Current-Voltage Characteristics in the *p*-type Si/SiGe Heterostructures in the Ultra-Quantum Limit

I.L. Drichko, I.Yu. Smirnov (Ioffe PTI); A.V. Suslov (NHMFL); O.A. Mironov (University of Warwick Science Park); D.R. Leadley (University of Warwick, Physics); Yu.M. Galperin (Ioffe PTI; University of Oslo, Physics); V.M. Vinokur (Argonne National Laboratory)

Introduction

Measurements of acoustoelectric effects, current-voltage (*I-V*) characteristics and magnetoresistance in *p-type* Si/SiGe heterostructures in high magnetic field at low temperatures [1,2] have shown that observed behavior of DC and AC conductance could be interpreted as an evidence of a pinned Wigner crystal (glass) formation. A strong argument for this conclusion was the measured *I-V* characteristics. At the magnetic fields $B > 13$ T and temperatures $T < 0.7$ K the *I-V* curves appeared to be nonlinear. The specifics of the *I-V* curves are the following: (i) a threshold-like shape being asymmetric with respect to the V-axis; (ii) the *I-V* curves show a hysteresis with a change of the current sweep direction at small *I*; (iii) with measurements of the *I-V* characteristics at the different current ramp rate it is found that the threshold voltage depends on the current sweep time; (iv) the law $I \sim \exp(-A/V^{\mu})$ typical for a creep in a crystal observed for the lowest current ramp rates. However, a *detailed* study of the creep and hysteresis of *I-V* curves as most prominent manifestation of the Wigner crystal has not been done: namely evolution of the *I-V* characteristics with change of magnetic field and temperature were carried out only with the relatively fast current rate. Thus, detailed study of the "creep" phenomenon required extra experiments with staking on low current sweep rate measurements of the voltage-current characteristics and their dependences on *B* and *T*.

Experimental

In present experiments we studied of the sub-threshold region of the *I-V* curves in the *p*-type Si/SiGe heterostructures. *I-V* characteristics at the low ramping rate of 0.02 nA/min have been measured in the range of -1 nA $< I <$ 1 nA. We studied the temperature evolution of the *I-V* characteristics at temperatures T=0.3-1.0 K in fields B = 18 T. As it was necessary to have the highest possible temperature stabilization the experiments were performed in the 18/20 T superconducting magnet, with dilution refrigerator.

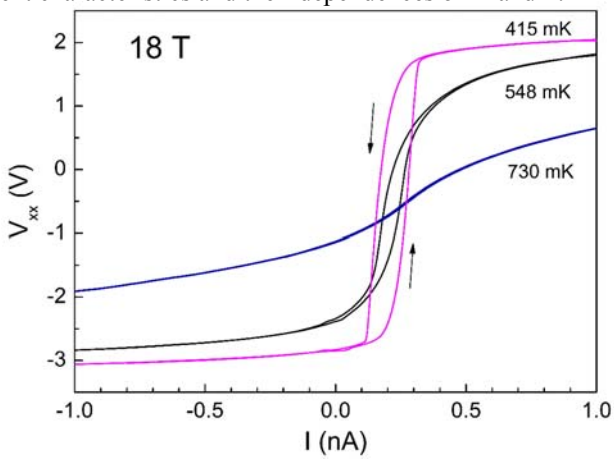

Fig. 1. Voltage-current curves for B = 18 T and different temperatures. The current ramping rate is 0.02 nA/min

Results and Discussion

A strong transformation of the voltage-current characteristics was observed in the extreme quantum limit. Fig. 1 illustrates voltage-current curves at B = 18 T and different temperatures with current sweeps up and down. Low temperature curves show a hysteresis when the current ramp direction is changed. At higher temperatures ($T > 0.7$ K) the hysteresis collapses. Fig. 2 shows the symmetrized log-log plot of the *I-V*-curves taken at 0.02 nA/min at different temperatures at B = 18 T. Even at the highest field B = 18 T, at $T >$ 0.9K the *V-I* dependence is linear within the range of -1 nA $< I <$ 1 nA. As the temperature gets lower a nonlinear behavior of the *V-I* curves typical for creep becomes pronounced. We believe the creep and hysteresis observed at the lowest temperatures could confirm a hypothesis of the Wigner glass formation in this system.

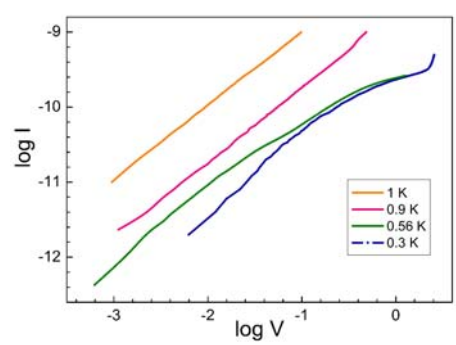

Fig. 2. log-log plot of the *I-V*-curves with the current sweep rate 0.02 nA/min at B = 18 T at different temperatures.

References

[1] Drichko, I. L., *et al*., Phys. Rev. B, **77**, 085327 (2008).
[2] Drichko, I. L., *et al*., Phys. Stat. Sol. (c), **5**, 829 (2008).