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AHARONOV–BOHM EFFECT AT MISFIT DISLOCATIONS IN GaAsSb/GaAs HETEROSTRUCTURES

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We examined the current flowing through p^+–n junction of the lattice mismatched $GaAs_{1-x}Sb_x/GaAs$ heterostructure in a transverse magnetic field at 1.8 K. We have found the appearance of current oscillations, periodic as a function of the magnetic field, that are due to the Aharonov–Bohm effect of holes passed around charged dislocations.

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Here we present the appearance of the quantum Aharonov–Bohm (AB) interference [1] in a macroscopic system: semiconductor heterostructure containing an array of misfit dislocations.

Let us consider a straight-line dislocation threading a heavily-doped semiconductor crystal. Localized states of the dislocation core (dangling bonds) accept the majority charge carriers from the bulk of material thus making the dislocation to be surrounded by a screening carrier-free cylinder. In GaAs with the carrier concentration of 10^{17} cm^{-3} the cylinder diameter is of the order of 100 nm that is presumably smaller than the phase-coherence length of the carrier wave function at liquid-helium temperatures.

The charge carrier which meets the dislocation has to pass around the cylinder either clockwise or counter-clockwise. When a magnetic field, $\boldsymbol{B}$, is applied parallel to the dislocation axis, these two alternative paths are non-equivalent since the vector potential of the magnetic field alters the wave-function phase differently on each path. As a result, the wave function behind the cylinder, which results from the interference of partial waves on these two paths, becomes a periodic function of the magnetic flux enclosed inside the carrier-free cylinder, so that the squared modulus of the wave function will exhibit the period $\Phi_0 = h/e$. The same period might be expected for the carrier transmission probability and so for the conductance measured normal to the dislocation axis.

However, for a macroscopic piece of semiconductor, as investigated in this work, there is an infinite number of paths that circumscribe the cylinder. The magnetic field will cause a random phase shift for paths enclosing different area and, consequently, their contribution to the AB oscillations at low magnetic fields will be averaged toward zero [2,3]. Instead, at high magnetic fields, such that $(h/eB)^{1/2}$ is smaller than the radius of the carrier-free cylinder, the net current around the cylinder is carried via states near its edge [3]. Then the carrier trajectory is well defined by the cylinder circumference but the carrier can only move in either clockwise or counter-clockwise direction, depending on the sense of the magnetic field vector. The interference occurs between the primary wave which meets the cylinder circumference and the wave which circles once round the cylinder. Then, the backscattering probability will be an oscillating function of the enclosed flux with the same period as previously: $\Phi_0 = h/e$.

The actual object of our investigations were p^+–n junctions fabricated by liquid-phase-epitaxy growth of $GaAs_{1-x}Sb_x$ layers ($x = 0.01$ and 0.02) on (001) oriented p-type GaAs:Zn substrates. A two-dimensional array of α and β dislocations lying along two different orthogonal $\langle 110 \rangle$ directions at the interface has been induced by the lattice mismatch in the heterostructures, as seen directly with spatially resolved cathodoluminescence [4]. The area of the investigated junctions was of the order of 1 mm^2.

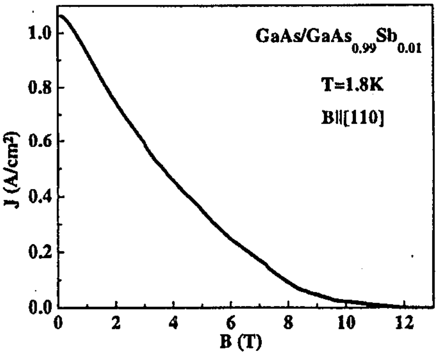

Fig. 1. Forward-current density through the investigated heterojunction vs. magnetic field along the [110] direction, transverse with respect to the current, measured at a temperature of 1.8 K.

We examined the forward current flowing through the junction at temperatures down to 1.8 K in a magnetic field transverse with respect to the current (Fig. 1). This current is limited by the diffusion of injected holes. We have found a striking behaviour of this current as a function of the magnetic field and bias voltage.

The principal finding has been the appearance of the current oscillatory structure which is periodic as a function of the magnetic field. This structure is

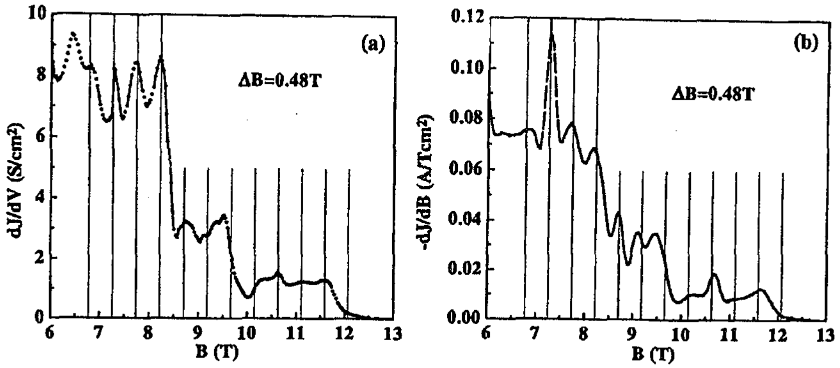

Fig. 2. (a) High-magnetic-field part of the derivative of the current density with respect to the voltage vs. magnetic field, measured under the same conditions as in Fig. 1; (b) high-magnetic-field part of the derivative of the current density with respect to the magnetic field computed from the dependence shown in Fig. 1. Vertical lines indicate the oscillatory structure with a period of 0.48 T.

clearly seen at 1.8 K for the magnetic fields higher than about 5 T while measuring the derivative of the current with respect to the bias voltage (Fig. 2a). The same structure has been obtained while computing the derivative of the current with respect to the magnetic field (Fig. 2b). This structure disappears after elevating the temperature above *ca.* 8 K and does not appear at all when the magnetic field is parallel to the current or when a diode is essentially free from misfit dislocations.

A direct connection of the oscillatory structure with the dislocation array has been evidenced by changing the angle, φ, between the magnetic field direction and dislocation axes. When $\varphi = 45^\circ$ the period of the oscillations is $1.4 \approx 1/\cos(45^\circ)$ of its value at $\varphi = 0^\circ$ (or 90°). Accepting that the oscillations are due to the magnetic Aharonov–Bohm effect caused by holes, we have found the diameter of the hole-free cylinder to be about 100 nm. This value corresponds to the occupation fraction of the dislocation dangling bonds by holes equal about 0.1 that is compatible with the results of other experiments.

Another significant finding is a blockade of the current flowing through the junction for the transverse magnetic field exceeding some critical magnitude whose value rises with increasing voltage applied to the junction (Fig. 1). This blockade has been also demonstrated by measuring the current–voltage characteristic in high magnetic fields at 1.8 K. Under forward bias the current is essentially zero up to certain voltage, depending on the magnetic field intensity, above which it grows up rapidly displaying a distinct quasi-oscillatory structure.

A detailed explanation of these observed features needs further studies. It seems, however, to be evidenced that we are dealing here with the AB type interference of holes which occurs owing to the presence of misfit dislocations. The dislocations make that the investigated structure behaves as a multiply connected conductor.

The observed phenomenon would be complementary to the conventional AB effect observed in metallic or semiconductor rings of nanoscopic size. While the latter effect vanishes in the quantizing-magnetic-field regime [3], the present phenomenon only appears there.

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