Temperature Scaling Anomalies in Quantum Hall Plateau Transitions with Ultra-Short Period Lateral Superlattice

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Abstract. The quantum Hall plateau transitions in GaAs/AlGaAs quantum wells with ultrashort (12 nm) period unidirectional potential modulation have been studied. For the magnetoresistance ρ_{yy} with probe current passed along the stripe, the transition peak width decreases very rapidly as temperature is lowered below 1 K, yielding substantially smaller values of localization length exponent than the canonical cases. By contrast, the ρ_{xx} peaks appear to conform with the canonical scaling behavior. The origin of this anomalous exponent is sought in the directionally correlated disorder characteristic in these systems.

Keywords: GaAs/AlGaAs, quantum Hall plateau transition, localization
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Two-dimensional electron system (2DES) formed at semiconductor heterointerface, GaAs/AlGaAs in particular, offers an ideal experimental stage for various aspects of electron transport - most notably integer and fractional quantum Hall (QH) effects. The QH plateau transition is one of the most thoroughly investigated examples of localization-delocalization transition [1-3]. The localization length ξ diverges as $|E-E_c|^{-\gamma}$, when the energy E approaches the Landau Level (LL) center E_c and that the scaling exponent γ is believed to depend only on the fundamental symmetry of the systems. The canonical behavior is that $\gamma \sim 2.3$ for spin-polarized LLs and ~ 4.6 for spin-degenerate LLs[4]. Our recent study on bilayer QH system has shown $\gamma \sim 2.3$ for layer-degenerate spin-polarized LLs[5], contrary to a theoretical prediction that $\gamma \sim 4.6$.

In this work, we have investigated the QH plateau transitions in lateral superlattice (LSL), *i.e.* periodic structure built upon 2DES, with ultrashort (12 nm) period unidirectional modulation. We have found that the values of γ in these samples are substantially smaller than the canonical cases. The present system is unique in that the LSL period is much smaller than those typically fabricated by lithographical technique and is comparable to the magnetic length in the field range of interest.

The ultrashort period LSL quantum well wafers were prepared by the group in Osaka University by molecular beam epitaxy utilizing step-bunching growth mode on the (775)B surface of GaAs[6]. By suitable tuning of the growth conditions, well-ordered periodic faceting is produced resulting in a unidirectionally corrugated GaAs/AlGaAs interface with period $a = 12$ nm as illustrated in the inset of Fig. 1. The amplitude of potential modulations due to the corrugated interface depends on the thickness L_w of the quantum well layer. Measurements of the anisotropic magnetotransport were made on samples prepared in an L-shaped Hall bar pattern. In an earlier paper, we discussed the QH effect in these samples[7]. Theoretical treatment of the electronic structure of the present system is given by Zheng and Ando[8]. In this paper, we reanalyze the results for the $L_w = 10$ and 7 nm samples in the context of scaling of QH plateau transition. Scaling theory of QH transition predicts a temperature scaling of the width of the transition peak, $\Delta B \propto T^{\kappa}$, where the exponent κ is related with the localization length scaling exponent γ by $\kappa = 1/\gamma z$, z being the dynamical scaling exponent known to be unity. The characteristic length scales of the present system include, the modulation period $a = 12$ nm, the magnetic length at a typical field $\ell_B \sim 10$ nm, and, the correlation length of the random potential $R_{\rm cor} \sim 10$ nm (assuming that it is comparable to the spacer layer thickness)

Figure 1 shows the traces of magnetoresistance for the $L_w = 10$ nm quantum well at different temperatures ranging from 40 to 1000 mK. The resistance with the current passed parallel to the stripes (ρ_{yy}) is shown. It is seen that the width of the magnetoresistance peak decreases very rapidly as temperature is lowered below 1 K. By contrast, the behavior of resistance peak in ρ_{xx} (current perpendicular to the stripes) looks similar to the canonical case. Two sets of measurements made on the same sample before and after illumination with a light-emitting diode have yielded similar results.

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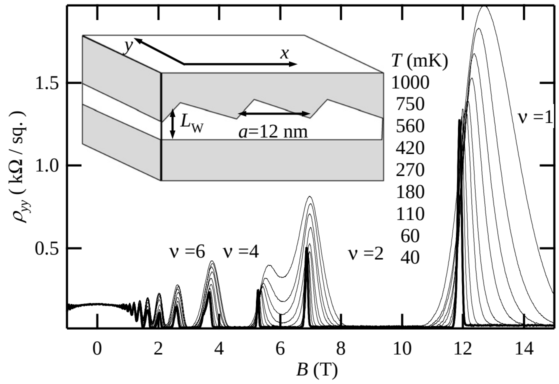

FIGURE 1. The insets shows the sample structure. Magnetoresistance traces of the ultrashort period LSL quantum well ($L_w = 10$ nm, before illumination).

TABLE 1. Localization length exponent γ for various filling factors in the quantum well with $L_w =$ 10 nm.

ν	1-2	2-3	3-4	6-8
γ from ρ_{yy} before illum.	1.3	1.5	1.4	3.1
γ from ρ_{yy} after illum.	-	1.4	1.3	3.1
γ from ρ_{xx} after illum.	-	2.3	2.1	4.4

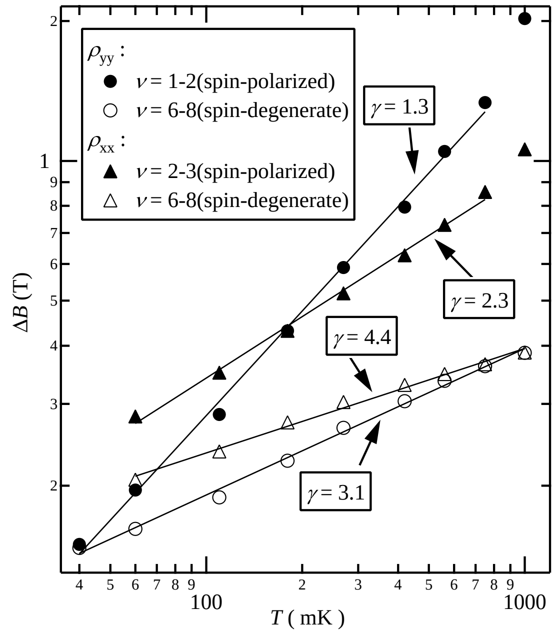

FIGURE 2. Width ΔB of the magnetoresistance peaks ρ_{yy} shown in Fig.1 and ρ_{xx} after illuminated as a function of temperature T.

Figure 2 shows typical results of the temperature scaling of the peak width ΔB corresponding to the QH plateau transitions between various filling factors ν. Four sets of data shown in this figure represent ρ_{yy} and ρ_{xx} for spin-polarized and spin-degenerate LLs, respectively. Similar scaling plots for the $L_w = 7$ nm quantum well sample yielded less straight lines, so that the value of exponent was difficult to extract unambiguously. However, the qualitative behavior is consistent with the results for the $L_w = 10$ nm quantum well sample.

Table 1 summarizes the values of localization length exponent γ obtained in the present study. The values of γ for ρ_{xx} are consistent with the canonical values, *i.e.* ~ 2.3 for spin-polarized case and ~ 4.6 for spin-degenerate case. By contrast, significantly smaller values of γ are obtained for ρ_{yy}; $\gamma \sim 1.4$ and ~ 3 for the spin-polarized and spin-degenerate cases, respectively. It is noteworthy that the doubling of the γ value for the spin-degenerate case seems to hold in this case.

In the field range of interest, σ_{xx} and σ_{yy} is much smaller than σ_{xy}, σ_{yx} so that $\rho_{xx} = \sigma_{yy}/(\sigma_{xx}\sigma_{yy} - \sigma_{xy}\sigma_{yx})$ essentially reflects σ_{yy}, and ρ_{yy} reflects σ_{xx}. Therefore the former is principally associated to ξ_y and the latter to ξ_x.

The question is, how the anisotropy introduced by unidirectional modulation affects the scaling behavior of the localization length. To the best of our knowledge, the situation exactly corresponding to the present system has not been discussed theoretically. Huckestein considered the effect of periodic potential on the QH transition, and concluded that the effect is expressed in terms of irrelevant scaling index[2]. Even if the irrelevant perturbation becomes eventually irrelevant, how it affects the phenomenon in the practical temperature range critically depends on the value of the irrelevant scaling index. This may be the reason for the observed deviation of the localization length exponent for ρ_{yy}. Unfortunately, it is difficult at the moment to put this speculation on a quantitative basis.

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