Spin precession observation in quantum corrections to resistance of $Si_{0.7}Ge_{0.3}/Si_{0.2}Ge_{0.8}$ heterostructure with 2D gas

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Abstract

The two dimensional hole gas (2DHG) magnetoresistivity of $Si_{0.7}Ge_{0.3}/Si_{0.2}Ge_{0.8}$ heterostructure in a wide range of temperatures T=0.335K-20K and transport currents I=100 nA - 50 mkA is measured. In the vicinity of zero magnetic field, a sharp and positive in sign feature on smooth negative magnetoresistance is observed at the lowest temperatures. The amplitude of this feature quickly fades with temperature and transport current. For the analysis of the experimental data the theory of weak localization for 2DHG is applied.

The values of τ_{so} and τ_{tr} obtained are used for the first time to define zero magnetic field splitting in the hole energy spectrum for a $Si_{0.7}Ge_{0.3}/Si_{0.2}Ge_{0.8}$ heterostructure: Δ=1.65 meV.

Key words: heterostructure, spin-splitting, WL

1. Introduction

The spin-splitting interaction – controlled spin splitting in the energy spectrum of a two –dimensional hole gas of charged particles offers promise for creation devices in which not only charge transport but spin transport as well can be realized [1]. It is found [2] that the spin splitting in the energy spectrum of bulk semiconductors (3D) in zero magnetic field is caused by the lack of inversion symmetry of their crystal lattices. The spin splitting value turns out to be proportional to the cubed wave vector of charge carriers, $\sim k^3$ (the Dresselhaus cubed term). The formation of a symmetric quantum well in such a crystal is responsible for a further decrease in its symmetry [3] and gives rise to an additive contribution to the spin splitting which is linearly dependent on wave vector $\sim k$ (the Dresselhaus linear term) [4]. Generation of an asymmetric quantum well results in an extra spin splitting which also is in linear dependence on wave vector (the Rushba term) [5,6]. As

shown in [7], the contributions of these linear terms to the resultant spin splitting cannot be considered additive.

The spin splitting in zero magnetic field gives rise to two electron subsystems similar in characteristic parameters. Examples of the splitting manifestation are: dramatic beats in Shubnikov – de Haas oscillations [8]; two effective masses of charge carriers revealed with the cyclotron resonance technique [9]; positive magnetoresistivity in low magnetic field in the weak localization effect [10] with increasing asymmetry of the two – dimensional potential well, etc.

2. Experimental results

The paper concerns the quantum interference and oscillation effects in the borum – modulation doped $Si_{0.7}Ge_{0.3}/Si_{0.2}Ge_{0.8}/Si_{0.7}Ge_{0.3}$ heterostructure in wide ranges of magnetic fields (up to 11 T), temperatures (down to 0.346 K) and transport currents (100 nA – 40 μA). The dependence $\rho(T)$ at $T \approx$

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40 K exhibited a minimum resistance. A decrease in temperature caused the resistance to increase. The dependence $\rho(B)$ displayed a change from the positive to negative magnetoresistance with increasing magnetic field. The increase in temperature up to ~ 3 K or in transport current up to ~ 40 μA caused the positive magnetoresistivity to disappear (fig. 1). This behavior is indicate of contributions of the weak localization effects under strong spin – orbit interaction.

The analysis of the Shubnikov – de Haas oscillations made it possible to obtain the following values of charge carrier concentration and effective mass: $p_{SdH}=1.46 \cdot 10^{12}$ cm^{-2} (close to $p_H=1.36 \cdot 10^{12}$ cm^{-2} obtained from the measurements of the Hal coefficient) and $m*=0.16 m_o$. Using the above values of $m*$ and p_H and the relationships for the 2D system: $v_F = \frac{\hbar}{m^*} (2\pi \, p_2)^{1/2}, D = \frac{1}{2} \cdot v_F^2 \tau$ and $\varepsilon_F = \pi \, \hbar^2 p_2 / m^*$, we estimated inelastic scattering time, τs, hole free path, l, Fermi velocity, v_F, mobility, μ, diffusion coefficient, D, and Fermi energy, ε_F, as being equal to $0.147 \cdot 10^{-12} s$, $310 \overset{0}{A}$, $2.11 \cdot 10^{7} cm \cdot s^{-1}$, $1590 cm^2 \cdot V^{-1} \cdot s^{-1}$, $32.7 cm^2 \cdot s^{-1}$ and $20.35 meV$, respectively. The analysis of the temperature dependence of quantum corrections in zero magnetic field, made by the theory in [11] permitted the times of energy and spin relaxations to be estimated. The relaxation times may be estimated more precisely by analyzing the magnetic field dependences of resistance and using the above estimated values. Such an analysis was made by the theory [12] in magnetic fields of ~ 0.3 T, because the weak localization effects manifested themselves in magnetic field with meeting inequality $L_H > l$ where L_H is the magnetic length. For the sample studied this corresponds to the limiting value of magnetic field strength $H = 0.36 T$. We obtained the following relaxation times: $\tau_\varphi = 4.5 \cdot 10^{-12} T^{-1} s$ and $\tau_{so} = 4.41 \cdot 10^{-12} s$. The antilocalization effects (positive magnetoresistivity) disappear with increasing temperature where inequality $\tau_{so} > \tau_\varphi$ is met.

The main mechanism of spin relaxation in noncentrisymmetrical semiconductors and semiconducting structures is a Djakonov – Perel (DP) mechanism [13]. A prerequisite to the realization of this mechanism is the predominance of impurity smearing over spin splitting ($\hbar \tau_{tr}^{-1} > \Delta$). Our values of τ_{tr} offers the fulfillment of the above inequality up to $\Delta = 4.8$ meV. The spin relaxation time makes it possible to estimate the value of spin splitting by the relationship $\tau_{so}^{-1} = \langle \Delta^2 \rangle \tau_{tr} / 4 \hbar^2$ [14] and to obtain $\Delta = 1.65 meV$ for the sample studied.

An increase in transport current causes electron overheat to appear and positive magnetoresistivity to disappear as in the case of temperature increase. The effect of electron overheat was used to determine the temperature dependence of hole – phonon relaxation
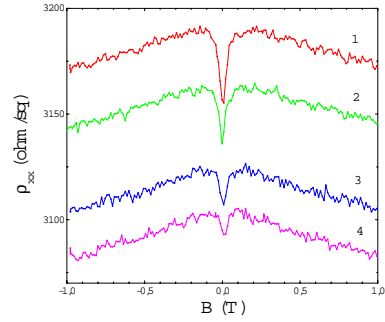

Fig. 1. Records of magnetoresistivity of the sample studied. Temperature, K: (1) 0.346, (2) 0.754, (3) 1.44, (4) 1.738.

time $\tau_{pph} = 11 \cdot 10^{-8} T^{-2} s$.

Thus, relying on the analysis of weak localization in the $Si_{0.7}Ge_{0.3}/Si_{0.2}Ge_{0.8}/Si_{0.7}Ge_{0.3}$ heterostructure, we estimate the value of spin splitting in the energy spectrum of charge carriers. The observation of antilocalization testifies that the contribution of the Rushba term to the spin splitting is dominant [4]. The results of our investigation suggest that Si– and Ge– based heterostructures may be applied in spin transport – controlled electron devices.

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