Transport and Quantum Lifetime Dependence on Electron Density in Gated GaAs/AlGaAs Heterostructures

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In the transport theory one must deal with two different characteristic times—the quantum lifetime τ_q which is given by total scattering rate and the transport lifetime τ_t which is weighted by the scattering angle θ. For a short-range scattering potential τ_q and τ_t are approximately equal, but for GaAs/$Ga_{1-x}Al_xAs$ heterostructures, where the dominate scattering mechanism is the long-range potential associated with ionized donors which produce predominantly small-angle scattering, τ_q can be considerably smaller than τ_t.

Quantum lifetimes can be determined experimentally from Dingle plots. The amplitude $\Delta\rho$ of the Shubnikov-de Haas (SdH) oscillation is given by [1]

$$\Delta\rho = 4\rho_0 \frac{\chi}{\sinh\chi} \exp\left[-\frac{\pi}{\omega_c \tau_q}\right] \tag{1}$$

where ρ_0 is the zero-field resistivity, ω_c is the cyclotron frequency, and $\chi = 2\pi^2 kT/\hbar\omega_c$.

Though several studies of τ_q in GaAs/$Ga_{1-x}Al_xAs$ heterostructures with different electron densities have been reported, but to date there seems to have been no systematic studies of transport and quantum lifetime dependence on electron density. It is well known that at liquid helium temperature, the distribution and density of ionized donors remain constant. Therefore by measuring a gated GaAs heterostructure, one can study both the transport and quantum lifetime as a function of electron density at a *fixed* ionized donors' distribution and density, and it is the purpose of this paper to report such measurements.

Using the sample with high mobility about 300 m^2/Vs for the experiments, our results show that the quantum lifetime decreases with decreasing electron density, as shown in Fig. 1. But with decreasing electron density, τ_q appears to show an exponential decrease and we get an empirical fit: $\tau_q = 1.261\times10^{-12} + 1.25\times10^{-30}\exp(2.85\times10^{-14} n_e)$ (sec). Moreover, after studying the transport lifetime dependence on electron density we obtain the results that the ratios of τ_t / τ_q increase from about 45 to 90 as the electron density decreases, as shown in Fig. 2. This figure not only shows the importance of the long-range impurity scattering in our sample, but also strongly proves that the transport (τ_t) and quantum (τ_q) lifetimes have two different characteristic dependences on electron density.

References:
[1] P. T. Coleridge, Phys. Rev. B. 44, 3793 (1991).

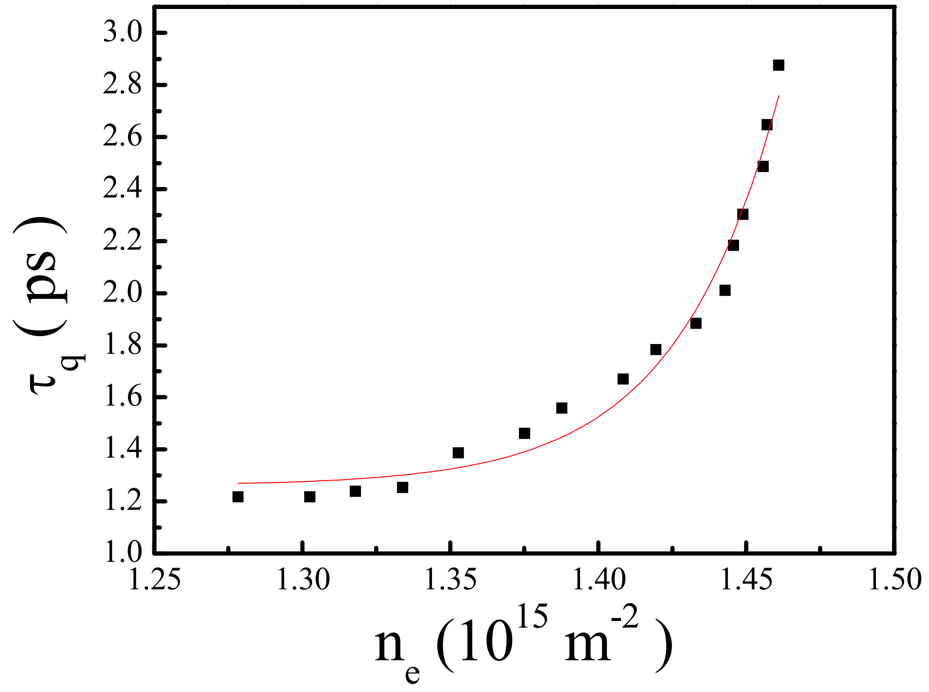

Fig. 1. The quantum lifetime measured from the Dingle plots is plotted against electron density. The quantum lifetime has an exponential increase as electron density. The exponential fit is $\tau_q = 1.261\times10^{-12}+1.25\times10^{-30}\exp(2.85\times10^{-14}n_e)$ (sec).

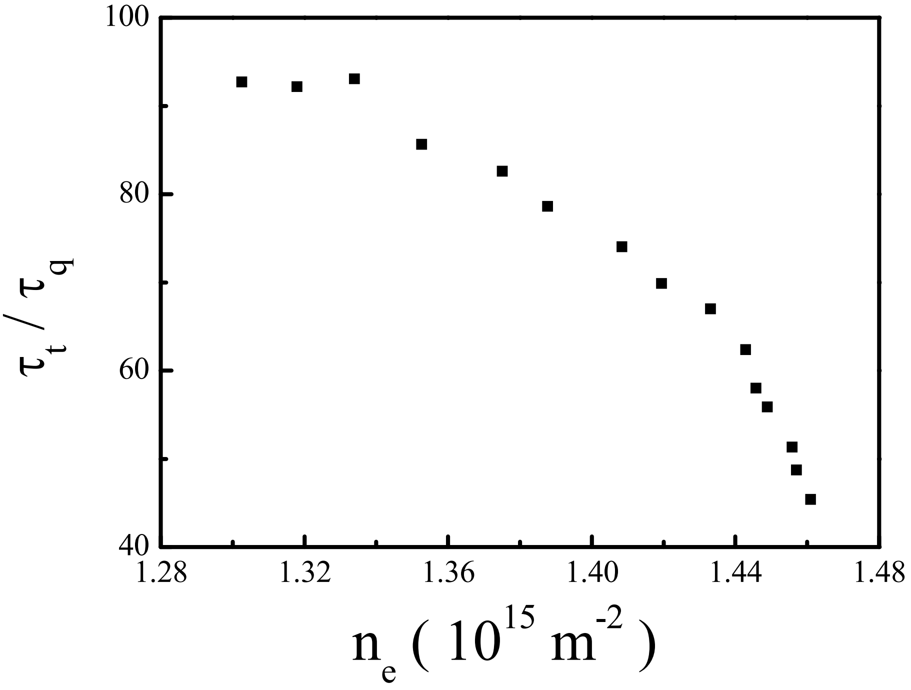

Fig. 2. The ratios τ_t / τ_q are plotted against electron density.