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Microscopic Modelling of Interference Processes in On-facet Quantum Wires

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On-facet quantum wire[1] is a new mesoscopic system which has several unique features. Cross sectional views of two types with different channel locations are shown in Fig. 1. Basic properties of typical samples in these two types are listed in Table 1. The characteristics of the on-facet wire are high mobility despite large carrier density and almost no depletion layer in the channel side[2]. Localization dimensions and transport regimes in temperature ranges 1.4K to 10K are clarified by comparing characteristic dimensions such as W(channel width), L_e(mean free path) and L_{in}(phase coherence length) with each other. Sample A is decided to be 1D and quasi-ballistic while B is 2D and diffusive.

This work describes the models of microscopic scattering processes underlying the conductance fluctuations(CFs) in both diffusive and quasi-ballistic regimes. We assume the coherent back scattering model[3] and try to visualize the microscopic electron paths which form a closed loop after a number of elastic scattering events. Taylor et al.[4] reported the microscopic views of CFs in n^+-GaAs wire by analyzing the Fast Fourier Transformation(FFT) spectrum. In a 2DEG channel, since the range of magnetic fields in which CFs are observed is limited and the FFT cannot give proper results, the Maximum Entropy Method(MEM) is used to get an accurate spectrum. The reliability of the MEM spectrum is confirmed by the fact that the shift of MEM peak frequencies against the angle of the magnetic field has cosine dependence[2].

The CF and MEM spectrum of sample B are shown in Fig. 2. As the spectrum peak frequency correspond to the loop area[4], a set of loop orbits which relate to constructive interferences can be drawn in each transport regime. In the diffusive regime, electrons paths close before being scattered by the channel walls. One of the possible loops is shown in Fig.3a. The loop is assumed to be circular. Actually each loop shape is a different polygon which cannot be determined uniquely from its loop area. From the experimental results the area of the smallest circle is almost equal to an equilateral triangle of side length L_e. In the quasi-ballistic regime, frequent scattering by the channel walls occur. Models of electron paths can be drawn as shown in Fig.3b. This model assumes that the walls are specular and that impurities form scattering centers , playing almost the same role as the walls. The model also assumes that the number of impurity scattering event is made as small as possible. Since loops for the diffusive model cannot be drawn in this regime, it is evident that flux cancellation[5] occurs. It is manifested from these models that the CFs are composed of at most 10 modes of such loops and are caused by closed loops which are smaller than several L_{in}(T)s. Dependences of CFs and the loop charts on temperature for sample B are shown in Fig.4. It is clear that the fine structure in CF corresponding to the longer loop vanishes faster when the temperature is raised. Basic fluctuation is found to come from the smallest loop.

We have analyzed the conductance fluctuations of on-facet quantum wires. Microscopic elastic scattering process is visualized by the "loop chart model". The real sizes of the closed paths composing the CFs are manifested. This knowledge is useful not only for understanding the interference effects but also for designing new mesoscopic devices.

References
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Table 1 Some basic properties of the on-facet quantum wires.

Sample	n_s ($\times 10^{12}$cm^{-2})	μ (m^2/V·s)	W_{sem} (μm)	W_{fit} (μm)	L_e (μm)	L_{in} (μm)
A	3.46	3.4	0.3	0.3	0.7	$0.85T^{-1/5}$
B	1.75	0.6	0.64	0.6	0.1	$0.45T^{-1/4}$

n_s:carrier density, μ:mobility,
W_{sem}:width determined by SEM photograph,
W_{fit}:width determined by fitting.

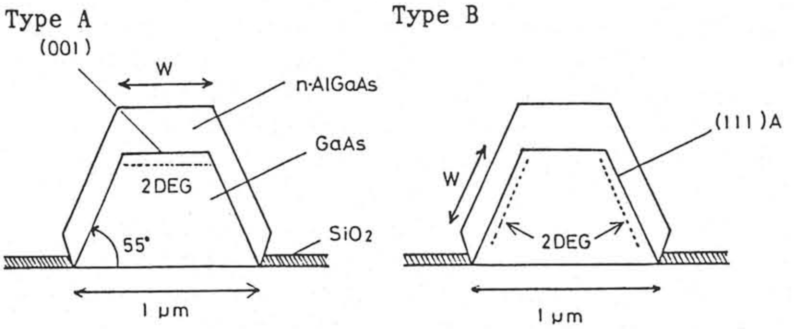

Fig.1 Cross-sectional views of the on-facet 2DEG channels.

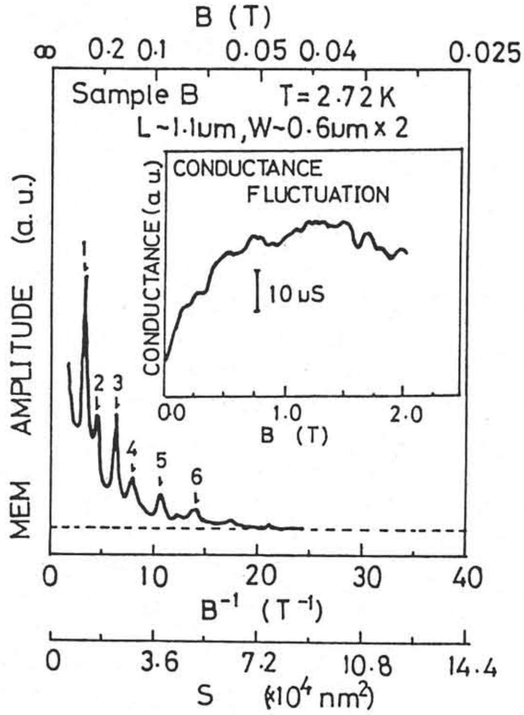

Fig.2 MEM spectrum of conductance fluctuation(inset).

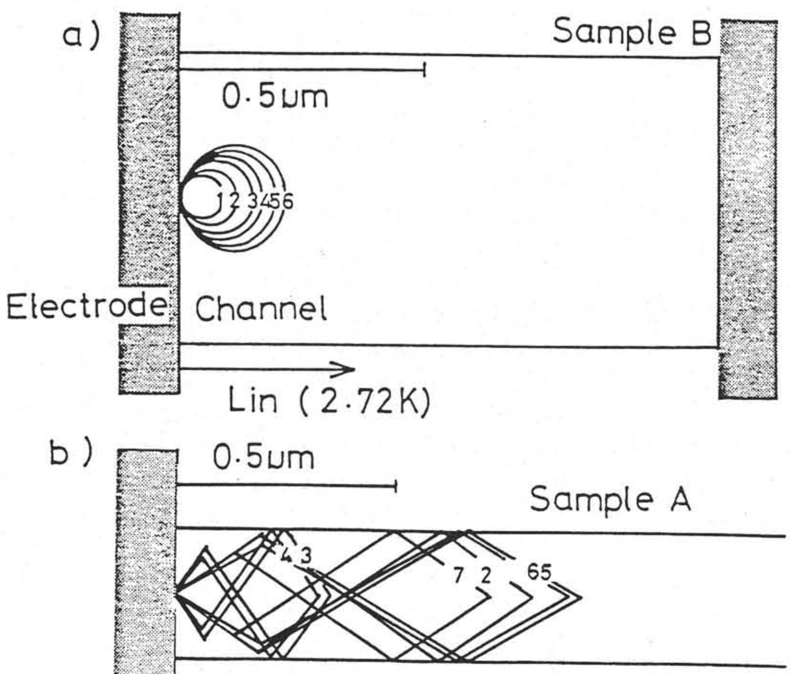

Fig.3 Examples of loops relating to constructive interferences in diffusive (a) and quasi-ballistic(b) channels.

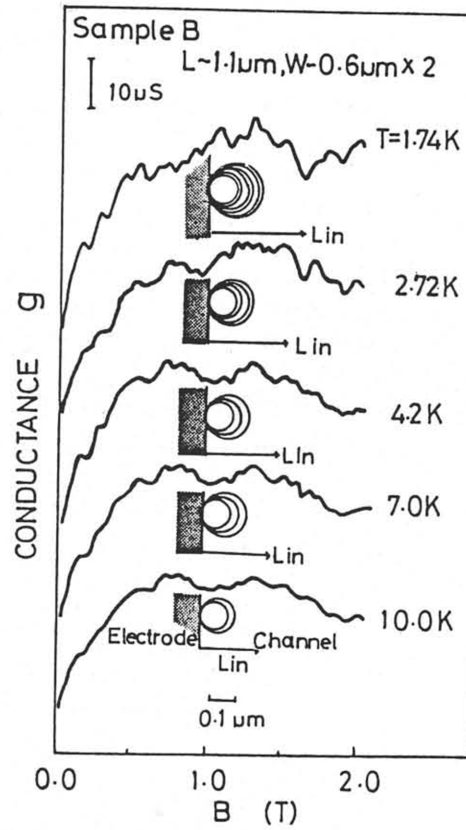

Fig.4 Temperature dependences of conductance fluctuations and their loop charts.