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Transverse Magnetoresistive Effects in a Quasi-One-Dimensional Electron System Over Superfluid Helium

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The transverse magnetoresistive effects in a nondegenerate quasi-one-dimensional (Q1D) electron system over superfluid helium have been investigated experimentally. The longitudinal magnetoresistance ρ_{xx} *have been measured in magnetic fields B up to 2.5 T in the temperature range 0.48 - 2 K. The width of conducting channels was 90 nm and 35 μm, the mean electron density varied from* $\sim 10^9$ m^{-2} *to* 1.5×10^{12} m^{-2}*. It has been shown that the value of* ρ_{xx} *practically does not depend on B at low B and* $\rho_{xx} \sim B$ *in the quantum regime. The effective mobility of electrons in narrow channels increases under decreasing temperature and is determined by electron scattering by gas atoms, ripplons, and non-uniformities of the substrate. The mobility of electrons in wide channels increases with decreasing temperature and, below some temperatute* T_m*, decreases. The negative magnetoresistance has been observed in the gas- and ripplon-scattering region. This effect has been explained by weak localization of carriers caused by the interaction of electrons with gas atoms in vapor at high temperatures and with ripplons or with non-uniformities of the substrate at low temperatures.*
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1. INTRODUCTION

The successes in nanoelectronics stimulate investigations of quasi-one-dimensional conducting structures which have properties concerning to the mesoscopic systems. The carrier transport is sensitive to a magnetic field especially at low temperature. The transverse magnetoresistive effect is convenient for the investigation of system with restricted geometry.

The surface electrons (SE) over superfluid helium form unique classical low-dimensional system because of purity of liquid substrate and weak coupling to the surface. The magnetotransport in a two-dimensional electron system over liquid helium has been investigated in classical and quantum regimes in Refs. 1-4.

In addition to one-dimensional (1D) systems performed in thin metal wires or in semiconductors, carbon nanotubes, organic conductors etc. an one-dimensional system with using electrons over helium is of increasing interest. Such a 1D electron system has been proposed and realized in Refs. 5 and 6, consequently. Electrons over the liquid helium surface are localized in grooves of a profiled dielectric substrate. The electron transport and magnetotransport have been studied theoretically in Refs. 7 and 8.

The localization processes which change the kinetic properties of carriers are essential for 1D systems. At $k_T l_0 > 1$ (here $k_T = 2\pi/\lambda_T$, is the electron wave vector, $\lambda_T = (\hbar/2mkT)^{1/2}$ is the electron de Broglie wave length and l_0 is the electron free path) the weak localization (WL) effects takes place. Weak localization is connected with the constructive interference of electron waves during the interaction with elastic scatterers. WL can be destroyed by inelastic scattering which changes the electron state and by magnetic field leading to the phase shift between electron wave and its inverse in time. The correction to the conductivity in the Q1D electron system over superfluid helium was described in Ref. 9. Preliminary measurements of the magnetoresistance have been performed in Refs. 9-12.

In the present work, transverse magnetoresistive effects in Q1D have been investigated in magnetic fields up to 2.5 T in the temperature range 0.48 - 2.0 K. The width of conducting channels was 90 nm and 35 μm, the average electron densities were $\sim 10^9$ m^{-2} and 1.5×10^{12} m^{-2}, respectively.

2. RESULTS AND DISCUSSION

The method of low frequency measurement was similar to that described in Refs. 10 and 13. The substrate consists of nylon threads of 100 μm diameter arranged in a row. The helium surface was charged at a small holding potential ($\sim$ 0.1 V) at temperature 1.3 K. After that the potential was increased. Such a method allows to charge the strips over all surface uniformly and to exclude the penetration of electrons on the dielectric surface. The magnitudes of the effective mobility μ^* and mean electron density n_s were determined as follows. At low electron density the temperature dependence of experimental value $\sigma/(ne)$ (here σ is conductivity) is in agreement with the theoretically calculated mobility μ (Ref. 7). The theoretical magnitudies of

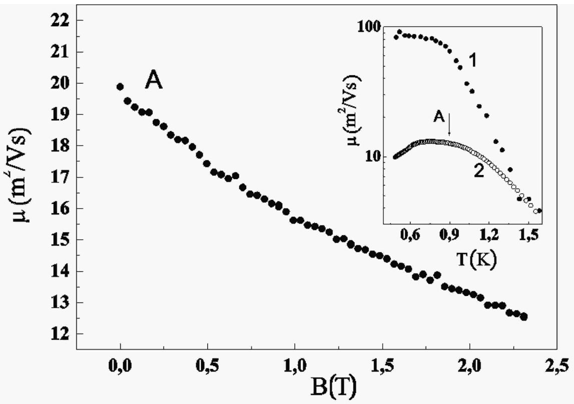

Fig. 1. The effective mobility of electrons in a Q1D system vs magnetic field at $T = 0.9$ K; n_s=1.5×10^{12} m^{-2}. The channel width is 35 μm. Inset: the temperature dependence of the value of μ^* for Q1D channels: (1) - narrow channels; (2) - wide channels.

μ which coincide with the experimental data at relatively high temperature is used as fitting curve. Supposing the mobility of the electrons on thin helium film to be zero, we obtain the electron density in channels $\sigma/(e\mu)(A/(2a))$ (here A is distance between channels and $2a$ is channel width). The effective mobility at any temperature is $\mu^* = \sigma/(ne)$.

The main characteristic of the narrow conducting channels is the typical size of the electron localization across the channel: $y_n = y_0(kT/\hbar\omega_0)^{1/2}$, ($k$ is Boltzmann's constant; $y_0 = (\hbar/m\omega_0)^{1/2}$, and $\omega_0 = (eE_\perp/mR)^{1/2}$ where R is the curvature radius of the liquid surface). At low temperature and for $E_\perp = 2.5$ kV/cm the value of y_n is 90 nm. The electron free path at $T = 2$ K is about 10^{-5} cm being less then y_n. The magnetic length $l_m = (\hbar/eB)^{1/2}$ is larger then y_n at magnetic fields smaller than 10^{-2} T. The condition $l_0 > y_n$ is satisfied at low temperatures. So the system studied in narrow channel is close to 1D at low T and it has the properties of a 2D system at high temperature. The system is close to 2D for wide channels. The width of channel in this case is determined as $2a = 4(eRn_s/E_\perp)^{1/2}$. The electron density across a wide channel has a maximum in the center of a channel and is zero near the edges (Ref. 14).

The values of 0- and 90- degree components of the electron current were measured by two phase lock-in-amplifier and then we calculated the value of ρ_{xx} (Ref. 15). In magnetic field, the effective mobility μ^* decreases due to transverse magnetoresistive effect [14]. The dependence of the mobility on B for $T = 0.9$ K is shown in Fig. 1. The value of μ^* is proportional to B^{-1}, the magnitude of μ^* decreases with magnetic field from 20 m^2/Vs to 13 m^2/Vs. One can see some irregularities on this dependence which enhance the noise level. They can be induced by some structure changing of the electron system (Ref. 16).

The temperature dependence of μ^* for the wide channels (curve 2, inset of Fig. 1) essentially differs from that for narrow channels (1). The value of μ^* increases with decreasing T, and after some magnitude T_m, decreases. Anomalous behaviour of the mobility can be explained by electron ordering in the electron system or formation of polarons and by the influence of the viscosity (Refs. 15 and 16).

The magnetoresistive effects has been investigated for wide channels at $T = 1.62$ K (Fig. 2) and for narrow channels at $T = 0.6$ K (Fig. 2, inset). For

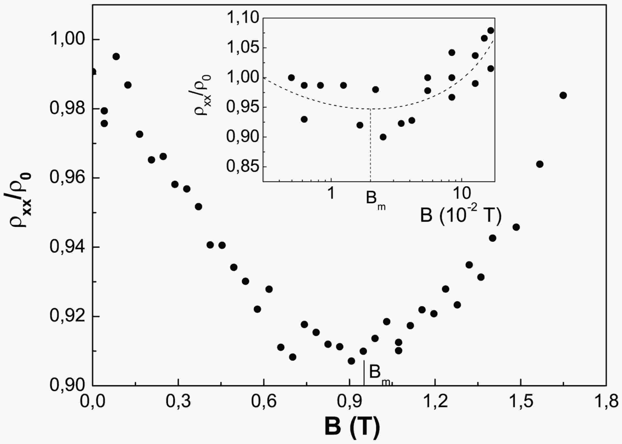

Fig. 2. Dependence of the value ρ_{xx}/ρ_0 on magnetic field. $T = 1.62$ K, $n_s = 1.5 \times 10^{12} m^{-2}$. B_m is the magnitude of magnetic field for maximum negative magnetoresistance. Inset: The same dependence for channels of 90 nm width and interelectron distance near 10^{-5}m ($T = 0.6$ K; $V_\perp = 600$ V).

wide channels negative magnetoresistance is caused by weak localization of carriers on the gas atoms in vapor. The value of ρ_{xx}/ρ_0 (ρ_0 is the resistance at zero magnetic field) achieves 0.91 at $B_m = 0.96$ T. This value is much smaller than that for the narrow channels at T=1.62 K [9]. Nevertheless the magnitudes of B_m are practically coinciding. The Coulomb energy is about 50 K. This may cause the decrease of the WL effects because electron-electron interaction [17]. One should note that the magnetic length at B_m is of the order of electron de Broglie wave length. The negative magnetoresistance of the narrow channels was observed too (Fig. 2, inset). The value of ρ_{xx}/ρ_0 is near 0.97 at B_m =0.025 T. We have supposed this effect is caused by weak localization of electrons either on the ripplons or on the non-uniformities of the substrate at low temperature.

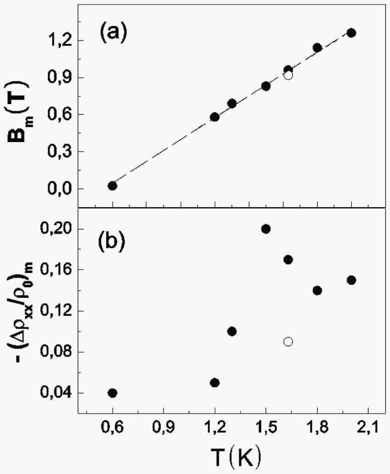

Fig. 3. (a) - the value of B_m and (b) - maximum of the relative change of negative magnetoresistance $(\Delta\rho_{xx}/\rho_0)_m$ as a function of the temperatute. ● - narrow channels; ○ - wide channels.

The value of B_m for maximum magnitude of the negative magnetoresistance as a function of temperature is presented in Fig. 3a where the data of this work and data from Refs. 9, 12 are shown. The temperature dependence of the value of B_m shows the linear behavior on T and the position of B_m does not depend on electron density. The magnitude of B_m at low temperature practically corresponds to the total dependence B_m from T. This can be by confirmation of the WL electrons at low temperature. Dependence of the value $(\Delta\rho_{xx}/\rho_0)_m$ on T (here $\Delta\rho_{xx}$ is change of the resistance in magnetic field) is placed in Fig. 3b. It achieves the value of 0.2 at T = 1.5 K. One should note that the value of $\Delta\rho_{xx}/\rho_0$ at T=1.62 K for wide channels is about 0.09, being much smaller than that for narrow channels. This can be caused by electron-electron interaction (Ref. 17) or by influence of the channel edges charged by electrons on thin helium film.

3. CONCLUSION

The transverse magnetoresistive effects in a Q1D electron system over superfluid helium have been investigated in magnetic field B up to 2.5 T in temperature range $T = 0.48$ - 2.0 K. The value of ρ_{xx} mainly increases with increasing the magnetic field. The negative magnetoresistance has been observed in both the ripplon and the gas-scattering region. The value of negative magnetoresistance decreases with increasing the electron density and the width of channels. This effect has been explained by weak localization of carriers caused by the interaction of electrons with gas atoms in vapor at high temperatures and with ripplons or with non-uniformities of the substrate at low temperatures.

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