# Transport of the Quasi-Three-Dimensional Hole Gas in a Magnetic Field in the Ultra-Quantum Limit

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The Hartree-Fock approximation predicts several electronic phases for three-dimensional electron gas (3DEG) in a strong magnetic field in the extreme quantum limit due to the electron-electron interaction effects [1]. It has been proposed, that the ground state changes from uniform density states to a charge density wave state and then to a Wigner crystal, when magnetic field increases. Behaviour of the correlated phases strongly depends on the parameter $\mathbf{r_s}=(4\pi n_{bulk}/3)^{-1/3}a_B^{-1}$, where $a_B$ is the effective Bohr radius, $n_{bulk}$ is the bulk concentration. However, many body effects in low density three-dimensional electron gas in the presence of a strong magnetic field have not yet been identified unambiguously.

The best candidate for the study of three-dimensional (3D) many-body effects in a strong magnetic field is a remotely doped wide parabolic quantum well (PQW), because it allows to form a wide (~1000 A) layer of dilute, high mobility carriers with a uniform density. In peprendicular magnetic field such system behaves as a two-dimensional electron gas with several subbands occupied. However, the energy spectrum of the electrons in a wide PQW in the presence of a strong in-plane magnetic field is expected to be identical to the energy spectrum of a pure 3D systems, since magnetic length in typical magnetic field B~10 T is much smaller than the width of the well. Recently the features has been observed in the magnetoresistance of a wide PQW with electrons at fields three times larger than fundamental field corresponding to depopulation of the last Landau level [2]. The dimensionless interelectron spacing $\boldsymbol{r_s}$ was around 3 in these wells. In present work we report magnetotransport measurements of ***3D holes*** in AlGaAs parabolic quantum wells with different widths (1000 - 3000 Å) in the presence of the in-plane magnetic field $B_{II}$. Interaction parameter $\boldsymbol{r_s} \approx 14$ ( $m^*=0.4m_0$ ) leads to more pronounced many –body effect, than we found for electrons. Samples were grown on (311)A GaAs substrate, and peak mobility was around $10^5$ $cm^2/Vs$, which is much higher than in conventional 3D semiconductors films.

We have observed anomalous oscillations in the magnetoresistance at low temperature T=50 mK in the quantum limit. Amplitude of the anomalous oscillations is much larger than diamagnetic Shubnikov oscillations at low fields. Position of the oscillations can not be identified with spin splitting. In parabolic well the bulk Fermi energy in depends on the bare well width W, therefore ultra quantum limit occurs at lower magnetic field in wider well. We found that anomalous oscillations in the quantum limit moves to lower magnetic field in accordance with the shift of the last Landau level minima (n=1). The oscillations have strong temperature dependence with activation energy ~ 0.04 meV. We atribute these anomalous oscillations to the formation of the correlated electronic states. The behavior of this phase is not consistent with prediction of the Hartree model [1].

## References

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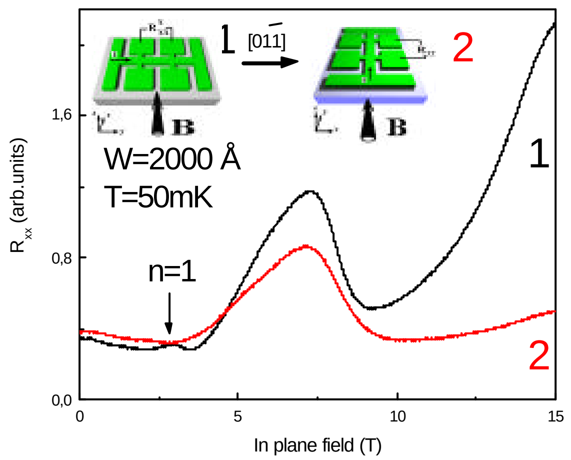
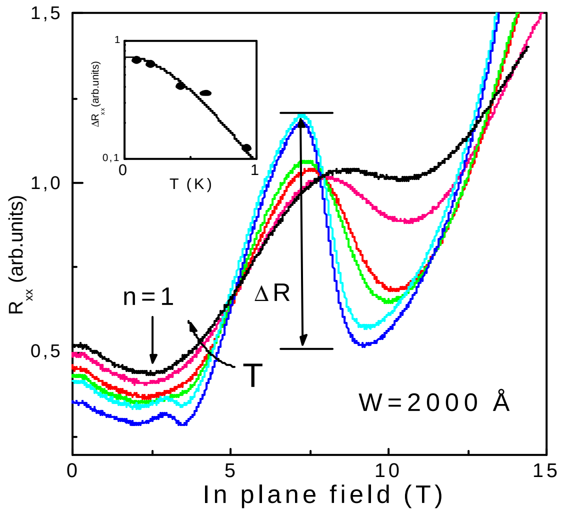
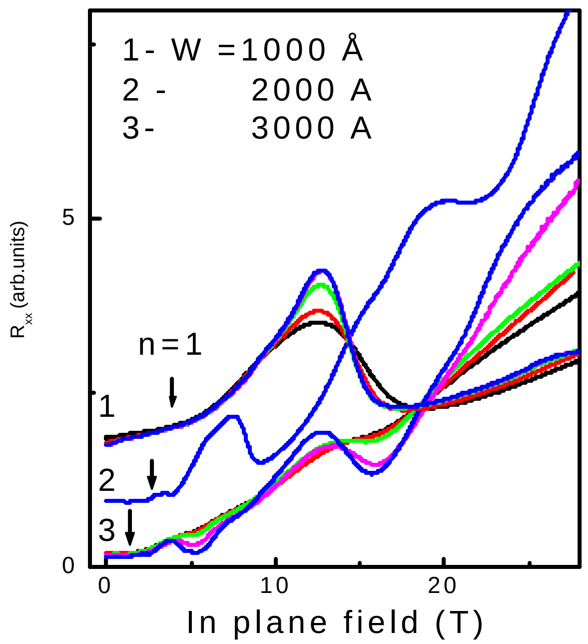
2. G.M.Gusev et al, Phys.Rev.B, **65**, 205316 (2002).




Magnetoresistance of a 2000 Å PQW as a function of the in-plane magnetic field at T = 50 mK. In-plane magnetic-field is directed along to the x axis, parallel to the current flow (1) and perpendicular to the current (2) . Inserts - schematic view of the sample and experiment geometry.




Magnetoresistance of a 2000 Å PQW as a function of the in-plane magnetic field for different temperatures (1.1K-50mK). Insert- circles shows temperature dependence of the peak. Line- dependence T/Sinh(T/0.24(K)).




Magnetoresistance of a 1000, 2000 and 3000 Å PQW as a function of the in-plane magnetic field. Curves are shifted for clarity. Curves for 1000 and 3000 Å PQW are shown for different temperatures (1.1K-50mK, blue lines –50 mK). Ultra quantum limit n=1 is indicated by arrows.