Diffusive Relaxation of Hot Electrons in a Quantum Hall Edge Channel Studied with a Hilltop Quantum Dot

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Ballistic transport of hot electrons in a quantum Hall edge channel is attractive for developing electronic analog of quantum optics [1]. When hot electrons are coupled even weakly to the environment, such as cold electrons in the channel, the hot electrons will relax toward lower energies with spectral diffusion. This diffusive relaxation is investigated by measuring the energy distribution function using a static quantum dot (QD) on a high potential hilltop, which we call hilltop QD. The spectroscopic measurement with high energy resolution allows us to estimate the fundamental characteristics of interacting electrons in the system.

Figure 1(a) shows the schematic energy diagram of a hot-electron injector with a point contact (PC) and a spectrometer with a hilltop QD between the emitter (E), base (B), and reference (R) regions. With the emitter chemical potential ($\mu_E = +eV_E = 0 - 15$ meV) higher than the grounded reference ($\mu_R = 0$), hot electrons injected from the PC fly over the base region with highly negative chemical potential ($\mu_B = -eV_B = -30 - -90$ meV) and reach the spectrometer. The initial energy distribution function has a high-energy cutoff at μ_E with broad low-energy decay due to the weak energy dependence of the tunneling probability, as shown in the inset (i). If the hot electrons scatter with cold electrons in the base, the energy distribution function broadens further at the analyzer, as shown in the inset (ii). The distribution function can be measured with the hilltop QD with tunable electrochemical potential ε_1 for the first electron. At positive ε_1 ($> \mu_R$), a fraction of hot electrons with energy greater than ε_1 is transferred to the reference region to yield current I_R (< 0). Therefore, the energy distribution function $f_h \sim -dI_R/dV_{GP}$ can be obtained from the derivative of I_R with respect to the gate voltage V_{GP} that changes ε_1.

The measurement was done with a mesoscopic quantum Hall device in an AlGaAs/GaAs heterostructure at Landau-level filling factor $\nu = 2$ under a magnetic field of 3.8 T at a low temperature of about 100 mK. The PC and the hilltop QD were formed with a distance of $L = 2$ μm. Figure 1(b) shows the obtained distribution function at fixed $V_E = 11$ mV, where the strength of electron-electron scattering is controlled by V_B without changing the emitter-spectrometer setup. The high energy cutoff at $\varepsilon_1 = \mu_E$ (= 11 meV) is seen clearly at $V_B = 90$ mV, where the cold electrons are spatially and energetically separated from the hot electrons. As V_B is reduced to 30 mV, the distribution shifts to lower energies and broadens significantly. This can be understood by using the Fokker-Planck equation for the electron-electron scattering [2]. The relation between the peak shift (energy relaxation) and broadening (diffusion) can be used to extract the maximum energy exchange per scattering ($\Delta E_{e\text{-}e} \sim 2$ meV), which is an important parameter to describe interacting electrons in the edge channel [2,3].

In this way, the novel hilltop QD can used to study hot-electron transport with high energy resolution. Moreover, the QD works as a tunable hot-electron injector by setting $\varepsilon_1 < \mu_E$.

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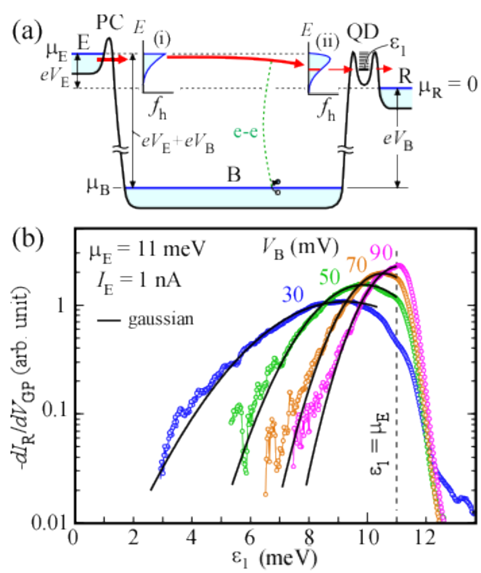

Fig.1. (a) Energy diagram of the hot-electron spectroscopy with a hilltop QD (b) Energy distribution function of hot electrons weakly scattered with cold electrons.

References

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