Physics and technology in quantum point contacts

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Quantum point contacts (QPCs) are fundamental nanostructures and are used for many semiconductor nano-devices, such as laterally confined quantum dots. The quantized conductance arising from the ballistic nature of high-quality QPC has been studied longer than a decade. In this lecture, I will summarize fundamental experimental aspects of QPCs.

QPCs are fabricated by making a short narrow one-dimensional channel, which is accomplished by using split Schottky gates or other insulating techniques, such as in-plane-gates and focused-ion-beam implantation. Well-fabricated QPCs show quantized steps ($G_i=2ie^2/h$, i: integer) when conductance is controlled by channel width or channel carrier density. However, the detailed conductance characteristics depend on the confinement potential shape. A soft confinement obscures quantized features and a sharp transition between the QPC and wide two-dimensional regions at both sides of the QPC results in oscillatory features overlapping the quantized steps. I will also discuss the fundamental experimental aspects of the so-called 0.7 structure. This structure appears as an additional step around i=0.7 even for QPCs of the highest quality and is considered to be a manifestation of electron interaction in a one-dimensional channel.

When transport characteristics are measured in a perpendicular magnetic field, selection of voltage terminals becomes important. I will discuss the differences between two-terminal and four-terminal measurements. Transport characteristics of series and multi-parallel QPCs will also be addressed. A perpendicular magnetic field enhances direct transmission probability between two series QPCs and induces a large magneto-depopulation in multiple-parallel QPCs.

QPC devices are usually fabricated on semiconductor heterostructures, mainly AlGaAs/GaAs. The area between Schottky gates is bare GaAs (AlGaAs) surface in most devices so that an understanding of the fermi level at the surface is very important in determining the confinement potential. From the recent study of a back-gated heterostructure, it has become clear that a free surface of GaAs is not in thermal equilibrium at low temperatures. This surface feature may explain some instability observed in QPCs and related devices operating in a certain condition.

Finally, I will cover nanoscale characterization of QPCs. Recent nanoprobe technology enables us to directly visualize the path of electron flow through a QPC [M. A. Topinka *et al.*, Science 289, 2323 (2000)]. Such nanoscale observations deepen our understanding of actual semiconductor nanostructures.

References: There are many references for QPC experiments. I will cite these in the lecture. Here, I cite two typical textbooks on QPCs.

1. C. W. J. Beenakker and H. van Houten, “Quantum Transport in Semiconductor Nanostructures”, Solid State Physics (Ed. by H. Ehrenreich and D. Turnbull) vol.44 (Academic Press, 1991).
2. H. van Houten, C. W. J. Beenakker and B. J. van Wees, “Quantum Point Contacts”, Semiconductors and Semimetals (Ed. by M. A. Reed) vol. 35 (Academic Press, 1992).