Anomalous Density Dependence of Anisotropic Resistivity at Half-filling of $N \geq 2$ Landau Levels in Short-period Unidirectional Lateral Superlattice

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States of two-dimensional electron system (2DES) at half-filling of high ($N \geq 2$) Landau levels (LLs) has been attracting much interest since the discovery of strongly anisotropic transport in ultraclean (mobility $\mu \geq 1000$ m^2/Vs) plain 2DESs [1]. The strong anisotropy is now widely believed to be the manifestation in transport of theoretically predicted unidirectional charge density wave (UCDW) state [2]. In search for direct experimental evidence of the UCDW state, we have been doing transport measurements on 2DESs with short-period ($a = 92$ nm) external modulation [3,4]. The UCDW with period a_{CDW} is expected to exhibit strong response to the external modulation whose period a is close to a_{CDW}, which is theoretically estimated to be order of 100 nm (4-8 times the magnetic length $l = \sqrt{\hbar / eB}$).

The device for the present study is made of GaAs/AlGaAs 2DES ($\mu = 70$ m^2/Vs), lithographically defined into 40×40 μm^2 square with eight arms. A grating is placed on the surface to introduce modulation (see the inset of Fig 3 (a)). By selecting current and voltage probes properly, resistivity both perpendicular (R_{xx}) and parallel (R_{yy}) to the modulation can be measured within a single device. Fine tuning of the ratio a / a_{CDW} is done by varying the electron density n_e, by altering the magnetic length for a fixed filling factor ν. In our previous studies [4], we used successive LED illumination to vary n_e. However, it was difficult to achieve very high n_e resolution. More importantly, one can only increase the density by this method. Therefore the method does not allow access to the hysteretic behavior that might take place in collective phenomena such as CDW formation. In the present study, we use back gate at about 100 μm distance from the 2DES plane.

Figs. 1 and 2 show evolution of magnetoresistance traces by varying back gate voltage V_{bg} (varying density n_e) in the filling factor range of 4-8 ($N = 2$ and 3 LLs). The traces do not change very much for resistivity along the modulation (R_{yy} Fig. 2) as is expected for this rather narrow n_e range. However, for resistivity across the grating (R_{xx} Fig. 1), the height of the transition peaks between adjacent quantum Hall states increase rapidly with density for $n_e \geq 1.98 \times 10^{15}$ m^{-2}. The trend is more conspicuous for higher spin subbranch (ν=9/2, 13/2) of each LLs. For $n_e \geq 1.98 \times 10^{15}$ m^{-2}, the ν=9/2 peak becomes very high and somewhat unstable as is evidenced by the emergence of sharp protrusions and ditches.

The instability of the peak is more impressively demonstrated in Fig. 3. The thick and thin traces are both for R_{xx} with the same back gate voltage. The thin trace was taken after V_{bg} experiencing various values. At lower magnetic fields, the two traces almost completely overlap each other, attesting that electron densities are almost exactly the same. At around ν=9/2, however, deep minimum observed in the thick trace, which probably represents optimized version of what we observed before [3], is gone and sharp peak appears instead. In contrast, R_{yy} (dotted line) is quite featureless. The development of peak/dip may possibly represent the development of UCDW, with the hysteretic behavior resulting from the reorientation of UCDW. Similar hysteretic behavior is also reported for ultrahigh mobility plain 2DESs [5].

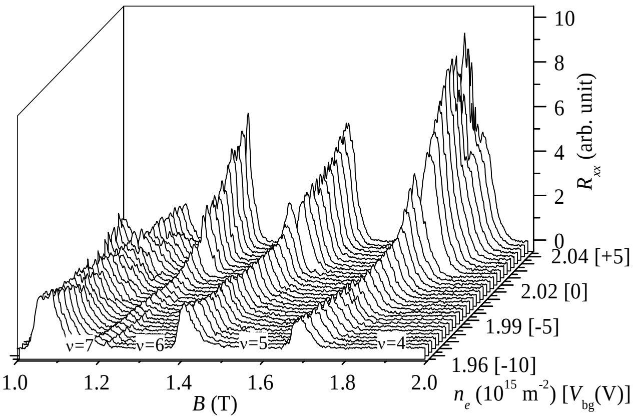

Fig. 1 Evolution with electron density of magnetoresistance traces perpendicular to the modulation.

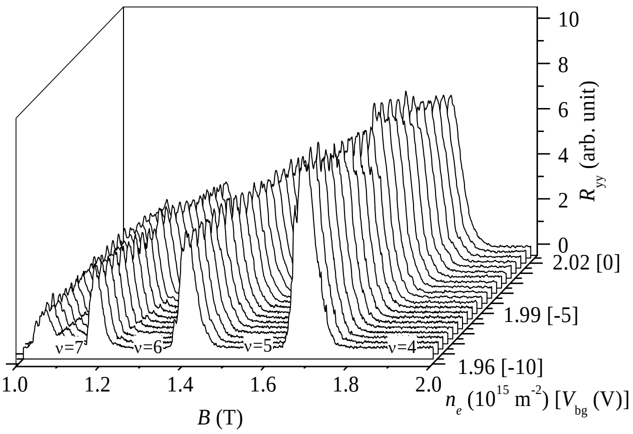

Fig. 2 Evolution with electron density of magnetoresistance traces parallel to the modulation.

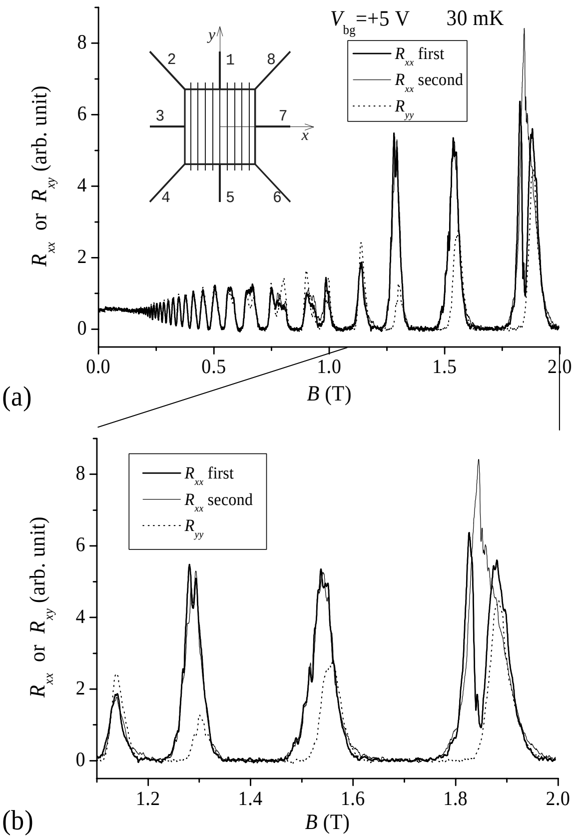

Fig. 3 (a) Magnetoresistance traces perpendicular (solid curves) or parallel (dotted curve) to the modulation for the same back gate voltage. Thick and thin curves are for different runs. (b) Blow up of (a) for N=2 and 3 LLs.

[1] M. P. Lilly *et al.*, Phys. Rev. Lett. **82** (1999) 394; R. R. Du et al. Solid State Commun. **109** (1999) 389.

[2] A. A. Koulakov et al., Phys. Rev. Lett. **76** (1996) 499; R. Moessner and J. T. Chalker Phys. Rev. B **54** (1996) 5006.

[3] A. Endo and Y. Iye, Solid State Commun. **117** (2001) 249.

[4] A. Endo and Y. Iye, Phys. Rev. B **66** (2002) 075333, and Physica E in press.

[5] J. Zhu et al., Phys. Rev. Lett. **88** (2002) 116803.