Current fluctuations in single barrier vertical GaAs/AlAs/GaAs tunneling devices

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Abstract

The experimental results for current noise measurement in the single barrier tunneling device are presented.

Why to measure the noise?

Time dependent fluctuations of a tunneling current reflects the temporal correlations between charge transfer events through a conductor. For mesoscopic systems where Pauli priciple and Coulomb interactions play important role, the deviations from the classical Poissonian full shot noise power density $2eI$ can provide additional information about interactions between electrons inside the tunneling barrier and the mechanism of the transport (e.g. existence and number of localized states which participate in transport) [1].

The system

- Single-barrier resonant tunneling GaAs/AlAs/GaAs structure with Si δ-doping ($3{*}10^9$ cm^{-2}) in the center of the 10 nm thick AlAs barrier. The dimensions of the mesa structure was 200 μm by 200 μm.

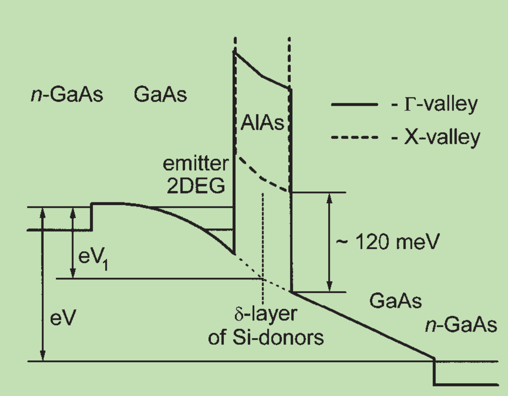

Figure (left): A schematic conduction-band diagram of a single barrier tunneling device under an applied voltage V. Figure from I. E. Itskevich, L. Eaves, P. C. Main, M. Henini, and G. Hill, *Phys. Rev.* B 57, 7214-7218 (1998)

I-V Characteristics

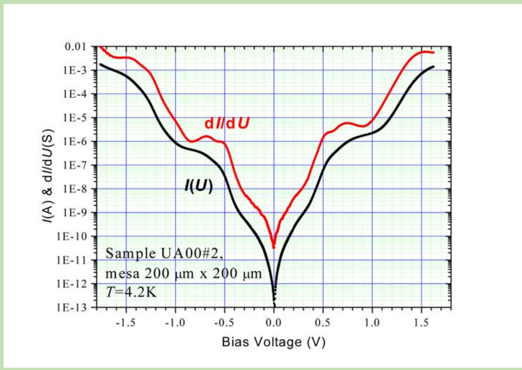

Figure (left): I-V characteristics of the single barrier resonant tunneling heterostructures. We expect that for different bias voltages i.e. for various transport mechanisms the temporal fluctuations of the tunneling current will be different.

The measure of current fluctuations is the Power Spectral Density of the signal

$$S_I(f) = \frac{\left\langle (dI(f,\Delta f))^2 \right\rangle}{\Delta f}$$

and Fano factor

$$F = \frac{S_{I,real}}{2eI}$$

which indicates whether the signal is super- (F>1) or subpoissonian (F<1).

We are searching for the interesting physics related to the resonant tunneling transport through small amount of impurities in the barrier. Currents in such a transport are on the level of 10^{-13}-10^{-6} A. Therefore we develop the technique which shall enable the noise measurement at the level at least of 1 fA/√Hz.

How to measure noise-signal ?

The Idea of crosscorrelation method:

- to have two independent amplifiers in two independent signal-carrying channels
- to correlate these signals at higher level
- the uncorrelated noise of amplifiers will not appear in crosscorrelation spectra
- the sample-related correlated noise will be measured

Experimental setup

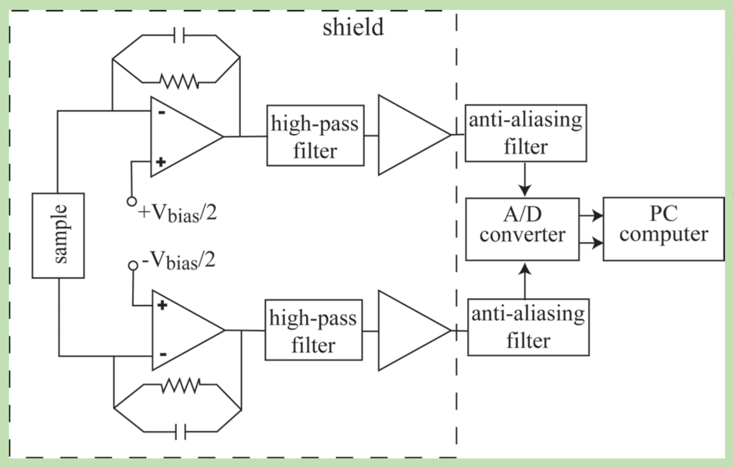

Figure (left): Basic scheme for current measurements using the correlation spectrum analyzer. The signal from the sample is fed to two distinct and independent input amplifiers operated in parallel [3].

E x p e r i m e n t a l R e s u l t s :

Current noise spectra

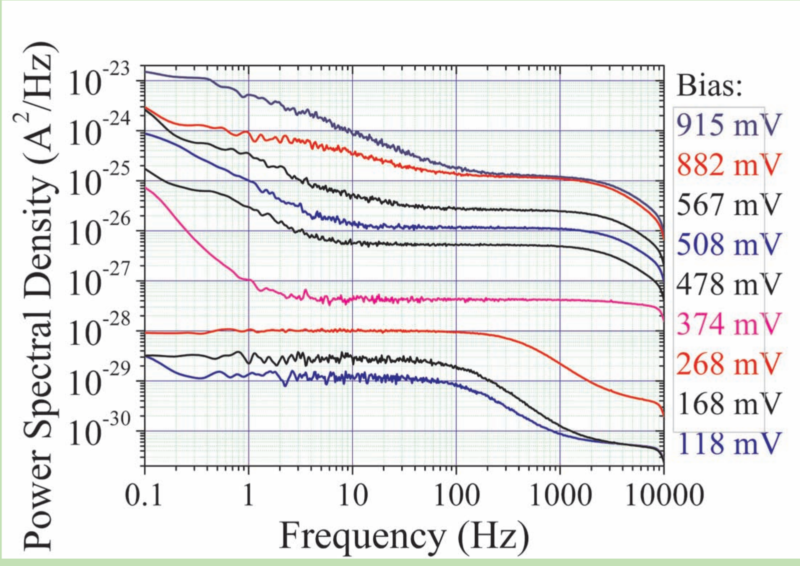

Figure (up): Typical PSD (crosscorrelation) spectra for sample UA00#2 at T=4.2K and several biasing voltages indicated on the right hand side. For lower biases the spectra are almost flat (white noise) and starting from ca U=0.3V they become more and more complicated, revealing different shapes at different biases.

Fitting procedure

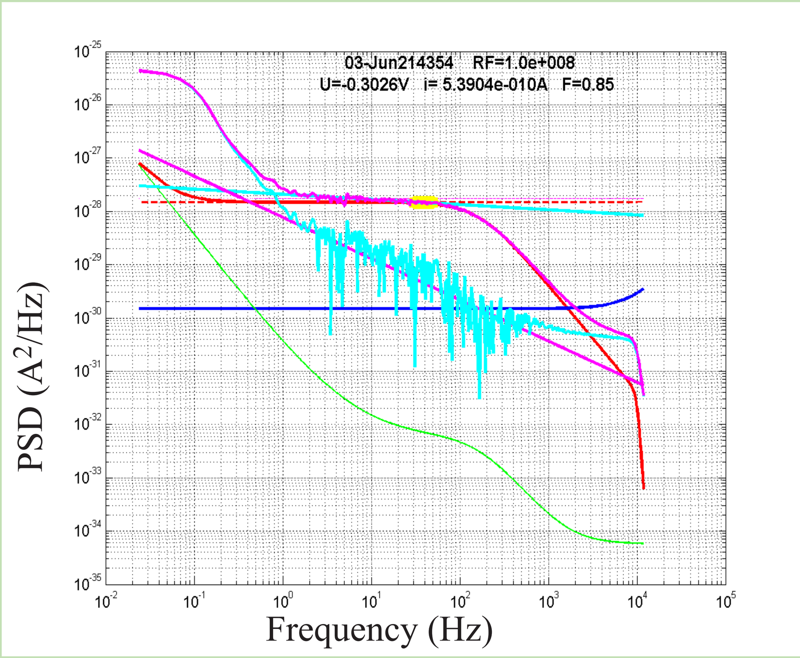

Figure (up): In order to determine the Fano factor from the spectra we fitted the amplifier characteristic (red line) to the high frequency tail of the spectra (magenta) assuming that the shotnoise is a white noise with PSD independent on frequency.The extracted 1/f-like noise is shown in cyjan. The green line is the correlated noise of amplifier originating from the voltage noise of amplifiers. The crosscorrelation method do not allow to get rid of it. However, in our spectra it remains very small.

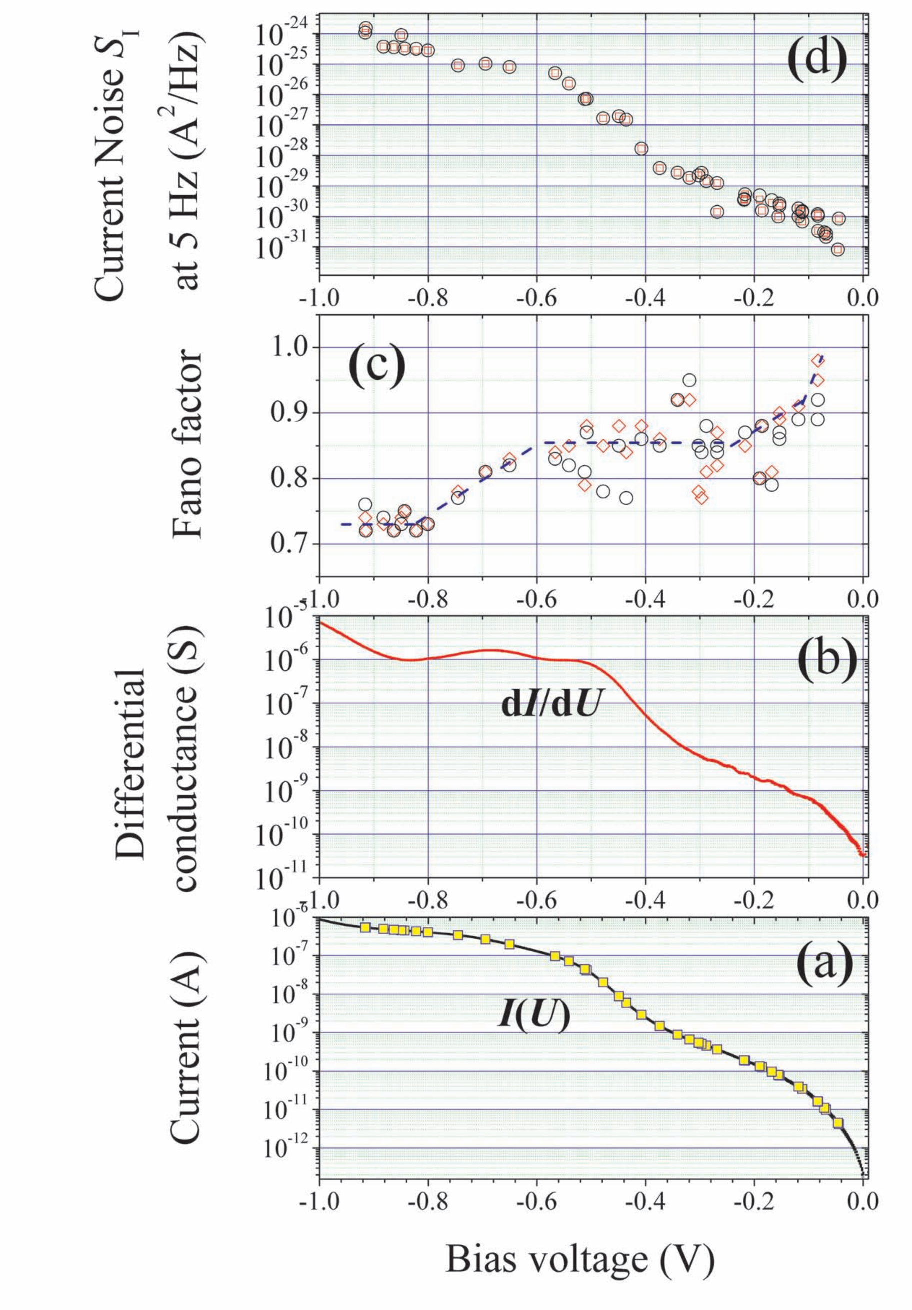

Figure (left): (d) Noise at 5Hz after subtracting the shot noise as a function of bias.

Figure (left): (c) Fano factor determined for several bias voltages marked in (a). The dashed line is only to guide the eyes;

Figure (left): (b) Differential conductance dI/dU numerically calculated from I(V) characteristics; in the region 0.5V-0.8V one can see two bumps originating from the tunneling process with the participation of the Si impurities in the barrier;

Figure (left): (a) I(V) characteristics for the sample at T=4.2K, squares indicates the polarisations for which noise measurements were performed;

- For biases smaller than those for which resonant tunneling through intentionally introduced impurities is observed (U<500mV), we have observed Fano factors **lower than 1** which indicates that even below this voltages we have a variety of different transport mechanisms.
- Only for the lowest biasing (U<0.1V) voltages the Fano factors tend to the value F=1.
- Unexpectedly, for higher biasing voltages 500mV<U<700mV, where in I(V) characteristics the resonant tunneling through the impurity states is observed, we have measured the Fano factor close to F=0.85.
- The Fano factor F=0.75, expected for the transport of electrons tunneling the barrier with impurities placed in its center [4], appeared for biasing voltages U>800mV. Because noise originating from the trapping electrons on impurities/imperfections superimposes on the shot noise, the measurements of the shot noise only is difficult in the configuration of experimental setup with transimpedance amplifier which limits the band below 100Hz for the highest gains used.

Conclusion:

In our experiment Fano factor F do not exceed one, it means that in our tunneling device we have **multiple uncorrelated sequential and/or parallel transport channels** each of which is govern by a full Poissonian process and a resulting transport statistics of a whole system is exclusively sub-Poissonian (F<1).

Acknowledgments

We are very much indebted to Dr Antonella Cavanna and Dr Giancarlo Faini from Laboratoire de Photonique et Nanostructures, Marcoussis, France for the growth of the samples.

References

[1] Ya.M. Blanter, M. Büttiker, Shot Noise in Mesoscopic Conductors, Physics Reports 336 (2000) 1-166;

[2] B.Jouault, M.Gryglas, G.Faini, U.Gennser, A.Cavanna, M.Baj, D.K.Maude, “Single impurity tunnelling spectroscopy to probe the discrete states of a two-dimensional electron gas in a quantizing magnetic field”, Phys. Rev. B 73, 155415 (2006);

[3] G. Ferrari and M. Sampietro, Correlation spectrum analyzer for direct measurement of device current noise, Rev. of Sci. Instr., 73, 2717 (2002)

[4] Y.V. Nazarov, J. J. R. Struben, Universal excess noise in resonant tunneling via strongly localized states, Phys. Rev. B 53, 15 466 (1996)