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Spectroscopy of Ballistic Hot Electrons Propagating 1.8 μm...18 μm through a 2D Electron Gas

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Abstract

Current transfer ratios for hot electrons propagating through a two dimensional electron gas have been measured in structures consisting of two quantum point contacts spaced $1.8\mu \ldots 17.8\mu m$ apart. The derivative of the current transfer is related to the electron energy distribution. We find a strong manifestation of LO phonon emission in the current transfer characteristics. The measurements allow to investigate ballistic electron transport in detail.

Analysis of hot electron transport and electron cooling is of fundamental importance for understanding hot electron transistors, proposed coherent electron structures, and other device structures. We use hot electron transport spectroscopy[1] to analyze the energy distribution of hot electrons propagating through a two dimensional electron gas with mean free path of $4\mu m$ over distances of $1.8 \ldots 17.8\mu m$— therefore we can investigate the transition between diffusive and ballistic transport.

Using electron beam lithography, two split gate point contacts have been fabricated on top of a two dimensional electron gas (carrier density $0.34 \times 10^{12} cm^{-2}$, mobility $7.0 \times 10^5 cm^2/Vs$) in a $Al_xGa_{1-x}As - GaAs$ modulation doped structure. The gates are negatively biased forming two quantum point contacts, and the source—base region is biased to inject electrons with an excess energy through the source point contact into the base region. The experimental arrangement is shown in Fig. 1. The conduction band outline is shown schematically in Fig. 2, demonstrating the use of the drain gate as an analyzer for the hot electron distribution. Experiments are at $T = 4.2K$.

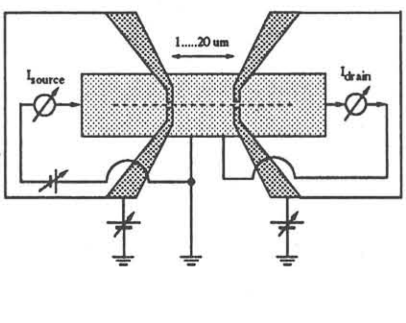

Fig. 1. *Schematic drawing of sample structure and experimental arrangement.*

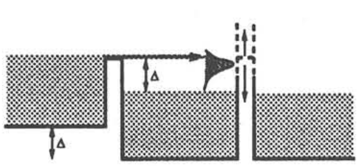

Fig. 2. *Outline of the conduction band for the experimental structure of Fig. 1.*

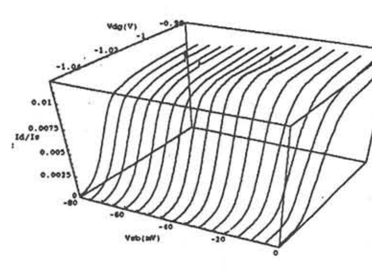

Fig. 3. *Measured current transfer ratio I_{drain}/I_{source} as a function of source-base Voltage (V_{sb}) and drain gate voltage (V_{dg}). ($d_{source-drain} = 17.8\mu m$)*

In Fig. 3, Fig. 4 and Fig. 5, we first show results for a structure with a source—drain separation of $17.8\mu m$. Fig. 3 shows the current transfer ratio as a function of source—base bias V_{sb} and as a function of drain gate voltage V_{dg}. Fig. 4 and Fig. 5 show the first derivative $d(I_{drain}/I_{source})/dV_{dg}$ of the measured current transfer ratio with respect to the drain gate voltage. $d(I_{drain}/I_{source})/dV_{dg}$ is expected to be related to the energy distribution of electrons.

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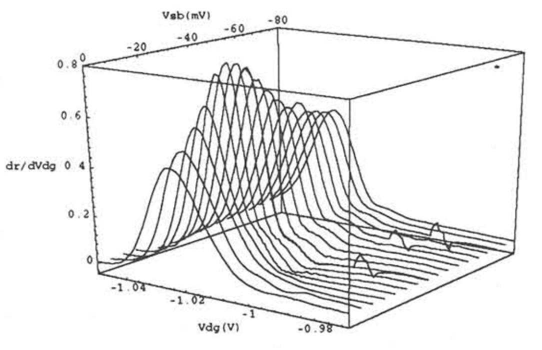

Fig. 4. *Derivative of experimental current transfer ratio* $dr/dV_{dg} = d(I_{drain}/I_{source})/dV_{dg}$ *from Fig. 3 as a function of electron injection voltage (source base voltage* V_{sb}*) and drain gate voltage (*V_{dg}*). (*$d_{drain-source} = 17.8\mu m$*, T=4.2K).*

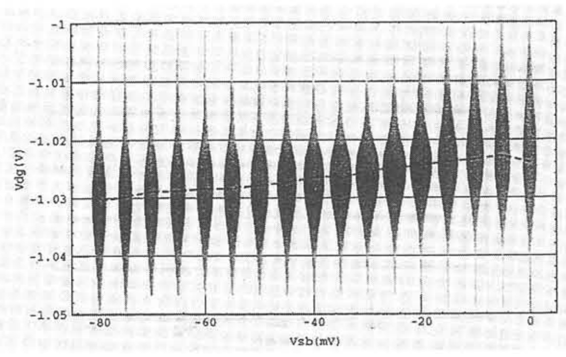

Fig. 5. *Same data as in Fig. 4, but showing current transfer ratio as a projection diagram, where width and darkness of curves is proportional to* $d(I_{drain}/I_{source})/dV_{dg}$. *Dashed line shows position of peak.*

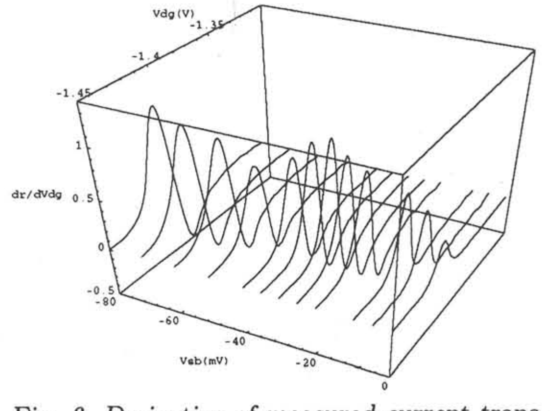

Fig. 6. *Derivative of measured current transfer ratio* $dr/dV_{dg} = d(I_{drain}/I_{source})/dV_{dg}$ *as a function of electron injection voltage (source base voltage* V_{sb}*) and drain gate voltage (*V_{dg}*). (*$d_{drain-source} = 2.75\mu m$*, T=4.2K). This figure also indicates resonance effects between the two point contacts.*

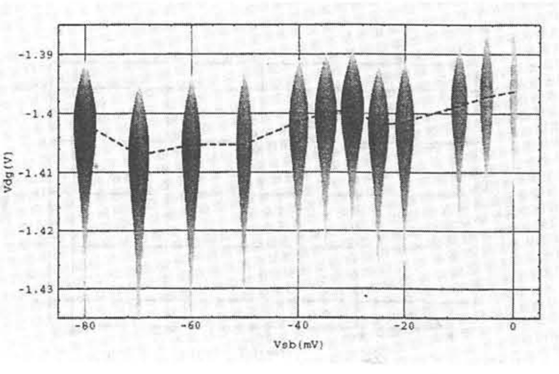

Fig. 7. *Same data as in Fig. 6, but showing derivative of current transfer ratio as a projection diagram, where the width and darkness of curves is proportional to* $d(I_{drain}/I_{source})/dV_{dg}$. *Dashed line shows position of peak. Structure around* $36meV$ *and* $72meV$ *is due to LO phonon emission by the ballistic electrons.*

In Fig. 6 and Fig. 7 we show the corresponding derivatives of the current transfer ratios for a structure with a source—drain separation of $2.75\mu m$, i.e. in the ballistic limit, since $d_{source-drain}$ is around 2/3 of the mean free path. In this case there is a very clear manifestation of scattering by LO phonons for injection bias near the LO phonon energy of $E_{LO} = 36.4meV$, and near $2 \times E_{LO} = 72.8meV$. Transfer ratio, slope, and position of the maximum in the derivative of the transfer ratio all show an initial increase as a function of increased injection energy, followed by a characteristic decrease around the LO phonon energy of $36.4meV$. The peak position in the derivative shown in Fig. 7 also indicates a second decrease a $2 \times E_{LO}$.

Summary. We have investigated hot electron transport through a two-dimensional electron gas over distances $1.8\mu m \ldots 17.8\mu m$ by measuring the current transfer ratios through two quantum point contacts. The measurements allow to obtain information about the electron energy distribution as a function of injection excess energy. There is clear evidence of LO phonon scattering. This method allows to obtain very detailed information on ballistic and diffusive electron transport.

[1] e.g. M. Heiblum et. al., Phys. Rev. Lett. **55**, 2200 (1985), S. Muto et. al. Electron. Lett. **21**, 555(1985), J. R. Hayes et. al. IEEE J. Qu. Electronics **22**, 1744 (1986), A. P. Long et. al. Semicond. Sci. and Technol. **1**, 63 (1986), U. Sivan et. al. Phys. Rev. Lett. **63**, 992 (1989).