On the low-field insulator-quantum Hall conductor transitions

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The low-field insulator-quantum Hall conductor (I-QH) transitions in the integer quantum Hall effect (IQHE) have attracted much attention. According to the global phase diagram (GPD) suggested by Kivelson, Lee and Zhang, [1] in the IQHE the I-QH transitions are between the insulating state and ν=1 quantum Hall state, where ν represents the Landau level filling factor. On the other hand, it is shown that at low magnetic fields a two-dimensional (2D) system can enter quantum Hall states with arbitrary ν from the insulating state and hence the low-field I-QH transitions do not always follow the GPD [2,3]. It is argued that the low-field I-QH transitions inconsistent with the GPD are not phase transitions, but are crossovers from weak localization to Landau quantization under finite temperatures and/or sizes [4]. Since weak localization and Landau quantization are important when $\mu B<1$ and $\mu B>1$, respectively, a crossover occurs near a magnetic field $B\sim 1/\mu$. Here μ corresponds to the mobility. Huckestein's argument can explain why the low-field I-QH transitions inconsistent with the GPD usually occur when the ratio $\rho_{xy}/\rho_{xx}\sim\mu B$ is close to 1, where ρ_{xy} and ρ_{xx} are the Hall and longitudinal resistivities. However, D. N. Sheng *et al.* [5] and C. F. Huang *et al.* [6] showed that the low-field I-QH transitions can have properties of phase transitions even when they do not obey the selection rules of GPD.

To further study the low-field I-QH transitions, we performed a magneto-transport study on a 2D GaAs electron system containing self-assembled InAs quantum dots. Figure 1 shows the curve $\rho_{xy}(B)$ at the temperature T=0.52 K and the curves of $\rho_{xx}(B)$ at T=0.52-1.60 K when the gate voltage V_g=-0.07V. We can see in Fig. 1 that the sample enters the quantum Hall state of ν=4 directly from the low-field insulator as $B=B_c\equiv 0.9$ T, and hence we observed a low-field I-QH transition inconsistent with the GPD. When $B<B_c$, the sample behaves as an insulator since ρ_{xx} increases as T decreases. On the other hand, as shown in Fig. 1, Shubnikov-de Haas (SdH) oscillations can be identified when $B>B_s\sim 0.45$ T. The inset of Fig. 1 shows the curves between the magnetic fields B_s and B_c.

Since the insulating behavior and SdH oscillations are features of low-field localization and Landau quantization, respectively, the region between B_s and B_c corresponds to the crossover in the Huckestein's argument. The crossover contains the point B_a at which ρ_{xy}/ρ_{xx}~1 when T=0.52K-1.60K, but B_a is *not* the critical point of the I-QH transition and the crossover covers 0.45 T in B rather than only a small region near B_a. At the critical magnetic field B_c, actually ρ_{xy}/ρ_{xx} is about 1.5>1. From our study, therefore, a crossover from the low-field localization to Landau quantization can cover a wide range with respect to the magnetic field rather than only a small range around the critical point of an I-QH transition. With increasing the magnetic field, the crossover can be followed by the low-field I-QH transition inconsistent with the global phase diagram. In such a transition, in fact, at the critical point the relation that ρ_{xy}/ρ_{xx}~1 can fail.

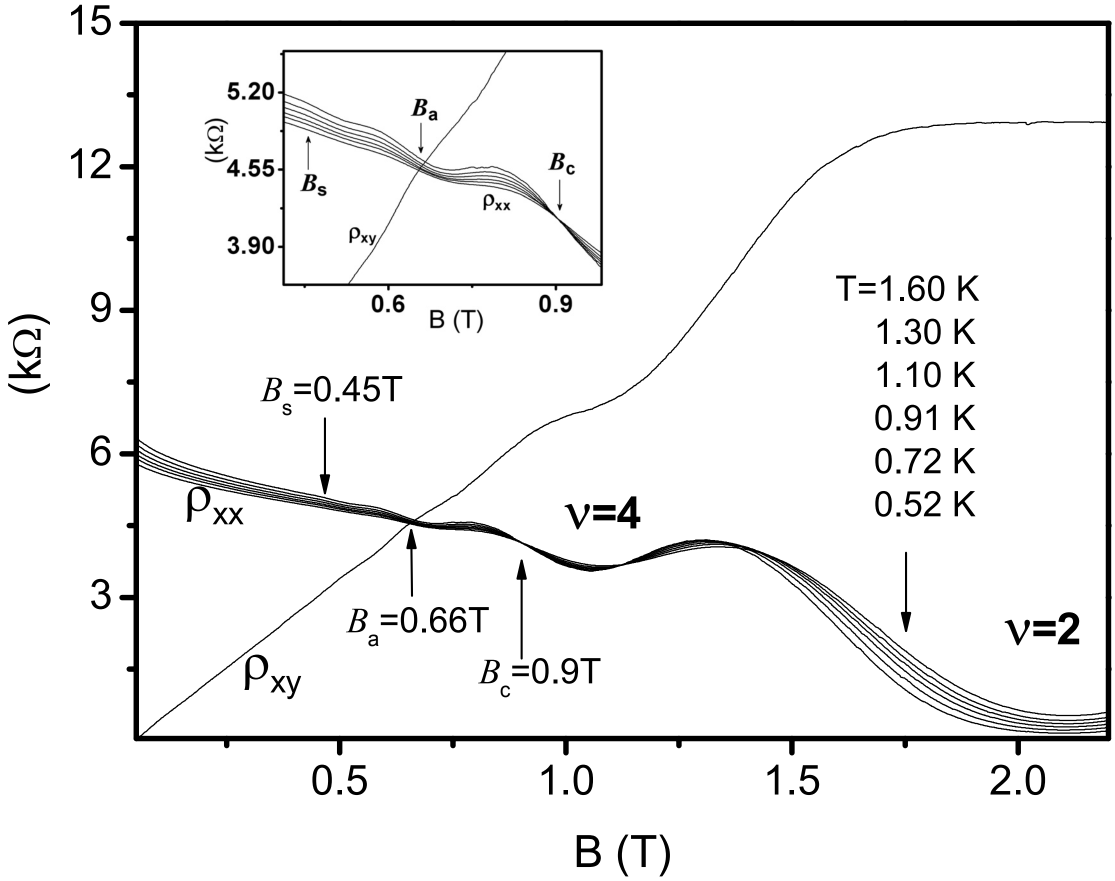

Figure 1 The curves of ρ_{xx}(B) at T = 0.52 – 1.60 K. The curve ρ_{xy}(B) at T=0.52 K. The inset shows the curves between the magnetic fields B_s and B_c.

References:

[1] S. Kivelson, D.-H. Lee and S.C. Zhang, Phys. Rev. B **46**, 2223 (1992).
[2] S.-H. Song *et al.,* Phys. Rev. Lett. **78**, 2200 (1997).
[3] C. H. Lee *et al.,* Phys. Rev. B **58**, 10629 (1998).
[4] B. Huckestein, Phys. Rev. Lett. **84**, 3141 (2000).
[5] D. N. Sheng *et al.,* Phys. Rev. B **64**, 165317 (2001).
[6] C. F. Huang *et al.,* Phys. Rev. B **65**, 045303 (2002).