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THE TUNNEL CURRENT OSCILLATIONS IN A GaAs/AlAs DOUBLE-BARRIER HETEROSTRUCTURE

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A fine structure (oscillations) of tunnel current in resonant-tunneling double-barrier quantum heterostructures based on AlAs/GaAs/AlAs with a wide spacer layer was observed. The oscillations have a period that close to $\hbar\omega_{LO}/e$, where $\hbar\omega_{LO}$ is the longitudinal optic phonon energy in GaAs. To explain similar *LO* phonon-related oscillatory structure in the tunneling devices the model was suggested according to which carriers injected from n^+-emitter lose energy gained in a strong electric field by the emission of *LO* phonons whether in the accumulation layer on the emitter side or in the depletion region adjacent to collector barrier in dependence on where the spacer layer is designed on.

The remarkable oscillatory structure in the voltage-current characteristics, $I(V)$, of single and double barrier tunneling devices based on AlGaAs/GaAs heterostructures has recently been investigated by several groups [1 – 4]. In some cases the oscillations have a period that close to $\hbar\omega_{LO}/e$, where $\hbar\omega_{LO}$ is the longitudinal optic phonon energy in GaAs. To explain similar *LO* phonon-related oscillatory structure in the *n*- or *p*-type tunneling devices the model was suggested according to which hot carriers (electrons or holes) injected through the tunnel barrier lose energy by the emission of *LO* phonons. This happens in the depletion layer adjacent to the collector contact. On the other hand, the oscillations can also arise due to interference effects in the wide well [4]. At the same time there are no experiments in which the oscillatory picture due to the processes occuring in the accumulation layer has been observed.

In this paper, we report the observation of *LO* phonon oscillations in the $I(V)$ curves of double barrier AlAs/GaAs/AlAs heterostructure. On our opinion, the processes connected with the energy loses of carriers injected from virtual cathode play the crucial role in appearance of these oscillations. The samples used in this study were grown by MBE and the layer structure is following: i)$n^+-<100>$GaAs substrate; ii)n^+ -GaAs(100 nm, N(Si)= $10^{18}\,\mathrm{cm}^{-3}$); iii)undoped GaAs (~ 100 nm)-spacer layer; iv)undoped AlAs(2 nm); v)undoped GaAs(4 nm); vi)undoped AlAs(2 nm), vii)n^+ -GaAs(100 nm, N(Si)=$10^{18}\,\mathrm{cm}^{-3}$)-top contact layer. Two quasi-bound states of the well are expected to appear in this structure: E_0 = 0.18 eV and E_1 = 0.68 eV. We measured the current-voltage characteristics $I(V)$ and differential conductance $G = dI/dV$ of square mesa diodes of the area $(32\,\mu\mathrm{m})^2$ fabricated from this structure. The typical liquid nitrogen-temperature $I(V)$ curve is shown in Fig.1. Surprizingly, three resonant peaks were observed

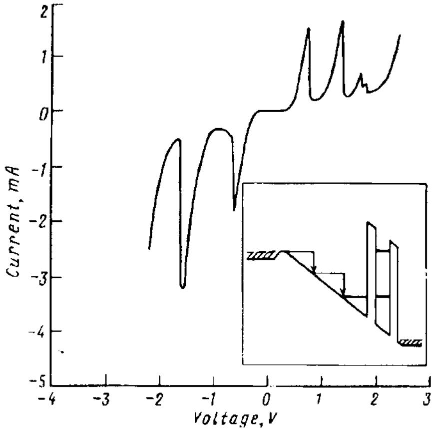

Fig.1

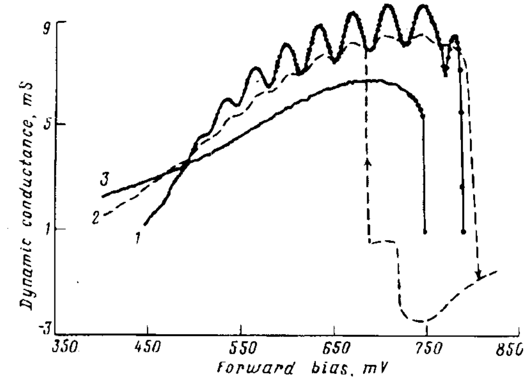

Fig.2

Fig.1. Current voltage characteristics of the double-barrier structure measured at T=77 K. In the inset the potential profile of the conduction band for the double-barrier structure is depicted in the forward bias

Fig.2. Dynamic conductance versus applied voltage corresponding to the first peak.T,K: 4.2 - 1; 80 - 2; 140 -3

at low temperature when electrons were injected from the spacer side (forward bias), instead of two peaks that actually appeared when the bias polarity was reversed. The *LO* phonon- related oscillatory structure is too weak to be seen directly in $I(V)$, but is clearly revealed by voltage modulation. Up to 10 peaks are observed as shown in Fig.2, which plots $G(V) = f(V)$ at various temperatures. The oscillations are observed in both bias directions on the low voltage slope of the first and second resonant peaks. There are no oscillations for the third resonant peak in the forward bias. The oscillatory structure has a well defined period $\Delta V = (36 \pm 1)\,\mathrm{mV}$ for the first peaks and $\Delta V = (38 \pm 1)\,\mathrm{mV}$ for the second ones. This period is very close to the *LO* phonon energy in GaAs. The period of oscillations does not depend on temperature while their amplitude linearly decreases with the temperature growth up to 120 K. It should be noted out that the amplitude monotonously increases with applied voltage in opposite to the cases described early [2, 3]. The interference effects cannot be a reason for appearance of fine structure in our case because the expected period must be noticealy greater for the well of width 4 nm [4]. To explain the above mentioned features of the $G(V)$ we have at first to discuss the mechanisms by which the tunneling process in the structure studied occurs. In the reverse bias the voltage drop is entirely across the double barrier structure and the depletion layer on the collector side. The influence of the accumulation layer on the emitter side may be neglected in this case. Such a situation is very similar to that observed in [2, 3] taking into account the small width of the barriers and the well in our structure. Thus, in the reverse bias the oscillations of $G(V)$ are determined by modulation with the periodicity of the $\hbar\omega$ of the impedance in the region adjacent to collector barrier. In the forward bias the situation is quite different. In this case the emitter side of the structure contains undoped GaAs layer. An applied voltage produces the accumulation layer in the region close to the emitter barrier because of the light doping. In resonance-off regime, when a current through the structure is small, this layer is in thermodynamic equilibrium with emitter and does not differ on proper enriched layers being on hetero- boundaries. In resonance regime, when the noticeable ballistic current flows through the structure, the accumulation layer is formed as the result of dynamic equilibrium between the electrons getting out the ballistic regime and thermalized in the accumulation layer and ones coming out the layer by thermal activation manner [5].. The voltage drop in the case of forward bias is expected across the accumulation layer and the double barrier structure. The depletion layer on the collector side may be neglected due to heavy doping of the n^+-GaAs top contact layer. Thus, under the forward bias conditions the electrons can be injected into the well from n^+-type emitter either ballistically or via a subband of an accumulation region in the spacer layer. This fact leads to appearance the additional peak and to the bistability because of space charge built-up. On the other hand, if the accumulation layer length d_{ac} lesser than the mean free path of accelerating electrons l_{opt} , the latters can reflect several times on the right and left boundaries of the accumulation layer before emitting the LO phonon. In opposite case, $d_{ac} > l_{opt}$, the emission of LO phonon occurs before electron gets to the emitter barrier (see inset in Fig.1). The latter one is obviously fulfilled for our structure. If the energy difference between the virtual cathode and the quantum-sized level in the well equals to $n\hbar\omega_{LO}$, where n is a number of emitted phonons, the enhance of tunneling current may occur. So, the modulation of the current may be observed with periodicity of the $\hbar\omega_{LO}$. This happens due to electrostatic feedback effect. Such situation does not take place when the electrons start to tunnel from a subband of an accumulation region in the spacer layer and therefore there are no oscillations on the low-voltage slope of the third peak. In conclusion, we should like to emphasize that in spite of the similarity of the oscillation pictures in the forward and reverse biases the origins of its are quite different.

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