$ and $b_{\vec{k}\lambda}$ are operators of creation and destruction of phonons in state $\vec{k}\lambda$ and λ is the number from 1 to 6 (number of acoustical and optical modes in diatomic crystal), $a^{+}_{\vec{k}^{\nu}}$ and $a_{\vec{k}^{\nu}}$ are operators of the creation and of the destruction of electrons in state $\vec{k}^{\nu}$, $E(\vec{k}^{\nu})$ is the term for energy: $E(\vec{k}^{\nu}) = \frac{h^2}{2m_t}\, \alpha_{ij}{}^{\nu}\, k_i{}^{\nu}\, k_j{}^{\nu}$, and where $Q_{\lambda}^{(\nu)}(\vec{k})$ is in the form:

$$Q_{\lambda}^{(\nu)}(\vec{k}) = \Theta_d (e_{k\lambda})_i k_i + \Theta_n (e_i^{(\nu)} k_i)(e_{k\lambda})_j e_j^{(\nu)} \qquad \lambda = 1,2,3;\ \nu = 1,2$$

when acoustic phonons are in consideration, or:

$$Q_{\lambda}^{\nu}(k) = D_0 (e_{\vec{k}\lambda})_i e_i^{(\nu)}$$

when the optical phonons are dominant.

Starting from these Hamiltonians we can calculate the density of states, transition probability and cross section for the mentioned interaction.

Starting from the theoretical result, and from the well known truth that III-V mixed crystals are one mode behaviour crystals, for numerical calculations one can use mathematical model of one damped Lorentzian oscillator with an additional term for plasmon-phonon coupling[3,4]. The dielectric function is:

$$\varepsilon(\omega) = \varepsilon_{\infty}\left[1 - \frac{\omega_p^2}{\omega(\omega + i\gamma_p)} + \frac{\varepsilon_{\infty}^{-1} S\omega_T^2}{\omega_T^2 - i\omega\,\gamma_T - \omega^2}\right]$$

or in a more useful form:

$$\varepsilon(\omega) = \varepsilon_{\infty} \frac{(\omega^2 + i\gamma_{1L}\,\omega - \omega_{1L}^2)(\omega^2 + i\gamma_{2L}\omega - \omega_{2L}^2)}{\omega(\omega + i\gamma_p)(\omega^2 + i\gamma_T\,\omega - \omega_T^2)}$$

ε_{∞} constant denotes contribution of the excitations at high frequencies relative to the spectral interval of interest, ω_{iL}, γ_{iL} should be understood as the eigenfrequencies and damping coeficients and γ_p describe the LP-mode damping coefficient .

The calculations between the dielectric function, reflection coefficients and refractive index are:

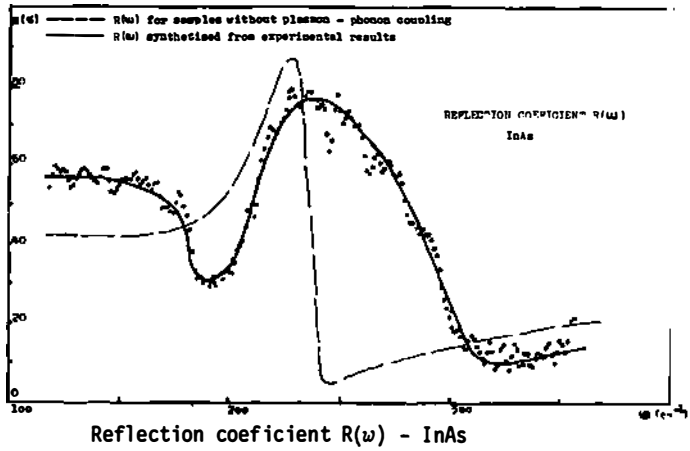
$$R(\omega) = \frac{(n-1)^2+k^2}{(n+1)^2+k^2} \quad ; \quad n = \sqrt{\frac{\varepsilon_1}{2} + \sqrt{\varepsilon_1^2 + \varepsilon_2^2}} \quad ; \quad k = \frac{\varepsilon_2}{\sqrt{2\varepsilon_1 + 2\sqrt{\varepsilon_1^2 + \varepsilon_2^2}}}$$

$$\bar{\varepsilon}(\omega) = \varepsilon_1(\omega) + i\varepsilon_2(\omega) \qquad \bar{n}(\omega) = n(\omega) + ik(\omega)$$

III. EXPERIMENTAL RESULTS

As already mentioned the Fourier spectrophotometer Beckman FS 720 is used for measuring the spectral charasteristic $R(\omega)$ in far infrared spectra (ω=50-400cm^{-1}). The Fourier transformation of the result is done on line. The spectrogram is taken on Perkin - Elmer 577 from ω = 300 cm^{-1} to 600 cm^{-1}. The samples were enough big to close the window, and Al mirror is used. Figs. 1 and 2 show reflection spectra obtained from measuring samples with a plasmon-phonon coupling and the same figures display the results for GaAs and InAs without interaction.

Reflectivity spectra measurements are used for calculations. Numerical optimization of parameters is done on computer. Numerical results of LO-phonons and TO-phonons and damping constatans as well as a dielectric constant are presented in Table 1.



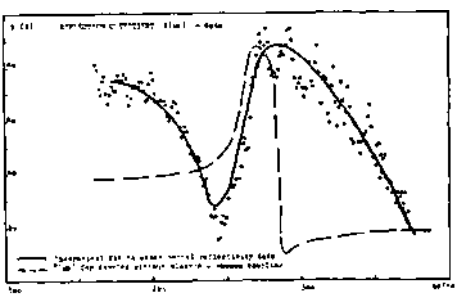
Reflection coeficient $R(\omega)$ - InAs

Fig. 1.

Table 1.

	ϵ_∞	$\gamma_p \mid cm^{-1}$	$\omega_T \mid cm^{-1}$	$\gamma_T \mid cm^{-1}$	$\omega_{L1} \mid cm^{-1}$	$\gamma_{L1} \mid cm^{-1}$	$\omega_{L2} \mid cm^{-1}$	$\gamma_{L2} \mid cm^{-1}$
GaAs	13,20(13.0)	90(-)	272(273)	5.1(3.7)	330(297)	28(3.9)	245(-)	31(-)
InAs	15.0 (15.1)	71(-)	218(218)	4.8(3.1)	268(241)	26)(3.8)	190(-)	47(-)

The parameters from literature for samples without plasmon-phonon coupling, are in brackets and the results of this work are beyond brackets.



Reflection coefficient $R(\omega)$ - GaAs
Fig. 2.

IV. CONCLUSION

The theoretical and numerical methods are developed for treating the plasmon--phonon interaction in III-V mixed crystals. Using the experimental results of optical measurements for numerical calculations it is shown that the presented method gives satisfactory results.

It is necessary to say that a confirmation of all these results have be obtained by Raman spectroscopy.

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