Large Quasiclassical Positive Magnetoresistance in High Mobility 2D Electron Gas: Interplay of Short and Long range Scattering

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Lately, there has been some revival of interest to the quasiclassical transport in a two-dimensional electron gas (2DEG), especially with respect to the magnetoresistance (MR) behavior. This is due, on the one hand, to the progress in the preparation of high mobility heterostructures, in which the impurities are separated from the 2D electron gas by a thick spacer, and also of 2D electron systems with artificial scatterers or modulating potential (antidot lattices, weak modulated one-dimensional structures etc). And on the other hand, it is due to a significant theoretical progress made in the understanding of the quasiclassical MR due to the memory effects that are not included in the Boltzmann theory.

We report the observation of a large quasiclassical positive magnetoresistance in a high mobility 2D electron gas in a AlGaAs/GaAs heterostructure. The magnetoresistance $\rho_{xx}(B)$ does not saturate with magnetic field and increases as $\rho_{xx}(B) \sim B$. In the antidot lattice this MR follows after a negative MR. We show that the behavior of the MR in both cases is well described by the recent theory advanced in [1] where nonsaturating positive MR is the consequence of a concurrent existence of short and long range scattering.

The experimental samples were: 1) A two-dimensional electron gas (2DEG) in a AlGaAs/GaAs heterostructure with the mobility $\mu = (4\text{-}10)\cdot 10^5$ cm^2/V·c and the electron density $N_s = (1.5 – 5)\cdot 10^{11}$; 2) An antidot lattice fabricated on the basis this 2DEG. The magnetoresistance of these samples was measured in magnetic fields up to 15 T and at temperatures 1.6 – 40 K. At the lowest temperature the ordinary SdH oscillations can be seen (fig.1). Increasing the temperature results in a decrease of these oscillations which practically disappear at 30-40 K. According to the conventional Boltzmann approach no magnetoresistance should be observed in this case and one would expect $\rho_{xx}(B) = \rho_{xx}(B=0)$. On the contrary, in our experiment ρ_{xx} increases with the magnetic field approximately as $\rho_{xx}(B) \sim B$ without any saturation up to highest magnetic field corresponding to $\omega_c\tau = 10^3$. The samples with the antidot lattice behave in a more complicated way (fig.2). In the magnetic field range 0 – 1 T a large negative magnetoresistance appears which is due to rosette trajectories. However, at magnetic fields about 1 T this negative MR is replaced by a positive MR. Thus we observe a non-monotonic beahavior of $\rho_{xx}(B)$

We compare the above results with the recently advanced theory of magnetoresistance in a high mobility 2D electron gas [1] in the presence of a short- and long-range disorder. According to this theory, while $\rho_{xx}(B)$ would vanish in the limit of large B when only one type of disorder is present, it is expected to keep increasing with B in the case where there are simultaneously two types of the disorder: a short range (impurities, hard discs) and a smooth long-range disorder. In the case of a “hydrodynamic limit” the theory predicts a large positive MR with the asymptotic form $\rho_{xx}(B) \sim B^{0.8}$ which is close to that observed experimentally in the unpatterned high mobility samples. For intermediate magnetic fields in a dilute antidot array this theory predicts a strong negative MR which leads to a nonmonotonnic behavior of $\rho_{xx}(B)$ also observed in the experiment (fig.2).

1. D.G.Polyakov, F.Evers, A.D.Mirlin, and P.Wolfe, PRB, B64, 205306 (2001)

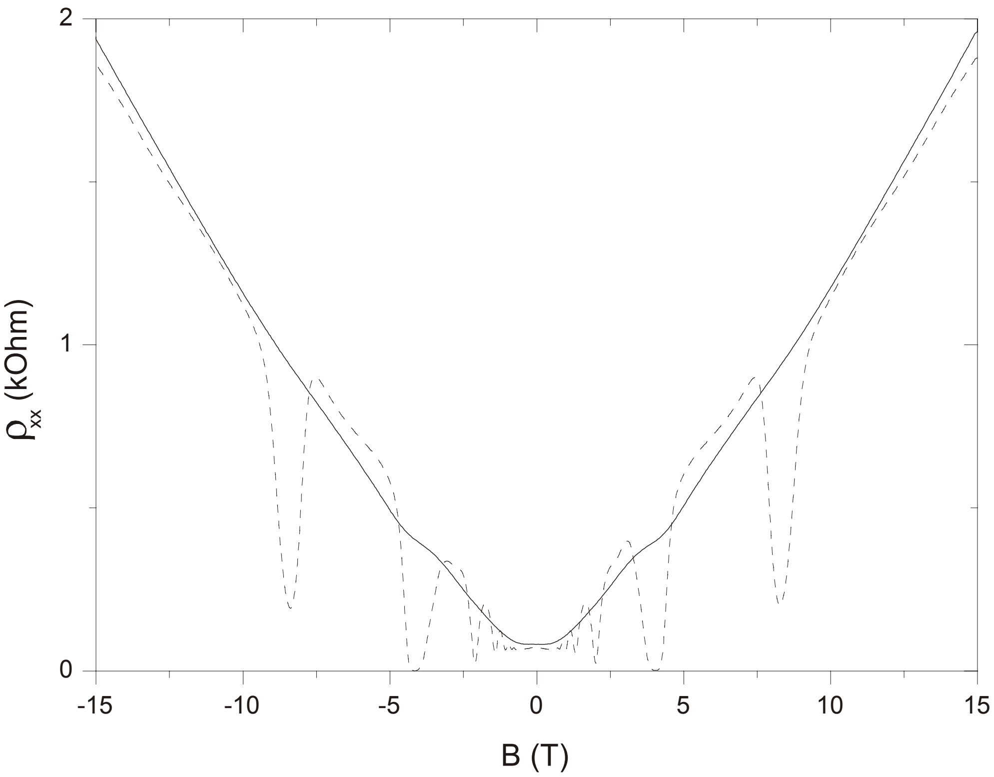

Fig.1. $\rho_{xx}(B)$ at low (3.7 K, dashed curve) and high (29.5 K, solid curve) temperatures in high mobility 2DEG

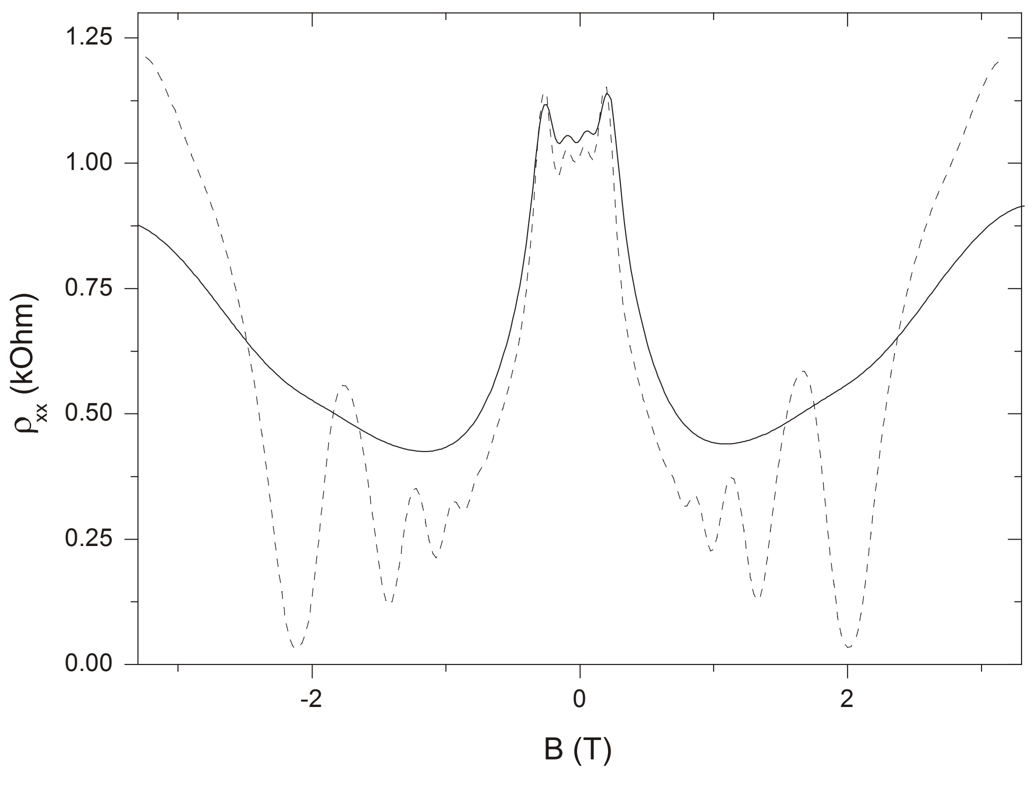

Fig.2. $\rho_{xx}(B)$ at low (3 K, dashed curve) and high (16.1 K, solid curve) temperatures in 2DEG with antidot lattice