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Magnetoresistance in a Quasi-Ballistic Narrow Wire Confined by Split Metal Gates

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Analysing the amplitude of Shubnikov-de Haas oscillations in the low-temperature magnetoresistances, we study a size effect on quasi-ballistic transport regime of a narrow wire. From this size effect of electronwaves in a wire, a boundary field related to single-particle relaxation times is determined by a simple relationship between the conducting width and the corresponding cyclotron radius.

1. INTRODUCTION

Analysing the amplitude of Shubnikov-de Haas oscillations (SdH) in the low-temperature magneto-resistance, we study a size effect in the quasi-ballistic transport regime of a narrow wire. It is very important to determine the scattering processes of a quasi-ballistic narrow wire rather than pure-ballistic one as long as a recent device application to mesoscopic transports. Carrier scattering mechnisms have previously been widely studied in two dimentional electron gas (2DEG) systems through an analysis of the amplitude and periodisity of the SdH oscillations. The former provide an indication of the single particle relaxation time τs while the latter can be used to determine the carrier density n of the 2DEG.[1] Recently, such an analysis has been applied to the narrow wire samples.[2] In the low temperature magneto-resistance for GaAs/AlGaAs narrow wires, two relaxation times, τsh and τsl, at high and low fields have been obtained in amplitude analysis of the SdH oscillations.[3] The boundary field which distinguishes these relaxation times is considered to be determine by a simple relationship between the conducting width and the corresponding cyclotron radius. In this paper, we discuss trajectory change originated such a size effect of electronwaves in quasi-ballistic quantum wires employing four-terminal and split-gate geometries.

2. EXPERIMENTS

The Hall-bar-type wires were defined by electron beam lithography and a dry etching technique. Since sidewall depletion is not negligible after dry etching, the effective conducting width of the wire should be smaller than the lithographic width, determined from optical and scanning electron microscopy observations. The length between the voltage probes is about 2 μm in all these wires. The sample characteristics and main parameters are reported in a previous paper.[4] Narrow wires were also defined by means of split-metal-gates deposited onto an MBE grown GaAs/AlGaAs heterojunction. The split-metal-gates were fabricated by electron beam lithography chemical etching. The magnetoresistance of the four-terminal and split-gate wires was measured using a ^{3}He cooling system in applied magnetic fields up to 8 T. We try to control the conducting width by means of a

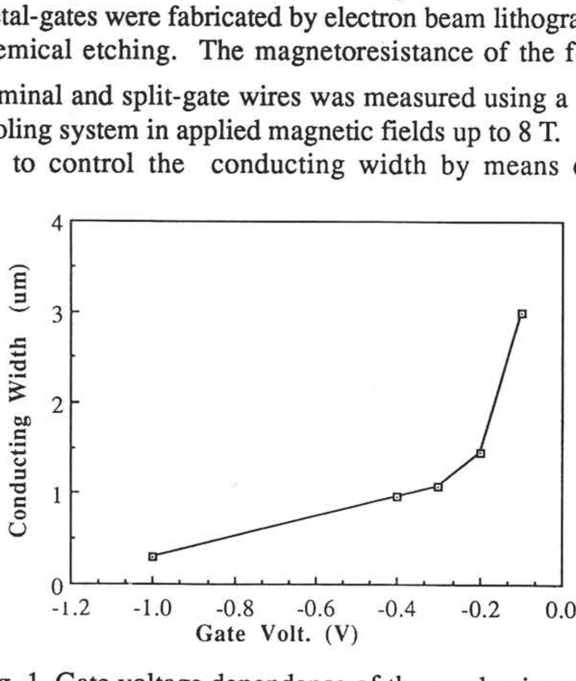

Fig. 1 Gate voltage dependence of the conducting width in a split-gated narrow wire at 1.2 K.

negative bias applied to the split-gates. Figure 1 shows the conducting width which is determined by the resistance change of the sample using the length of the split-gates and the original 2DEG geometry.

3. RESULTS AND DISCUSSIONS

In the amplitude analysis of the four-terminal narrow wires, the trajectory change gives different scattering times τ_{sh} and τ_{sl}, with respect to the field strength. The boundary magnetic field between these two field ranges depends mainly on the width of the wire. Varing the width of the wire, we observe the size effect which is originated to the change in trajectory of electron wave propagations in quasi-ballistic wires. We consider that the change corresponds to the formation of edge channels at the sidewall of the wire. The boundary field for the edge channel formation in a quasi-ballistic wire is considered to be a few times higher than that in pure-ballistic one.[5] The difference between the two regimes seems to come from an existence of a few scatters in the wire. Considering the ratio of the width W_e to cyclotron radius r_c at the boundary field, we can determine an coefficient of electron wave scatterings in the wire from the following relation

$$W_e = A\, r_c \qquad (1)$$

where A is a constant around 6 as shown in Fig. 2. As the mean free path becomes longer, this coefficient seems to tend to the value in ballistic limit.

Next, we show the results of the split-gate system. As the gate voltage increases, the SdH oscillations becomes weaker. We have also analyzed the amplitudes of the SdH oscillations in the case of the split-gate samples. Varing the width of the wire, we can expect to observe the size effect for electron wave trajectry change. Figure 3 shows the amplitude analysis in split-gate sample at gate voltages of 0 and -1.0 V. In the case of -1.0 V, we can determine the two single-particle relaxation times, τ_{sh} and

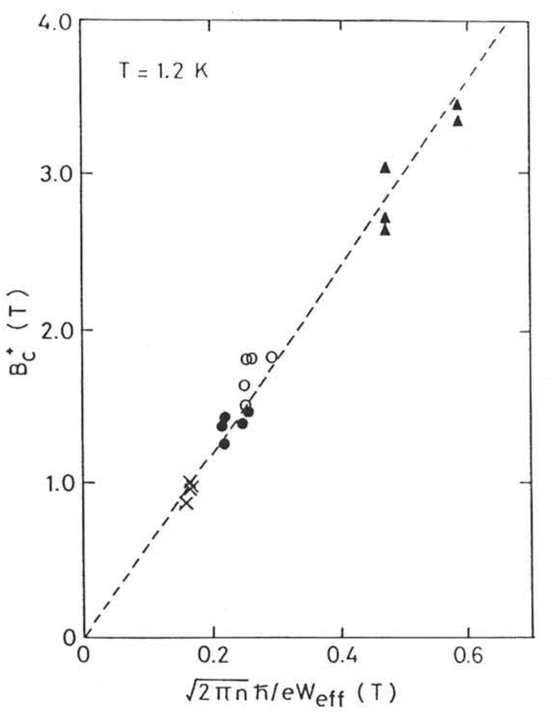

Fig. 2 The boundary field,B^+c, vs. the field at which the cyclotron radius is just equal to a half of the effective conducting width. The carrier concentration was controled by the LED lightening due to persistent photo conductivitities at 1.2 K.

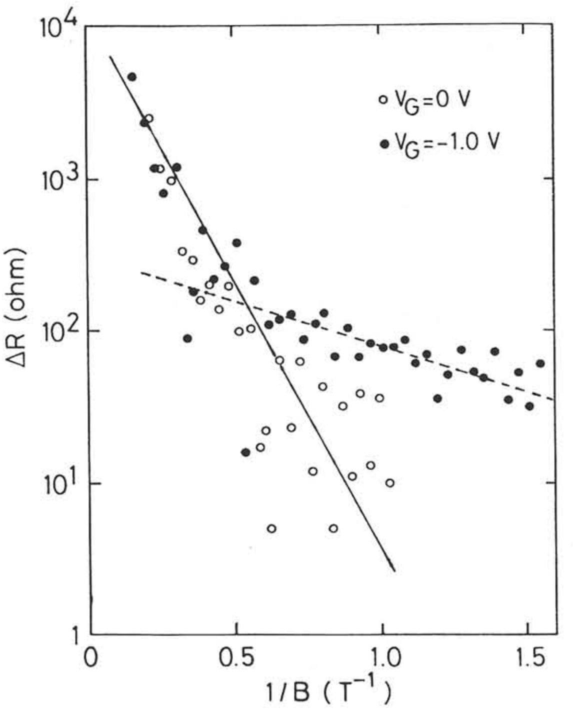

Fig. 3 Amplitude of the SdH oscillations in the split-gate geometry as a function of the inverse magnetic field for the gate voltages, 0 and -1 volts at 1.2 K.

τ_{sl}, which are $1.54x10^{-13}$ and $7.3x10^{-13}$ s, respectevely. However, in the case of zero gate voltage, there exists only single-particle relaxation time of the order of 10^{-13} s. And the relaxation time almost agrees with τ_{sh} in the case of -1.0 V. In Fig. 3, the boundary field is located at about 0.5 T^{-1} which gives the width, 0.28μm by means of the size effect estimation in Eq. (1) of A=4. This estimated width is nearly the same with the value in Fig. 1. Therefore, in this split-gate sample, it is considered that the coefficient A is about 4. However, it is not so clear because of scattered data points as shown in Fig. 3 Nevertheless, the coefficient in this split-gate system is considered to be close to pure-ballistic case rather than that in four-terminal wires. The difference between the two wires seems to come from a slightly higher mobility of the split-gate wire.

4. CONCLUSION

Considering the ratio of the width to cyclotron radius at the boundary field, we can determine a certain coefficient on electron wave scatterings in the wire. As the mean free path becomes longer, such a coefficient seems to tend to the value in ballistic limit. We consider that this quasi-ballistic narrow wire system, where the cyclotron length is nearly equal to the wire width, is very suitable to study dynamical transports in quantum wires.

5. ACKNOWLEDGEMENTS

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