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Effective Interference Area of Universal Conductance Fluctuations in Narrow GaAs/AlGaAs Wires

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Analysing the amplitude of universal conductance fluctuations in the low-temperature magnetoresistances, we study a quantum interference effect on mesoscopic narrow wire system. From the magetic field dependence of the conductance fluctuations, each conduction path in a mesoscopic wire has been resolved using a precise analysis of quantum interference of electron waves.

1. INTRODUCTION

Using a recent semiconductor fabrication technique, we can obtain quantum narrow wires of Si-MOSFET and GaAs/AlGaAs heterojunction by confineing their two-dimensional electron gas (2DEG) systems. Low temperature magnetoresistance (MR) in narrow GaAs/AlGaAs wires have been measured in order to clarify the quantum interference effects in a mesoscopic system where the dimensions are comparable or less than the phase coherent length of electron transports in such a narrow wire. Electrons in a quantum wire system bahave coherently and the phase coherence of the electron wave gives rise to the quantum interference. Applying magnetic fields to a mesoscopic wire system, we can observed quantum interference oscillations due to Aharanov-Bohm (AB) effect in the MR for a ring of high mobility GaAs/AlGaAs heterostructure ring.[1)] In high magnetic fields, suppression of quantum interference effects has been observed and the period of the oscillation shifts to lower frequency in the field dependence of Fourier spectrum (FS) of the MR.[2)] A similar low frequency shift of the dacay part in the FS has been observed in a wire of GaAs/AlGaAs heterojunction.[3)]

In this study we discuss the magnetic field dependence of conductance fluctuations in the MR by means of analysing the Fourier transform of the fluctuations.

2. EXPERIMENTS

Narrow wire samples are two types of GaAs/AlGaAs double and single heterojunctions grown by the molecular beam epitaxy technique and made by using electron beam lithography and dry etching technique. The double heterojunction wire (named DHW-08) has a 800 nm-thick nondoped GaAs buffer layer, a 10nm-thick cap layer, two 2 nm-thick spacers, and a 10 nm-thick GaAs layer sandwiched between two Si-doped AlGaAs layers of 60 nm-thickness. The single heterojunction wire (named SHW-02) has a nondoped GaAs buffer layer followed by a 6 nm-thick nondoped AlGaAs spacer layer and the 50 nm-thick Si-doped AlGaAs layer. The lithographical width of those wires was about 700 nm and the length were 3000 nm for DHW-08 and 1700 nm for SHW-02. The actual width for electrical conduction is less than lithographical one and about 400nm for the two wires because of existence of a surface depletion layer. The mean free paths of DHW-08 and SHW-02 are less than 150 and 430 nm, respectively. Mobilities are estimated to be about 8600 cm^2/Vs for DHW-08 and 25000 cm^2/Vs for SHW-02 at 4.2 K. The MR measurement was carried out in a ^3He-^4He dilution refrigerator and a ^3He cooling system in applied magnetic fields up to 8.5 T.

3. RESULTS AND DISCUSSIONS

Universal conductance fluctuations [4,5] can be observed in the MR with an amplitude of the order e^2/h for the two samples. Although DWH-08 shows MR fluctuations up to 8 T, such fluctuations in SHW-02 cannot be detected in higher fields about 2 T because of the appearance of Shubnikov-de Haas oscillations. FS of the MR in the two samples were analysed in various ranges of the magnetic field and are relevant to the area enclosed by a pair of electron trjectories. If the oscillation is caused by the AB effect in each conduction path in the wire, the period of ΔB in a certain oscillation component of the fluctuations is connected with the enclosed area S by the relation $\Delta B=h/e$. With increasing magnetic fields we have observed a low frequency shift of the decay part of the fluctuations in the spectrum for DHW-08.[3] A similar shift has been observed in the case of SHW-02. Here we define a maximum length l_{max} which corresponds to the maximum area where the quantum interference can be successfully performed. l_{max}/l_0 of the two samples are plotted in Fig. 1, where l_0 is the effective conduction length at the lowest field range in Fourier transformation. Near the critical field of $\omega_c\tau=1$, the decay of aperiodic fluctuations, which is observed in the low frequency side of the FS, begins to shift to low frequencies. And ω_c is the cyclotron frequency and τ is the transport relaxation time. The shift can be explained by reduction of the effective area for the interference. We consider that the reduction comes from the formation of a certain conduction channel which does not affect quantum interference.

Figure 2 shows Fourier power spectrum at the lowest field range between 0 to 2 T from the MR in DHW-08 at 80 mK. It is noted that the spectrum has a back ground component whose slope is almost $f^{-1.5}$ as indicated with a dotted line. If the back ground does not originate in quantum interferences, the band spectrum from 5 to 40 T^{-1} must correspond to the component due to the net work of the actual conduction paths in a wire. Since in the case of DHW-08 the lowest field range is in $\omega_c\tau<1$, the reduction of effective coherent area, as mentioned above, does not occur. It means that using a precise analysis of the interference of the electron waves, we will be able to resolve each conduction path in a mesoscopic wire. As for $f^{-1.5}$component in Fig. 2, we can not determine the origin even from our transport results. We think that it may come from a certain process in measurement systems.

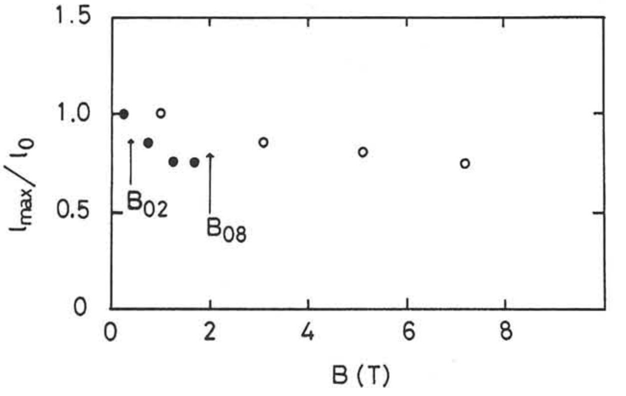

Fig. 1 Magnetic field dependence of l_{max}/l_0 at 80 mK for DHW-08 (open circle) and 1.2 K for SHW-02 (closed circle). B02 and B08 stand for the critical fields for SHW-02 and DHW-08, respectively.

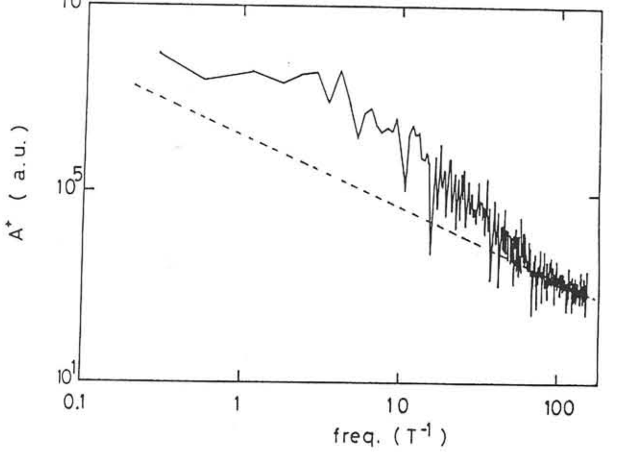

Fig. 2 Fourier power spectrum between 0 to 2 T in DHW-08 at 80 mK. Dotted line shows $f^{-1.5}$ dependence.

4. CONCLUSION

Considering the field dependence of the coductance fluctuations, we can determine a certain critical field on electron wave scatterings in the wire. As the magnetic field becomes higher than above critical field, the effective coherent area of electron waves gradually decreases. If we use a more precise analysis on FS of MR, each conduction path in a mesoscopic wire can be resolved. We consider that this quasi-ballistic narrow wire system is very suitable to study dynamical transports in quantum wires.

5. ACKNOWLEDGEMENTS

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