Interference correction and dephasing at decreasing conductance

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Standard theory for the interference quantum correction to the conductivity have been developed in the first order in $1/g$ [g is dimensionless (in units of e^2/h) conductance], therefore they cannot, strictly speaking, be used for *quantitative* analysis of the experimental data for low g. In this report we present the results of both experimental and theoretical investigation of weak localization phenomenon at low conductivity. The resume of theoretical consideration is the following:
1. $B = 0$. The taking into account the terms of the second order in $1/g$ does not change the conductivity in zero magnetic field. This means that the temperature dependence of the conductivity σ at $B = 0$ due to that of the interference correction has experimentally to be the same as for the case $g \gg 1$: $\sigma(T) \propto -G_0 \ln(\tau_\varphi(T)/\tau)$ where τ where τ_φ are the momentum and phase relaxation time, respectively;
2. $B \neq 0$. The terms of the second order in $1/g$ does not influence the shape of the magnetic field dependence of the interference correction leading only to decreasing of the prefactor. We show that the magnetoconductance should be described by the well-known expression [2]

$$\Delta\sigma(b) = \alpha G_0 \left\{\psi\left(0.5 + \gamma b^{-1}\right) - \psi\left(0.5 + b^{-1}\right) - \ln\gamma\right\} \tag{1}$$

with the following prefactor

$$\alpha = 1 - 2G_0/\sigma\,, \tag{2}$$

where $\psi(x)$ is a digamma function, $b = B/B_{tr}$, B_{tr} is the transport magnetic field, $\gamma = \tau/\tau_\varphi$.

In order to testify quantitatively these theoretical predictions, we have investigated three types of the gated GaAs/80Å-$In_{0.2}Ga_{0.8}As$/GaAs single quantum well structures with only one size-quantized subband occupied. They are distinguished by a starting disorder that is achieved by a different manner of doping. Structure H451 with high starting disorder had Si δ doping layer in the center of the quantum well. The electron density n and mobility μ in this structure were $n = 0.89 \times 10^{16}$ m^{-2} and $\mu = 0.23$ m^2/Vs. Structure Z88 had lower starting disorder because the doping δ layers were disposed on each side of the quantum well and were separated from it by the 60 Å spacer of undoped GaAs. The parameters of structure Z88 were $n = 5.1 \times 10^{15}$ m^{-2} and $\mu = 1.3$ m^2/Vs. Finally, the third structure 3509 had not δ doping layers. The conductivity of this structure was less than $10^{-2}\,G_0$ at liquid helium temperatures. The thickness of undoped GaAs cap layer was 3000 Å for all structures. The samples were mesa etched into standard Hall bars and then an Al gate electrode was deposited onto the cap layer of the structures H451 and Z88. The conductivity of structure 3509 was changed via an illumination. All the structures demonstrated the universal behavior.

Fig. 1(a) shows experimental dependences $\Delta\sigma(B)$ for different σ changed by applying gate voltage for $T = 1.5$ K. The close in the shape negative magnetoresistance is observed for all σ values down to $\sigma \ll e^2/h = \pi\,G_0$. Moreover, it is well seen that (1) well describes the experimental data. The conductivity dependence of the fitting parameters γ and α are shown in Fig. 1(b) and Fig. 1(c) respectively. The parameter γ weakly changes over whole conductivity range. In the range of σ from $60\,G_0$ to $10\,G_0$, the prefactor α is slightly less than unity and then it rapidly decreases down to approximately 0.1 when σ lowers. Solid line in Fig. 1(c) is

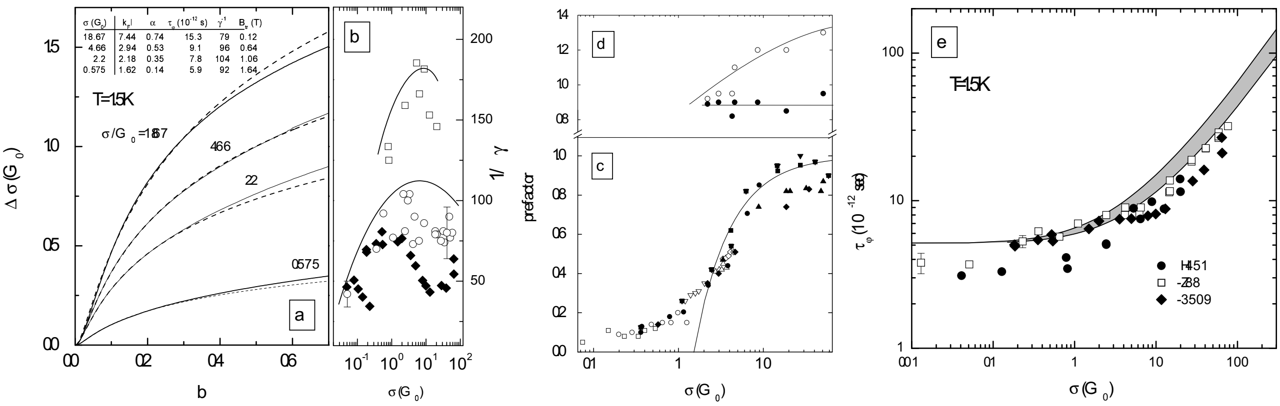

Figure 1: (a) The magnetic field dependence of $\Delta\sigma$ measured for structure Z88 at different σ. Solid curves are the experimental data, dashed curves are the best fit by (1) with γ and α given in the table. (b) and (c) The conductivity dependence of γ^{-1} and α, respectively, for structures Z88 (circles), H451 (squares), and 3509 (diamonds). The line in the panel (c) is given by (2). (d) The slope of the σ-versus-ln T dependence (open symbols), and the prefactor in the temperature dependence of the interference quantum correction (solid symbols) determined experimentally as a function of σ. (e) The conductivity dependence of τ_φ. Shadow area is theory [1] for different values of the Fermi liquid constant F_0^σ from the range $-0.45...1.38$.

equation (2). Thus, an excellent agreement with the second theoretical prediction is evident down to $\sigma \simeq 2\,G_0$.

Turn now to the first prediction. Our measurements show that in the structure investigated the temperature dependence of σ is actually logarithmic within the temperature range from 0.45 K to 4.2 K while the value of σ remains higher than $(1.0-1.5)\,G_0$. The slope of this dependence as a function of σ at $T = 1.5$ K is shown in Fig. 1(d) by open symbols. In order to obtain the wanted values of the prefactor in the *interference* correction at $B = 0$ we have subtracted from these data the part that is responsible for the electron-electron interaction contribution [3]. The final results are shown in Fig. 1(d) by solid symbols. Comparing figures 1(c) and 1(d) we see that the prefactor α in magnetoconductance noticeably deviates down from unity at $\sigma \simeq (7-8)\,G_0$, whereas the prefactor in the temperature dependence of σ at $B = 0$ remains close to unity down to $\sigma \simeq 2\,G_0$.

Thus, taking into account the terms of the second order in $1/g$ in the weak-localization theory allows us to understand quantitatively the magnetic field and temperature dependences of the conductivity for two-dimensional structures with different starting disorder down to low value of the conductivity, $\sigma \simeq 2\,G_0$. It allows us to attribute the fitting parameter γ with τ to τ_φ ratio and, thus, find experimentally the phase breaking time within whole conductivity range. As Fig. 1(e) illustrates the τ_φ-versus-σ experimental data are in excellent agreement with theoretical prediction [1]. This attests that the transport is unambiguously diffusive down to $\sigma \simeq 2\,G_0 < e^2/h$. It should be mentioned that the qualitative agreement, as seen from Fig. 1(e), remains to be down to significantly lesser conductivity, $\sigma \simeq 0.01\,e^2/h$. To our opinion, this indicates that there is no transition from the diffusion to hopping in this conductivity range.

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