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THE STUDY OF CONTRIBUTION OF THERMIONIC AND TUNNEL COMPONENTS IN HETEROSTRUCTURES WITH A SINGLE QUANTUM WELL InGaAs/GaAs BY ADMITTANCE METHODS

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I. INTRODUCTION

Quantum-dimensional structures are characterized by discrete energy spectrum and at specific conditions may reveal another quantum-mechanical effect namely, tunnel effect. The admittance method is the most prime and efficient research technique, both for bulk semiconductors and heterostructures with quantum well (QW) [1, 2, 5, 7]. It is known that in doped heterostructures due to redistribution of charge carriers the bottom of conduction band (or the top of valence band) are bent, forming additional barriers, close to triangular in form. In [4] the detailed theoretical and experimental studying of processes of capture and emission of charge carriers in heterostructures with QW is presented. It is shown that in heterostructures containing QW there are the competing mechanisms of emission of charge carriers: thermionic emission and tunneling, which make the different contribution to total conductance at different temperatures.

In this work the isotype -type heterojunctions with elastically strained single quantum well (SQW) $In_xGa_{1-x}As$/GaAs grown by MOCVD were investigated [1, 2]. The thickness of the active layer of samples were 6.0…9.5 nm. The parameters and quality of structures were controlled by HRXRD, local cathodoluminescence, etc. Measurements were taken in the temperature range from 10 to 375 K, voltage range of ±40 V, and the frequency range of test signal was 20 Hz – 2 MHz. The experiments on series of samples with SQW $In_xGa_{1-x}As$/GaAs (x=0.065 … 0.29) were carried out. It was found that at small content of In in solid solution it is not possible to notice the features in conductance spectra, related to the tunnel emission, because the small value of band discontinuity gives the response which cannot be registered even at low temperatures.

II. EXPERIMENTAL RESULTS AND DISCUSSION

The best qualitative characteristics are obtained for structure x=0.29 (end of pseudomorphous growth). Results are presented by the integrate figure 1, where in the center the characteristics CV-GV are located, and in the taken-out drawings – the temperature spectra of conductance in the reference points of the CV-curve; at the plateau, in adjacent to the plateau regions, and far from it. It is noticeable that at low temperatures the delay effects begin to play an important role, and at temperatures close to RT the SQW manages to relax at frequencies of the test signal (the quasi-static mode of measurements is implemented). The conductance-voltage (GV) characteristics of structure clearly demonstrate the complex, resonance mechanism of formation of the active conductance for the structure with SQW. The strong modification is experienced by temperature spectra of conductance of the structure depending of the reverse bias. Peaks are the most clearly expressed at the reverse bias -2.3 V that corresponds to the part of CV characteristic adjoining the plateau from the small biases. This area is responsible for the beginning of intensive thermionic emission of charge carriers from quantization levels with the electric field penetrating into the QW. The temperature shift of the maximum of conductance on frequency confirms the thermally activation nature of studied process. The observed phenomenon has resonance character and exists in a narrow voltage range, about 0.5 V.

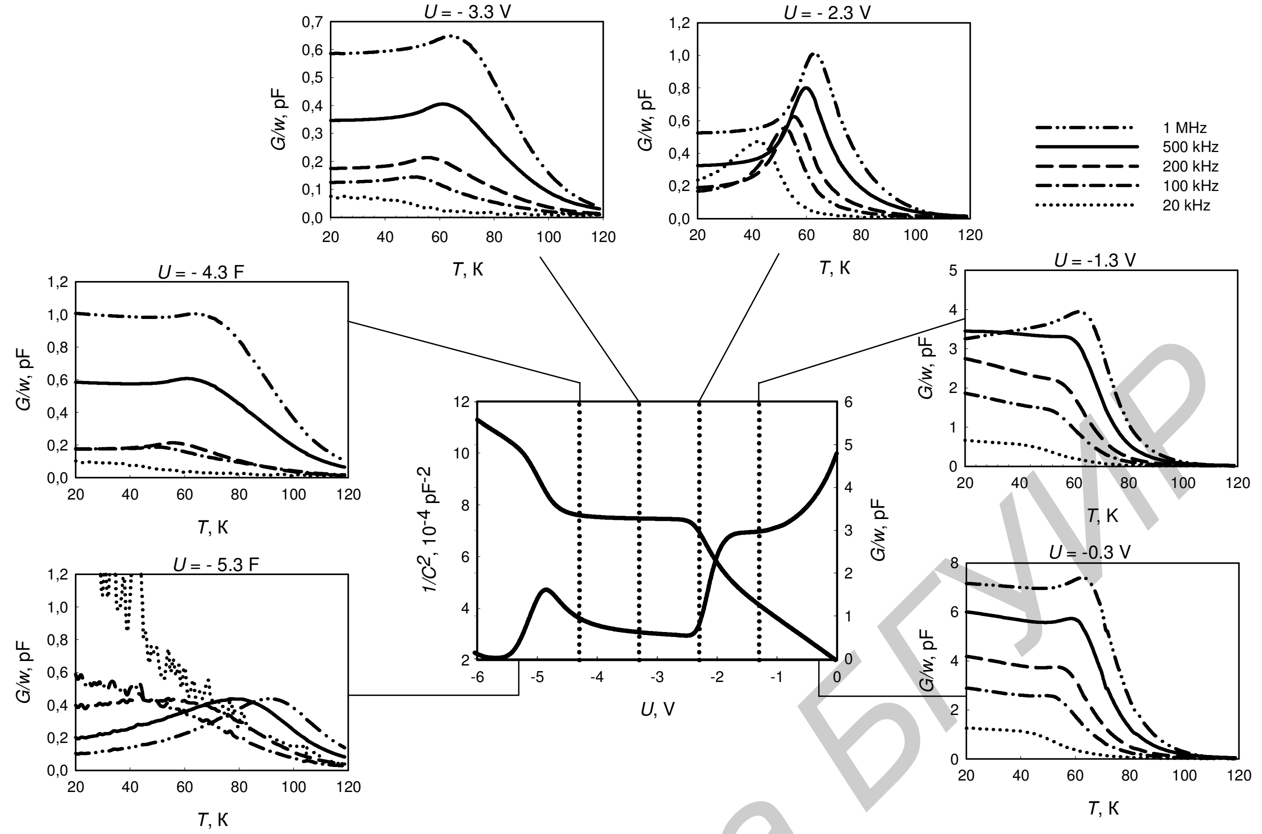

Figure 1 – Generalization results of the admittance measurements for structure with QW $In_{0.29}Ga_{0.71}As/GaAs$

The frequency dependence of peaks in the conduction spectra allows carrying out their reference processing by making of Arrhenius plots.

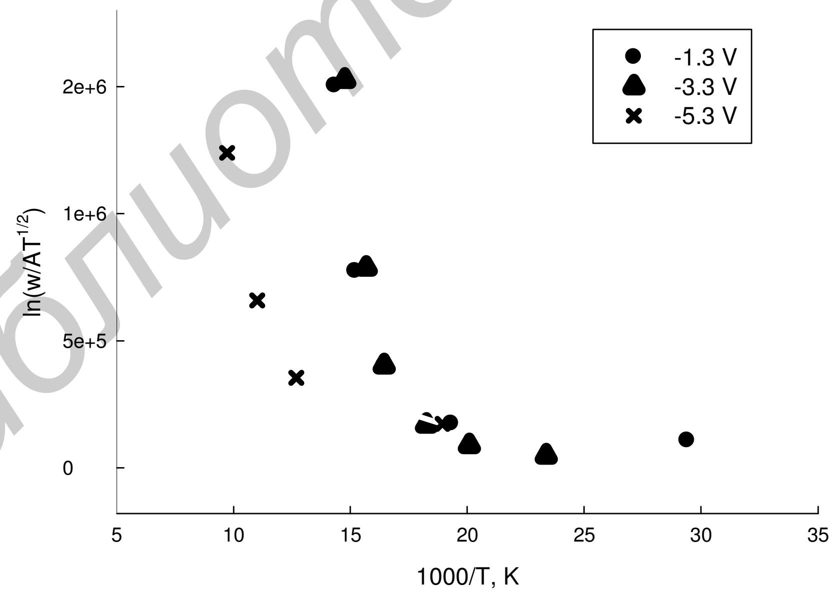

Figure 2 – The temperature dependences of emission rate of charge carriers from QW constructed in Arrhenius coordinates

The significant deviation from the linear is observed, that confirms the existence of the essential portion of tunnel component in emission [3, 4]. As was expected, in G-T experiments of "shelf" are observed at temperatures of 20-50 K that demonstrates existence of tunnel current. Thus, the net activation energy of an emission of charge carriers from SQW should be determined by the high-temperature part of the

Arrhenius curve, minus the tunnel component. The activation energy deviates from 36 to 70 meV depending on the reverse bias.

For adequate determination of activation energy, we will address the figure 1. Where in the temperature spectra of G/w peaks of the thermionic nature (at -2.3 V), the activation energy determined by the Arrhenius curve reaches the maximal value and the experimental points of the Arrhenius curve most exactly keep on a straight line. At other reverse biases, where the thermionic component is expressed poorly against the tunnel background, the experimental points in the Arrhenius plot significantly deviate from the straight line that leads to the considerable decrease of the activation energy. Thus, the variation of activation energy, derived from the experiment, is caused by the different contribution of tunnel and emission components.

III. SUMMARY

The study of high-quality heterostructures with SQW by admittance spectroscopy confirms the existence of two competing mechanisms for emission of charge carriers: thermionic and tunnel ones. It is shown that thermionic peaks in conductance spectra have the resonance character, showing the maxima in the narrow region of reverse biases. The "shelves" in the spectra corresponding to tunnel component at reverse biases 0 – 3.0 V accepted the maximal value at – 0.3 V, and then had sharp fall in more than 10 times. Such behavior of tunnel component can be explained basing on the features of resonance tunneling. For the considered case, it is necessary to bear in mind that the top part of the band diagram for doped heterostructures with a SQW represents a two-barrier structure in energy region $E > 0$. It was shown in [6] that the structure with identical barriers (that is the equal width and heights) has the greatest probability for carrier transmission. In this case, the probability for resonance tunneling gets maximum. The minor relative change of parameters of one of barriers leads to a strong reducing of transfer coefficient. This qualitative conclusion, based on analytical calculation, allows to explain the experimental results obtained here. Really, at small reverse biases, the external electric field does not reach yet the QW region, and the QW remains with symmetric barriers, identical in form. At the same time, the "shelves" on temperature conductance spectra get the maximal values. On increasing of reverse bias the left-hand edge of space charge region begins "to rise", a symmetry of barriers is broken and the tunnel transfer probability drastically falls. In the experimental results, it is expressed by sharp falling of the "shelf" at U = -1.3 V.

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ATOMIC STRUCTURE OF MONOELEMENT NANOCRYSTALS

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The distribution of atoms in nanocrystals should be analyzed taking into account the structure of the macroscopic analogue [1]. The aim of the study was to develop a method for calculating the crystallographic orbits for single-element spherical nanocrystalline particles with different sizes.

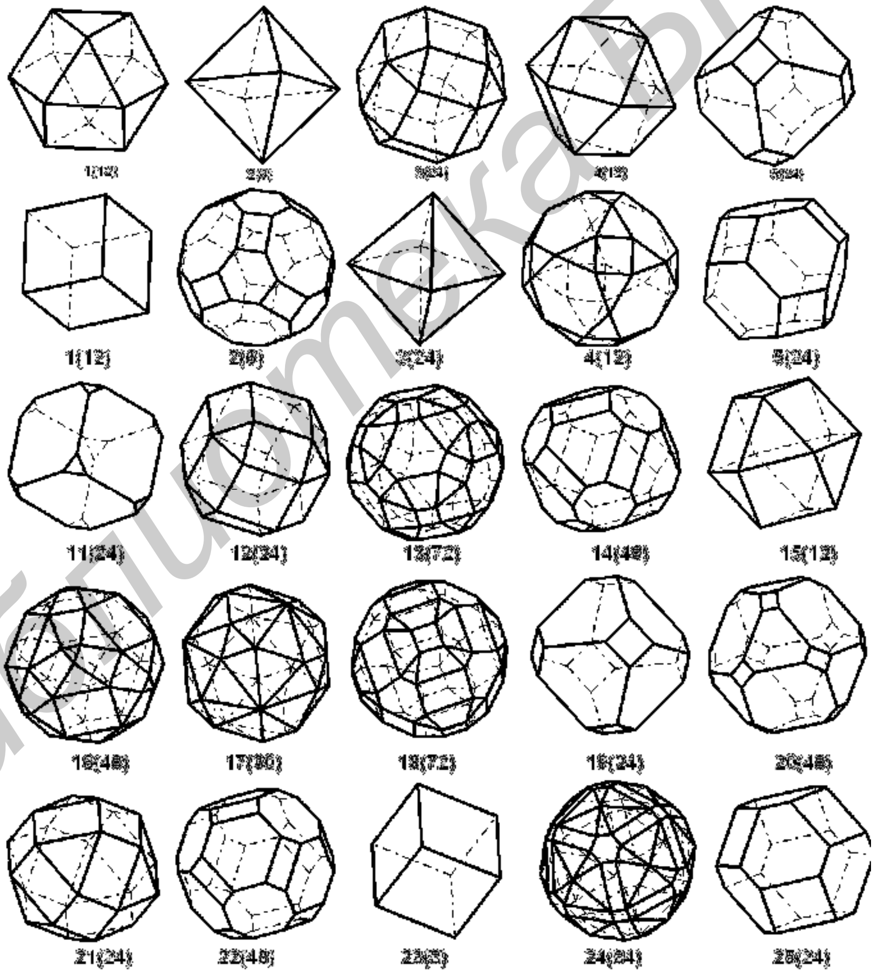

Figure 1 – Fm3m. Face centered cubic

The computer program gives possibility to determine the parameters of coordination polyhedron. There are the radius-vectors of every external atoms (R), atoms quantity of the surface (N) and in volume particle (S) and coordinates of all atoms in it.