Interband Optical Transitions in the Region of Excitonic Resonance in $In_{0.3}Ga_{0.7}As/GaAs$ Quantum Wells

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Abstract* – Reflection spectra of *$In_{0.3}Ga_{0.7}As$* layers with 8nm thickness with quantum wells limited by *GaAs* barrier layer with *100nm* thickness (bottom) and *9nm* (upper) had been measured at *S* and *P* polarizations in the interval of photon energies *0.6 – 1.6eV* at an incident angle near the normal one (*4.5^o*) and Brewster angle (*76^o*). Thin absorption lines *0.9021eV, 1.0161eV, 1.1302eV, 1.1973eV, 1.2766eV* conditioned by the transitions *hh1-e1(1s), lh1-e1(1s), hh2-e2(1s), lh2e-2(1s), hh3-3(1s)* and *lh3-3e(1s)* had been revealed. The intensity of absorption lines changes in the limits *10 – 70%.

***Index Terms* – quantum wells, optical properties, exciton, resonance.**

I. INTRODUCTION

The study of semiconductor heterostructures with quantum points and wells are of big interest if talking about revealing fundamental electronic states of excitonic polaritons in quantum points and wells. At the same time, it has to be highlighted, that basing on quantum well structures are developed opto- and micro-electronic devices of new generation [1-3]. Injection lasers based on quantum points that prove a high temperature stability of threshold current density J_{th}, low value of J_{th} and continuous generation at room temperature with 3W output power are created at the moment.

II. EXPERIMENTAL DATA AND DISCUSSIONS

The optical reflection has been measured on JASCO-680 spectrometer at 300K and s and p polarizations, at different light angles incident on the surface of the heterojunction with quantum wells.

The reflection spectra $R(\omega)=|r(\omega)|^2$, among the photoluminescence analysis, is the simplest method of characterization of heterostructures with quantum wells.

The inferior surface of the structure was polished till a mirror state in order to study transparency spectra $T(\omega)=|t(\omega)|^2$. It is necessary to measure R and T to determine the absorption of structures with quantum wells, and to determine the $A(\omega)$ values.

$$A(\omega)=1-R(\omega)-R(T). \qquad (1)$$

It is known, that not the idealness of the structure influences the optical reflection and absorption spectra, broadening the exciton resonance frequency in heterostructures. The inhomogeneity can lead to a smooth coordinate dependence of ω_0 in the quantum well plane or in the volume of the supperlattice, which leads to a broadening of the absorption and reflection lines. The simplest and most effective method of accounting the inhomogeneous broadening while calculating the reflection coefficient is the change of the nonradiative decay Γ with the effective nonradiative decay in the respective expression $\Gamma_{eff}=\Gamma+\Gamma_{inh}$, where Γ_{inh} is the broadening parameter. Figure 1 shows the reflection spectra of *$In_{0.3}Ga_{0.7}As/GaAs$* with quantum wells at *300K* and incident angles *7^o* and 76^o (Brewster angle) for *S-S (A)* and *P-P (B)* lightwaves' polarization. The experimental rays' path is presented in the insertions *a* and *b*. The reflection minimums *b1- b6*, which have and increasing half with in case of Brewster angle, are present at *S-S* polarization at a *7^o* incident angle. The same minimums are present in reflection spectra at *P-P* polarization at a *7^o* incident angle.

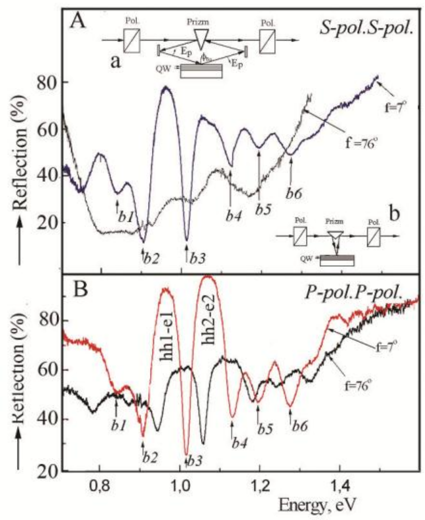

Fig. 1 Reflection spectra of GaAs /$In_{0.3}Ga_{0.7}As$/GaAs structure with quantum wells at 300K and incident light angle 7^o and 76^o (Brewster angle) for S-S (A) and P-P (Bpolarizations of lightwaves. The experimental rays' path is presented in the insertions *a* and *b*.

The minimums *a1- a6* are revealed in the reflection spectra at an incident angle equal to the Brewster one (*76^o*), i.e. they are shifted. The shifting value for all reflection minima is approx equal. The measurement amplitude of reflection spectra (max – min) is also twice decreased for this polarization.

Figure 2 shows the scheme of the periodical structure, consisted of $In_{0.3}Ga_{0.7}As$ layers with *8nm* thickness with quantum wells divided by *GaAs* barrier layers with *9nm* thickness and the electronic transitions from the ground excitonic states in quantum wells. The reflection spectra presented in figure 3 are measured at an incident angle of 7^o and the transparency spectra at a normal light angle incident to the $GaAs/In_{0.3}Ga_{0.7}As/GaAs$ heterostructure surface with quantum wells.

As the measurements were done at a spectrometer with high resolution, it can be noted that the minimums' energy of reflection spectra completely coincide with the energetic position of the maxima in the absorption spectra. The reflection geometry is presented in figure 1, *b*. The plane monochromatic wave $E(r,t) = E_0 \exp(-i\omega t + ikr)$ falls on the $In_{0.3}Ga_{0.7}As$ quantum well, positioned between two identical *GaAs* barriers, which are characterized by real permittivity ε_b. The lightwave vector is linked with the frequency correlation ω $k = (\omega/c)\sqrt{\varepsilon_b}$, where *c* – light speed in vacuum.

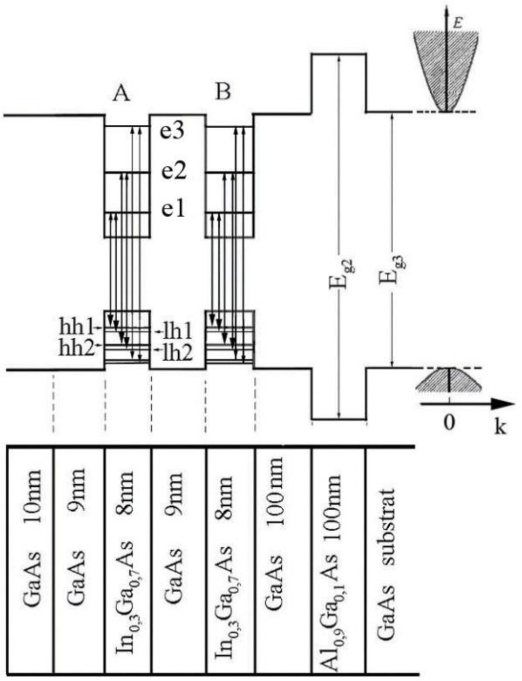

Fig. 2 Periodical structure consisted of two $In_{0.3}Ga_{0.7}As$ layers with 8nm thickness with quantum wells, divided by GaAs barrier layers with 9nm thickness and the electronic transitions from the excitonic states in quantum wells.

In case of normal incident light, when the lightwave vector *k* is parallel to the main structure axis *z*, the lightwave amplitude E_0 lays in the interface plane (x, y). As the system possesses axial symmetry in reference of *k* to *z* axis, the electrical vectors of the incident, reflected and passed lightwaves are parallel to each other and scalar amplitudes E_0, E_r and E_t can be used instead of vector amplitudes. The amplitude reflection and absorption coefficients are:

$$r = E_r/E_0\,, \qquad t = E_t/E_0 \tag{2}$$

In case of energy dissipation absence inside the quantum well the law of energy conservation lays on these coefficients:

$$|r|^2 + |t|^2 = 1 \tag{3}$$

In case of normal incident light the exciton with a null bidimensional wave vector is excited, i.e. with $K_x = K_y = 0$. A detailed analysis of the reflection and transparency coefficients of quantum well heterostructures is presented in the work [1], where the reflection r_{QW} has the expression:

$$r_{QW} = \frac{i\Gamma_0}{\omega_0 - \omega - i(\Gamma + \Gamma_0)} \tag{4}$$

$$\omega_0^* = \omega_0 + r_{10}\Gamma_0 \sin 2\varphi \qquad \Gamma_0 = \Gamma_0(1 + r_{10}\cos 2\varphi) \tag{5}$$

ω_0^* and Γ_0 are the resonance frequency and the radiative decay of the exciton, renormalized taking into account the exciton interaction with the lightwave, induced by this exciton and reflected from the external surface.

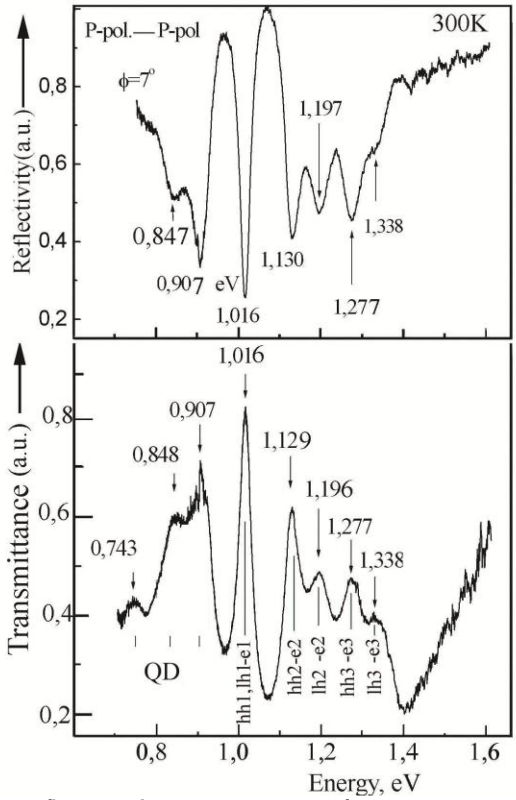

Fig. 3 Reflection and transparency spectra of $GaAs/In_{0.3}Ga_{0.7}As/GaAs$ heterojunctions with quantum wells.

The dependence of the reflection coefficient was established after some transformations [1] on the reflection and absorption coefficients:

$$R(\omega) = |r(\omega)|^2 = R_0 + \frac{A+Bx}{1+x^2} \tag{6}$$

$$X = \frac{\omega - \omega_0^*}{\Gamma}, \quad R_0 = r_{01}^2 \tag{7}$$

where

$$A = t_{01}t_{10}S[t_{01}t_{10}S - 2r_{01}(1+S^*)cos2\varphi] \tag{8}$$

$$B = 2r_{01}t_{01}t_{10}Ssin2\varphi, \; S = \frac{\Gamma_0}{\Gamma}, \; S^* = \frac{\Gamma_0^*}{\Gamma} \tag{9}$$

According to the Fresnel formulas, in case of normal incident light:

$$r_{10} = -r_{01} = \frac{n_b - 1}{n_b + 1}, \;\; t_{01}t_{10} = \frac{4n_b}{(n_b+1)^2} \tag{10}$$

The *A* and *B* coefficients can obtain different sign values, and, separately, become null, depending on the distance between the well center and the external surface. If $A = 0$, $B < 0$ the resonance contour is consisted of a maximum

$\omega < \omega_0^*$ and minimum at $\omega > \omega_0^*$. If $B = 0$, the spectra has one maximum ($A > 0$) or one minimum ($A < 0$) [1, 2].

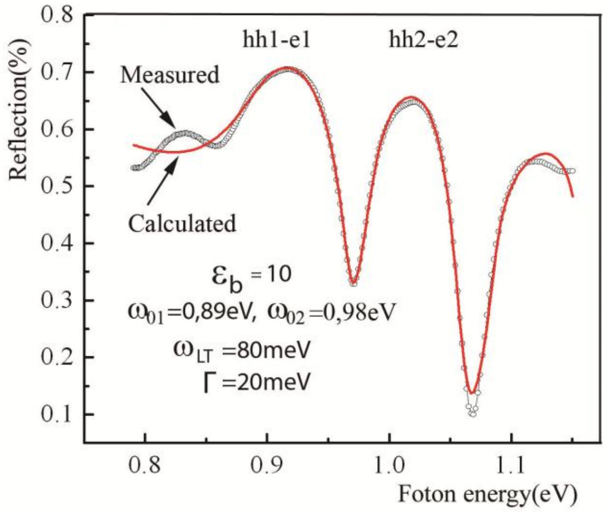

Fig.4 Experimental reflection spectra and the ground excitonic state contours in quantum wells of GaAs /$In_{0,3}Ga_{0,7}As$/GaAs heterojunctions calculated by the dispersion correlations.

The calculations of the reflection spectra of the ground excitonic states in quantum wells are made basing on the dispersion correlations which is based on multi oscillatory model [3].

The best correlation between calculated and experimental spectra was obtained at a decay factor $\Gamma \approx \Gamma_0$, $\Gamma_0 = (20 \pm 2)meV$, and background dielectric permittivity $\varepsilon_b = 10$ and the longitudinal-transversal permeability $\omega_{LT} = 80meV$. The exciton lifetime is $\tau_0 = (2\Gamma_0)^{-1} \approx 2 \cdot 10^{-11} s = 10\,ps$. The thin absorption and reflection lines and the theoretically obtained parameters can prove the quality of the structure with quantum wells.

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