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Saturation of Phase Coherence Length in GaAs/AlGaAs On-Facet Quantum Wires

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Phase coherence length (L_ϕ) is one of the important scales in design of quantum intereference devices. The dominant mechanisms determining phase coherence length in each demension are becoming clear. However,for GaAs/AlGaAs heterojunction wires[1,2] (quasi-1-dimensional wires) at $T \leq 0.3K$ there is no clear definition of temperature exponent or L_ϕ saturation. The poorly defined L_ϕ saturation may indicate a temperature-independent scattering mechanism at very low temperatures. It is thus interesting to determine the mechanism which dominates L_ϕ in that temperature range.

In this work quasi-1-dimensional (Q1D) and 2-dimensional(2D) on-facet quantum wires are used. These on-facet wires have a unique structure and properties[3]. In particular they have both high carrier concentration and high mobility, enabling them to have long L_ϕs. Further these wires are potentially damage free because the wire structure is formed by only one selective growth process[4]. The Q1D sample used here has a 0.3-μm channel width, whose basic properties are $\mu \sim 3.4m^2/Vs$, $N_s \sim 3.46x10^{12}cm^{-2}$,and L_e(mean free path)$\sim 0.7\mu m$. Sample lengths are $1.7\mu m$ and $20\mu m$. Conductance fluctuation is observed in the short sample. The 2D sample has a 0.8-μm channel width,$\mu \sim 1.3m^2/V.s$ and $n_s \sim 5.8x10^{11}cm^{-2}$.

Low temperature magnetoresistance measurement was performed down to 50mK. Magnetoresistance of Q1D shows a positive part implying antilocalization effect below 0.1K (in Fig. 1). L_ϕ for the Q1D sample is directly determined by the amplitude of the conductance fluctuation using $(L_\phi/L)^{3/2} = <\delta g^2>^{1/2}/0.52(e^2/h)$. As shown in Fig. 2 temperature exponent of L_ϕ decreases loosely as temperature decreases, and L_ϕ almost saturates below about 0.4K. In addition, phase coherence length is determined with correlation field of conductance fluctuation $L_\phi = \alpha/B_c(h/e)(1/w)$. Numerical constant α is uncertain , but a similar temperature dependence is obtained. For 2D wire, L_ϕ is determined by fitting with the 2D weak localization theory without spin-orbit scattering. L_ϕ saturation occures as for the Q1D wire as shown in Fig.3, although positive magnetoresistance is not seen in this temperature range.

These saturation phenomena are thought to be derived from spin-orbit interaction, corresponding to positive magnetoresistance, because electron jouhl heating was eliminated by using small ac current in the 10nA order and spin-flip scattering is not applied in these samples. In order to determine the spin-orbit scattering length, magnetoresistance data is fitted to the weak localization theory including spin-orbit interaction. For Q1D it is modified for the quasi-ballistic case, because $W<L_e$[5]. Characteristic length with spin-orbit scattering L_{so} ($=\sqrt{D\tau_{so}}$)which is about 2.8 μm(τ_{so} is 20 psec) and inelastic scattering length (L_{in}) are separated. The Q1D results are also shown in Fig.2. These two lengths converge, accompanying L_ϕ saturation. The temperature T_{so} below which spin-orbit interaction is effective is defined as $\hbar/\tau_{so}k_B$. In this case T_{so} is calculated at 0.38K and it is consistent with the beginning temperature of L_ϕ saturation. For 2D case, L_{so} is determined to be $2\mu m(\tau_{so}$=150psec.). In this case T_{so} is 0.05K, then loose saturation in L_ϕ is thought to be attributed to spin-orbit interaction as in the Q1D wire, although τ_{in} is 10 to 20 percent of τ_{so}. Spin-orbit scattering appears at a very low temperature and affects the electron coherency.

Characteristic time with spin-orbit interaction is expressed as $\tau_{so}=\tau_0/(g-2)^2R^2k_F^2$ [6], where R is some length scale of a scattering center for electrons and k_F is fermi wave number. The g-factor used here is 0.52. R is estimated to be 3.7Åand 2Åwhen experimental values of Q1D and 2D, respectively, are applied. Comparing these values with the atomic radius of Ga or As (1.2Å) shows good agreement. Scattering centers of several angstroms size are effective in spin-orbit scattering. However, the image of R is not clearly defined. There may be defects, impurities, interface roughness or lattice relaxation.

In conclusion, we obtained temperature dependence of phase coherence length L_ϕ from magnetoresistance at very low temperatures. The saturation of L_ϕ is observed and at very low temperatures spin-orbit interaction is effective as the scattering mechanism whose characteristic time is temperature independent.

References

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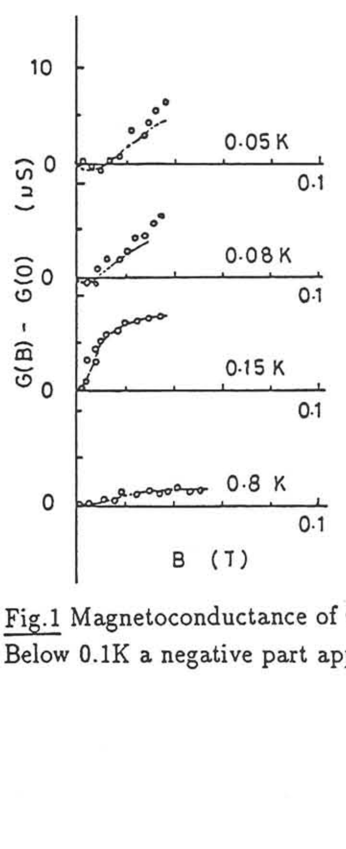

Fig.1 Magnetoconductance of Q1D wire. Below 0.1K a negative part appears.

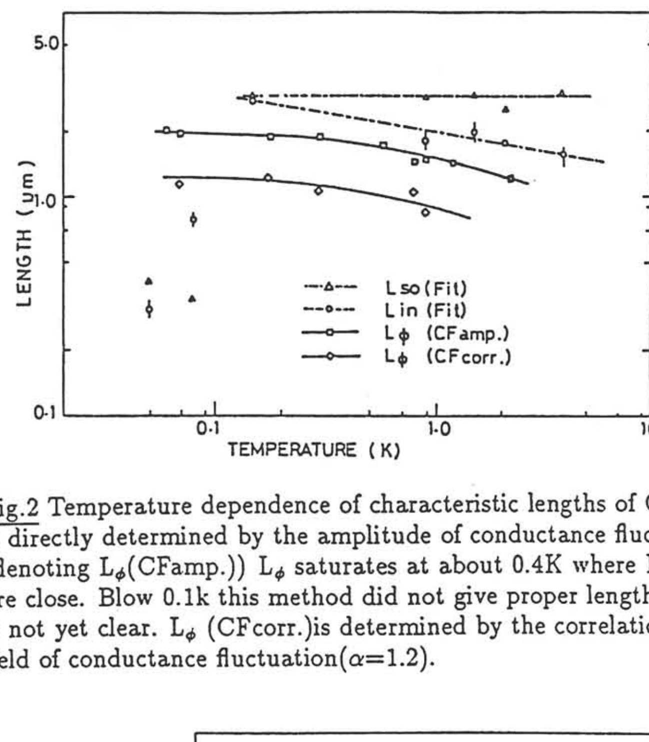

Fig.2 Temperature dependence of characteristic lengths of Q1D wire. L_ϕ is directly determined by the amplitude of conductance fluctuation (denoting L_ϕ(CFamp.)) L_ϕ saturates at about 0.4K where L_{so} and L_{in} are close. Blow 0.1k this method did not give proper length. The reason is not yet clear. L_ϕ (CFcorr.)is determined by the correlation field of conductance fluctuation(α=1.2).

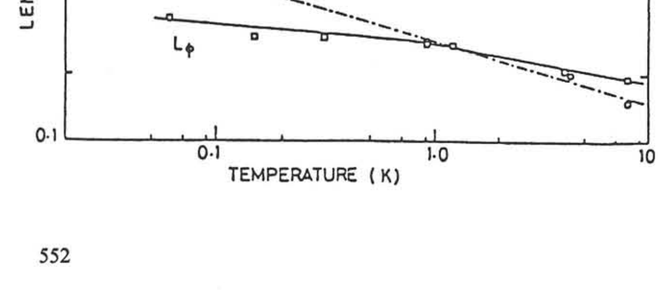

Fig.3 Temperature dependence of characteristic lengths of 2D wire. L_ϕ is determined by fitting with weak localization theory. L_{so} and L_{in} are obtained by fitting with the theory including spin-orbit interaction.L_ϕ saturates as for Q1D.