Quantum Shot Noise Measurements in Single C_{60} Transistors

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The discreteness of electrical charges leads to unavoidable current fluctuations called "shot noise." Shot noise measurements reveal more detailed information about the electron transport of a system than conventional electrical measurements. Shot noise is measured as the spectral density, S, of current fluctuations per unit bandwidth. For classical uncorrelated electrons, Poisson statistics predicts $S = 2eI$, where e is the electronic charge and I is the average DC current. The Fano factor, F, in a general system is defined as, $S(f) = 2eIF$. The Fano factor has been investigated in a number of systems, theoretically and experimentally, and it changes depending on the channel properties. A recent theoretical prediction suggests that in the presence of electronic coupling to local vibrational modes, a large Fano factor would be observed. Such a system cannot be realized until recent creation of single molecular devices. In these devices, molecules vibrate as electrons transport through them. Therefore this is the ideal system to study shot noise in vibrating channels.

Here, we present preliminary measurements of shot noise in single C_{60} devices at low temperature down to 4.2K using a high frequency approach coincident with DC measurements.

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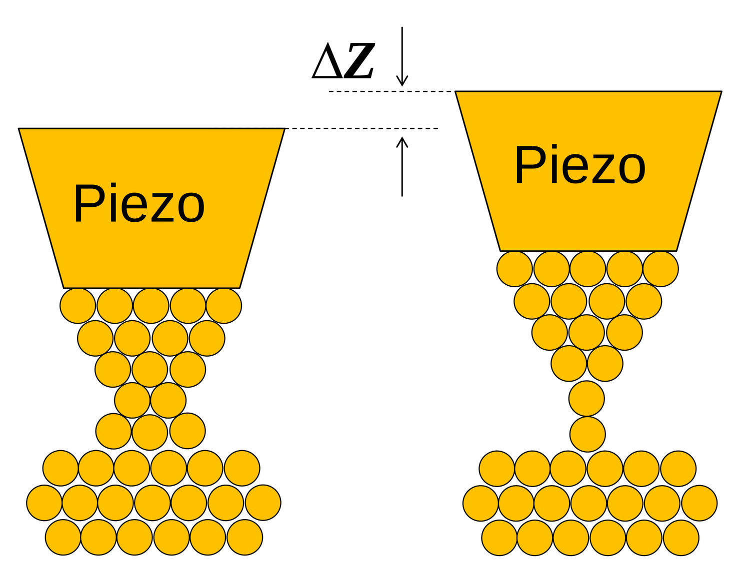
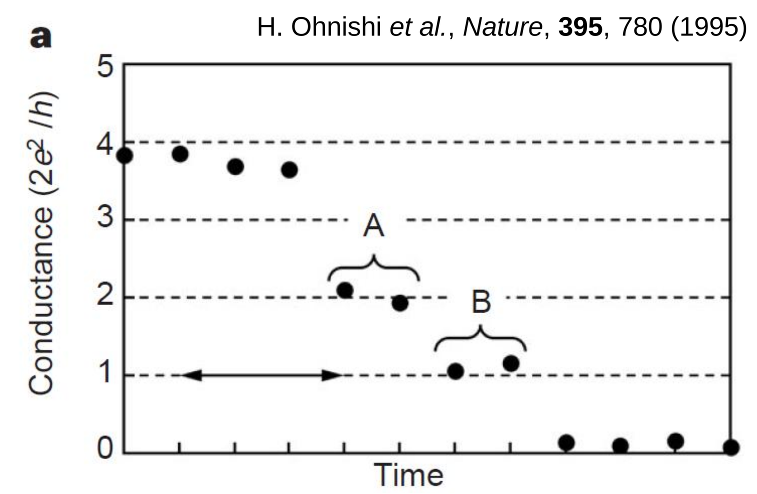
Introduction

Quantum conductance

■ When the constriction approach the Fermi wavelength of electrons (~40 nm), the conductance G becomes quantized as a function of the number of metal atoms.

Landauer formula: $G = \frac{2e^2}{h}\sum_n T_n$



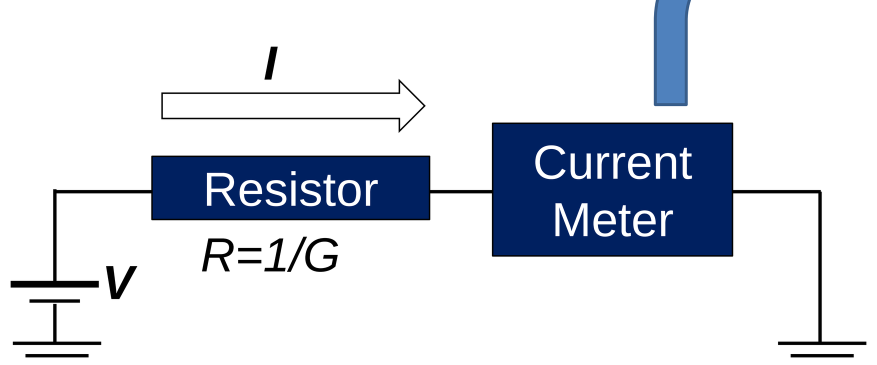


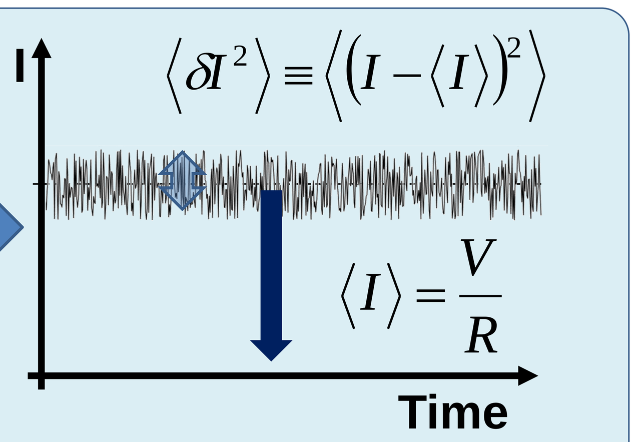
H. Ohnishi *et al.*, *Nature*, **395**, 780 (1995)

"The noise is the signal" R. Landauer, *Nature* **392**, 658 (1998)

What is noise ?

- ■Noise is fluctuations in electrical current.
- ■Noise is described as spectral density, S, which is the mean of the squared current fluctuation per unit bandwidth.





$\langle \delta I^2 \rangle \equiv \langle (I - \langle I \rangle)^2 \rangle$

$\langle I \rangle = \frac{V}{R}$

Current noise spectral density

$S_I(f) = \int e^{i2\pi f t} (\delta I)^2 dt \quad (A^2/Hz)$

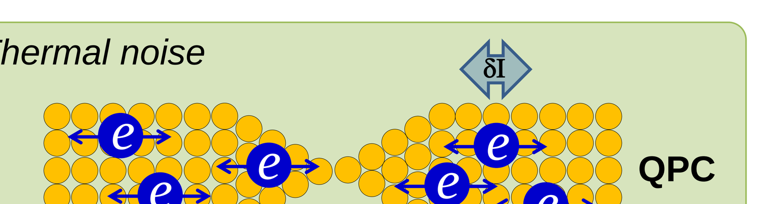
The information that noise have are followings…

- ■ How electrons flow through the conductor: quiet or noisy?
- ■ Absolute temperature of the conductor
- ■ Detailed information on the transmission channels

Theory: Noise in quantum point contact

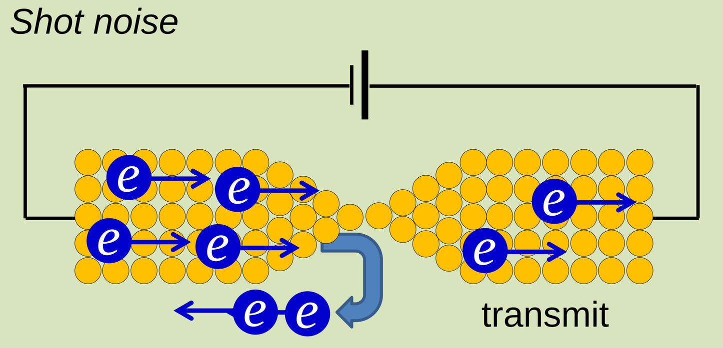
Noise spectral density : $S_I = S_I^{th} + S_I^{shot}$

Thermal noise



$S_I^{th} = 4k_B T G_0 \sum_n T_n \quad (A^2/Hz)$

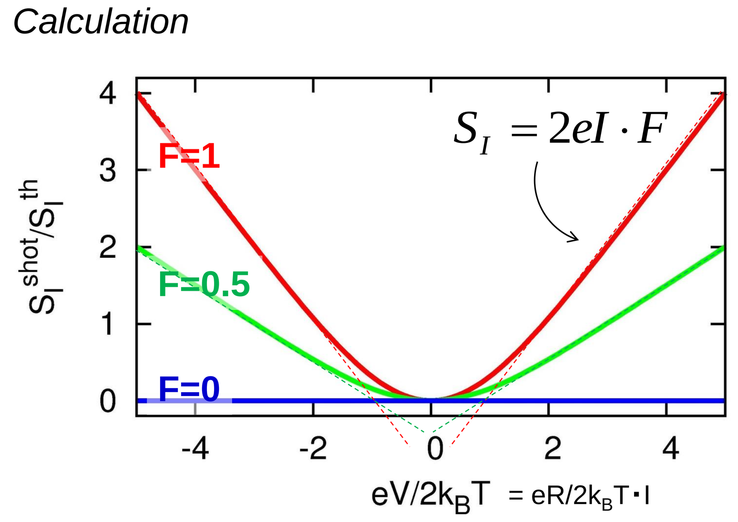
Shot noise

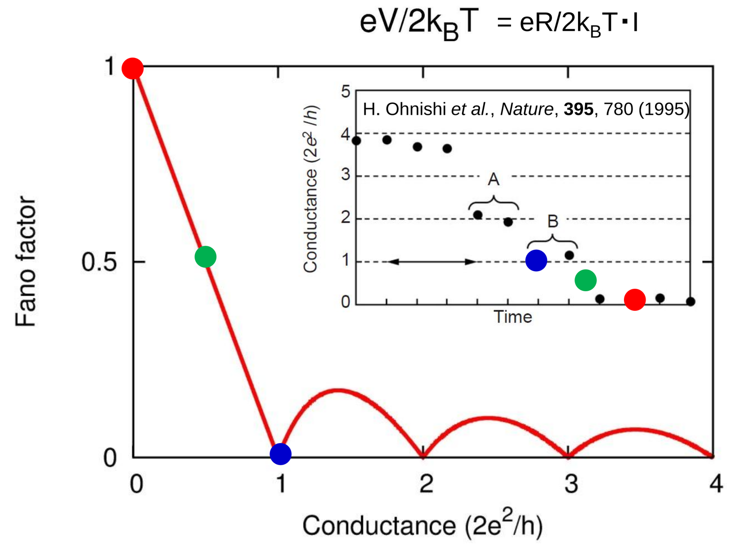


$S_I^{shot} = 2eIF\left(\coth\left(\frac{eV}{2k_BT}\right) - \frac{2k_BT}{eV}\right)$

Fano factor : $F = \sum_n T_n(1-T_n) / \sum_n T_n$

Calculation





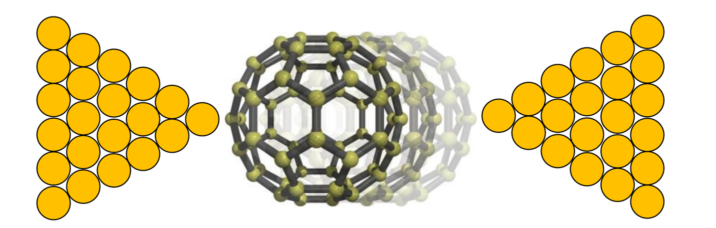
Purpose

Giant Fano factor in single molecule transistors

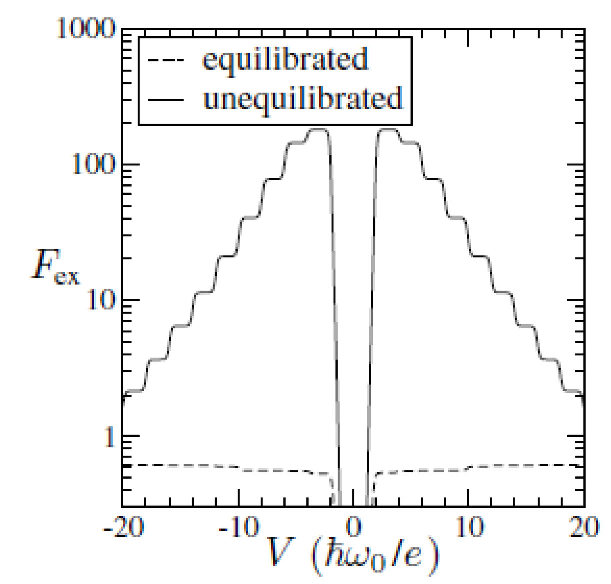
■ Recent theoretical prediction : in the presence of electronic coupling to local vibrational modes, a large Fano factor would be observed. J. Koch *et. al., Phys. Rev. Lett.*, 94.206804 (2005)

■ Single molecule devices are the ideal systems to study shot noise in vibrating channels.

■ Here, we present preliminary measurements of shot noise in single C_{60} devices using a high frequency approach coincident with DC measurements.



H. Park *et. al., Nature*, **407**, 57 (2000)

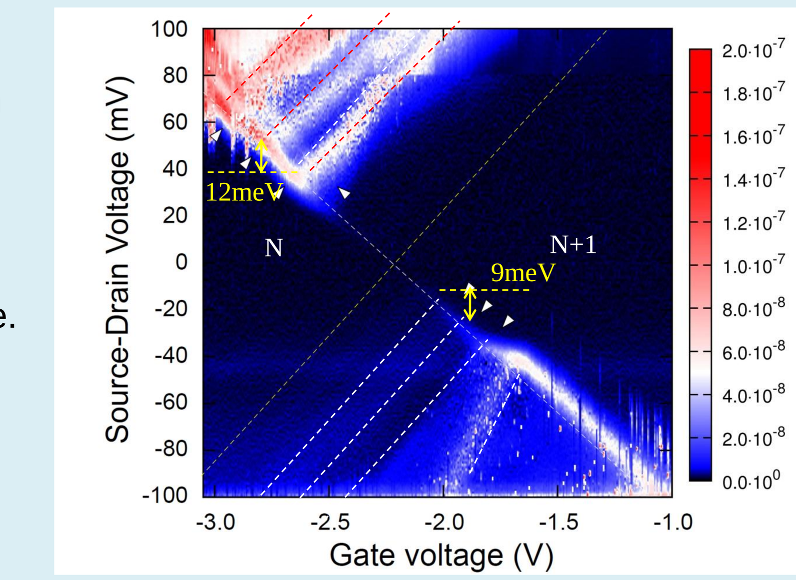


J. Koch *et. al., Phys. Rev. Lett.*, 94.206804 (2005)

Previous results on strong coupling to molecular vibration

■ (RIGHT FIGURE) DC Transport characteristic of single C_{60} transistor with strong coupling between conducting electron and molecular vibration.

■ In the existence of molecular vibration, electron transport become like avalanche. Therefore it is predicted that giant Fano factor would be observed.

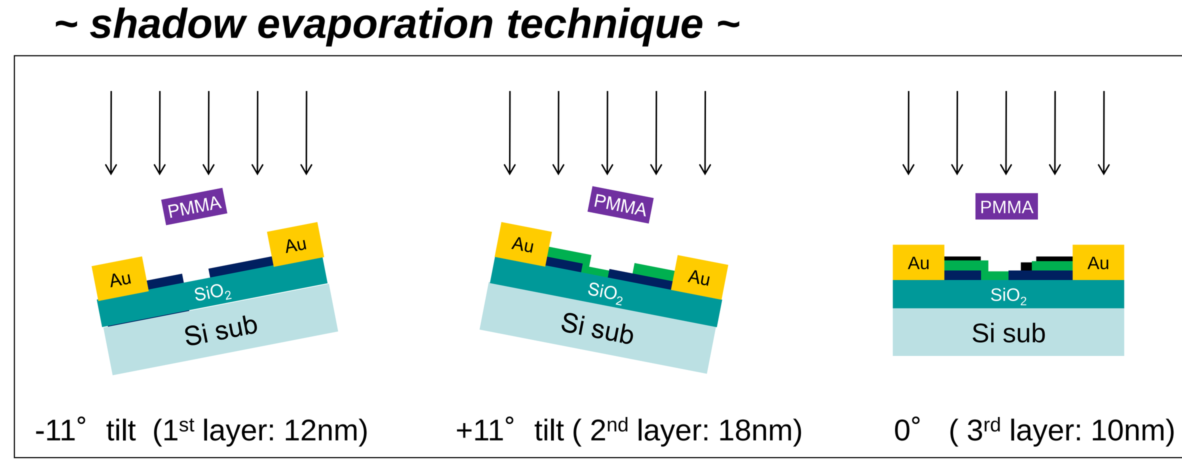


S.Sakata, unpublished

Fabrication & Experimental Set Up

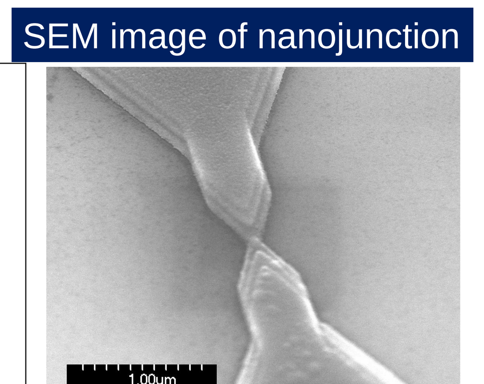
Fabrication of metal nanojunctions

~ shadow evaporation technique ~



-11° tilt (1st layer: 12nm) +11° tilt (2nd layer: 18nm) 0° (3rd layer: 10nm)

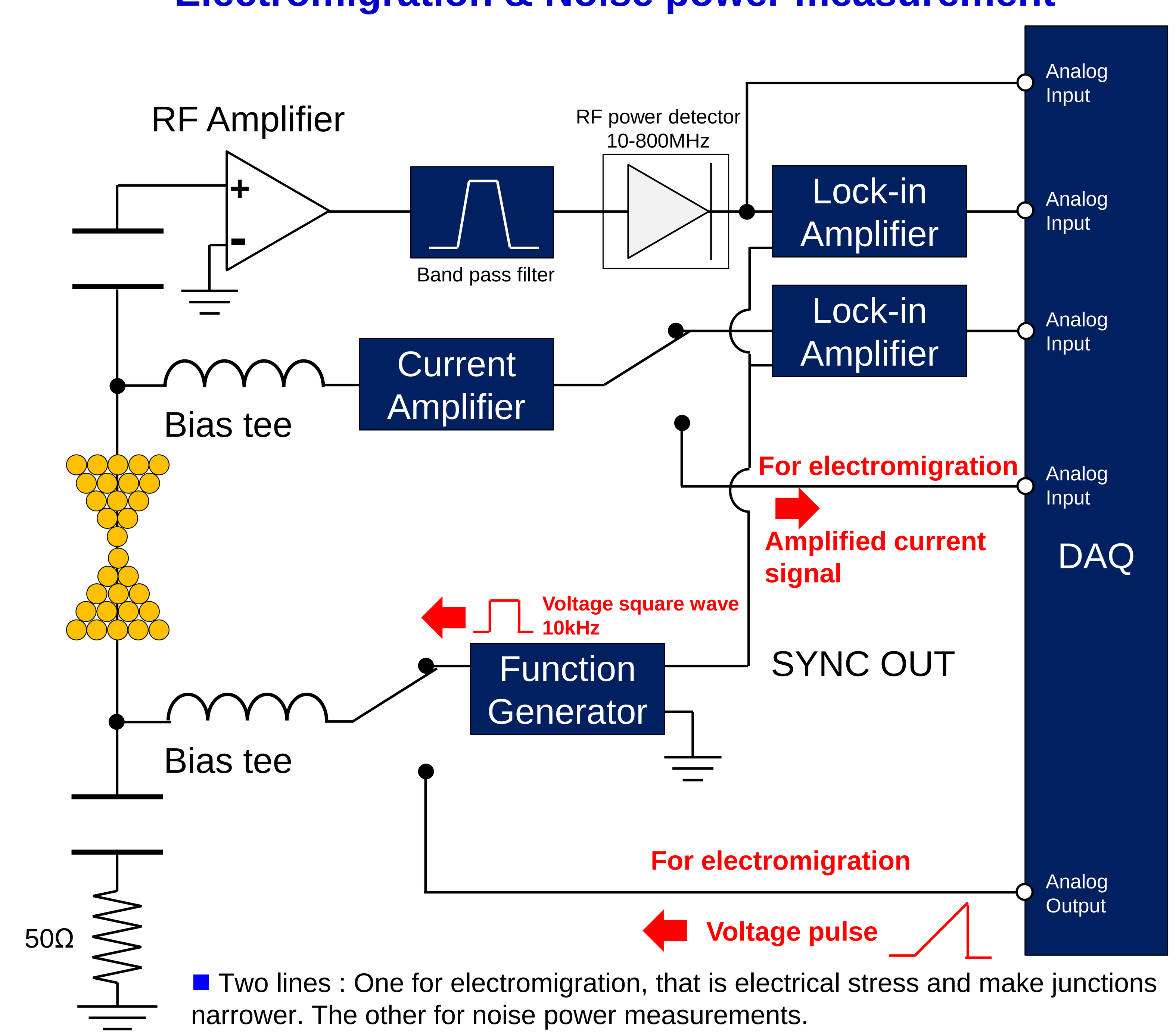
SEM image of nanojunction



•Junction height = 20-50nm
•Junction width = 50-100nm

■ Using shadow evaporation technique, the narrowest nanojunctions can be fabricated.
■ Electromigration, the following process, will occurred at the constriction, then we can get quantum point contacts and single molecule junctions, if molecules are coated on the junctions.

Electromigration & Noise power measurement

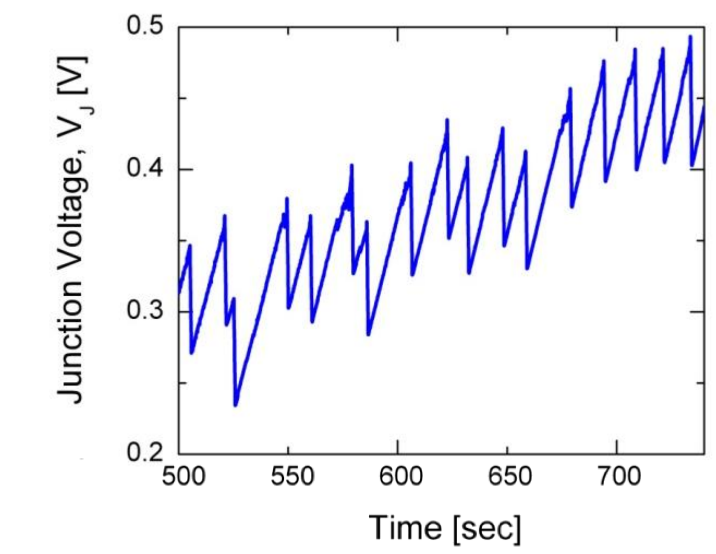


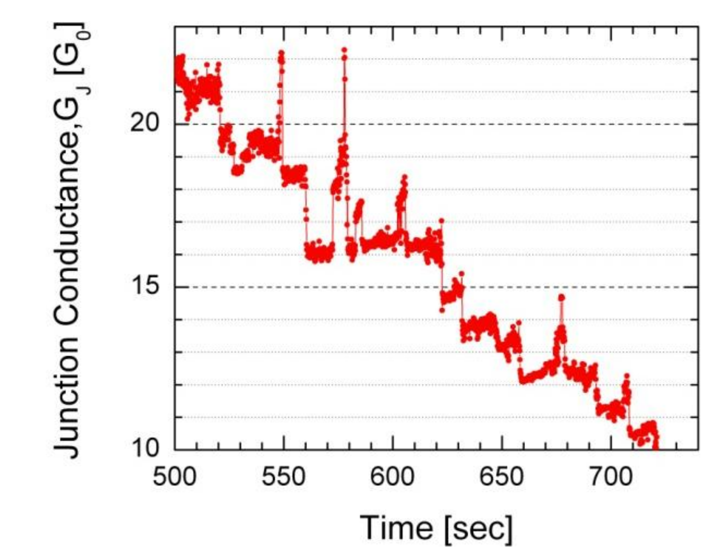
■ Two lines : One for electromigration, that is electrical stress and make junctions narrower. The other for noise power measurements.
■ The system above can measure noise power, SI, and DC current, I, simultaneously and produce S-I curve

Results & Discussion

Quantum conductance during electromigration

■ Feedback controlled Electromigration produced quantum point contacts



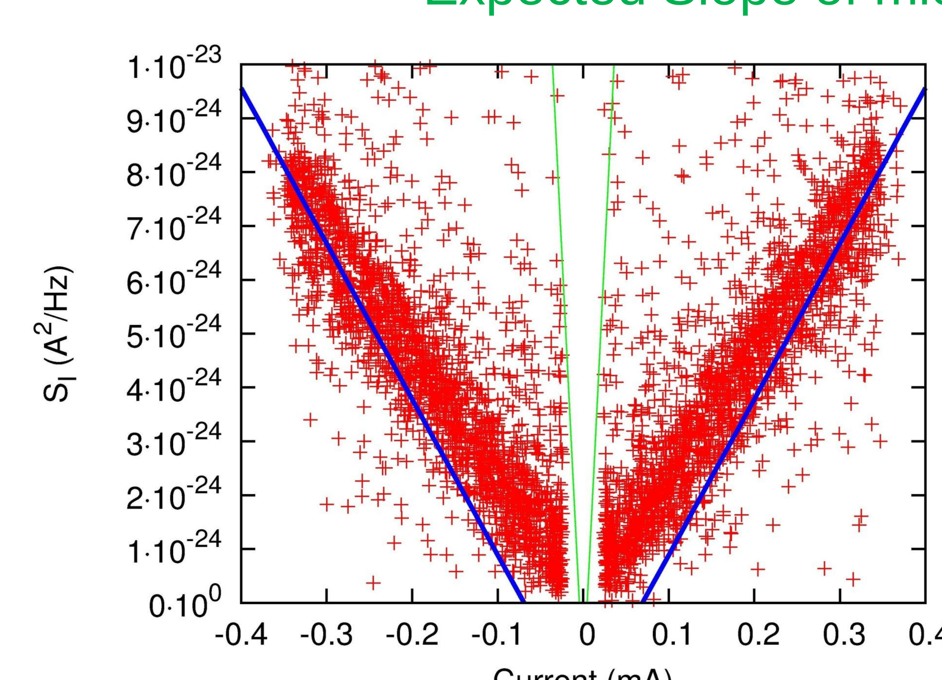


Noise measurement at G = $10G_0$ at room temperature

■ Noise measurement at $G=G_{10}$, which means junction consists of 10 metal atoms.
■ Fano factor is calculated as $8.08 \cdot 10^{-2}$, which is very small considered in microscopic junctions

Expected Slope of microscopic junction = 1/3

R. J. Shoelkopf *et. al., Phys. Rev. Lett.*, 78, 173370 (1997)



Fano factor = $8.08 \cdot 10^{-2}$

- ■ Quantum shot noise is slightly measured even at room temperature This is because channels are transmitting.
- ■ Noise of power is low because
  - ✓ Large thermal energy
  - ✓ Instability of atomic junction

Electron temperature = 535K

- ■ Order is correct.

Conclusion & Future Work

■ Quantum Point Contacts were realized by using feedback controlled electromigration.
■ Noise measurement at G = $10G_0$ was conducted and show Fano factor as $8 \cdot 10^{-3}$ which is very smaller than the expected value of the microscopic junctions and electron temperature as 535K which is bigger than room temperature, but order is correct. So the system work fine.

Future work

■ Conductance dependence of Noise power and Fano factor.
■ Fano factor measurement at single molecule transistors with strong electron-vibron coupling

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