Research of influence Al on luminescence and dark current-voltage characteristics of InAs/GaAs heterostructures

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Abstract. A study was made of Al₁ₓGa₁₋ₓAs wide-bandgap potential barriers influence on photoluminescence and dark current-voltage characteristics of InAs/GaAs heterostructures obtained by an ion-beam deposition method. It was established that employing Al₁ₓGa₁₋ₓAs barriers cause a shift of InAs quantum dots ground-state photoluminescence emission peak in high-energy band (blue shift), increase in intensity and decrease of full width a half at maximum. In addition, the measurements of dark current-voltage characteristics show that increase of Al content in barrier leads to decrease of bias voltage (to 0.48 V) of altering carriers transfer mechanism from thermoelectron emission to tunnelling assisted by external electric field. It was established that the use of the Al₁₀,Ga₄₀,₆As potential barrier can produce minimal dark current (10⁻⁸ A) in InAs/GaAs heterostructures with quantum dots.

1. Introduction

The quantum dots (QDs) heterostructures based on AlIIBV materials [1-3], Ge/Si [4] et al are of great interest for the researchers. This is due to next generation high-efficient photosensitive optoelectronic devices development. The major problem for existing infrared photodetectors (HgCdTe, II-type superlattices, GaSb) is necessity their cooling to increase the detectivity. One way to solve this problem is to grow semiconductor heterostructures with QDs. The photogenerated charge carriers confinement in QD produces a decrease of thermoelectron emission and dark current. Therefore, a study of charge carrier transfer mechanism and photoluminescence of InAs/GaAs heterostructures with wide-bandgap potential barrier are of special importance.

2. Experimental details

The paper studies InAs/GaAs heterostructures grown by ion-beam deposition method [5]. Deposition was carried out on GaAs semi-insulating substrate with a crystallographic orientation (100). The calibration functions of InAs and GaAs sputtering yield, beam energy, oblique angle and charge density were shown in works [5-6].

The polycrystalline targets were used as sources of growth material for AlGaAs potential barrier. Three types of samples are developed: 1) with GaAs barrier; 2) with Al₀.₃Ga₄₀,₆As barrier; 3) with Al₀.₄Ga₀.₆As barrier. As a first step n⁺-GaAs buffer layer was formed at the temperature of 883 K and the pressure in the growth chamber of 3.7·10⁻⁷ Pa. The accelerating beam voltage was 450 V at the current density of 3.2·10⁻⁴ A/cm². At the next step an i-GaAs barrier was deposited at the same conditions. Then the temperature was down to 808 K after 15 s pause. The InAs QDs were formed at the beam voltage of 250 V and the ion current density of 4.5·10⁻⁶ A/cm². The QDs...
coating by the AlGaAs barrier layer was accompanied an increase in temperature to 823 K. Further, a n+-GaAs front layer was grown on it. An investigation of luminescent properties was carried out at temperature of 90 K in spectral range of 0.9 – 1.3 eV. The source of optical radiation was an injection laser with a wavelength of 402 nm and power 8.5 mW. The photoluminescent signal registration was carried out by the MDR-23 monochromator and a photodetector device with photodiode PDG-3600. The effect of exciting laser radiation on the photoluminescence spectra of heterostructures was eliminated by an optical filter Y-1.4x. Figure 1 shows optical scheme for measuring photoluminescence.

Figure 1. Optical measuring scheme of experimental samples photoluminescence

The measurements of dark current-voltage characteristics were made of using picoammeter Keithley 6485.

3. Results and discussion

The photoluminescent properties of grown heterostructures were studies. In a steady state mode, the radiation and recombination rate came to equilibrium and stood reliant on the photogenerated charge carrier lifetime at the QD energy level or energy level formed by the GaAs wetting layer (WL) during photoluminescence excitation in the sample. As a result, QDs ground-state (GS) and WL were photoluminescent sources in formed samples.

Figure 2 shows photoluminescence spectrum for three types of samples with the different barriers: GaAs; Al_{0.2}Ga_{0.8}As; Al_{0.4}Ga_{0.6}As. The existence of peaks from WL suggests QDs grew in the Stransky-Krastanov mode [7].

3.1 Photoluminescence

Photoluminescence spectrum of sample with GaAs barrier is characterized by GS peaks with energy 1.15 eV. The large width of GS photoluminescence emission peak is a resulting from InAs QDs size dispersion. The QDs locate in close proximity (surface density varies from 10^{10} to 10^{12} cm^{-2}). The electron wave-function overlap on discrete energy level arises in QDs array. It leads to a formation of the energy subband in quantum well. The emission and absorption spectra depend up the subband location. The smaller the dimensional variation of QD and mechanical stresses influence the smaller the width of the energy subband and photoluminescence spectrum. The InAs QDs are in electrostatic field of GaAs barrier at the thickness of the barrier layer of 10 nm. This field provides for an excited electron emission from QDs level to the i-GaAs heterostructures matrix by two main
mechanisms: overbarrier emission and tunnelling. The potential barrier height for electrons is 0.52 eV. The second emission peak is shifted to a blue region of spectrum (1.26 eV). This peak characterizes emission transition in WL.

The AlGaAs solid solutions are a wide-bandgap semiconductor. The energy gap width depends up a composition and varies from 1.4 to 2.1 eV. The wide-bandgap materials usage makes possible the functional characteristics improvement [8; 9]. Application of these potential barriers alters an elastic strain distribution in QDs layer and gives rise to shift to high-energy region.

The measurement results for Al$_{0.2}$Ga$_{0.8}$As barrier with energy gap width of 1.71 eV are presented on figure 2. The GS peaks of the sample are shifted on \( \approx 0.39 \) eV compared to GaAs barrier. At the same time, WL peaks aren’t shifted because InAs QDs were covered from above. A high intensity of photoluminescence spectrum of sample with Al$_{0.2}$Ga$_{0.8}$As barrier is accounted by photogenerated charge carrier localization in quantum well formed by InAs QD. Al$_x$Ga$_{1-x}$As potential barrier height for \( x = 0.2 \) at.% is 0.65 eV and for \( x = 0.4 \) at.% is 0.77 eV.

![Figure 2](image1.png)  
**Figure 2.** Measurement of photoluminescence spectrum with a different potential barriers Al$_x$Ga$_{1-x}$As

3.2 *Dark current-voltage characteristics*

The dark current-voltage characteristics of samples were measured for charge carrier transport investigate. The results are presented on figure 3. It was established that in the 0 – 0.5 V range charge carrier transport mechanism from QD to conduction band of heterostructure is a thermoelectron emission. The current reaches saturation for all types of samples. In addition, increase of bias voltage is appeared in the 0.5 – 1.5 V range. At the voltage over 1.5 V transport mechanism alters from thermoelectron emission to tunnelling assisted by an external electric field. It is accounted for by the shift band scheme in the direction of field. This is valid for the samples with Al$_x$Ga$_{1-x}$As barriers. Along with that, the width of potential barrier decreases, as a result, probability of charge carrier tunnelling through AlGaAs barrier increases essentially. The main transport mechanism from InAs QD becomes tunnelling. Figure 3 is shown that Al$_{0.4}$Ga$_{0.6}$As barrier causes decrease of bias voltage as high as 0.48 V. It was established that the usage of the Al$_{0.4}$Ga$_{0.6}$As potential barrier can produce minimal dark current (\( 10^{-8} \) A) in InAs/GaAs heterostructures with QDs.

![Figure 3](image2.png)  
**Figure 3.** Dark current-voltage characteristics of InAs/GaAs heterostructures with a different potential barriers

4. **Conclusion**

Thus the employing of Al$_x$Ga$_{1-x}$As wide-bandgap potential barriers leads to a blue shift of photoluminescence emission peak, an intensity increase and a decrease of full width a half at
maximum. This effect is accounted for by an increase of the charge carriers localization in a quantum well under an increase of Al$_x$Ga$_{1-x}$As potential barrier height.

The measurements of dark current-voltage characteristics of the samples show that an increase of Al content in barrier leads to decrease of voltage at which alters charge carriers transport from thermoelectron emission to tunnelling assisted by an external electric field. It was established that the usage of the Al$_{0.4}$Ga$_{0.6}$As potential barrier can produce minimal dark current ($10^{-8}$ A) in InAs/GaAs heterostructures with QDs. That results can be employed when developing of effective infrared photodetector.

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