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Electron Wave Interference in the Terminal Region of Split-Gated Quantum Wire

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Aperiodic resistance fluctuations have been studied in the low temperature magnetoresistance of narrowed GaAs/AlGaAs wires. We have observed the magnetic field dependence of the Lee-Stone correlation field (B_c) in a quasiballistic narrow wire. We have focused on the width dependence of the boundary field where the B_c begins to deviate from Lee-Stone theory. As the width becomes narrow, the boundary field becomes large and a mixed contribution from wire-boundary and impurity scatterings is observed in the field dependence of the B_c. This implies that the B_c is strongly affected to a detail of scatterings of electron-waves.

1.Introduction

In near future device applications using quantum wires, it is very important to determine the phase coherent region of electron wave interference in quantum wire systems. Especially, in quasiballistic transport regime, we must consider geometrical details of the phase coherence region because of the spreading of electron waves over the both sides of the wire.

On the other hand, quasiballistic system is suitable for studying the effects of small number impurities on the performance of the electron wave guide and the effects of magnetic field on the propagation of electron waves in quantum wires. In this abstract, we focus on width dependence of the boundary field, where the correlation field, B_c, begins to deviate from Lee and Stone theory.[1)] The result suggests that correlation field analysis is a powerful tool for geometrical probe for boundary scatterings in electron wave propagation in quasiballistic narrow wires.

2.Universal Conductance Fluctuations

Quantum interference effects at quasiballistic transport regime were investigated in terms of universal conductance fluctuations (UCF), which were demonstrated in the theoretical study of Lee and Stone,[1)] in the low temperature magnetoresistance (MR) of narrow wires.

In order to determine the phase coherent length of quasiballistic wires, the negative magnetoresistance near the zero field was studied and compared with the theoretical correction based on weak localization effect in quasi-one dimensional wire. We have observed such interference effects through the UCF in the low temperature MR of both etched[3)] and split-gated GaAs/AlGaAs quasiballistic wires.

In the latter wires, since the width of the wire can be easily varied by controlling the negative gate voltage, we have obtained the wire-width and magnetic field dependences of B_c by analysing auto-correlation function of the UCF in the low field MR as following formula,

$$F(\delta B)=<R(B)R(B+\delta B)>_{av} - <R(B)>_{av}^2 \quad (1)$$

where $R(B)$ is the MR value at B and the averaging is performed over the same field interval. The Lee-Stone correlation field, B_c, can be determined as the value of δB where $F(\delta B)$ takes one half of the original $F(0)$ value. Then, B_c corresponds to the change in B during a phase coherent period by an order of one flux quantum, h/e.

At lower fields, B_c is almost field independent and gives a measure of the field scale of the interference of the electron waves.[1)] On the other hand, at higher fields ($\omega_c\tau>1$), Landau quantization becomes dominant and the Lee-Stone treatment, based on perturbation, is difficult to apply to those systems. As the field increases, suppression of interference effects has been observed and B_c shifts to a higher field. It seems that the effective area for the interference channels is reduced by the high magnetic field.

Here, it is also important to clarify the field dependence of the B_c. We can discuss the dynamical properties of the electron waves under the fields by using field dependent transport parameters. However, the field dependence is not so simple since the conventional perturbation theory[2)] does not explain sufficiently the experimental results obtained.[3),4)]

3. Experiments

Using Al metal gates the split gated structure was fabricated on GaAs/AlGaAs wafer having low temperature mobility of 8 m^2/Vs at 4.2 K. The length was 6 μm and the elastic mean free path was 0.9 μm. The wafers were patterned into standard Hall bar geometries with a width of 100 μm and a voltage probe separation of 120 μm. The lithographic gap between the gates was 0.6 μm and the low temperature transport was expected to be in the quasiballistic regime.

The low temperature measurements were performed with using SCM in magnetic fields up to 8 T. As for split gated wire, we also analyse the B_c by using eq. (1) for the UCF of low temperature MR.

4. Results and Discussion

Typical results of the analysis is shown in Fig.1. Considering a certain boundary field, defined at $\omega_c\tau=1$, we can roughly estimate a mean free path in the case of a diffusive wire. However, in our quasiballistic wire of the width, W, such a boundary field, B_0, should be defined by $2r_c=W$, where r_c is cyclotron radius, instead of above criterion of $\omega_c\tau=1$. And B_c seems to increase slowly around the boundary field, B_0, and the deflection is not clear compared with the case of slight diffusive wire. Although B_c clearly increases above B_0, it is difficult to determine the field dependence. Therefore, the field dependence seems to be related to the mobility, the boundary roughness and the shape of the wire.

We can obtain the gate voltage dependence of the wire as shown in Fig. 2. B_0 is seen to increase as the gate voltage is increased. If the B_0 correspond to the same deflection field as discussed in diffusive case, B_0 should be defined with two elastic scattering effects of a criterion of $\omega_c\tau=1$ and a relation of $2r_c=W$. Therefore, we must introduce a new characteristic length or scale in such a case from two scattering processes.

Also, we found that B_0 increases with decreasing of W. Then we can obtain the width, W_{max}, at an upper limit. Probably the real width of the wire is smaller than W_{max}, because we must consider the development of the coherent interference area of the electron waves for quasiballistic transport regime.[5)] B_c must feel the extension of the coherent area at the wire edge and the B_c becomes an averaged value due to scatterings from several cyclotron circles in the coherent area. The reason why the deflection field is not so clear is considered to be due to an above averaging effect. Especially, in the narrow wire case with high gate voltages, it is difficult to determine the wire width because the coherent area is fully spread out over the both wire ends.

In quasiballistic case, although we can not determine clearly the field dependence of the B_c, it is considered as an almost linear dependence on the field. Probably, it is attributed to a mixed scattering of impurity and wire boundary.

5. Summary

We have demonstrated that the correlation field analysis in a mesoscopic narrow wire can use as a geometrical probing for electron wave propagations. It is found that the increase of the B_c, at the deflection field or boundary field B_0, depends strongly on a detail of scatterings of electron waves and variations of the size of the phase coherent region of the propagating electron waves. For split gated wire in quasiballistic regime, we can obtain the dynamical dependence of the upper limit of the wire width.

Our result on geometrical probing indicates a possibility on dynamical determination of the characteristic transport parameters for electron wave propagation in mesoscopic wire systems.

References

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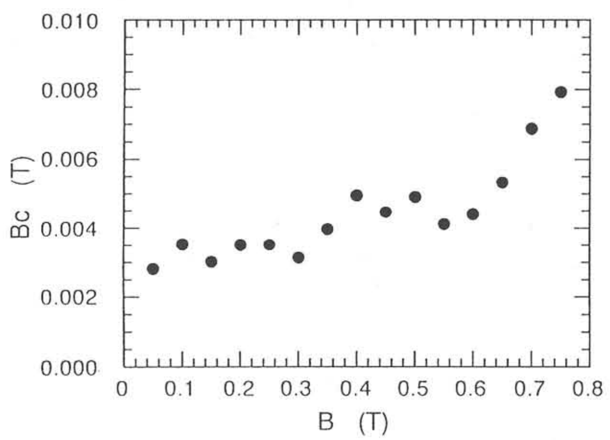

Fig. 1 Magnetic field dependence of the correlation field Bc at 1. 2K for 6 mm split gated wire. The increase of Bc can be seen around 0.6 T.

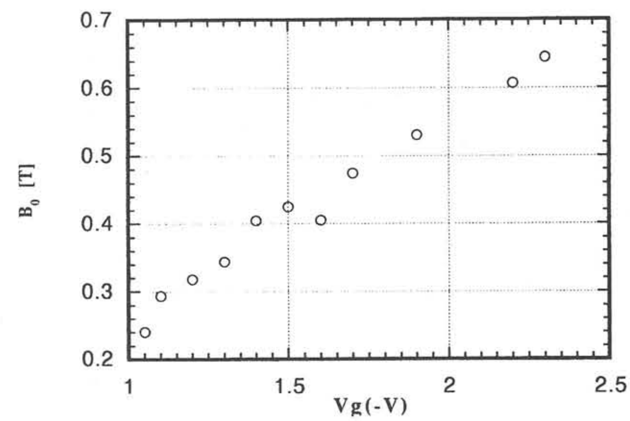

Fig. 2 Gate voltage dependence of the boundary field B_0 which seems to be almost propotional to the voltage.