One-dimensional quantum ballistic field effect transistor

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During the last two decades, the size of a typical field effect transistor (FET) in a microcomputer chip has been continuously reduced to the current value of just a few hundred nanometers. Its operation however remains essentially classical, i.e. in the diffusive regime.

An FET operating in the ballistic regime has been investigated by physicists and electrical engineers alike for several decades. A ballistic FET – a perfect FET – has no defects, kinks or obstacles other than a connection at each end to allow current flow through an external circuit. In the ballistic FET, significant performance improvement is expected as a consequence of the ballistic transport, and in addition the heating induced by collisions can be greatly reduced. The power dissipation or overheating caused by FETs is recognized as a major obstacle for further increase of integrated circuit (IC) densities. Therefore, the ballistic FET is set to be a new building block of ICs in the next decade or so.

Progress in nano-fabrication and optimization of a very high mobility two-dimensional electron gas (2DEG) in AlGaAs/GaAs heterostructure by molecular beam epitaxy (MBE) have allowed many laboratories to make various field effect ballistic devices. New quantum transport properties of electrons in the linear regime have been extensively investigated and demonstrated. However, turning this kind of device to a functional transistor has not yet been made possible, the key issue being the achievement of voltage gain (higher than unity). It is well known that in a classical (diffusive) FET, voltage gain is in general reached when the device operates in the non-linear or saturation regime. In the same way, voltage gain for a ballistic FET can be expected when a ballistic non-linear regime is attained.

In this work, a one-dimensional ballistic transistor has been fabricated and characterized at liquid helium temperature. The device is based on a one-dimensional channel of width a few tens of nanometers obtained by a quantum point contact (QPC) or split gate configuration on a high mobility 2DEG. High transconductances owing to one-dimensional subbands can be obtained under low drain bias and current in the quantum ballistic regime. On the other hand, the drain current-voltage characteristics as a function of the drain bias at different gate bias show that the non-linearity (leading to a low output conductance) takes place when there is a difference in the number of occupied one-dimensional subbands by the source reservoir and by the drain reservoir. We obtain a voltage gain of 2 with a drain bias of 8 mV and a power consumption of only 1.2 nW. To our knowledge, this is the first demonstration of a voltage gain in the quantum ballistic regime, and hence a 1D quantum ballistic FET.