Peculiarities of the bipolar electric transport and terahertz radiation of hot charge carriers in the double tunnel-coupled quantum wells GaAs/InGaAs/GaAs

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The aim of this work: to study peculiarities of the bipolar transport and terahertz radiation of charge carriers in the multilayer n-InGaAs/GaAs heterostructures with double tunnel-coupled quantum wells (QWs) under lateral electric fields in dependence on the barrier width between coupled wells, which determines bonding between wells via tunneling. In these structures we experimentally found an anomalously large drift length of holes (~ 4 mm) from the anode contact [1], which we associate with spatial separation of the electrons and holes between the narrow and wide QWs due to the built-in electric field.

The heterostructures under study:
n-$In_xGa_{1-x}As$/GaAs (x = 0.1÷0.15) with double tunnel-coupled QWs. The widths of the coupled wells were 160 and 80 A; the barrier width between wells d_b was 30 and 50 A. The number of periods in the structure: 20 through 50; δ-doping by Si in the narrow QW center, Nd = 1–2.7*10^{11} cm^{-2} for a period;
Samples: rectangular shape; distance between In or GeAu electrical contacts - 1.5 through 4 mm.
Research methods: measurements of the waveforms shape and amplitude of the electric current pulses and intersubband THz electroluminescence at different amplitude of the voltage pulses with duration τ = 1 through 2 μs in the temperature range 4.2 - 160 K

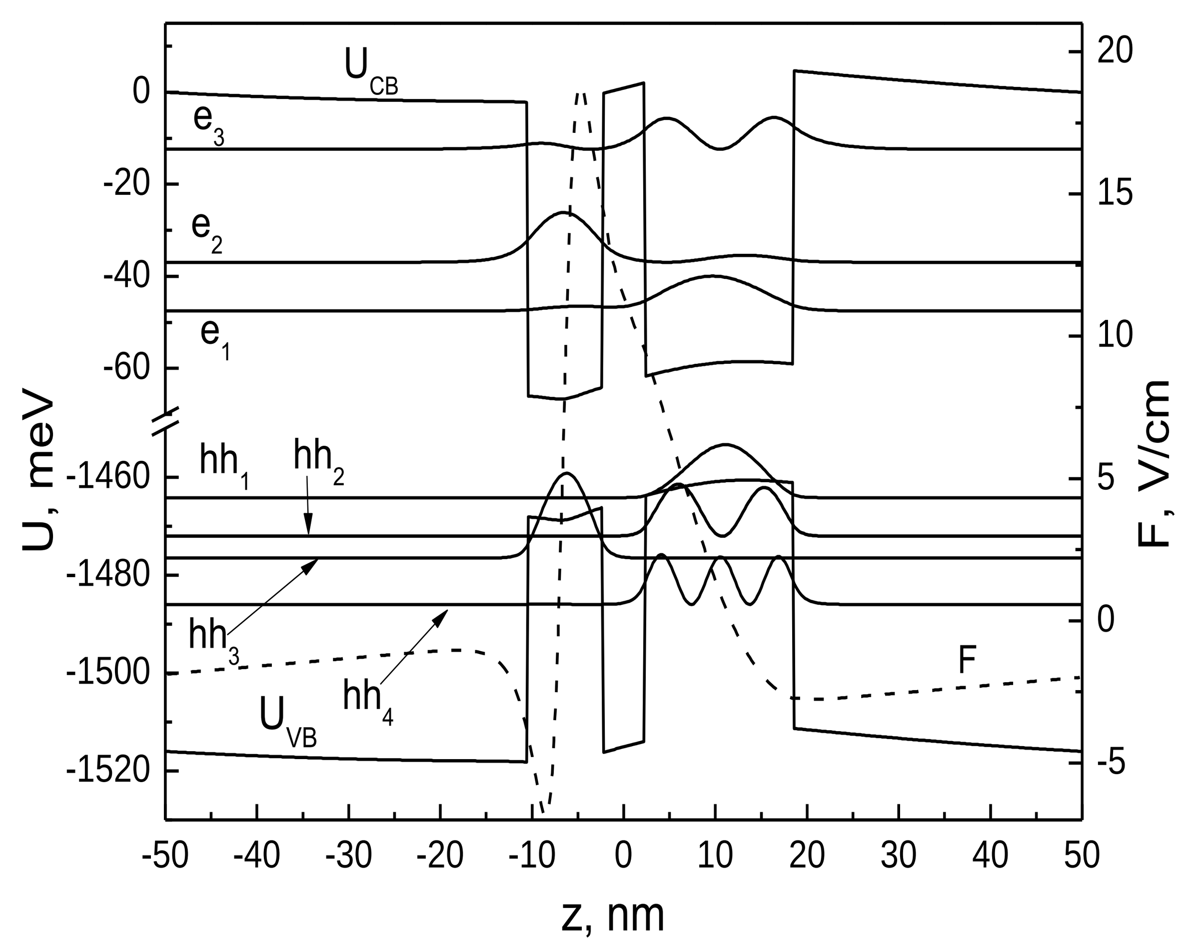
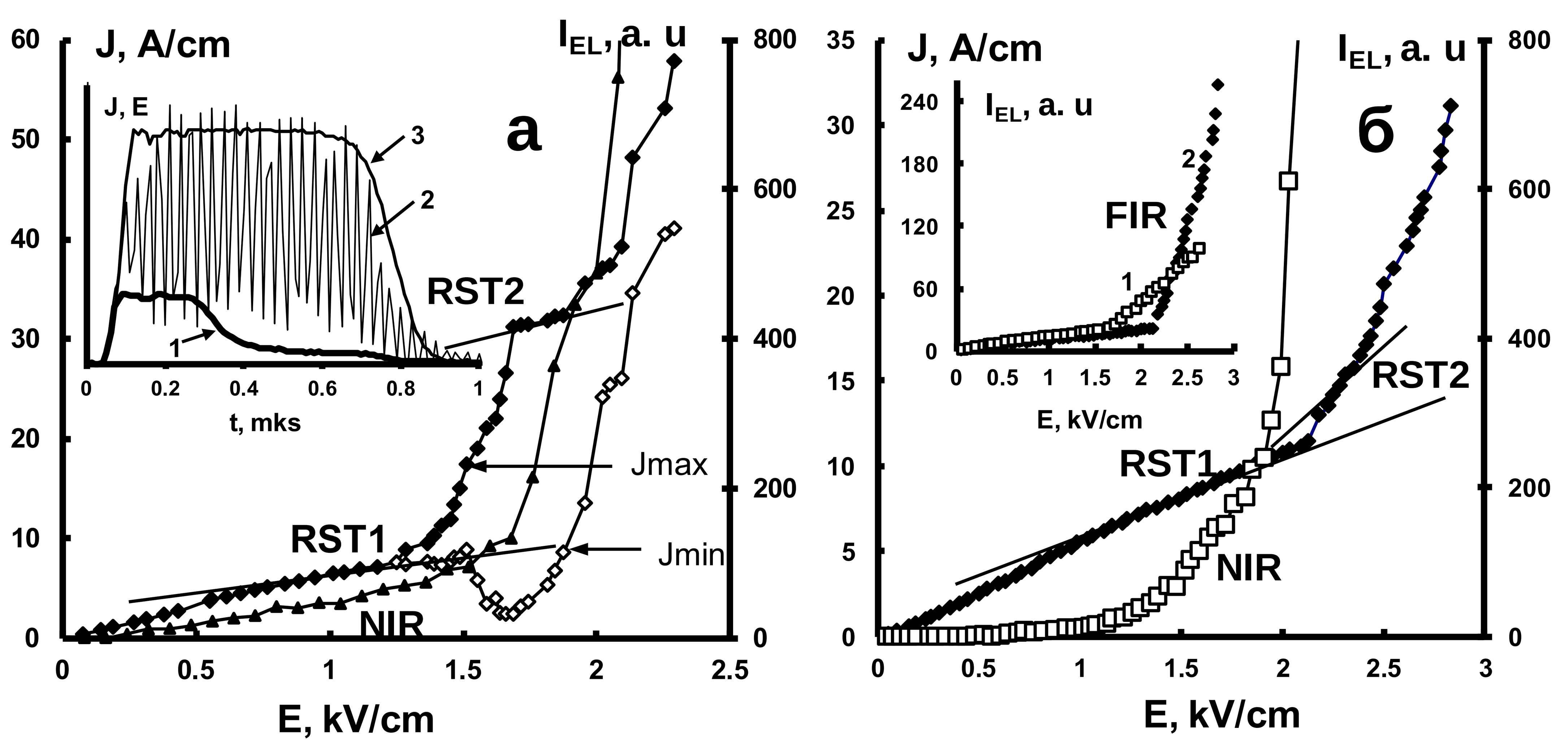


Fig. 1. The energy structure of the conduction band U_{CB} and valence band U_{VB} for 1 period, size quantization levels in QW with squared envelop wave functions for electrons and holes at these levels. F denotes the transverse distribution of the built-in electric field (numeric calculations).

Results
In structures with thick barriers (d_b ~ 50 A) in fields E ≥ 1 kV/cm (less the threshold of the Gunn kind instabilities) the high-frequency (tens MHz) current oscillations are observed (Fig. 2 a, curve 2, inset), and in structures with narrow barriers (d_b ~ 30 A) - a strong increase in the intensity of terahertz electroluminescence (Fig. 2b, curve 2, inset) [2]. Such behavior of current and intensity of the intraband terahertz radiation is explained by competition of two processes - radiative recombination of holes with electrons in narrow wells (characteristic time τ_{rec}) and tunneling of holes from the narrow QWs to wide ones (corresponding time τ_{tun}, Fig. 3) accompanied by direct radiative transitions between the size quantization levels of electrons and holes [3].



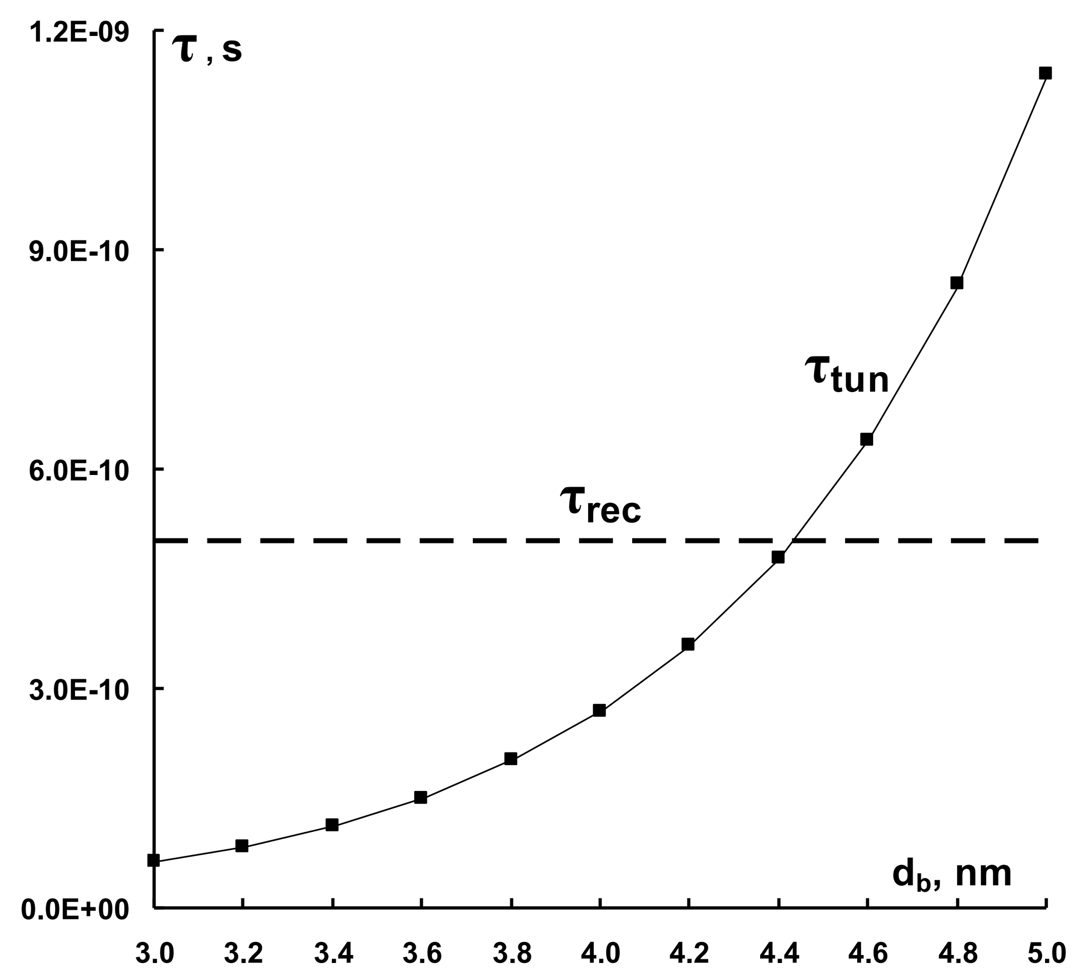


Fig. 2. Field dependences of current and interband electroluminescence intensity (NIR) of the n-InGaAs/GaAs heterostructures with double QWs: **a**: with a wide (~ 50 A) interwell barrier. For the NIR radiation intensity the averaged values between Imax and Imin oscillations are given. **b**: narrow (~ 30 A) interwell barrier. Insets: **a**: cr. 1 - the current waveform shape before oscillations onset, cr. 2 - current oscillations, cr. 3 - the shape of the field waveform; **b**: the field dependence of the terahertz electroluminescence intensity in the case of a wide barrier (d_b ~ 50 A) - cr. 1 and - narrow barrier (d_b ~ 30 A) - cr. 2. T = 4.2 K.

Fig. 3. The dependence of the hole tunneling time τ_{tun} between QWs on the of the interwell barrier width in the n-InGaAs/GaAs heterostructures (calculations). The dashed line shows the characteristic hole recombination time τ_{rec} in a narrow 80 A well.

1. P.A. Belevskii, M.N. Vinoslavskii, V.N. Poroshin, N.V. Baidus, B.N. Zvonkov, Physica E 74, 328 (2015).

2. M.M. Vinoslavskii, P.A. Belevskii, V.M. Poroshin, O.S. Pilipchuk, V.O. Kochelap, Semiconductor physics, quantum electronics and optoelectronics (SPQEO) 21(3), 256 (2018).

3. M.N. Vinoslavskii, P.A. Belevskii, V.N. Poroshin, V.V. Vainberg, and N.V. Baidus, Low Temperature Physics 46, 633 (2020)