Non-Gaussian dark current noise in a p-type quantum-well infrared photodetectors

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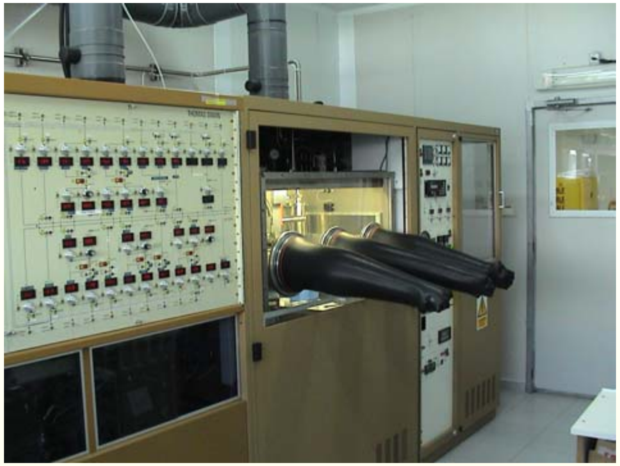
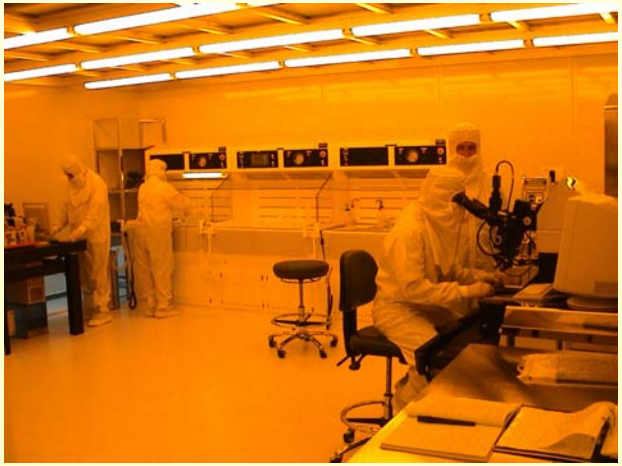
Soreq

MOCVD Growth
Vertical reactor



Material Characterization

Test Device realization
and Characterization



Class 100
Clean rooms

Present Activities

- InSb and InAsSb Layers Structures: Epitaxial Growth, diode – fabrication, characterizations and devices.

Appl. Phys. Lett. **84,** 5419 (2004)
Appl. Phys. Lett. **86,** 201103 (2005)

- Ternaries Antimonides: GaInSb (THz) , InAsSb, InSbN.

J Appl. Phys. **98** 023511 (2005)
Submitted to The European Physical Journal B
InAsSb detectors in preparations

- QWIP Studies – P and N type (voltage tunability, THz).

Infrared Phys. & Tech October (2005)

- Noise in Quantum wells.

Appl. Phys. Lett. **November** (2005)

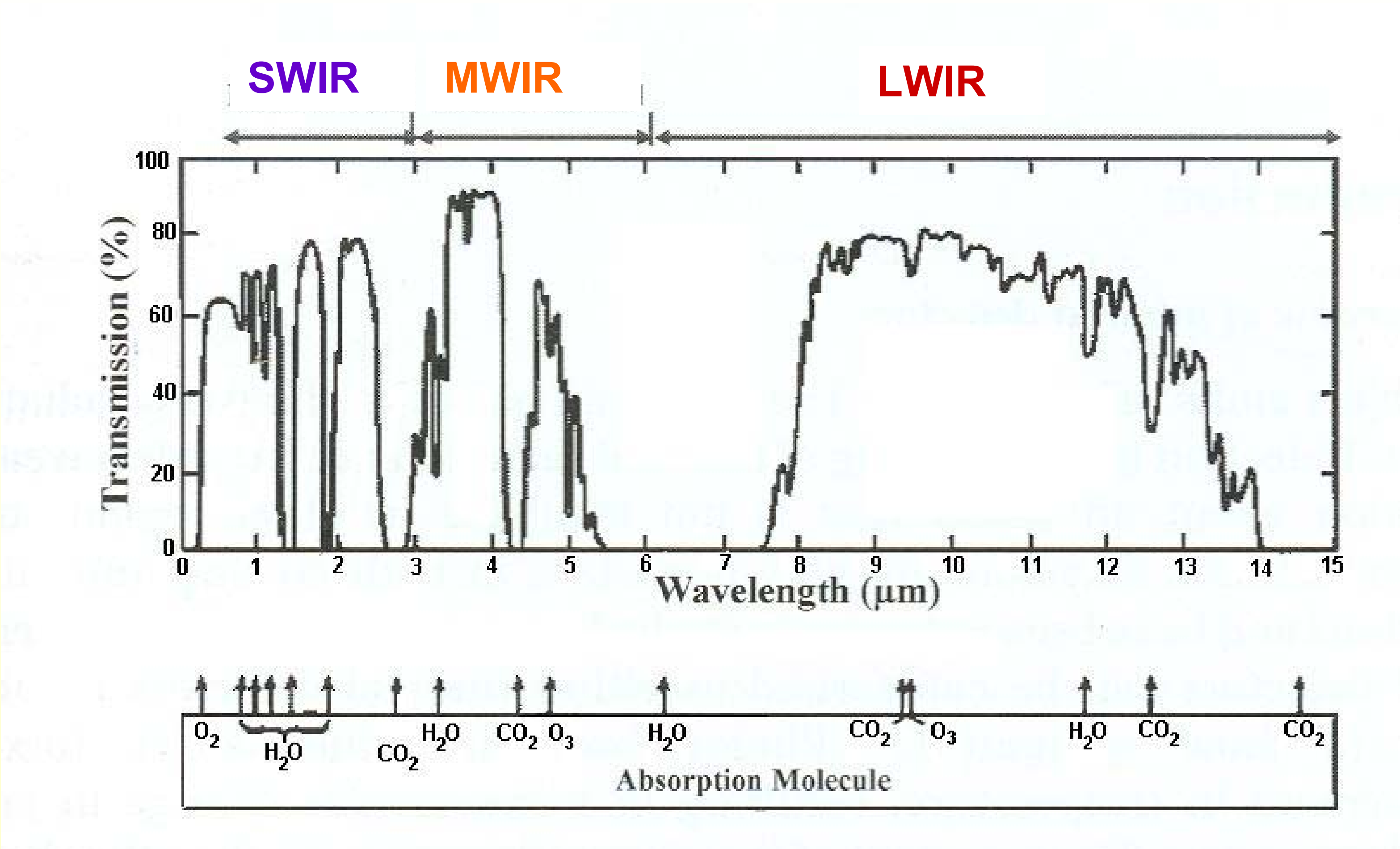
- Droplets epitaxy III-V nanodots.

Submitted to Journal of Crystal growth

- Nanocrystals

Accepted for publication in IEEE sensors journal
Nanogold enhancement and interactions in preparations

Atmospheric windows



THz

Nano Crystals

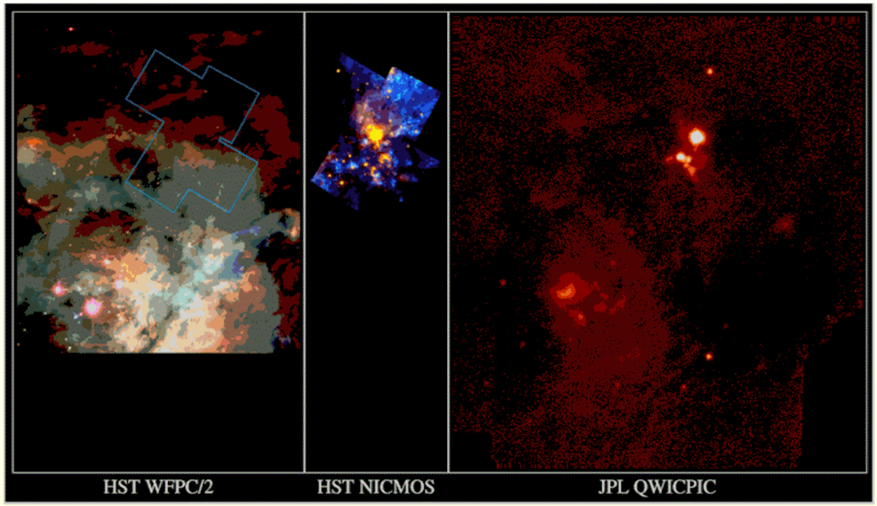
InSb
InAsSb
Nano-dots

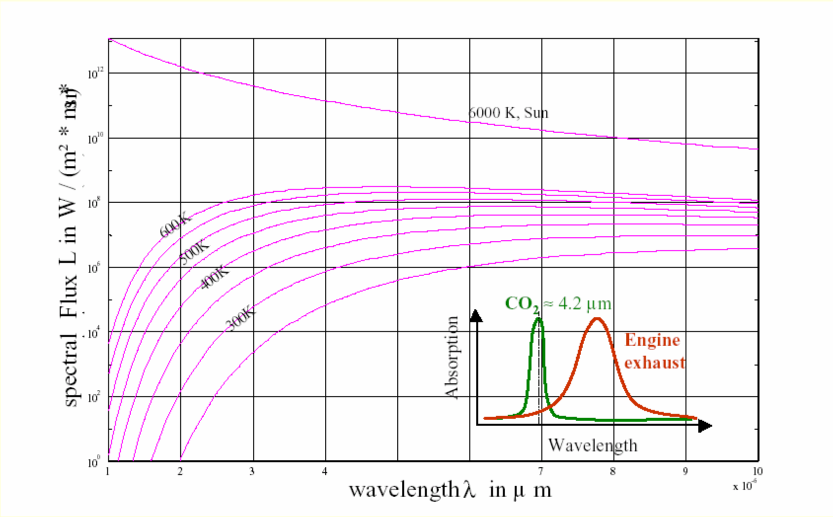
Quantum wells

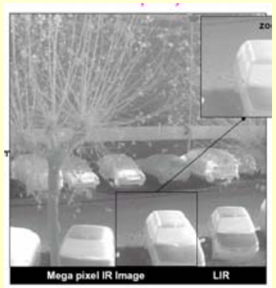
GaSb wells

IR Photodetectors Implementations

- Industrial
  - Electronics, Automotive, chemical sensing
- Space
  - Weather forecast, Astronomy
- Medical
- Military
  - Night vision, Target detection

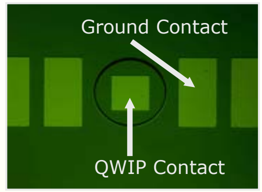




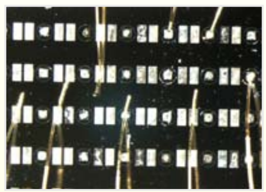


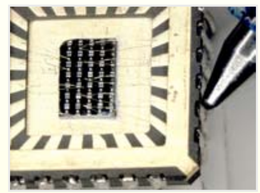
QWIP Process:

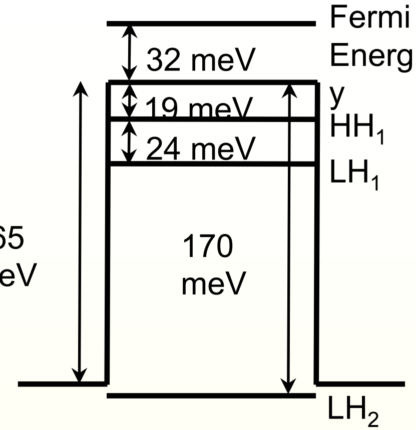
Fabrication:

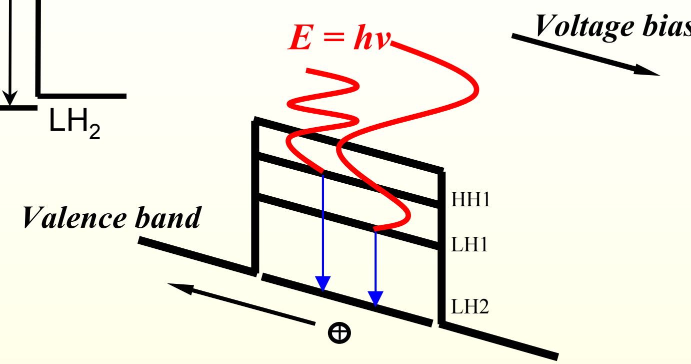


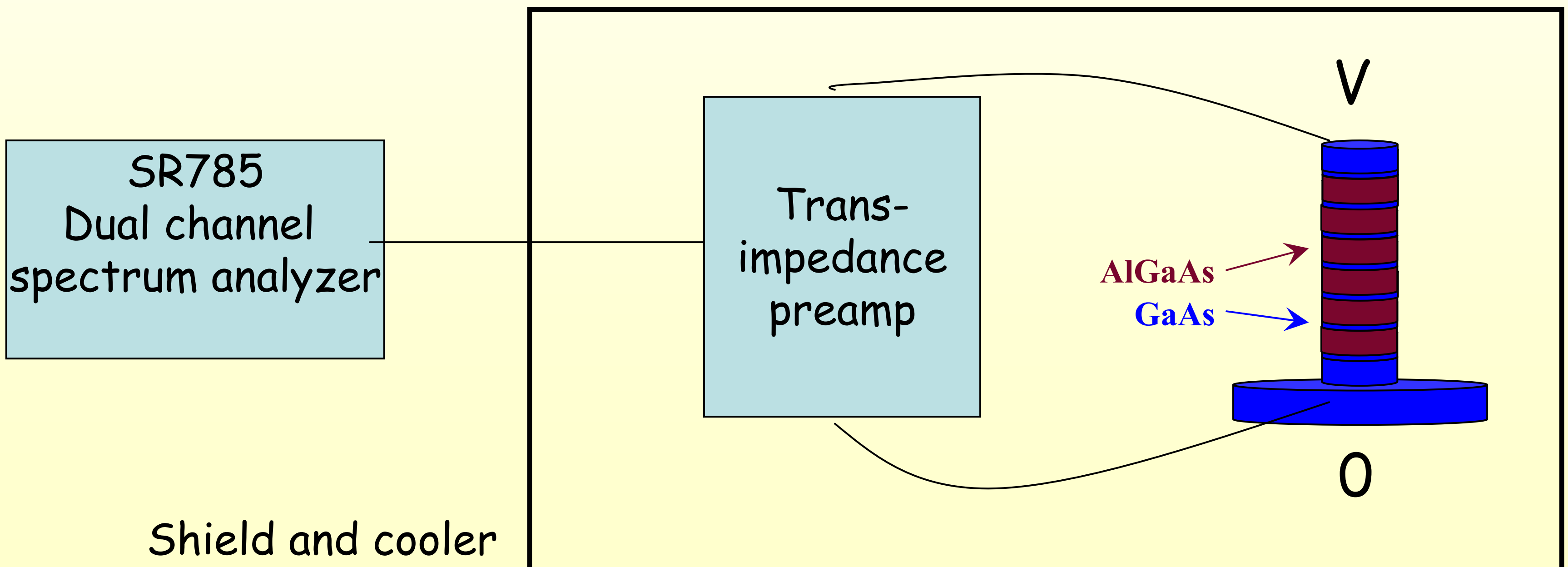
The measured device:





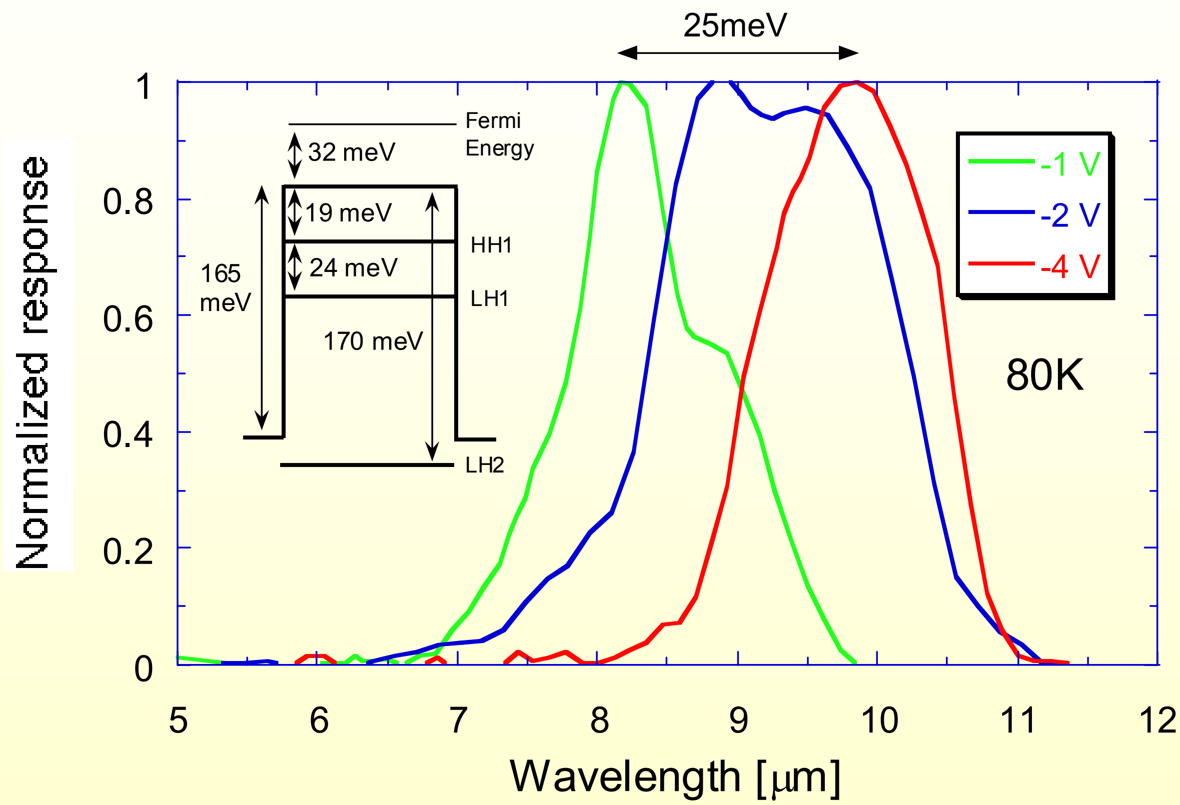


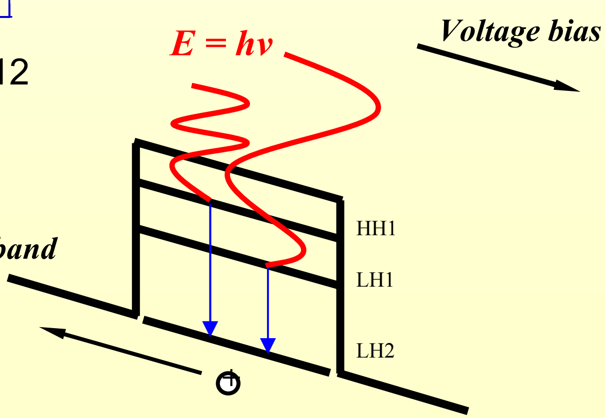




P type QWIP

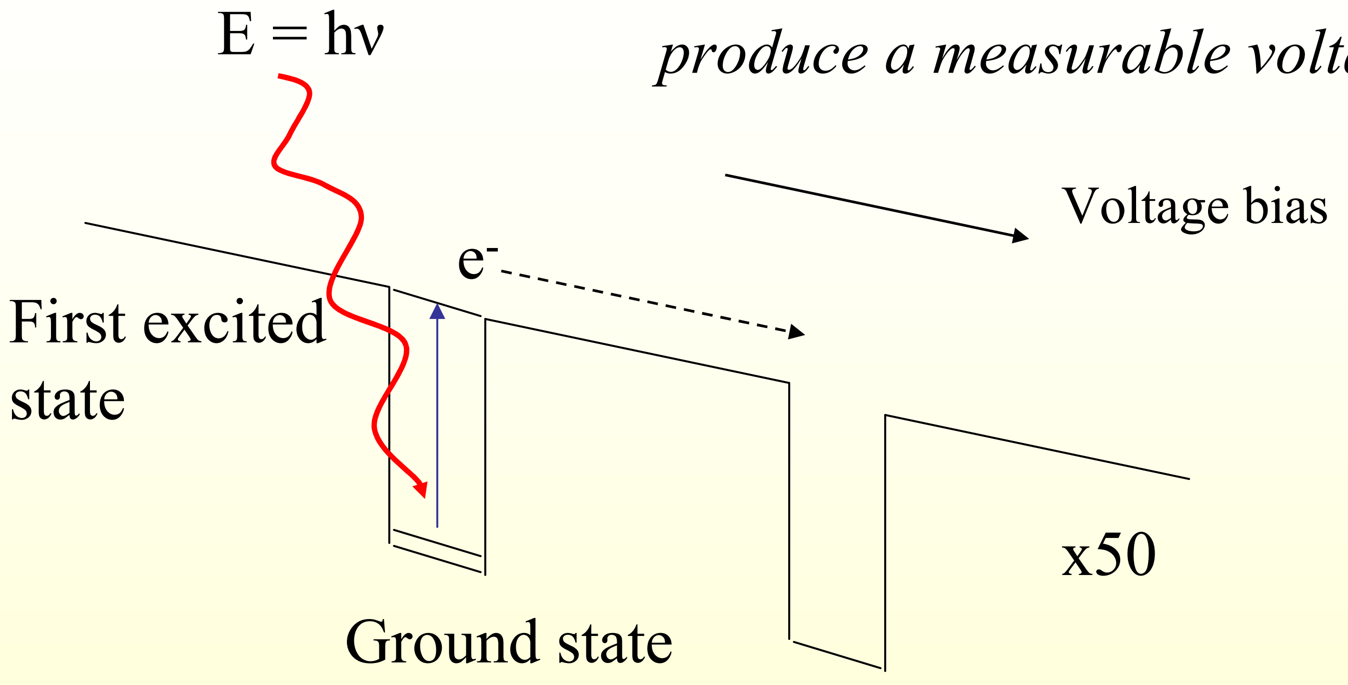
GaAs/AlGaAs Quantum well





Bulk approach to a Quantum Well

Photon excites an electron to produce a measurable voltage



Current GR noise $I_n^2 = 4gqI\Delta f$

$$S_i = I_n^2(f) = 4gqI\left[\frac{1}{1+\omega^2\tau^2}\right]$$

One expects to see the Gaussian noise…

Gaussian noise

The most familiar functions characterizing noise records of some variable $x(t)$ are:

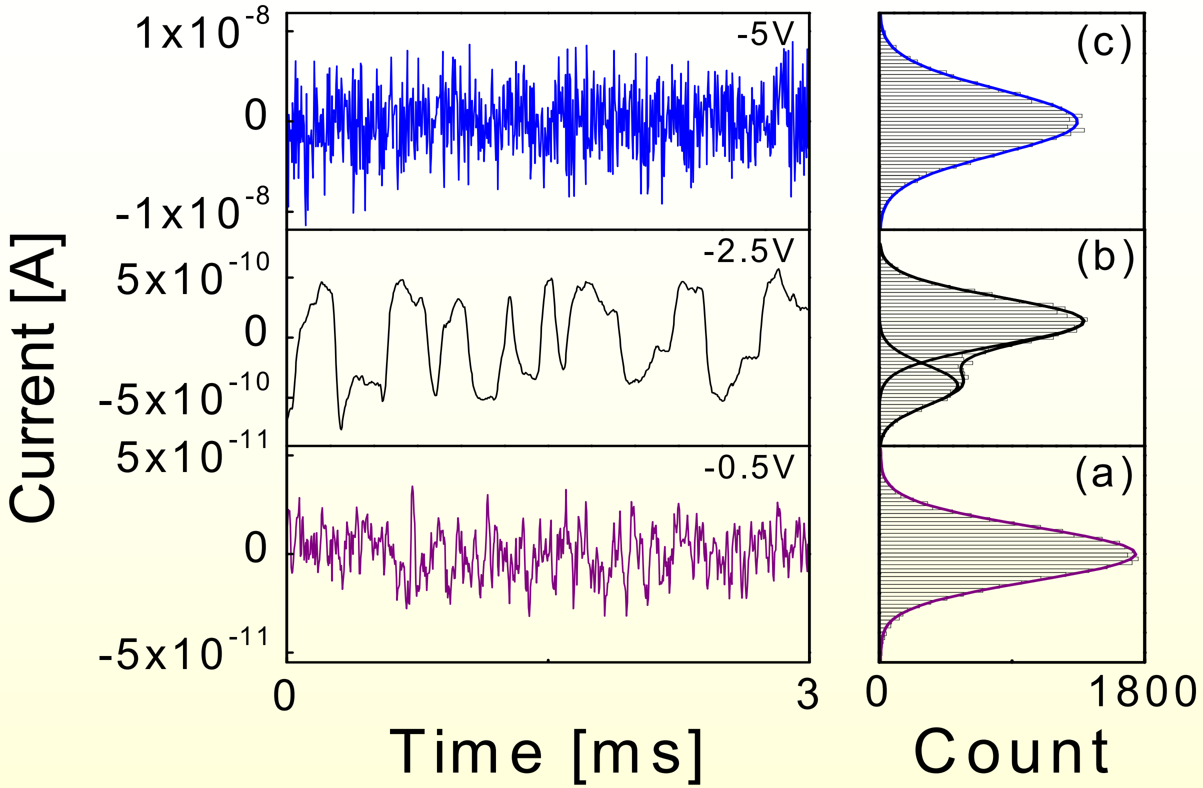
two-point correlation function $C_x(\tau) \equiv \langle x(t)x(t+\tau) \rangle$

power spectral density $S(\omega) = 4\int_0^\infty C_x(\tau)\cos(\omega\tau)d\tau$

Mathematically, Gaussianity means that every multipoint correlation function can be obtained by summing all factorizations into two-point products, each of which is replaced by the two-point correlation. For example, assuming $\langle x \rangle = 0$,

$$\langle x(t)x(t+\tau_1)x(t+\tau_2)x(t+\tau_3) \rangle = C(\tau_1)C(\tau_3-\tau_2) + C(\tau_2)C(\tau_3-\tau_1) + C(\tau_3)C(\tau_2-\tau_1)$$

For Gaussian noise all higher order time correlation functions and any of their Fourier relatives are fully determined by $S(\omega)$.



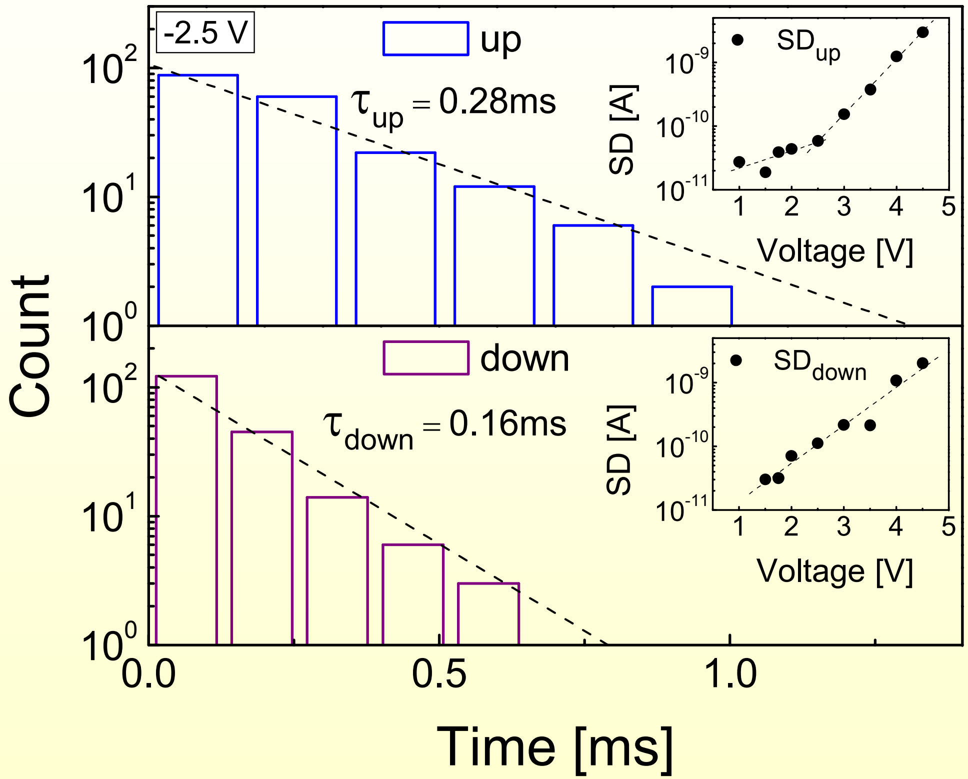
Time traces of the dark current and corresponding noise amplitude distributions for different bias voltages at 77 K.

Non Gaussian noise at intermediate bias level:

Meaning that in contrast to a bulk GR a limited number of fluctuators generates the noise

APL November 2005

Up and down level statistics



Lifetime of both states, follow the Poisson distribution as excepted for a random telegraph process

Non-Gaussian noise

- In the non-Gaussian noise higher moments are important and proper analysis requires measurements of multipoint correlations:

$$\langle x(t) - \bar{x} \rangle^n, \; n > 2$$

- All the information contained in a record of a Gaussian noise is obtainable from $S(\omega)$. For Gaussian systems all the information can be obtained from the response measurements.

- Only non-Gaussian fluctuations provide information which is not available otherwise.

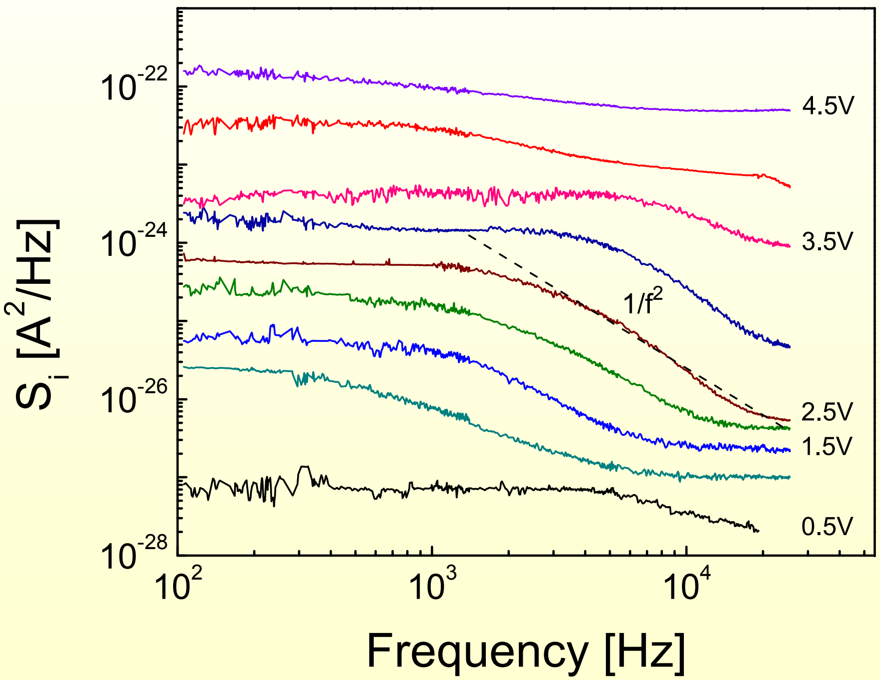
- Just the mere non-Gaussian character of the noise indicates that it cannot be due to a combined action of many elementary fluctuators.

Random Telegraph Noise $$2\pi f_c = 1/\tau_{up} + 1/\tau_{down}$$

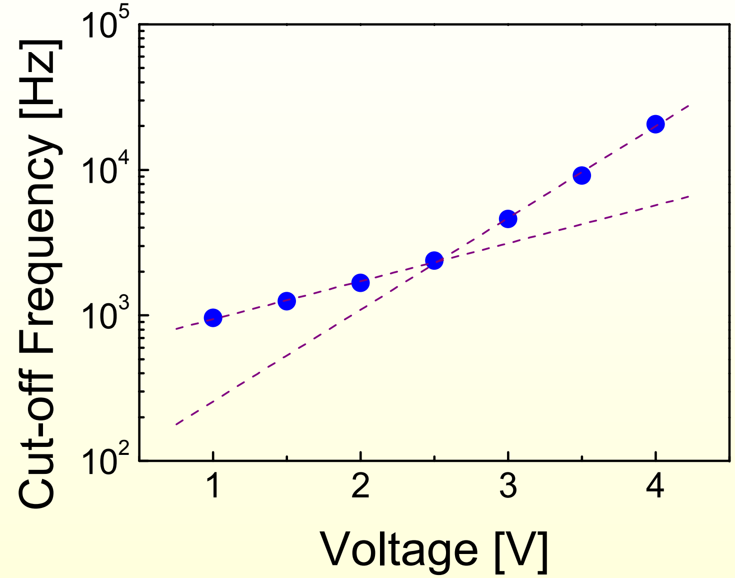
Where: τ_{up} and τ_{down} are the average life times at the up and down levels respectively.

Low frequency cutoff?

Frequency domain:



Dark current noise spectrum for different positive voltages at 77K.

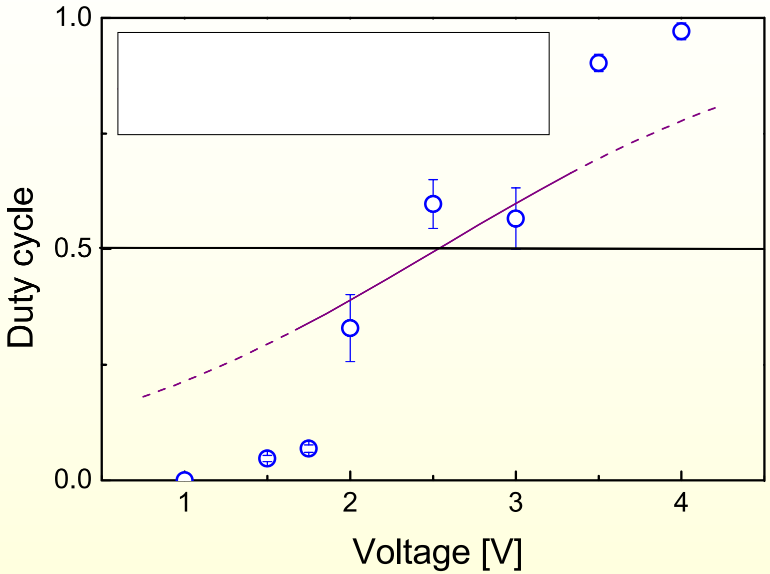


Bias dependence of the cut-off frequency determined from the spectra.

$$f_c(V) = f_{c0}\exp(\alpha V)$$

Exponential growth with different exponents a = 0.6 and a = 1.45 below and above 2.5 V, respectively.

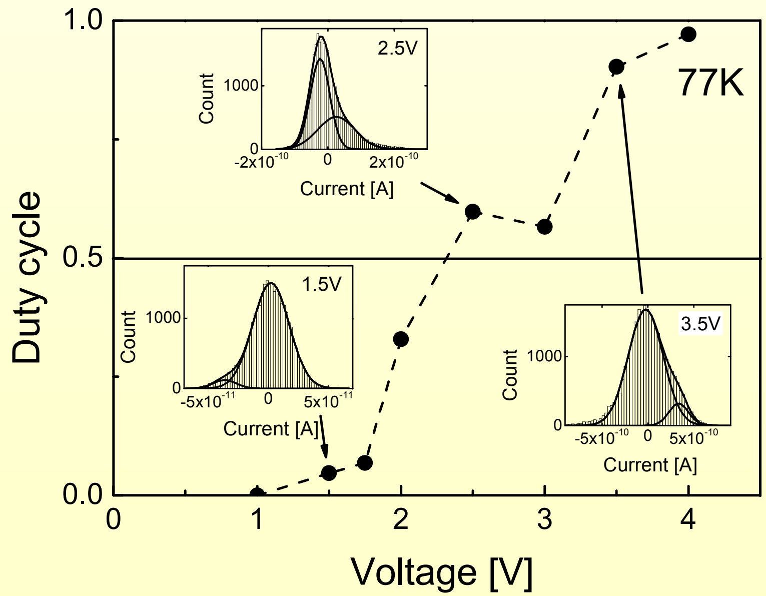
Duty cycle (D)



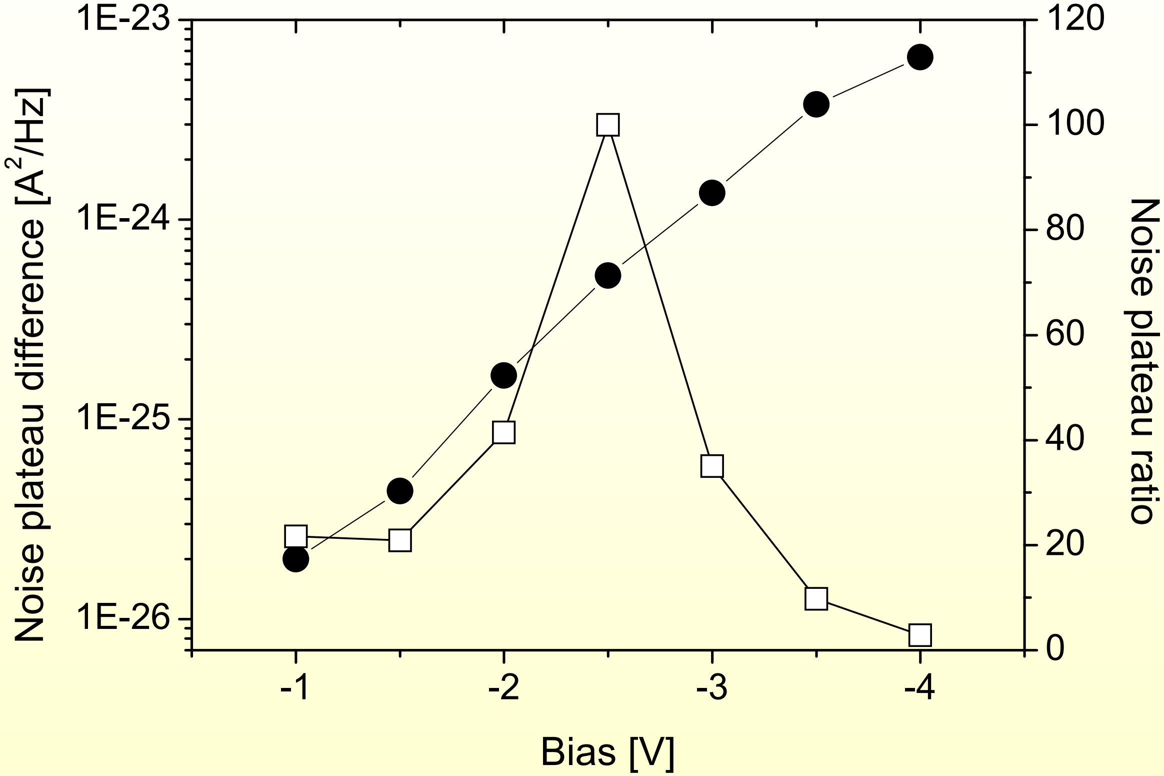
$$D = \tau_{up} / (\tau_{up} + \tau_{down})$$

Area (A) under the Gaussian is proportional to the total time spend in the level (τ).

$$D = A_{up} / (A_{up} + A_{down})$$

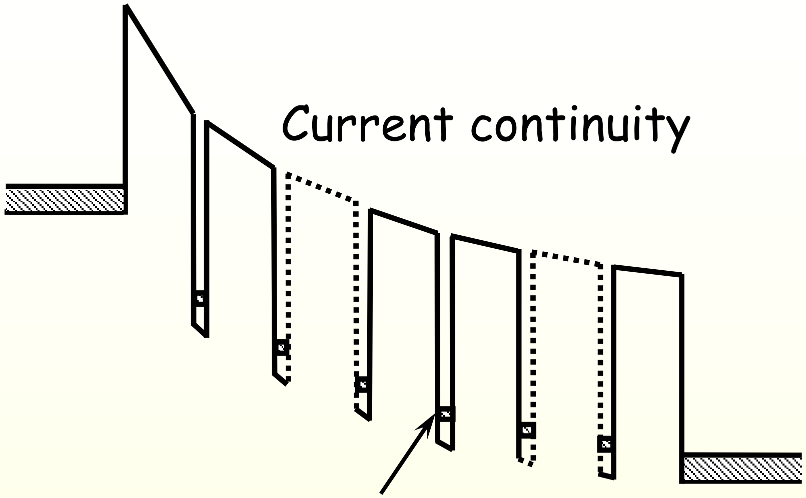


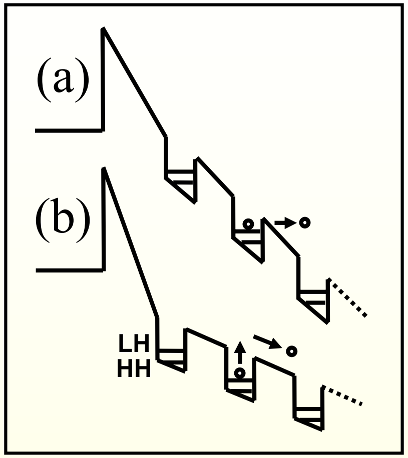
2.5V crossing point



Bias dependence of the RTN amplitude (solid circles) and ratio between the RTN plateau to the GR plateau (open squares).

Proposed fluctuator mechanism





Possible different resistivity states, characterized by different electric field distributions. (a) - “up” state, (b) - “down” state.

Discreet wells number ➡ discreet voltage distribution

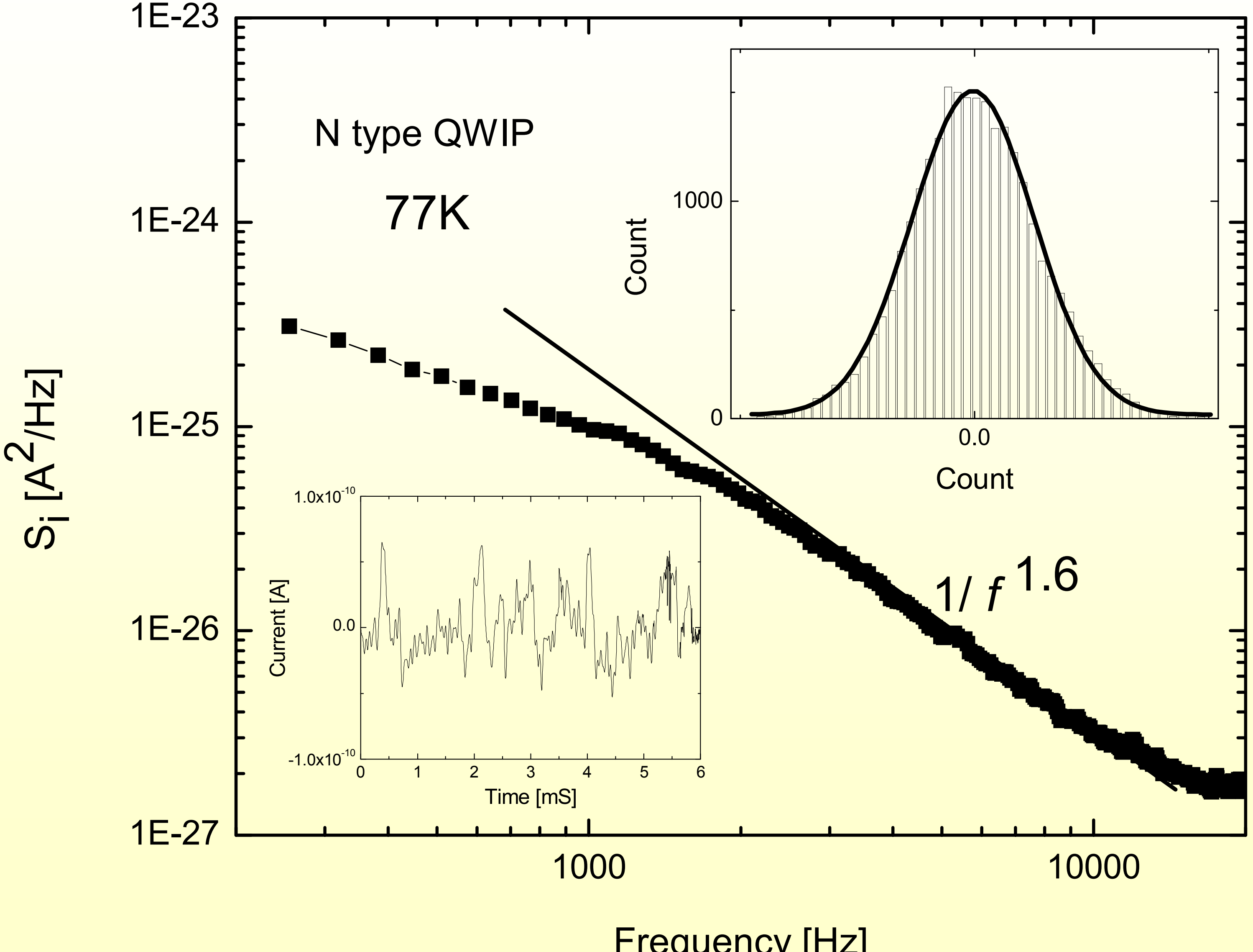
Tunneling from well (LH and HH) ➡ voltage distribution changes

First order like transition

Correlations between the tunneling from the emitter contact and the depletion due to tunneling from the wells.

Future works: Transport noise in nanodots and molecules nanocrystals system

N type



N type QWIP
77K
1E-23
1E-24
1E-25
1E-26
1E-27
S_i [A^2/Hz]
1000
10000
Frequency [Hz]
$1/f^{1.6}$
Count
1000
0
0.0
Count
$1.0x10^{-10}$
0.0
$-1.0x10^{-10}$
Current [A]
0
1
2
3
4
5
6
Time [mS]

Crackling noise

internal avalanche dynamics with widely distributed amplitudes → cackling noise

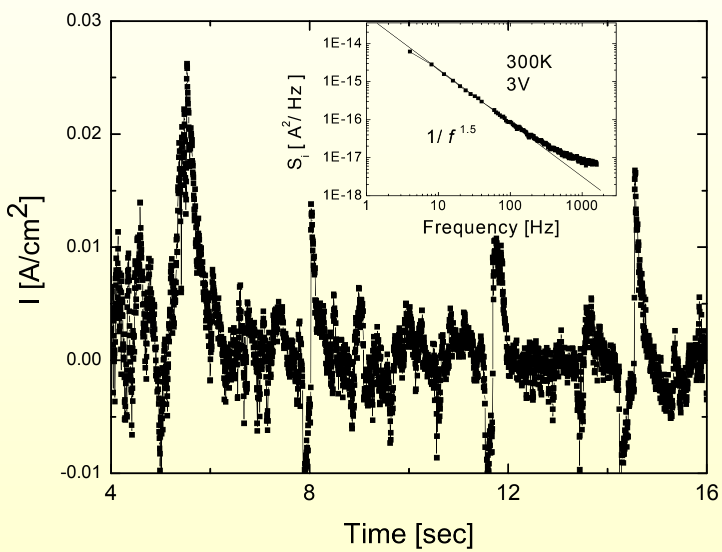
One possible general explanation

↓

proximity of some non-equilibrium critical point

↓

power-law distributions over several decades should occur, together with 1/f-type noise



Crackling avalanche noise as measured in transport through a nanodots system

Summary

• New type of noise - related to voltage distribution changes on emitter and wells

• Sensitive to voltage and is relevant in extreme conditions

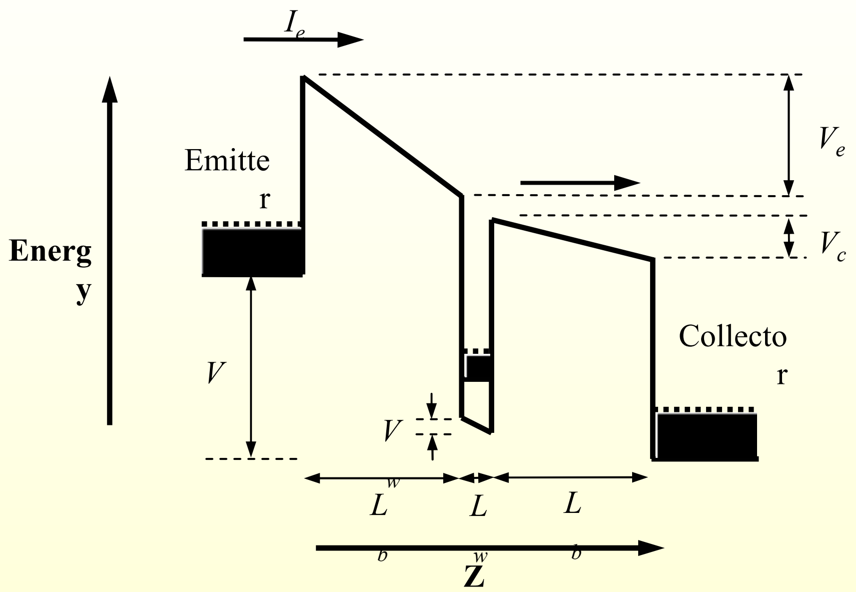
• Non Gaussian noise for both P and N type QWIPs

• In the QWIPs we have checked it is much stronger in P-QWIPs (LH and HH)

•With many wells the noise is average out and become Gaussian

•Crackling noise ?

Open Question



Why district voltage distributions?

A full model is missing

Contributors

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  - Research Staff: A. Sher, A. Raizman, M. Katz, A. Zussman
  - Technical support: M. Mizrahi, B. Bejerano, S. Saad, G. Shtrum.
  - Students: S. Shusterman, N. Snapi, Yaki Sharabani, Avi Ben Simon
- Collaborations
  - Grzegorz Jung - BGU (noise measurements)
  - Ron Naaman - Weizmann Institute (nano-crystals)
  - Uri Banin – Hebrew University (nano crystals)
  - Yossi Rosenwaks- Tel Aviv university
  - Chiaro Network - (GaAs FET process)
  - SCD - (InSb diodes and FPA)
  - D. Ban and H. C. Liu – NRC Ottawa Canada (up onversion)
  - U. Perera and Z. Hu - Georgia state university USA (THz)