The relationship between chaotic behavior and tunneling effect in quantum transport devices

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狭い金属ゲート(QPC)を両端に有する開放型量子ドットについて、零磁場近傍の磁気抵抗のピーク形状が、ゲート電圧を変化させることによってローレンツ型とカスプ型が交互に現れる現象が観測された。このローレンツ型とカスプ型が交互に現れる要因としては、QPCによるトンネリング効果と量子ドットによる弱局在の両方が関係しているものではないかと推測され、考察を行った。

We have studied transport properties in the low-temperature magnetoresistance through the ballistic narrow path restricted by short width metallic gates, which cause a quantum point contact (QPC) which have a saddle point potential, on the 2 dimensional electron gas (2DEG) system. An alternate and systematic variation between a Lorentzian line fitting and a cusp-like line fitting in the zero-field peaks has been observed, as sweeping the gate voltage. It indicates a possibility of existence of chaotic and regular paths on the short gated ballistic/tunneling transport. We will discuss on the quantum chaos behavior on the systematic variation between the Lorentzian and the cusp-like peakshape based on the disordered path system under the short gate, and suggest a relation with level repulsion of energy spectrum.

1. Experiment

The open quantum dot was fabricated with using electron beam lithography and lift-off processes on the surface of a GaAs/AlGaAs wafer. The electron density and mobility are 5.4×10^{15} m^{-2} and 4.2 m^2/Vs, respectively. The lithographic dimension of the dot is 0.5×0.6 μm^2 having 0.3 μm width gates on both side arms. The low temperature measurements were achieved at 70 mK by using a $^3He/^4He$ dilution refrigerator. And the measurements are carried out by using a four-terminal method with a longitudinal probe configuration as shown in FIG. 1 and a basic constant current mode with a low frequency lock-in detection.

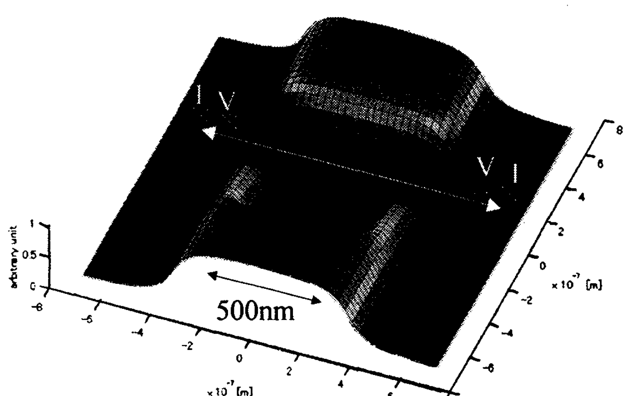

FIG.1. A surface plot of electric potential, which is controlled by gate voltage, and the schematic illustration of the measurement.

2. Results and Discussion

Regarding the zero-field (< 0.4T) peak shapes of magnetoconductance in a variety of gate voltages, some of the zero-filed peak shapes are fitted with the Lorentzian line fitting as shown in FIG. 2 (a), and others are fitted with a cusp-like lines fitting as shown in FIG. 2 (b).

These Lorentzian line fitting and cusp-like line fitting of the zero-field peak shape of magnetoresistance have been observed in chaotic and in regular systems, respectively,[1-4] and also reported in a double QPCs system.[5] In the latter case, though there is no evident closed dot, the reflections at QPCs are considered to make quasi-closed trajectories, which are affected by penetrating magnetic field.[5]

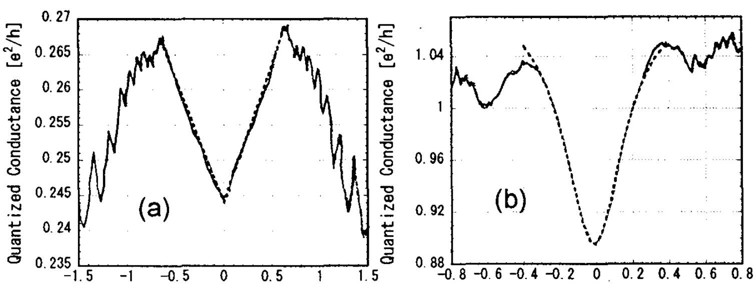

FIG.2. Zero-field peak shape of magnetoconductance correspond to (a) a cusp-like line fitting, (b) Lorentzian line fitting.

FIG. 3 shows the magnetoconductance for various gate voltages. These figures show that a Lorentzian line fitting or a cusp-like line fitting appears alternately and then very systematically. And we plotted the conductance at zero magnetic field as shown in FIG. 4. We can observe step-like gate voltage dependence of the conductance. These step-like behaviors are also observed in the case of QPCs.[6,7] Especially we remark that the Lorenzian line fitting are observed in the large gradient regions, which are considered to correspond to the tunneling regions of QPCs. Therefore we consider some explanations as mentioned below.

The tunneling region makes a quasi-closed quantum dot because of its large coefficient of reflection at channel of QPCs which are shown in FIG. 5, then quasi-closed trajectories are formed in the quantum dot. Magnetoconductance tends to be affected by the applied magnetic field, so that the zero-filed peak of magnetoresistance becomes a Lorentzian line fitting by an appearance of such quasi-closed trajectories. On the other hand, in the non-tunneling region, conductance is mainly devoted by normal channel modes and is affected with less closed trajectories. Then it doesn't tend to be affected by magnetic field and has a cusp-like line fitting.

In ref. 8, just an alternate variation between a Lorentzian line fitting and a cusp-like line fitting in the zero-field peaks is simulated and explained from the viewpoint of the existence of resonant states in the quantum dot. Though this explanation seems to be difficult to explain the step-like behavior of the gate voltage dependence of conductance, we suggest that this simulation indicates level repulsion, which is shown in the energy spectrum as a function of magnetic field and which causes quantum chaos.

And making an additional remark, plateaus of the above-mentioned step-like behaviors are observed in the regions of not only integers but also some fractions of the quantized conductance and/or thermal smearing of the steps.

Further investigations are currently in progress to confirm these explanations.

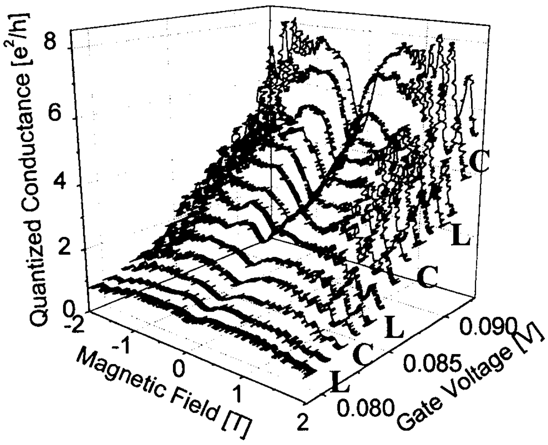

FIG. 3. Magnetoconductance in low magnetic field for various gate voltages. Mark "L" and "C" indicate a Lorentzian type and a cusp-like type, respectively.

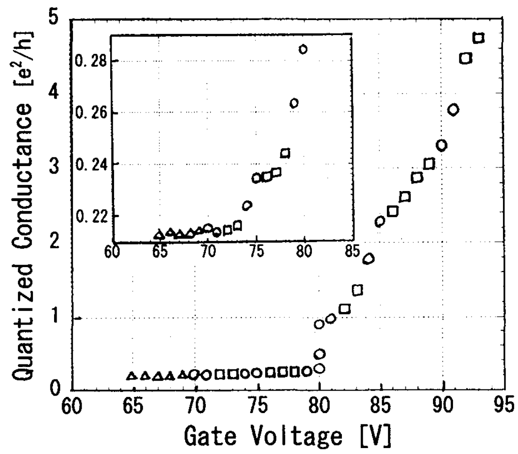

FIG. 4. Gate voltage dependence of the conductance at zero magnetic field. The open circle, open square, and open triangle indicate a Lorentzian type, a cusp-like type, and an uncertain type, respectively. The inset shows magnification of low conductance region

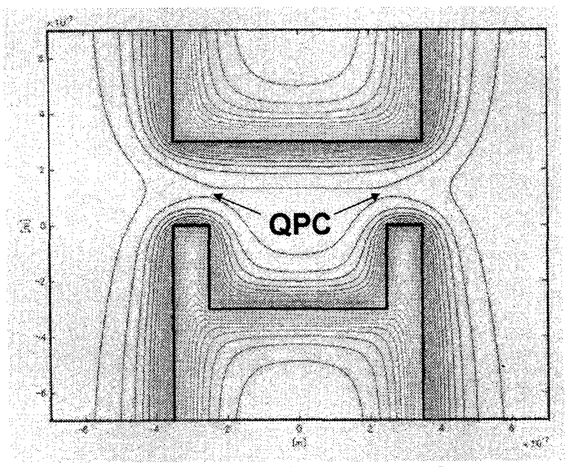

FIG. 5. A contour plot including surface gates. QPCs which are confined by depletion layers make a quasi-closed quantum trajectories in case of tunneling modes.

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