Large Magnetoresistance of a Dilute $p$-Si/SiGe/Si Quantum Well in a Parallel Magnetic Field

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Introduction

Studies of magnetoresistance in in-plane magnetic field in low-density heterostructures were carried out in a numerous objects: $n$-Si MOS, $n$-Si/SiGe, $n$-GaAs/AlGaAs, $p$-GaAs/AlGaAs, AlAs (for example, see [1]). Large in-plane magnetoresistance observed in these materials were generally attributed to the modification of spin system of the electrons/holes. Indeed orbital motion of 2D charge carriers is suppressed, and the Zeeman splitting arising in a parallel field lifts spin degeneracy. To explain nature of this effect several theories had been suggested which are based on effect of spin polarization. However, in such systems like $p$-Si/SiGe heterostructures spin effects could not be considered as responsible for observed in-plane magnetoresistance. Really, in this system the heavy hole–light hole degeneracy is split due to a strain in 2D SiGe. So, the heavy holes with $M=\pm 3/2$ are responsible for conductivity. In this case the Zeeman splitting is completely determined by component of applied field normal to the 2D-plane. This effect is manifested in a strong anisotropy of $g$-factor with respect to the field orientation relatively to the 2D channel: $g_\perp \approx 4.5$, $g_\parallel \approx 0$. That’s why it was hard to expect significant spin effects in the in-plane magnetoresistance in $p$-Si/SiGe [1].

Experimental

We have done measurements of DC magnetoresistance $\rho_{xx}$ in the in-plane field up to 18 T in two $p$-Si/SiGe/Si quantum wells (density $p=0.8$ and $1.6 \times 10^{11}$ cm$^{-2}$, mobility $10^3$ cm$^2$/Vs) at temperatures 0.3-2 K with two field orientations against the direction of current $I$: $B_\parallel \perp I$ and $B_\parallel \parallel I$. The samples were mounted on a single axis rotator that allowed the sample to be aligned with the field.

Results and Discussion

An in-plane magnetic field induces a large positive magnetoresistance in $p$-Si/SiGe/Si quantum well as seen on Fig.1. This effect is observed in the system with lowest density only. The resistivity there changes by more than three orders of magnitude, while in the sample with higher density $p=1.6 \times 10^{11}$ cm$^{-2}$ $\rho_{xx}$ increase is just several times. In the lowest density sample $d\rho_{xx}/dT$ changes its sign at $B_\parallel \approx 7.2$ T. It could be interpreted as a magnetic field suppression of the metallic state. In the sample with $p=1.6 \times 10^{11}$ cm$^{-2}$ the sign change of $d\rho_{xx}/dT$ was not observed. The experiments have shown that:

(i) magnetoresistance in sample with $p=0.8 \times 10^{11}$ cm$^{-2}$ is anisotropic - at $T=0.3$ K and $B_\parallel =18$ T $\rho_{xx}(B_\parallel \perp I) / \rho_{xx}(B_\parallel \parallel I)=3$;
(ii) on the metallic side the magnetoresistance obeys a power law $\Delta \rho_{xx}/\rho_{xx}(0) \propto B^2$. At $B_\parallel \approx 13$ T a transition from the law $\ln(\Delta \rho_{xx}/\rho_{xx}(0)) \propto B$ to $\ln\Delta \rho_{xx}/\rho_{xx}(0) \propto B$ was observed. The change in the functional form of the dependence $\rho_{xx}(B_\parallel)$ is illustrated on Fig.2.
(iii) there is reduction of the effect with increasing density.

These experimental facts could be explained qualitatively using the theory of [2], where the authors do not consider spin as playing a role in the a large positive magnetoresistance in quasi-2D systems, and account it as arising from the coupling of the parallel field to the carrier orbital motion due to the finite thickness of the quantum well and the low density of charge carriers.

References