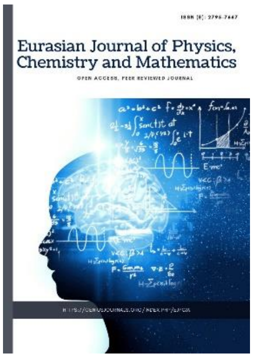

The effect of radiation on quantum-dimensional structures

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ABSTRACT

The effect of ionizing radiation (electrons with E = 1.8 MeV, γ-quanta ^{60}Co, X-ray emission with E≤100 keV) on the photoluminescence spectra and reflection spectra of CdZnTe / ZnTe quantum-size structures was investigated. For A^2B^6 quantum wells, degradation of photoluminescence takes place at much lower irradiation doses. The change in the profile of the wells as a result of irradiation was calculated with respect to shifts of photoluminescence peaks. The role of cadmium diffusion and internal stresses in radiation-induced degradation of quantum-size heterostructures is discussed.

Keywords: Heterostructures, Cadmium Telluride, Quantum Wells, Irradiation.

Introduction

Optical studies of ZnCdSe/ZnSe, ZnCdTe/ZnTe heterostructures with singular and multiple quantum wells and quantum dots arouse interest in connection with investigation of the hot carriers relaxation generated by electron injection or optical excitation. Multi-phonon relaxation of the hot electrons under optical excitation of the quantum-size ZnCdSe/ZnSe heterostructures had been considered before using photoluminescence and Raman scattering [1].

Experiment

A series of *n* narrow and rather intensive peaks in exciton band of the quantum-size ZnCdTe/ZnTe heterostructures low-temperature photoluminescence spectra, superimposed on the main photoluminescence hump, had been observed. These peaks are shifted relatively to excitation photon energy on a value, which is multiple to energy of LO-phonon.

Changes of the quantum-size ZnCdTe/ZnTe heterostructures optical properties after b- and X-ray irradiation had been studied using low-temperature photoluminescence technique [2]. These optical data allows to derive additional information about well shape transformation and stress relaxation after radiation treatment. This rearrangement of the heterostructure is caused with radiation-stimulated inter-diffusion of the semiconductor compound components and it leads to noticeable alteration of the multi-phonon relaxation processes.

Undoped CdZnTe/ZnTe structures had been grown by molecular-bean epitaxy. Amorphous ZnTe was deposited on a (100) semi-insulating GaAs wafers with subsequent soild-phase crystallization of this seeding coat and epitaxial growth of 1,5 μm ZnTe buffer epitaxial layer on the initial nucleation bed [3].

After this operation $Cd_XZn_{1-X}Te$ quantum well and tunnel transparent ZnTe barriers had been composed. Cd content in the quantum wells was controlled using low-temperature luminescence and reflectance spectra (see Table 1).

Photoluminescence and reflectance (R(λ)) spectra measurements was made at 4,2 and 80 K using 0,5 meV resolution spectrometer and LGN-503 laser with $\lambda_1 = 0.5145$ and $\lambda_2 = 0.4880$ mkm for excitation. Photoluminescence spectra for initial and irradiated $Cd_{0.17}Zn_{0.83}Te$/ZnTe structures with quantum wells are shown in the Fig.1 [4].

Table 1

№	Quantum wells	Treatment	Deformation ε (4,2K)
1	$Cd_{0.17}Zn_{0.83}Te$ $L_{z1}=L_{z2}=L_{z3}=2$ nm $L_B=2$ nm	Initial samples without radiation treatment	~$6,4 \cdot 10^{-4}$
2	$Cd_{0.17}Zn_{0.83}Te$ $L_{z1}=L_{z2}=L_{z3}=2$ nm $L_B=2$ nm	$E=1.8$ MeV $I=1$ mA·cm^{-2} $F=6 \cdot 10^{12}$ cm^{-2}·s^{-1} $D=4 \cdot 10^{16}$ cm^{-3}	~$5.0 \cdot 10^{-4}$
3	$Cd_{0.17}Zn_{0.83}Te$ $L_{z1}=L_{z2}=L_{z3}=2$ nm $L_B=2$ mn	X-ray irradiation $U=100$ kV $F\sim10$ cm^{-2}·s^{-1} $D=1 \cdot 10^4$ rad	~$5,4 \cdot 10^{-4}$

E - electron energy, *I* - current density, *F* - flux density, *D* - absorbed dose

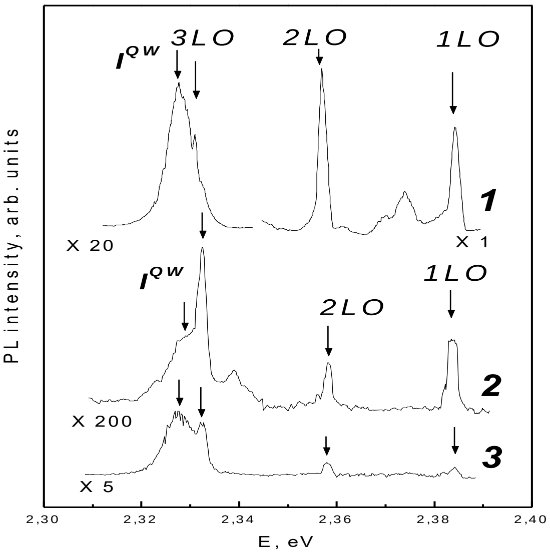

Fig.1. FL properties of three tunnel-transparent initial Cd0. 17Zn0.83Te/ZnTe QWs (curve 1), 2 nm thick, grown on GaAs substrates, and after their modification by electrons and x-ray quanta (3).

All the presented spectra were studied using exitation light □$_{\mathrm{EXC}}$ = 0.51453 мкм. Energy of this quantum exceeds forbidden zone gap E_g both for ZnTe (E_g = 2.39 эВ, 4.2 К) and for CdTe (E_g = 1.60 эВ, 4.2 К) and well-localised electron-hole pair recombination energy. The spectrum consists of few stripes in exciton band from bufer ZnTe epitaxial layer and dominating peaks from quantum wells, I^{QW}.

Photoluminescence spectra was measured using excitation light with 0.51453 mkm wavelength, so E$_{ext}$ > E$_g^{ZnTe}$ (2.39 ev, 4.2 K)> E$_g^{CdTe}$ (1.60 ev, 4.2 K) and exceeds quantum-well localised electron-hole pair recombination energy. There are few stripes in exciton band of the low-temperature photoluminescence spectra, from the ZnTe buffer layer, accompanied with intense quantum-well photolumiescence peaks [5].

There was irregular peak intensity increasing as it comes near resonance stripes (I^{QW}, I^{C}). Inter-peak interval was independent from excitation light wavelength and was equal to ~ 210 cm^{-1}. Measured energeis of the LO-phonon for ZnTe and CdTe bulk crystals were ~208 cm^{-1} and ~169 cm^{-1} respectively. Consequently, observed phonon repetitions correspond to LO-phonon of the ZnTe barrier[6].

Discussion

The resonance amplification of the narrow stripes intensity in a quantum wells shine being observed in quantum-size CdZnSe/ZnSe heterostructures [7] could be interpreted using a model from [8]. In obedience to this "cascade model" light-induced hot electrons can relax with sequential phonon emission. In our work an optical phonon frequency of the CdZnTe/ZnTe quantum-sized structures had been shifted into a biggest frequency range in a comparison with LO-phonon value for bulk mono-crystalline ZnTe.

Using constant optical excitation level (P$_{exc}$ = 1□10^{19} quanta/cm^{2}sec) and □$_{\mathrm{EXC}}$ = 0.5145 mm) we revealed that resonance gain of the LO-phonon intensification on the resonance stripes persists in the samples with three tunnel-coupled quantum wells after high energy electrons treatment as well as after X-ray irradiation, despite different nature of the radiation impact for X-ray (excitation of the electron subsystem only) and for the □-irradiation (creation of the intrinsic defects also [2]).

For the □-irradiated samples (curve 2) there was excessive single-order increasing of the resonance LO-phonon peak intensity(n=3, □=207 cm^{-1}).

For the X-ray irradiated samples (curve 3) there was inessential raise of the resonance LO-phonon peak intensity (n=3) and a frequency had been diminished against initial sample.

Earlier a shift of the photoluminescence peak into big energies from a quantum well (so called "blue shift" [9]) for the same heterostructures after ⍰-irradiation had been found. This dose-dependent shift was of 1 meV for the irradiation dose 4⍰10^{16} cm^{-3}. Numerical calculation [9] indicated that such a displacement of the photoluminescence maximum could be provided with well shape transformation due to radiation-induced diffusion of cadmium atoms and compound variation of a well's brink. From the one hand, there are conditions for the perfect congruence of the resonance and LO-phonon (n=3); from the other hand, the well smoothing reduces electron localization inside the well, making energy transfer between hot electrons in a quantum well and LO-phonons of the barrier layers easier.

Reduction of the edge photoluminescence from the barrier and buffer layers due to radiation-induced traps generation in ZnSe and increasing of nonradiative recombination makes an observation of this effect more clear.

Optical phonon energy shift indicates stress changes in ZnTe buffer layer on a ~1⍰10^{-5}. This disparity with other optical data regarding mechanical stresses in the heterostructures should be studied later.

There was negligible low-temperature luminescence peak shift to lower energies (red shift) after X-ray treatment of the samples. This shift was equal ⍰0⍰0.5 meV for the dose ~10^4 Rad. Notwithstanding this shift of the photoluminescence spectrum maximum couldn't be explained with a smoothing of the quantum well shape, we suppose an influence of the stress reduction in the barrier layer. Optical phonon energy shift also indicates a variation of the deformation of the epitaxial structure.

Conclusion

Hereby, possibility of the multi-phonon relaxation of the hot electrons generated by optical excitation by dint of energy exchange with barrier layer and LO-phonon emission in quantum-size CdZnTe/ZnTe heterostructures had been demonstrated (cascade process). Exploration of the electron and X-ray irradiated samples, which subsurface region, barrier layer and shape of the quantum well was transformed after radiation treatment, accentuates dominant factors of this optical process. These factors are localization extent of an exciton as well as resonance between the incident light frequency and fundamental transition in the quantum well.

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