Chapter 5. The Quantum Hall Effect in Narrow MOSFETs

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5.1 Project Description

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We are investigating the conductance of narrow MOSFETs that are subject to a strong magnetic field. This investigation was motivated by an experiment conducted by Professor Marc A. Kastner's group two years ago,[2] in which the group studied the transport properties of narrow MOSFETs (width ~ 500Å) subject to a large magnetic field of 5T to 10T. In these fields, only the lowest few Landau levels — in the quantum Hall regime — are occupied. At the same time, the cyclotron orbit is comparable to the sample width, making the finite size effect of the sample important. The experimentalists observed thresholds for large increases in conductance as a function of magnetic field, as well as ill-defined steps in the conductance of approximately $2e^2/h$. We tackled this problem using both computer simulation and analytic treatment of many-body effects.[3]

We use computer simulation to model disordered conductors subject to a large magnetic field. The model is defined on a tight binding lattice of finite width and length which is extended to infinity in both directions by connecting it to ideal lattices without randomness to simulate the source-drain leads. The novel feature of the model is that the leads are also subject to the same quantizing magnetic fields so that (1) the edge states in the leads consist of Landau level subject to a lateral boundary condition, and (2) the states at the Fermi level are edge states which are bound to the edge and propagate to the right along the upper edge and left along the lower edge. The conductance is then related to the transmission probability of these edge states using the Landauer formula. These transmission probabilities are computed numerically.

When the width of the wire is large compared with the cyclotron radius, the edge states are basically forward scattered in the disorder region so that the transmission probability is unity, leading to quantized Hall conductance of e^2/h. It is only when the width becomes comparable to the cyclotron

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[2] J. Scott-Thomas, S.B. Field, M.A. Kastner, H.I Smith, and D.A. Antoniades, *Phys. Rev. Lett.* 62:583 (1989).

[3] J. Kineret and P.A. Lee, to be published.

radius that the edge state can scatter across the width of the sample and is then reflected. The reduction in the transmission probability leads to ordinary metallic conduction. As the field is increased, the simulation shows a threshold for the appearance of quantized steps in the conductance in agreement with the experiment. The simulation also shows that in the step between plateaus, the system behaves as a metal in the sense that it exhibits conductance fluctuations in the order of e^2/h. The period of the fluctuation as given by the condition that the flux through the sample area is a flux quantum just as in universal conductance fluctuation.

The next puzzle to be resolved is understanding why the quantum Hall step is in units of $2e^2/h$. We believe that the $2e^2/h$ step is due to the presence of two degenerate valleys in the silicon interface, which is not resolved. In ordinary two dimensional samples, the valley degeneracy is resolved due to the exchange effect. It is more energetically favorable to occupy one valley first, rather than occupying both valleys equally, because the exchange energy is nonlinear in the density. However, this mechanism will be weakened in narrow wires, because the Landau level is no longer completely flat and it costs kinetic energy to preferentially occupy one valley. We calculated the exchange energy for a model system confined by a parabolic potential demonstrating this competition between kinetic and exchange terms in quasi-one-dimensional MOSFETs. We conclude that the combination of numerical simulation and analytic work to account for the many-body effect gives a quite satisfactory account of the transport properties of a narrow MOSFET wire in a quantizing magnetic field.