Shot noise suppresion in tunnelling through a single GaAs/AlAs/GaAs Si δ–doped barrier measured by crosscorrelation technique

Jacek.Przybytek@fuw.edu.pl

Institute of Experimental Physics, Warsaw University, Poland

Introduction -

Nowadays semiconductor heterostructures and devices become smaller and smaller. Therefore electronic transport properties of small electronic systems are substantially influenced by stochastic processes related to thermal agitation and quantum transitions of electrons and quasiparticles.
The purpose of this presentation is to present our first results of the shot noise maesurements in single barrier tunneling structure with planar d-doping inside the barrier.

Fluctuations (noise):

spontaneous, random (stochastic) deviations from the time-average of the physical quantity. They manifest a thermal agitation and quantum (discrete) nature of matter (charge, spin, etc...).

Quantum Shot Noise

- consequence of the quantization of charge;
- can be used to obtain information on a system which is not available through conductance measurements;
- shot noise experiments can determine the charge and statistics of the quasiparticles relevant for transport;
- is generally more sensitive to the effects of electron-electron interactions than the average conductance.

$$\langle I\rangle = \frac{2e^2}{h} V \sum_{n=1}^{N} T_n$$

Landauer formula, where $\frac{2e^2}{h}$ conductance quantum, and T_n transmissin probability of the channel n

$$S = 2e\frac{2e^2}{h} V \sum_{n=1}^{N} T_n(1-T_n)$$

Power Spectral Density (PSD) of the current through a single barrier

$$S_I(f) = \frac{\langle (\delta I)^2\rangle}{\Delta f} = 2e\langle I\rangle(1-T)$$

T<<1 → full shot noise (Poissonian) **(Schottky, 1918):**

$$S_I = 2e\langle I\rangle$$

***T*=1** → no shot noise

***0<T<1 intermediate situation*, reduction of noise by Fano factor:**

$$F \equiv \alpha \equiv \frac{S_{real}}{2e\langle I\rangle}$$

Shot noise in resonant tunneling through double barrier structure (DBS)

DBS

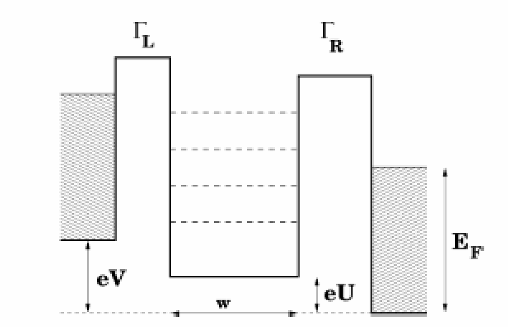


Figure from: Ya.M. Blanter, M. Büttiker, **Shot noise in mesoscopic conductors**, *Physics Reports* 336 (2000) 1-166

$$F = (\Gamma_L^2 + \Gamma_R^2)/\Gamma^2$$

$$S = 2e\frac{(\Gamma_L^2 + \Gamma_R^2)}{\Gamma^2}\langle I\rangle$$

Fano factor

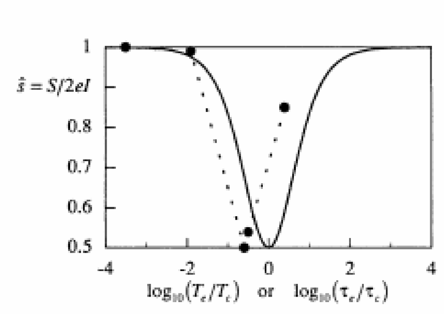


FIG. 3. Calculated ratio $\hat{s}(\omega=0)$ of shot noise to its full classical value $2eI$ for a resonant-tunneling diode, plotted as a function of the ratio of transmission coefficients T_e/T_c or escape rates τ_e/τ_c for the two barriers. The points are from the experiments of Li *et al.* (Ref. 5). The solid curve is the

Figure from: J.Davies, P.Hyldgaard, S. Hershfield, J.Wilkins, *Classical theory of shot noise in resonant tunneling*, PRB 46, 9620 (1992)

$F = \frac{1}{2}$ for tunneling through single resonant level and symmetrical barriers

$\Gamma_{L,R} = \hbar \nu T_{L,R}$ partial width of resonant state inside the barrier

$\Gamma = \Gamma_L + \Gamma_R$ ν – „attempt rate"

Single barrier with δ-doping

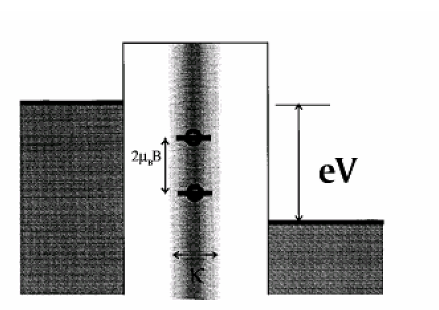
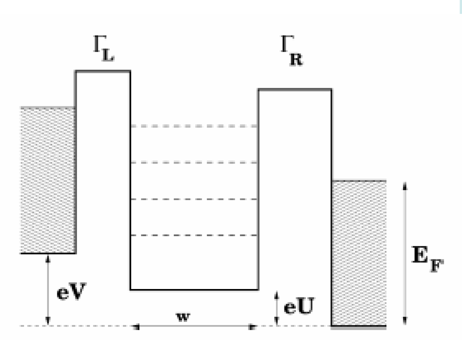


FIG. 1. Noise power of the disordered resonant tunneling conductor versus the current. The asymptotic slope corresponds $\alpha=\frac{3}{4}$.

≡

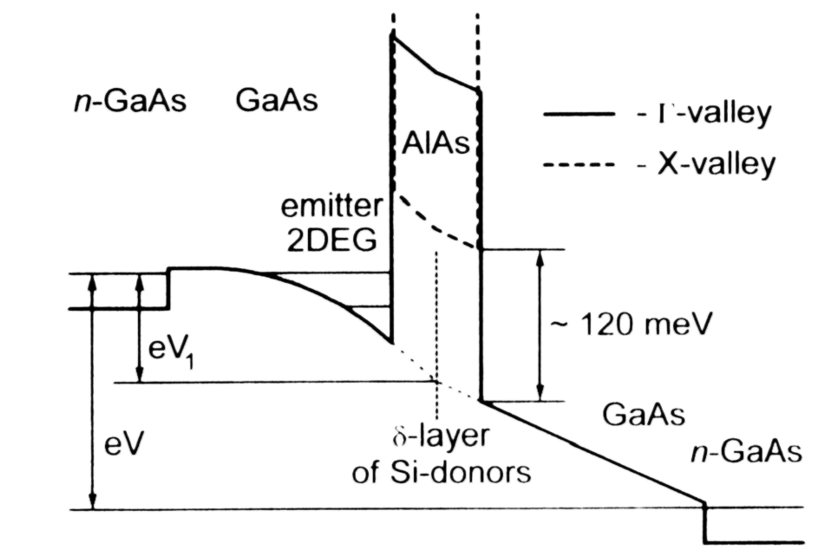


$$\Gamma_{L,R}(z) = \Gamma_0 \exp[\pm z/\xi], \quad |z| < w/2 .$$

$F = \frac{1}{2}$ for tunneling through single resonant level and symmetrical barriers

$F = \frac{3}{4}$ for tunneling through strongly localized states randomly distributed in the center of the barrier (Y.V. Nazarov, J. J. R. Struben, **Universal excess noise in resonant tunneling via strongly localized states,** *Phys. Rev.* **B 53,** 15 466 (1996))

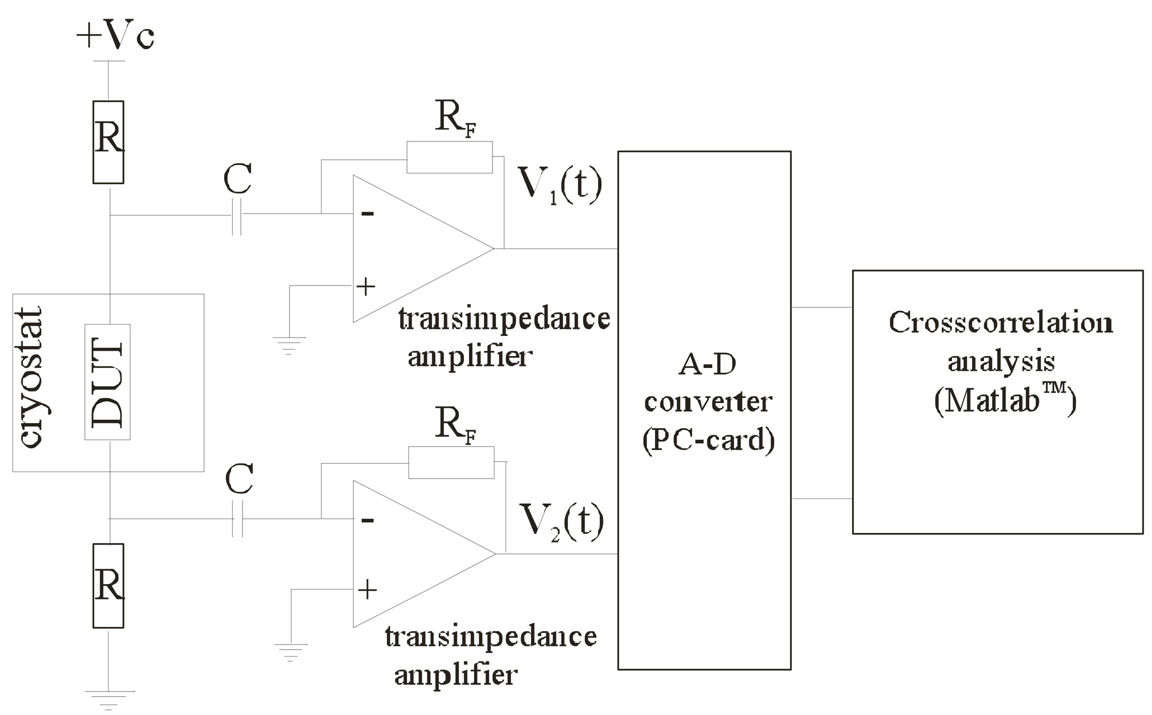
Samples



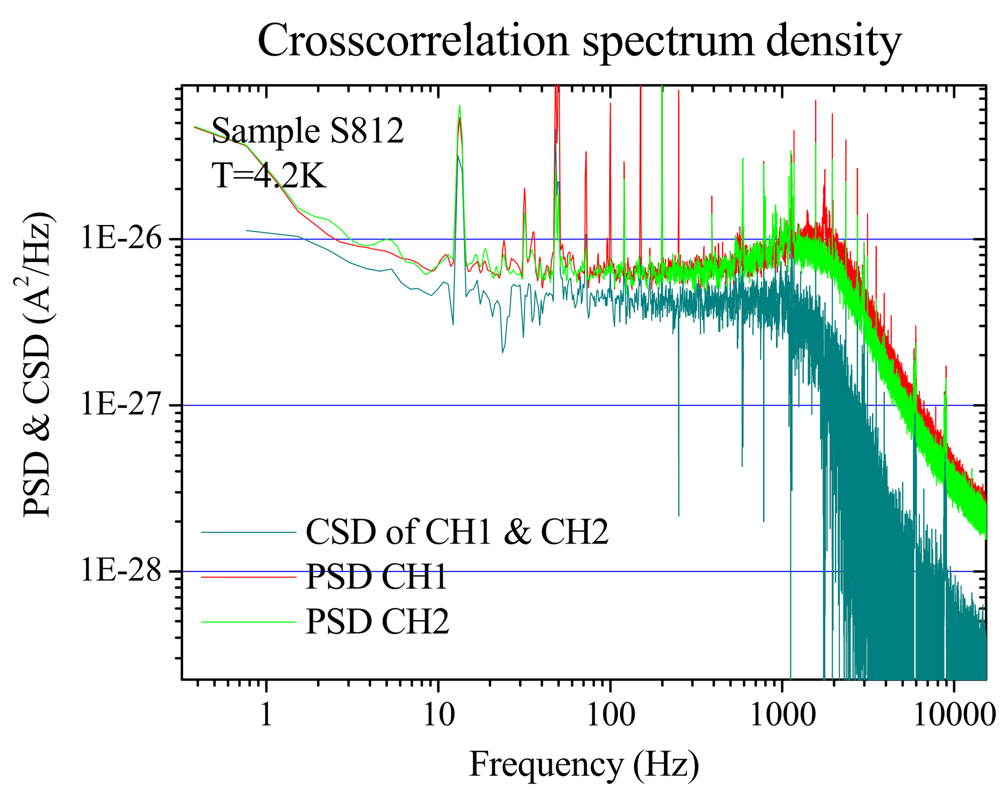
Single-barrier resonant tunneling GaAs/AlAs/GaAs structure with Si δ-doping ($3*10^9$ cm^{-2}) in the center of the 10 nm thick AlAs barrier. The diameter of the mesa structure was ca 150 µm.

The samples were grown in **Laboratoire de Photonique et Nanostructures, Marcoussis, France** by **Dr Antonella Cavanna** and **Dr Giancarlo Faini**, and the tunneling transport in these structures were thoroughly investigated by **Dr Marta Gryglas** in her PhD Thesis „Resonant tunnelling via single impurities in GaAs/AlAs/GaAs heterostructure", Warsaw University, Faculty of Physics, 2004.

Experimental setup for crosscorrelation technique of the current noise measurements

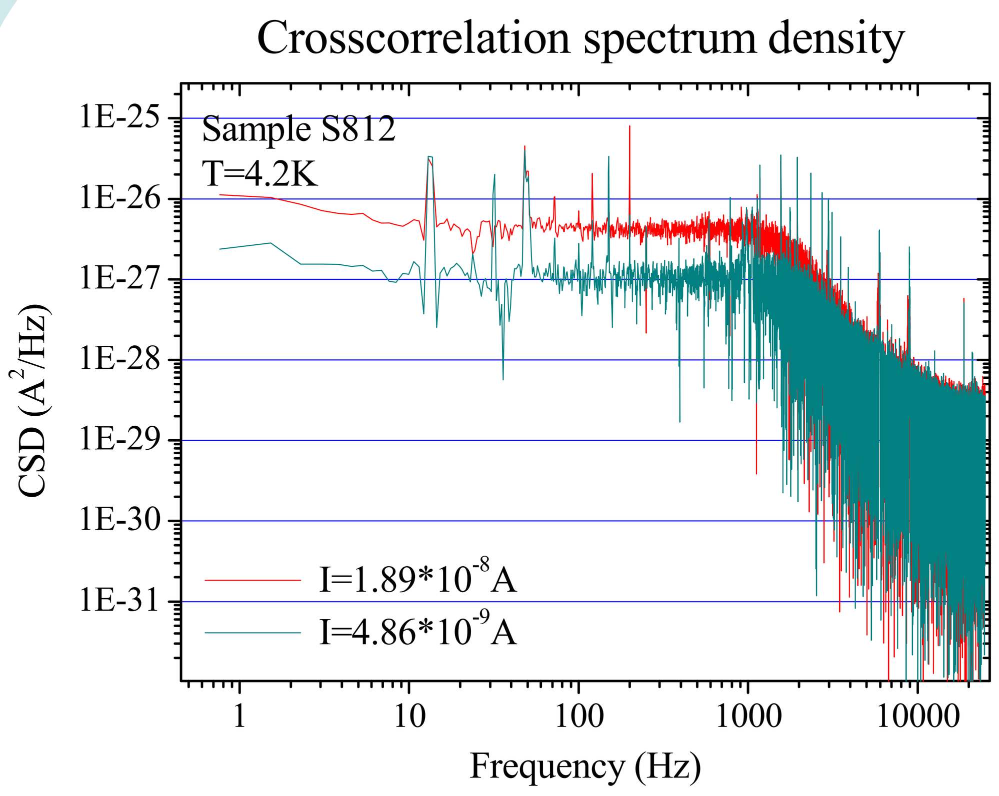


The electronic noise measurements were performed at low temperature T=4.2 K by means of two home-made transimpedance preamplifiers working in crosscorrelation regime. The idea of crosscorrelation technique has been taken from G. Ferrari and M. Sampietro (Correlation spectrum analyzer for direct measurement of device current noise, *Rev. of Scientific Instruments*, 73, 2717 2002).
Computer A/D converter card (Measurement Computing™ PCI-DAS1602/16) has been driven by Matlab™ software which performed also the numerical FFT analysis of the signal.

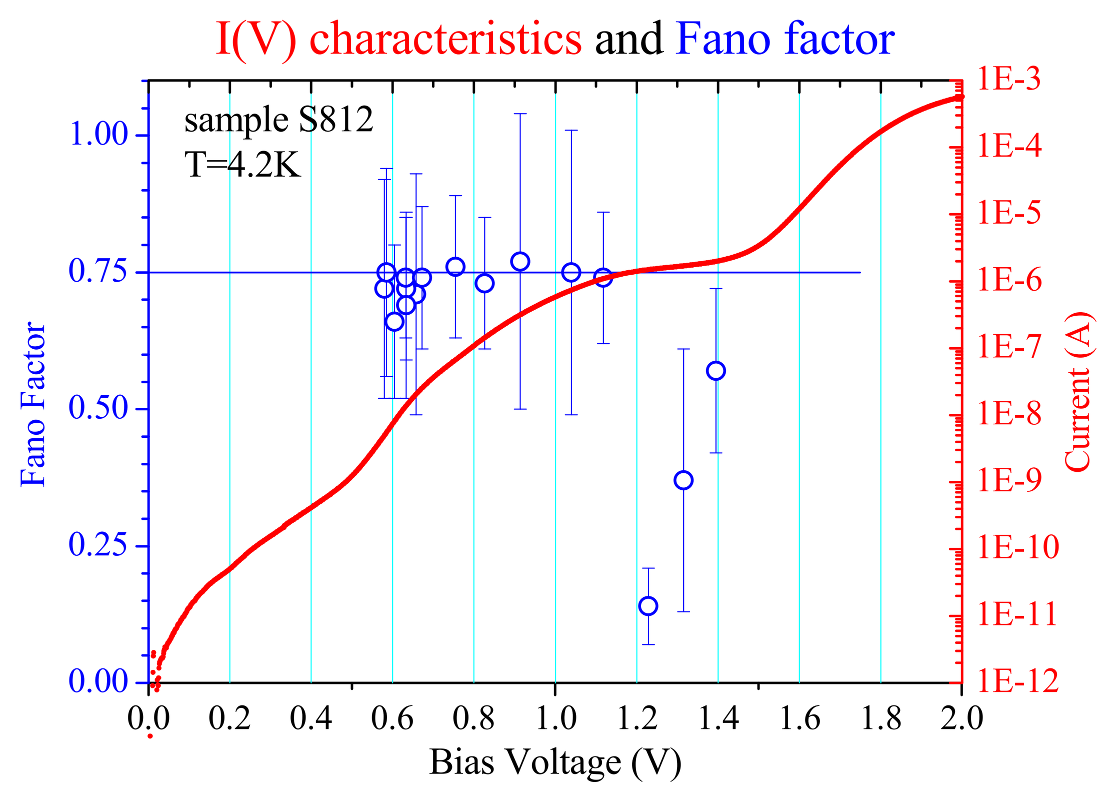


Crosscorrelation spectrum density (CSD) compared with power spectrum density PSD of the two independent channels. Crosscorrelation technique enables to get rid of independent noises of operational amplifiers in the two independent channels.

Results of the current noise measurements



Typical crosscorrelation spectra for two differend current values. The flat region between ca 5 and 1000 Hz comes from the white shot noise of the tunneling structure. Above 1000 Hz the low-pass filter of the transimpedance amplifier is observed.



For biasing voltages where in I(V) characteristics the tunnelling through the impurity states is observed, we have measured a shot noise with a value reduced by Fano factor 0.75 comparing to the full Poissonian value $2eI$. This result supports fully the theory of Nazarov and Struben who calculated the Fano factor 0.75 for the resonant tunnelling through strongly localized states which are randomly distributed inside the barrier. However, for larger biasing we observed the Fano factors much below the lowest value F=0.5 expected for this structure.

Conclusions

- The experimental setup is still under construction. The shot noise of the current higher than 1nA was easily measured. However, below the noise of 10^{-27} A^2/Hz we can observe a lot of external disturbing signals, not related to the sample.
- In the region, where in I(V) characteristics the tunneling through many randomly distributed impurities has been observed, we have measured the Fano factor 0.75 which agrees with the theory of Nazarov and Struben.
- The values of the Fano factor below 0.5 are not understood.
- More investigations and improvement of the experimental setup are needed.

General Conclusion:
There is the signal in the noise !

Acknowledgement:
Author would like to acknowledge a donation of the Measurement Computing™ PCI-DAS1602/16 A/D converter computer card from Dr M. Kończykowski (Ecole Polytechnique, France).