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Near and mid infrared spectroscopy of InGaAs/GaAs quantum dot structures

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Abstract. Results of a photo- and electroluminescence study of vertically coupled $In_{0.5}Ga_{0.5}As$/GaAs quantum dot structures with extended waveguide (1.24 μm thick) are presented. Spectra of spontaneous and stimulated near-infrared ($\lambda \simeq 1$ μm) emission as well as spectra of spontaneous mid-infrared ($\lambda \simeq 12$ μm) emission are obtained under optical and electrical pumping. It is shown that the observed mid-infrared emission is connected with intraband electron optical transitions in the quantum dot structures.

Introduction

The use of intraband (intersubband or intersublevel) optical transitions in quantum wells and quantum dots (QDs) allows to extend the emission spectrum of semiconductor lasers into the mid-infrared range (10–20 μm). QD structures attracted particular interest because of the high electron lifetimes on excited states (phonon bottleneck effect). The feasibility of bipolar mid-infrared (MIR) lasers based on electron intersublevel transitions in QD structures during near-infrared (NIR) interband lasing has been theoretically considered in [1, 2, 3]. The first experimental studies of MIR spontaneous emission accompanying NIR stimulated emission were performed with edge-emitting QD lasers under current injection [3, 4, 5].

Here we report on a study of spectra of interband spontaneous and stimulated emission as well as spectra of intraband (intersublevel) spontaneous emision from QD structures with extended waveguide. Optical and current pumping were used for electron-hole pair injection.

1. Samples and techniques

Quantum dot structures were grown by solid source MBE system on (001) GaAs substrates. The 0.24 μm active layer of the structures consisted of six periods of $In_{0.5}Ga_{0.5}As$/GaAs vertically coupled quantum dots embedded in a waveguide between doped cladding layers. The extended NIR waveguide was formed with two 0.5 μm low-doped graded $Al_xGa_{1-x}As$ layers. For studies of NIR stimulated interband emission the cavity length was chosen between 0.15 and 2.5 mm.

Optical pumping was provided by means of a 3 W Ar laser. A step-scan Fourier spectrometer with MCT detector (cut-off energy is 54 meV) was used for obtaining emission spectra. For the measurements of MIR spectra, the NIR radiation was blocked by an InAs filter. The emission under optical pumping was collected from the surface of the sample. In this case a part of the Be-doped top layers was removed with chemical etching. All measurements were carried out at 77 K.

2. Spontaneous and stimulated NIR emission

The aim of these studies was to find the electron energy structure in our samples. Spectra of spontaneous and stimulated interband NIR emission obtained under optical pumping are shown in Fig. 1. Investigations under optical pumping were carried out for different thicknesses of etched top layer and for different cavity lengths. These factors are responsible for the actual value of the optical losses in the waveguide. The results are shown in Fig. 1(a) (low losses) and 1(b) (high losses). The increase of excitation power in both cases leads to the blue shift of PL line position (curves 7–4). This can be explained by the presence of miniband-like electron energy spectra in QDs caused by vertical coupling. Spectra of spontaneous emission consist of two peaks probably connected with e-h transitions between ground and excited electron and hole states in QDs. Lasing appears at 1263 meV and at 1307 meV for samples with low and high losses, respectively. We connect these spectral features with laser emission through the ground and first excited states, respectively.

Electroluminescence (EL) spectra are presented in Fig. 2. In these spectra lines connected with ground state (near 1260 meV), first excited state (near 1310 meV) and a peak at 1400 meV probably connected with EL from wetting layer appear. The cavity length was 2.5 mm: thus lasing occurs through the ground state.

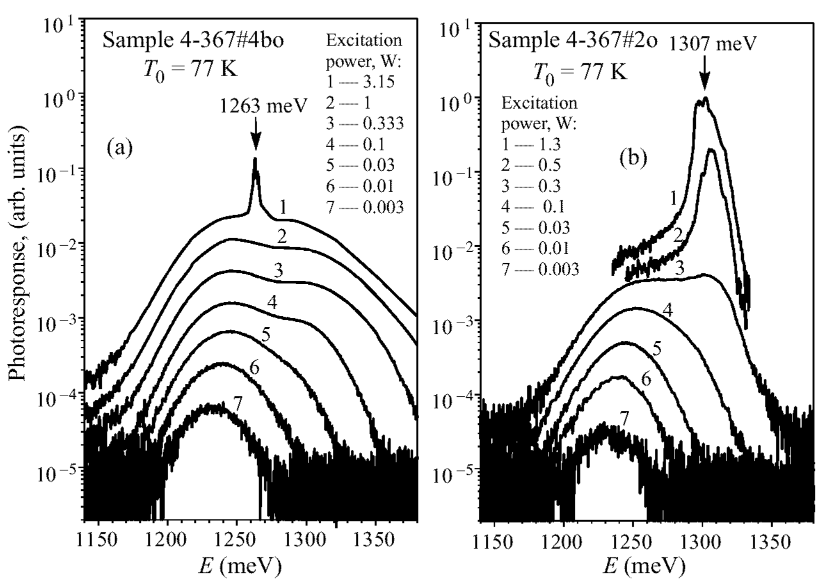

Fig. 1. NIR PL spectra under different pumping power: (a) for samples with low optical losses (etching time is more than 25 s, cavity length is 2.2 mm); (b) for samples with high optical losses (etching time is 25 s, cavity length is 1.1 mm).

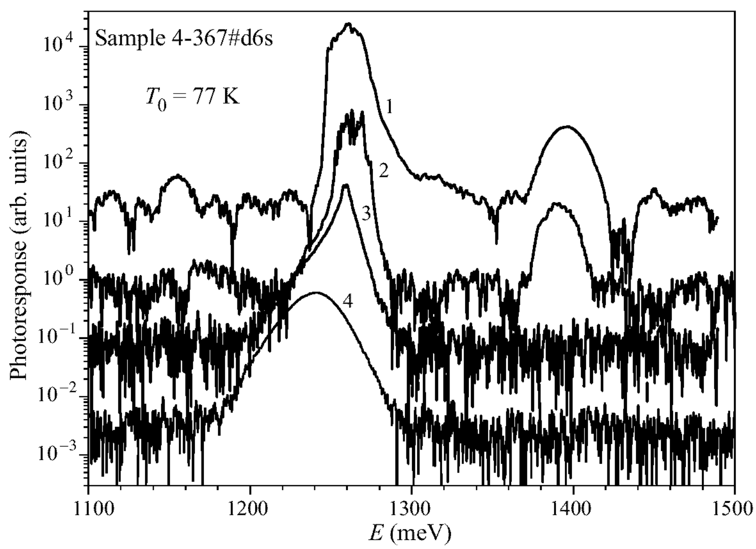

Fig. 2. NIR spectra of electroluminescence. Injection current (A) is: 4 (curve 1), 0.2 (curve 2), 0.08 (curve 3), 0.02 (curve 4). Cavity length is 2.5 mm, strip width is 100 μm.

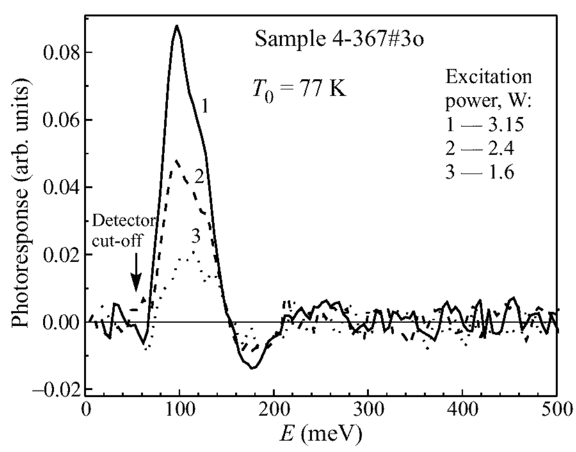

Fig. 3. The spectra of MIR photoresponse for different intensities of optical pumping. Cavity length is 1 mm, etching time is 15 s, excitation area is 0.0037 cm^2.

3. Spontaneous MIR emission

The MIR emission under optical pumping was studied for a set of samples, which were made from the same QD laser structure. They had different thicknesses of the top layer after etching. Measured spectra resulted from a superposition of MIR emission from the sample as well as photorefraction and photoinduced absorption of blackbody-like background radiation. The MIR photoresponse spectra for one of the samples, where the contributions of pumping induced absorption and refraction are the smallest, are presented in Fig. 3. For this sample approximately 1 μm top layer was removed by etching. The spectral position of the MIR emission line (about 100 meV) corresponds to the NIR emission spectra, namely it can be connected with electron transitions from the wetting layer states to the ground state of the QDs. We could not observe MIR emission connected with electron transitions from excited to ground QD states (all the more so for similar transitions for holes) because such transition energies are smaller then the present detector cut-off energy.

Conclusion

NIR and MIR emission from vertically coupled InGaAs/GaAs QDs under optical and electrical pumping were observed. The peculiarities of spectra of NIR stimulated and spontaneous emission are associated with e-h transitions between ground, excited and wetting layer states of electrons and holes. The wide peak of MIR ($\lambda \simeq 12\ \mu$m) spontaneous emission can be connected with electron transitions between wetting layer or second excited states and ground states of QDs. The next step should be to study MIR emission from QD structures with MIR waveguide in a spectral range extended to longer wavelengths as well as a comparison of these results with calculated electron and hole energy spectra in QDs.

Acknowledgements

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