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Transport Transition from Chaotic to Regular Trajectory in Corrugation Gated Quantum Wires

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We study quantum interference effects, observed in the low temperature magnetoresistance of corrugation gate wires on the two-dimensional electron gas system. And, we have observed small oscillations in the negative magnetoresistances. Those results show that a boundary related or geometrical effect should strongly affect the phase breaking mechanism in corrugation wires and the electron wave propagation has a clear difference between a narrow wire and a dot array depending on the gate voltage.

1. Introduction

We have studied quantum interference effects in the low temperature magnetoresistance of corrugation gate wires[1,2] on the two-dimensional electron gas (2DEG) system of GaAs/AlGaAs hetero-junction interface. It is well known while mesoscopic narrow wires show universal conduction fluctuations (UCF)[3,4], these are not observable in the pure ballistic transport regime. However, interference of the electron wave is seem to be strongly affected even at the ballistic system. The geometry and boundary related effects are expected to affect the interference nature in the ballistic motion of the electron wave in a dot or wire. On the other hand, electron localization is also an important effect even for the ballistic transport regime, in which the electron trapping in a chaotic or regular orbit in the ballistic regime introduces a ballistic localization via phase braking processes[5].

In this study, we discuss the geometry induced transport nature in a corrugation gate wire and the possible trajectories of electrons inside the wire. Also we discuss the transition from chaotic to regular trajectory[6,7,8].

2. Measurements

We have used a high mobility GaAs/AlGaAs wafer as the sample in our work. A standard mesa-etched Hall-bar geometry was subsequently defined in the GaAs cap layer by a wet etching method, and the corrugation gate was fabricated above this using Ti/Au alloy by lift-off technique. The designed width and height of the corrugation were 0.1 and 0.2μm, respectively. At 0.6 K the ungated (2DEG) carrier density was 4.0×10^{15} m^{-2}, and the low temperature mobility was 52 m^2/Vs. Applying negative bias voltage on the gate makes the actual 2DEG boundary depleted and forms the corrugation or wire system. The shape of the smallest corrugation gate is shown in Fig.1 and the details for three wires are listed in TableI.

Measurement is performed with a four probe method by two lock-in amplifiers at 21 Hz at a current of 80 nA for T=0.6 K. The estimated mean free path is about 5.5 μm; it can be considered here that the system is quasi-ballistic or ballistic since the mean free path is longer than the 3μm wirelength. Negative bias voltage is supplied to the split gate using a constant dc voltage source, and magnetic field up to 0.5 T is applied perpendicular to the 2DEG.

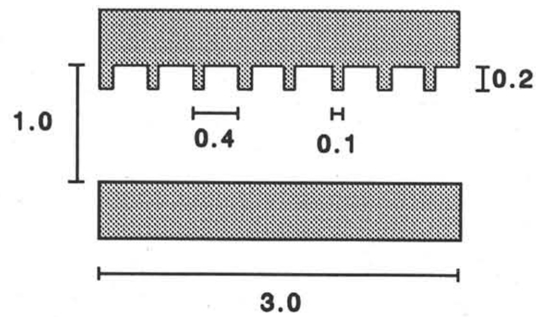


Fig.1 Schematic of split gate geometry for Gate1 with the corrugation periodicities of 0.4μm. The wirelength and width are the same for the three gates, 3.0 and 1.0μm, respectively.

Table I. Wire dimensions for corrugation gate geometry.

	Gate 1	Gate 2	Gate 3
Wirelength, L (μm)	3.0	3.0	3.0
Wirewidth, W (μm)	1.0	1.0	1.0
Corrugation period, a (μm)	0.4	0.7	1.1

3. Results and Discussions

When the gate bias is applied, we have observed that the resistance decreases linearly with magnetic field. It can be considered that this negative magnetoresistance (NMR) is attributed to sidewall backscattering inside the wire. At the higher field (more than 0.3 T) when the cyclotron orbit becomes shorter than the wirewidth, the electron skips on the wire boundary and the backscattering effect is considered

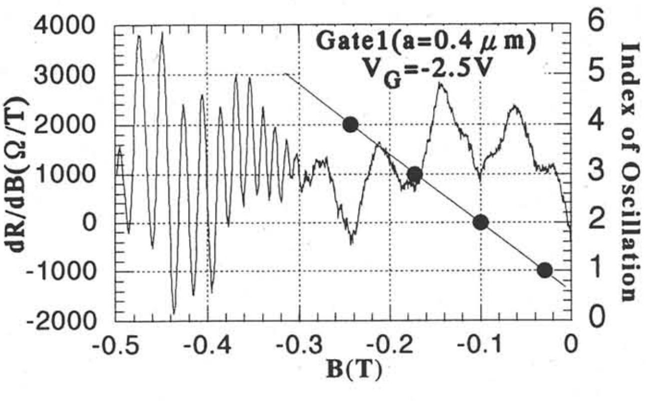


Fig.2 Derivative of the NMR calculated from the magnetoresistance data are plotted for Gate1 and the index of oscillations of the valley is determined from the derivative result.

to disappear. It is found that as the gate voltage increases or the wirewidth becomes narrower, the above critical behavior can be observed at a higher field.

Although SdH oscillations are found at high field, there is a small periodic structure upon the NMR at low field. Derivative of the NMR can be calculated from the magnetoresistance data and the periodic structure clearly appears as shown in Fig.2. Each valley or peak corresponds to an index of oscillations as shown in Fig.2, and the index is found to fit to a linear dependence on the magnetic field. The oscillation periodicity, ΔB, can be estimated using FFT techniques.

The periodic oscillations can be explained with an electron interference from the AB effect, in which electrons in the wire are scattered by the corrugation geometry and interfere with each other in an enclosed trajectory. Using the simple relation: $\Delta B=\phi/S$[9,10], we can calculate interference area S which enclosed by the interference trajectory. Figure 3 shows the interference area for three gates. It is shown that with increasing gate voltage, the interference area of all three gates becomes smaller. However, the decrease of the area depends for the corrugation periodicity; where on the longest corrugation periodicity (Gate 3), the decrease is much more rapid compared with Gate2 or Gate1.

At high gate voltage, the interference areas of the three gates seem to change so that there are different trajectories or mechanisms between the lower and the higher gate voltage. When the corrugation geometry is created by the gate depletion, an interference area can be considered to form and locate near the corrugations (A in Fig.4). The interference area becomes smaller with increasing gate voltage. Also, increment of the gate voltage makes the corrugation pattern smear out gradually; and just before the gate pinch off, the shape of the area becomes almost entirely a wire (B in Fig.4). Analogous to the above discussion, we have tried to estimate the height of the area from each separation between corrugations at low gate voltage. The height for Gate1, 2 and 3 at 0.5V are 0.16, 0.23, and 0.4μm, respectively; having nearly the same corrugation height (~0.2μm).

Next, we discuss the transition between the low and high gate voltage. Also found here is a similar shape in the NMR peak with the peak shape observed in a single dot in the narrow wire [7,8]. However, the field range of our NMR peak is larger by about one order than that in the single dot. And as the gate voltage increases or the width decreases, it can be observed that the NMR decreases almost linearly with increasing B and the Lorentzian peak shape changes into a triangular one (Fig.5).

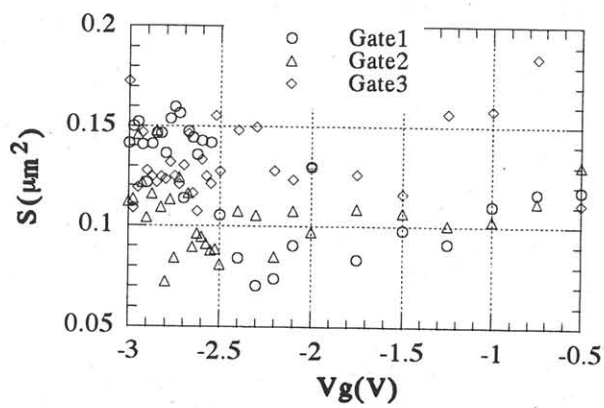


Fig.3 Interference area for Gate 1, 2, and 3. Interference area at low gate voltage decreases with increasing gate voltage. The area at high gate voltage has an almost similar value for three gates.

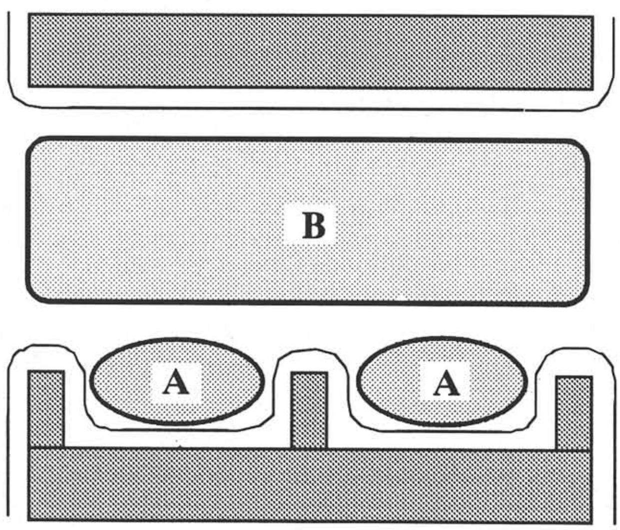
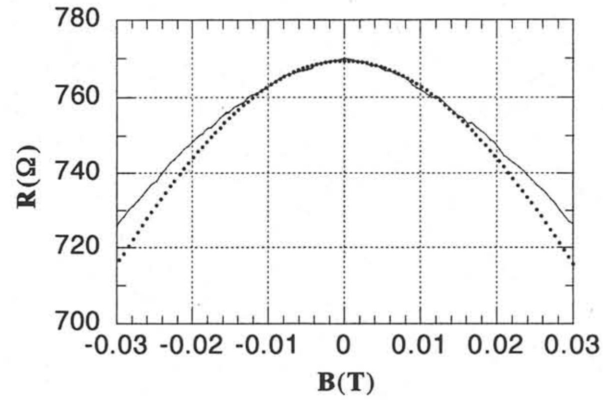


Fig.4 Schematic of possible interference regions: in the case for low gate voltage(A), and high gate voltage(B).



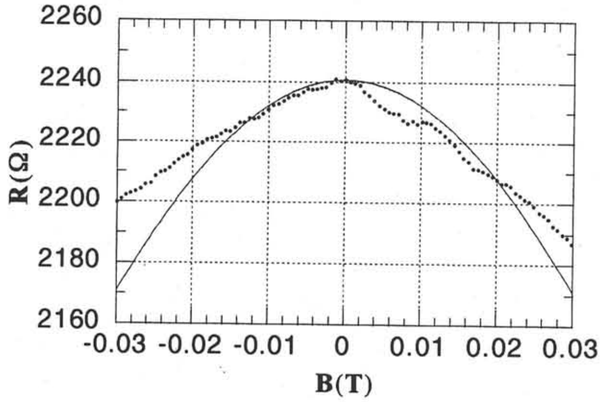


Fig.5 Lorentzian-line shape fitting on NMR for Gate 1 for the case of low gate voltage (a), and high gate voltage (b).

This suggests a transport transition from chaotic to regular trajectory. Several successive trapping or scattering in each similar interference areas near the corrugation structure seems to be related to chaotic motion of the electron at low voltage. However, we can observe interference orbits due to AB effect even at low gate voltage as shown in Fig.3. It should be better for the interference to consider come from a regular motion in a corrugation unit. Therefore, it is difficult to find a chaotic motion in our corrugation gate.

A similar wide peak in NMR is recently calculated in a corrugation wire and discussed as a novel weak localization effect, arising from multiple backscattering and resonance among the segments of the corrugation wire[11]. Especially, the calculation result is in a good agreement with our NMR up to around 0.1T. Therefore, the successive trapping or scattering must be related to such a novel localization effect.

4.Conclusion

We have measured magnetoresistance for corrugation gated wires. Upon applying negative gate voltage, negative magnetoresistances have been observed near zero magnetic field. It is found that a weak periodic component appears in the NMR. The magnetic field periodicity can be considered to come from an interference effect that occurs at the area near the corrugations, and the interference area can be estimated by the AB effect. We have obtained the estimated area from this AB effect and it is consistent with the schematic area considered by our model.

We also found that with increasing the gate voltage, the NMR peaks near zero field are changed slightly. It is possible to fit the NMR peak shapes at low voltage by Lorentzian fitting, while at higher voltage it is difficult to fit the peak by Lorentzian fitting. We believe that when the corrugation shape still dominates the electron trajectories at low gate voltage, there exist chaos-like electron trajectories beside the regular trajectories that reveal the interference areas considered above. However, it is difficult to deduce a clear evidence on chaos orbits. At the higher voltage, the corrugation structure gradually smears out so that only the regular electron trajectories remain. We must study further on the chaos-like trajectory area.

Acknowledgements

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