Magnetic-field-induced phase transitions in a Si/SiGe hole system

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Seminal theoretical work on the integer quantum Hall effect describes a two-parameter scaling [1] in which both the dissipative conductance σ_{xx} and the Hall conductance σ_{xx} vary with the sample length L. The renormalisation-group function can be illustrated by flow lines. After successive length-scale transformation the flow lines are directed towards fixed points (σ_{xx}, σ_{xy}) = (0,n) (in units of e^2/h) in which n = 0,1,2,…. is the Landau level index. In addition to these "localization fixed points" which describe the localisation of the electron wavefunctions near the Fermi energy, there are "intermediate-coupling fixed points" on $\sigma_{xy} = n+1/2$ which are related to transitions between quantum Hall states. Note that this theory was developed for zero temperature $T = 0$ and the length scale transformations are accomplished by varying the sample length L. It has been shown that, in practice, the effective sample size can be varied by changing the temperature [2]. The studies of the "temperature-driven flow lines" in GaAs systems and more recently in Ge/SiGe systems [3] support the two-parameter scaling theory of Pruisken [1]

Recently there has been a great deal of interest in Si/SiGe hole systems. For example, at a Landau level filling factor ν = 1.5, an insulating phase observed in such a system is not fully understood at present. It is called a "Hall insulator" since although ρ_{xx} approaches infinity, the Hall resistivity remains finite at approximately $h/(2e^2)$. This magneto-driven transition within the global phase scheme of Kivelson, Lee and Zhang. Moreover, or a Si/SiGe hole gas, the observed quantum Hall states are off odd filling factors at low magnetic fields, indicating that spin-splitting is comparable with the spacing between adjacent Landau levels. This provides an interesting system for the study of magnetic-field-induced transitions in the quantum Hall effect. In this paper, we present low-temperature transport measurements on a Si/SiGe hole system. In particular we report a study of the temperature-driven flow lines in the vicinity of the "Hall insulator" regime. We also observe magnetic-field-induced phase transitions which correspond to the temperature-independent points in σ_{xx} as shown in figure 1.

The temperature-driven flow lines are complicated thus we divided our results into four parts as shown in Fig. 2(a)-(d). It is evident that (σ_{xx}, σ_{xy}) = (1,0) for $\nu \to 1$, as illustrated by the T-driven flow lines as shown in Fig.2(a). Figure2 (b) and 2 (c) show the T-driven flow diagrams near the two critical points B_{B1} = 8.1 T and B_{B2} = 9.8 T, respectively. It is evident that (σ_{xx}, σ_{xy}) = (0,0) as $T \to 0$ for the "Hall insulator" since ρ_{xx} approaches infinity whereas ρ_{xy} remains finite. We can clearly see that the directions of the flow lines in the "Hall insulator" are different from those near a quantum Hall state. B_{B2}, labelled as full squares, is, in fact, the boundaryof the "Hall insulator" as well as the intermediate-coupling fixed point. It is worth mentioning that near B_{B1}, ρ_{xy} slowly varies at different temperatures. Thus, although B_{B1} corresponds to the boundary of the "Hall insulator" regime, the intermediate-coupling fixed point is estimated to be at around B = 8.2 T, ~0.1 T higher than B_{B1}. To the right of this fixed point, the flow lines all show a "kink". In contrast, to the left of the fixed point, the lines flow directly (0,0) as $T \to 0$. The main finding is that, in contrast to a *single* intermediate-coupling fixed point between neighoring quantum Hall states previously predicted and observed, there are *two* intermediate-coupling points in a SiGe hole system. The reason for this is the existence of the "anomalous Hall insulator" near ν = 1.5. Figure 2(d) shows the T-driven flow lines for $2<\nu<3$. At around A_2, the directions of the T-driven flow lines seem ambiguous. At present, the physical origin of this effect is not fully understood and awaits further experimental and theoretical investigations. Our new experimental results on T-driven flow lines, together with the poineering work on the "Hall insulator" urge further investigations in order to understand the physical origin of this "anomalous insulating state".

Referenmces:

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[3] M. Hilke *et al.*, Nature 400, 735 (1999).

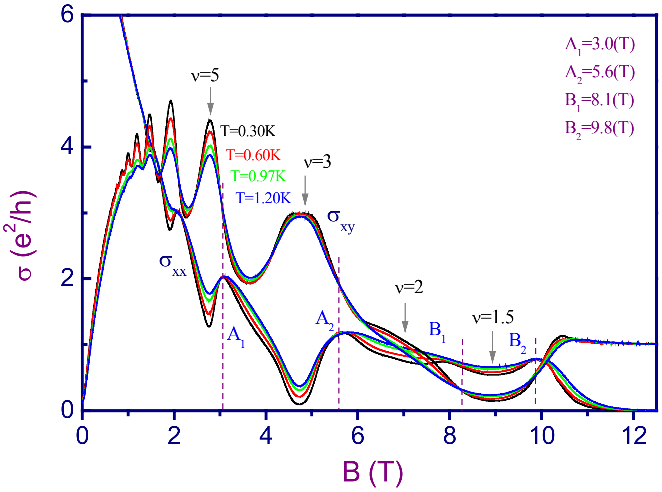

Figure 1. Conductivity σ_{xx} and σ_{xy} at various temperatures.

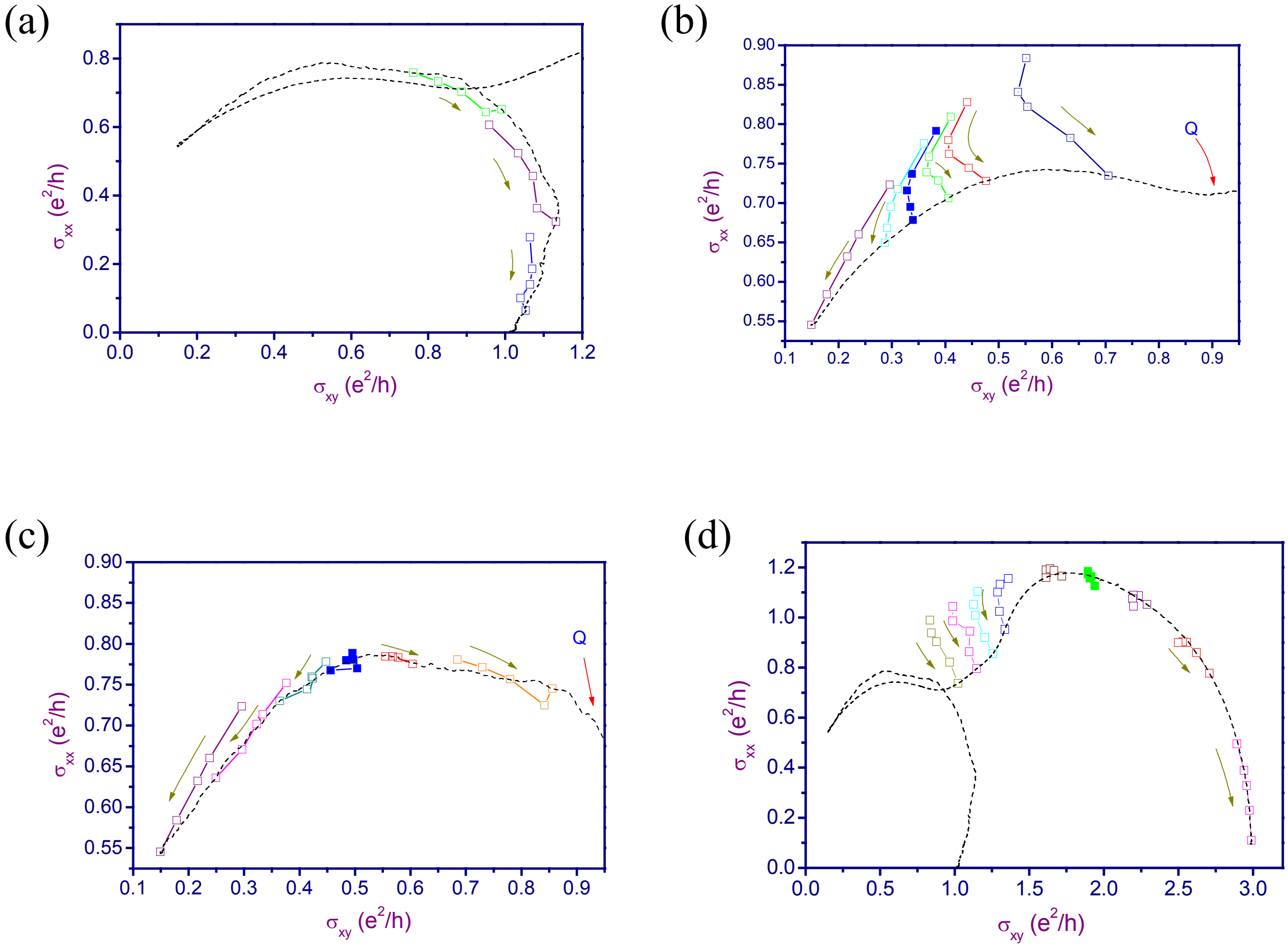

Figure 2 (a)-(d) Temperature-driven flow lines between $1 < \nu < 3$. The arrows indicate the directions of the flow lines (From high-T to low-T) and the full squares correspond to intermediate-coupling fixed points. The dotted line represents $\sigma_{xx}(\sigma_{xy})$ at T = 0.3 K.