12.0 Quantum Transport in Low Dimensional Disordered Systems

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12.1 Effect of a Magnetic Field on Hopping Conduction in Quasi-One-Dimensional MOSFET's

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Electronic transport measurements in 1D metal-oxide-semiconductor field-effect transistors (MOSFET's) reveal unusually large fluctuations in conductance with variations in gate voltage. According to our recent work,[1] this random structure is a manifestation of Mott's variable-range hopping conduction.The original motivation for this explanation was that MOSFET wires are typically 30-70 times the localization length. Since a Mott hop covers several localization lengths, only a few hops are required to traverse the entire sample. In the hopping model, each hop is exponentially activated and the resistance of the sample is determined by a critical hop at the percolation threshold. Since the resistors have a log-normal distribution, variations of chemical potential can change the sample resistance by orders of magnitude. A recent study of resistance fluctuations as a function of sample size[2] reveals that the average of the logarithm of the resistance increases as $(\ln 2\alpha L)^{1/2}$ while the relative magnitude of the fluctuations decreases as $(\ln 2\alpha L)^{-1/2}$ where α is the inverse localization length and L the sample size. The resistance fluctuations are therefore inherent in the hopping model and not just due to finite-size effects. The similarity between resistance fluctuations in the hopping model and those observed experimentally suggests that the experiments are probing something fundamental, namely, a critical hop between a pair of localized states. This presents the exciting possibility of investigating the effect of magnetic field on an individual hop between a pair of localized states. The investigation of the effects of a magnetic field on hopping conduction is the subject of our recent work.[3]

The influence of magnetic field on variable-range hopping conduction enters through the Zeeman shift and changes in wave functions of localized states. With an increased magnetic field, we find that the Zeeman effect rigidly moves conductance fluctuations to lower or higher values of chemical potential; on the other hand, the orbital effect does not cause any systematic shifts in the fluctuation spectrum. Rigid shifts due to the Zeeman effect reflect the nature of the dominant hopping process which, in turn, is related to the relative population of singly and doubly occupied sites in the system. Together with density-of-states measurements, this information can be used to estimate the value of the intrasite Coulomb repulsion in 1D MOSFET's.

The experimental implications of our results are as follows. Orbital and Zeeman effects can be experimentally separated by the orientation of the magnetic field. If the field is parallel to the sample, we predict that the fluctuations in conductance arise because of hopping from either (a) singly occupied sites to unoccupied sites, or (b) doubly occupied sites to singly occupied sites. With an increase in magnetic field, the fluctuations associated with weak links of type (a) shift to lower while those corresponding to process (b) shift to higher gate voltages. If the magnetic field is perpendicular to the sample, both the orbital effect and the Zeeman shift influence conductance fluctuations. But systematic shifts in the conductance-fluctuation spectrum can be solely attributed to Zeeman shifts of occupied sites. Recent experiments by Webb, Wainer and Fowler at IBM are in good agreement with our predictions.

References

[1] P.A. Lee, Phys. Rev. Lett. *52*, 1641 (1984).

[2] R.A. Serota, R.K. Kalia and P.A. Lee, Phys. Rev. B *33*, 8441 (1986).

[3] R.K. Kalia, W. Xue and P.A. Lee, Phys. Rev. Lett. *57*, 1615 (1986).