

Giant tunnel magnetoresistance in double quantum well structures under an in-plane magnetic field

E N Morozova¹, V A Volkov¹ and J – C Portal²

¹ V.A. Kotelnikov Institute of Radio-engineering and Electronics of RAS, Moscow, Russia

² IUF-INSA, Toulouse and CNRS-LNCMI, Grenoble, France

E-mail: elena.morozova@gmail.com

Abstract. The vertical Ohmic magnetotransport in the structures with low but wide barrier $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ between two quantum wells GaAs, in temperature range $T=3\text{K} - 45\text{K}$ under in-plane magnetic fields $B=0 - 9\text{ T}$ is investigated. At zero-bias voltage, two mechanisms that determine the transitions well-barrier-well observed. The low-temperature regime ($3\text{K} - 20\text{K}$) is corresponded to the tunnel transport. The above-barrier ballistic transport with activation energy 50 meV is realized in high-temperature regime ($35\text{K} - 45\text{K}$). Magnetoresistance $R(B)/R(0)$ in the high-temperature regime doesn't depend on T and is increased two times at $B=0 - 5\text{ T}$. At low temperatures $R(B)/R(0)$ is increased 10 times at $B=0-5\text{ T}$ and 400 times at $B=0 - 9\text{ T}$. The effect is explained by suppression by in-plane magnetic field of resonant tunneling processes conserving the in-plane momentum.

1. Introduction.

Properties of the 2D tunnel heterostructures have been investigated for a long time. The basic attention is paid to research of 2D electron systems separating by thin barriers. Influence of an in-plane magnetic field \mathbf{B} on the Ohmic resistance was studied [1-3]. The field \mathbf{B} turns the momentum of tunnelling electron [2] and changes resistance. The resulting magnetoresistance is small, as a rule. In this work three-barrier tunnel heterostructure with wide barrier separating two narrow quantum wells was examined, see figure 1. The vertical Ohmic magnetotransport in this structure is investigated. It is shown that the large width of the central barrier, which is a feature of the investigated system, leads to the giant magnetoresistance in the Ohmic regime. Tunneling electron experiences the action of the Lorentz force in magnetic field $\mathbf{B}=(0, B, 0)$. It leads to the 2D momentum change of the tunneling electron. This variation is proportional to the magnetic field and tunnel length [4], [5]:

$$\Delta p_x = eBd.$$

It is expected this influence would be increased with the barrier width increasing. However, the in-plane magnetic field \mathbf{B} leads to an increase in effective barrier height and a strong suppression of the tunneling current [6], [7]. So in this work structures with wide but low barrier $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$ was used.



2. Structures. Heterostructures were grown on the high doped substrate n^+ -GaAs by MBE.

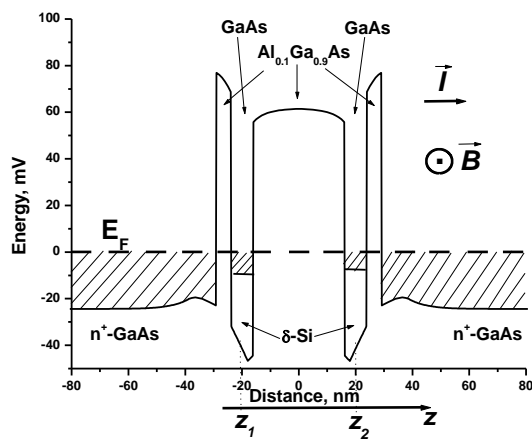


Figure 1. Energy band diagram of the three-barrier structure tunnel structure. Current I flows along the growth direction OZ and is perpendicular to an in-plane magnetic field B .

The thickness of the external barriers of symmetric heterostructures is 5,1 nm, the central barrier is 33,6 nm, the each quantum well is 8,4 nm. A relatively small value of the barrier height (about 10 meV) is provided by a low Al content (10%). Two-dimensional electron layers with an impurity concentration of $2.8 \cdot 10^{11} \text{ cm}^{-2}$ were formed in each quantum well by using the silicon delta-doping. Undoped GaAs layers with thickness of 10,8 nm of each separate the external barriers from the heavily doped n^+ -GaAs layers (a concentration of $3 \cdot 10^{17} \text{ cm}^{-3}$ and a thickness of 60 nm). This was followed by a transition layer to the substrate with a concentration of 10^{18} cm^{-3} , on the one hand, and a contact layer of 0.3 μm n^+ -GaAs with the same concentration, on the other.

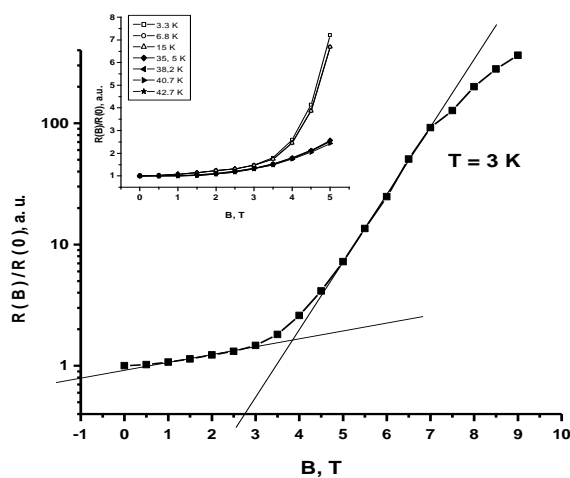


Figure 3. The dependence of the resistivity $R(B) / R(0)$ on the magnetic field B at $T = 3 \text{ K}$. The inset - this same dependence for different temperatures.

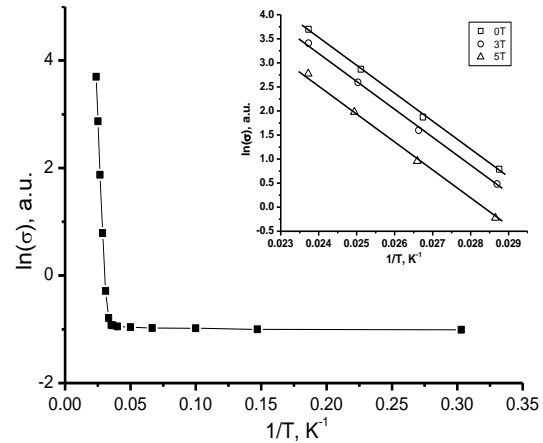


Figure 2. The temperature dependence of the Ohmic conductivity of the three-barrier structure.

The measured current flows from the heavily doped GaAs-emitter to the GaAs-collector. The electrons tunnel through the narrow outer barrier quickly and are accumulated in the well, and the bias voltage drops on the wide barrier. Measurements were carried out under the in-plane magnetic field B from 0 to 9 T at the temperatures from 3 to 45 K.

3. Results and discussions.

The differential tunnelling conductance near zero-bias voltage has a broad peak associated with the 2D-2D interwell tunnel resonance. The zero-bias anomaly of the dip-type is observed in the centre of the peak at low temperatures (it is not discussed in the paper). By increasing the temperature to 30K, the anomaly and the peak disappear. In this work the conductance σ (or resistance

$R = 1/\sigma$) are investigated at zero-bias voltage.

Depending on the ohmic conductivity of the inverse temperature, see figure 2, there are revealed two qualitatively different temperature regimes: tunnel behaviour at low temperatures and an activation regime at high T (associated with the above-barrier activation). In tunnel regime ($T=3-20\text{K}$) the conductivity at $B=0$ is increased slightly (10%) with increasing temperature. In the activation mode ($T=30-45\text{K}$) the conductance is increased exponentially by almost two orders of magnitude with the activation energy of 50 meV. Magnitude of the B -independent activation energy is correlated with the calculated value of the barrier height U (approximately 80 meV). Magnetic field dependence of the differential resistance demonstrates the same two temperature regimes, low-temperature and high-temperature ones. In each of these modes, the magnetoresistance $R(B)/R(0)$ does not depend on temperature.

In the both temperature regimes, a giant magnetoresistance is revealed. In activation regime the

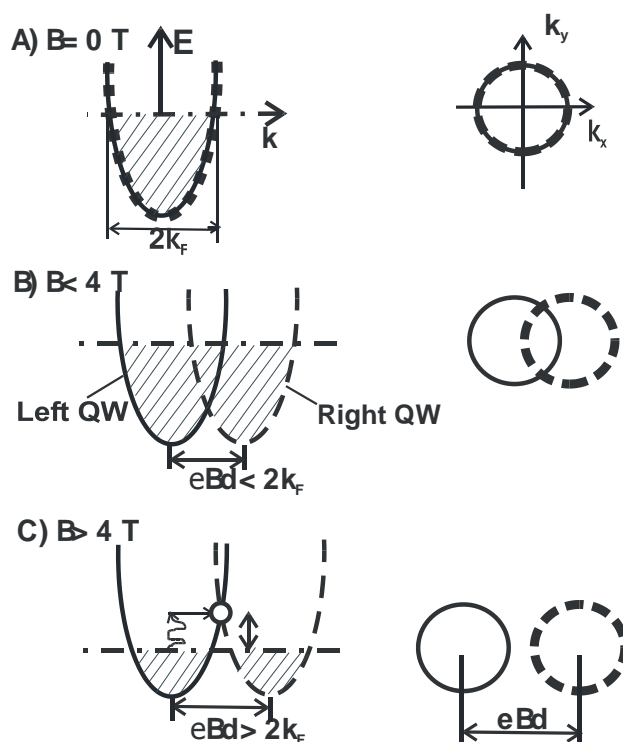


Figure 4. Combined dispersion of electrons in the left and right wells for $B = 0$ (figure 4A), $0 < B < 4\text{ T}$ (figure 4B), $B > 4\text{ T}$ (figure 4C).

wells (before and after the tunneling event) is shown on fig. 4. Parabolas are coincided at $B=0$, all electrons are included in the resonance tunneling with conserving of the 2D momentum. The number of these electrons decreases with increasing B and disappears at $eBd = 2k_F$ (d is width of the central barrier, k_F is the Fermi momentum). With a further increase of the magnetic field B tunneling resonance is possible only through the circle region, that unreal at $T=0$. As a result, the magnetoresistance is increased dramatically with magnetic field increase from 5 to 9 T.

4. Conclusion.

The zero-bias resistance and conductivity of a wide, but low barrier $\text{Al}_{0.1}\text{Ga}_{0.9}\text{As}$, separating two narrow quantum wells GaAs, were investigated in a temperature range 3- 45 K under in-plane

magnetoresistance increases in two times in the range from 0 to 5 T. In low-temperature regime $R(B)/R(0)$ increases two times in the same magnetic fields range and 400 times in the range $B = 0-9\text{ T}$. Let us consider each of these modes in more detail.

In the activation mode, see figure 3, resistance remains practically unchanged at $B < 4\text{ T}$, while it begins to increase at $B > 4\text{ T}$. The electrons in this regime fill a shallow well, formed by a top of the wide barrier and the narrow lateral barriers (height of about 10 meV). Calculations show that the Larmor diameter is compared at $B = 4\text{ T}$ with the width of this well. Therefore, for $B > 2\text{ T}$ the electrons are localized in this well and the resistance is increased.

In tunnel mode, an increase in resistance with in-plane magnetic field is apparently due to the influence of the Lorentz force on the momentum of the tunnelling electrons. There is a crossover of the mechanisms of formation of $R(B)$ near $B = 4\text{ T}$, see figure 4. It can be attributed to the B -induced change of momentum of tunnelling electrons [1].

The combined dispersion of electrons i.e. the superposition of two dispersion parabolas for electron in the left and right

magnetic fields $B = 0 - 9$ T. At low temperatures ($T = 3 - 20$ K) the conductivity does not depend on temperature practically (tunneling regime). At high temperatures ($T = 35 - 45$ K) the conductivity has an activation character with an activation energy of 50 meV that is independent of B (over-barrier regime). In both temperature regimes, giant magnetoresistance was revealed. In the low-temperature regime $R(B)/R(0)$ increases by 10 times at $B = 0 - 5$ T and 400 times as B increases from 0 to 9 T. This is associated with suppression ($B = 0 - 4$ T) and disappearance ($B > 4$ T) of a channel of resonant tunneling between the QWs conserving the 2D electron momentum.

Acknowledgments

This work is supported by RFBR (Russia) and PICS (France).

References:

- [1] Eisenstein J P, Gramila T J, Pfeiffer L N, West K W 1991 *Phys. Rev. B*. V.**44**. 6511
- [2] Smoliner J, Demmerle W, Berthold G, Gornik E, Weimann G and Schlapp W 1989 *Phys. Rev. Lett.* **63**. 2116
- [3] Berk Y, Kamenev A, Palevski A, Pfeiffer L N, West K W 1995 *Phys. Rev. B*. **51**. 2604
- [4] Snell et al 1987 *Phys Rev Lett.* **59**, 2806
- [5] Hayden, Maude, Eaves L et al 1991 *Phys. Rev. Lett.* **66**, 1749
- [6] L. Eaves, K. W. H. Stevens, and F. W. Sheard, in *Physics and Fabrication of Microstructures and Devices*, Springer Proceedings in Physics, vol.13 (Springer-Verlag, Berlin, 1986), p.343
- [7] Gueret P, Baratoff A and Marclay E 1987 *Europhys. Lett* **3**, 367