

Chapter 3. Transport Through a Quantum Dot

Academic and Research Staff

Professor Patrick A. Lee, Dr. Yigal Meir, Dr. Ned S. Wingreen

Graduate Students

Jari M. Kinaret

Technical and Support Staff

Imadiel Ariel

3.1 Project Description

Sponsor

Joint Services Electronics Program
Contract DAAL03-89-C-0001
Contract DAAL03-92-C-0001

We continue the study of electron transport through a quantum dot. It is now well established both experimentally¹ and theoretically² that Coulomb blockade plays a key role in this problem and is responsible for the conductance peaks which have been observed to be periodic as a function of gate voltage. Each of these conductance peaks occurs at a gate voltage where the energy of N and $N+1$ electron state are degenerate and each peak corresponds to the addition of a single electron to the quantum dot. In the past year, the general formalism developed by Meir et al.² has been extended and applied to the case where a strong magnetic field is applied to the system. The field is strong enough so that only the lowest two Landau levels are occupied, i.e., the system would be in the integer quantum Hall regime in the bulk. The advantage of this system is that the single particle states are well known to be edge states, and the energy of these states are well understood as a function of magnetic field. Thus, the successful application of the theory to explain the experimental data³ provides strong support for the general theory² of Coulomb blockade in resonant tunneling.

Experimentally it was found that in the presence of a strong magnetic field, the location in gate

voltage of each conductance peak exhibits small periodic fluctuation. At the same time, the magnitude of each conductance peak goes through deep minima. This can be explained based on a model where the low lying states are the edge states of the first and second Landau levels. For a given conductance peak, the number of electrons on the quantum fluctuates between N and $N+1$. However, as the magnetic field is increased, the N electrons are distributed between the two Landau levels in a different way, and electrons are transferred from the second Landau level to the first. The transfer occurs when the edge state of the first Landau level crosses the edge state of the second Landau level. Thus, as a function of a magnetic field, we are watching the transfer of electrons from the second to the first Landau level, one electron at a time. Furthermore, since the dependence of the energy of the edge state on magnetic field is understood, the periodic fluctuation of the resonant energy with magnetic field can be understood. The dips in the magnitude of the conductance peak can also be explained as being due to the fact that the edge state of the second Landau level is more tightly bound, and its coupling to the leads is much smaller so that a dip occurs every time the second Landau level moves through the chemical potential of the leads. Based on this picture, quantitative calculation of the temperature dependence of the peak position was made and successfully compared with the experiment. Indeed, we now have sufficient confidence in the model that the problem can be turned around, and we can use the experiment as a spectroscopy of the single particle level, i.e., we can

¹ U. Meirav, M.A. Kastner, and S.J. Wind, *Phys. Rev. Lett.* 65: 771 (1990).

² Y. Meir, N.S. Wingreen, and P.A. Lee, "Transport through a Strongly Interacting Electron System: Theory of Periodic Conductance Oscillations," *Phys. Rev. Lett.* 66: 3048 (1991).

³ P.L. McEuen, E.B. Foxman, U. Meirav, M.A. Kastner, Y. Meir, N.S. Wingreen, and S.J. Wind, "Transport Spectroscopy of a Coulomb Island in the Quantum Hall Regime," *Phys. Rev. Lett.* 66: 1926 (1991).

extract the dependence of the edge state energy level as a function of magnetic field.

Publications

Feng, S., and P.A. Lee. "Mesoscopic Conductors and Correlations in Laser Speckle Patterns." *Sci.* 251: 633 (1991).

Kinaret, J., and P.A. Lee. "Conductance of a Disordered Narrow Wire in a Strong Magnetic Field." *Phys. Rev. B.* Forthcoming.

Lee, P.A. "Small Structures: A Laboratory for Studying Strongly Interacting Systems," *Pro-*

ceedings of the Taniguchi Symposium on Mesoscopic Physics 1991. Shima, Japan. Forthcoming.

McEuen, P.L., E.B. Foxman, U. Meirav, M.A. Kastner, Y. Meir, N.S. Wingreen, and S.J. Wind. "Transport Spectroscopy of a Coulomb Island in the Quantum Hall Regime." *Phys. Rev. Lett.* 66: 1926 (1991).

Meir, Y., N. Wingreen, and P.A. Lee. "Transport Through a Strongly Interacting Electron System: Theory of Periodic Conductance Oscillations." *Phys. Rev. Lett.* 66: 3048 (1991).