# Noise enhanced transport in nanoelectronic devices

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# Outline



- Technology & working principle
  - 2-DEG: Growth and fabrication
  - Y-branch junction and resonant tunneling diode (RTDs)
- Noise enhanced transport in Y-branch junctions
  - Stochastic resonance at 1Hz
  - Nonlinear noise activated magnetic field sensor
- Universal logic gate switching in RTDs
  - Universal logic gate switching from NOR to NAND
  - Logic stochastic resonance (LSR)

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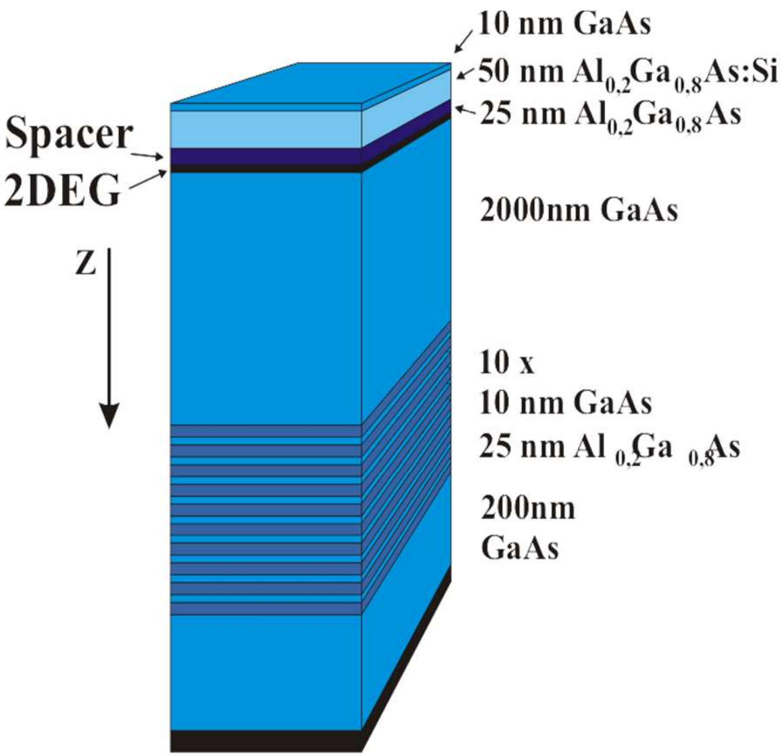
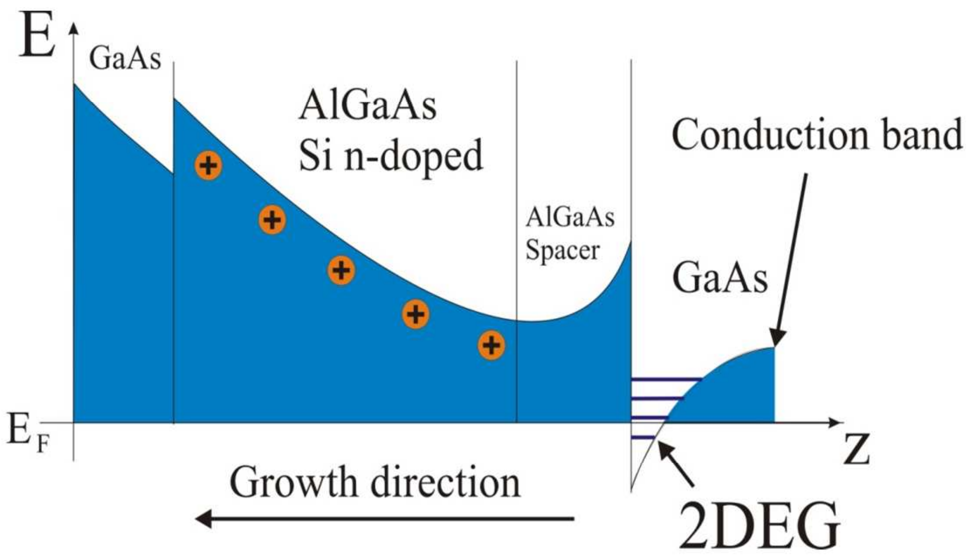
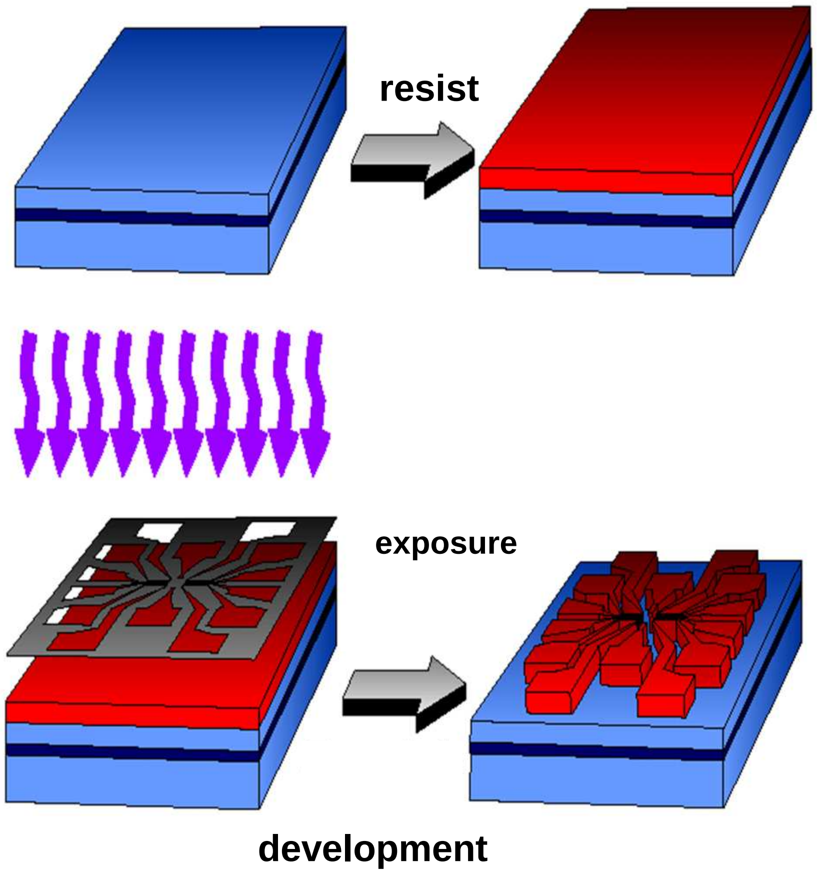
# Technology: Growth of 2-DEG



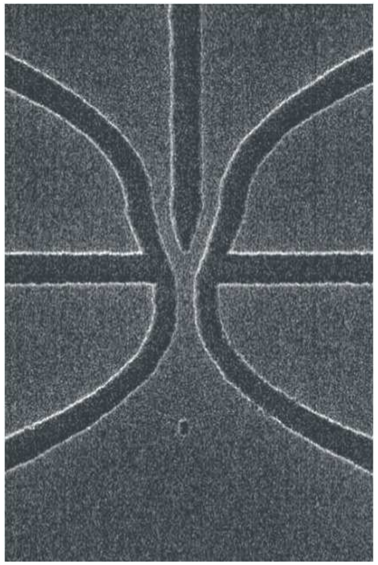

- ❒ Modulation doped GaAs/AlGaAs heterostructure (HEMT)
- ❒ High mobility μ = $1.1 \cdot 10^{6}$ $cm^2/Vs$ and charge density n = $3.7 \cdot 10^{11} cm^{-2}$

# Technology: Fabrication of Y-branch junction




- Electron beam lithography

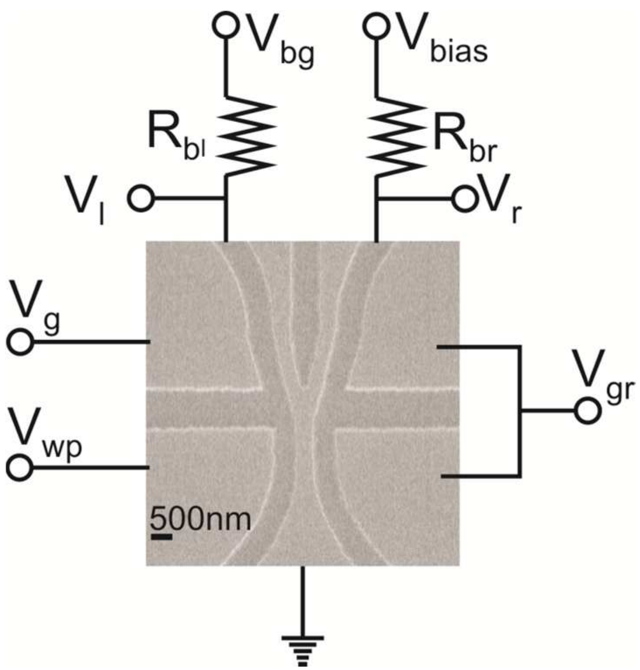
- Dry chemical etching was applied to define the Y-branch structure

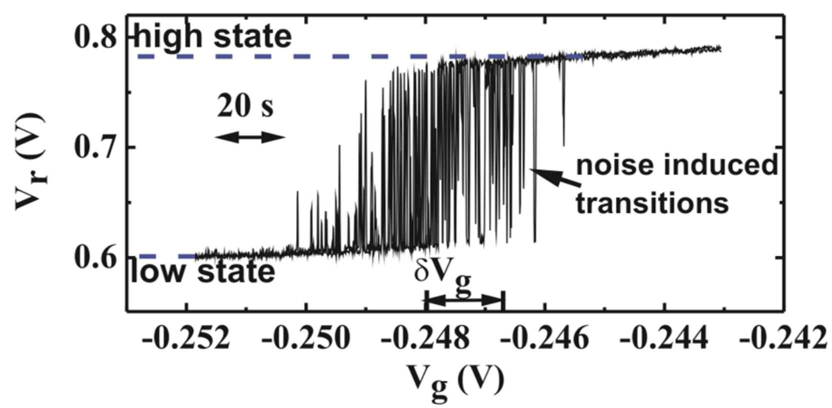


# Working principle: Noise activated switching



- the input and the working point voltages set the condition of the Y-branch switch
- self-gating leads to a bistable transfer characteristic
- noise induced oscillations occur
- all measurements @ 20K




Input signal:

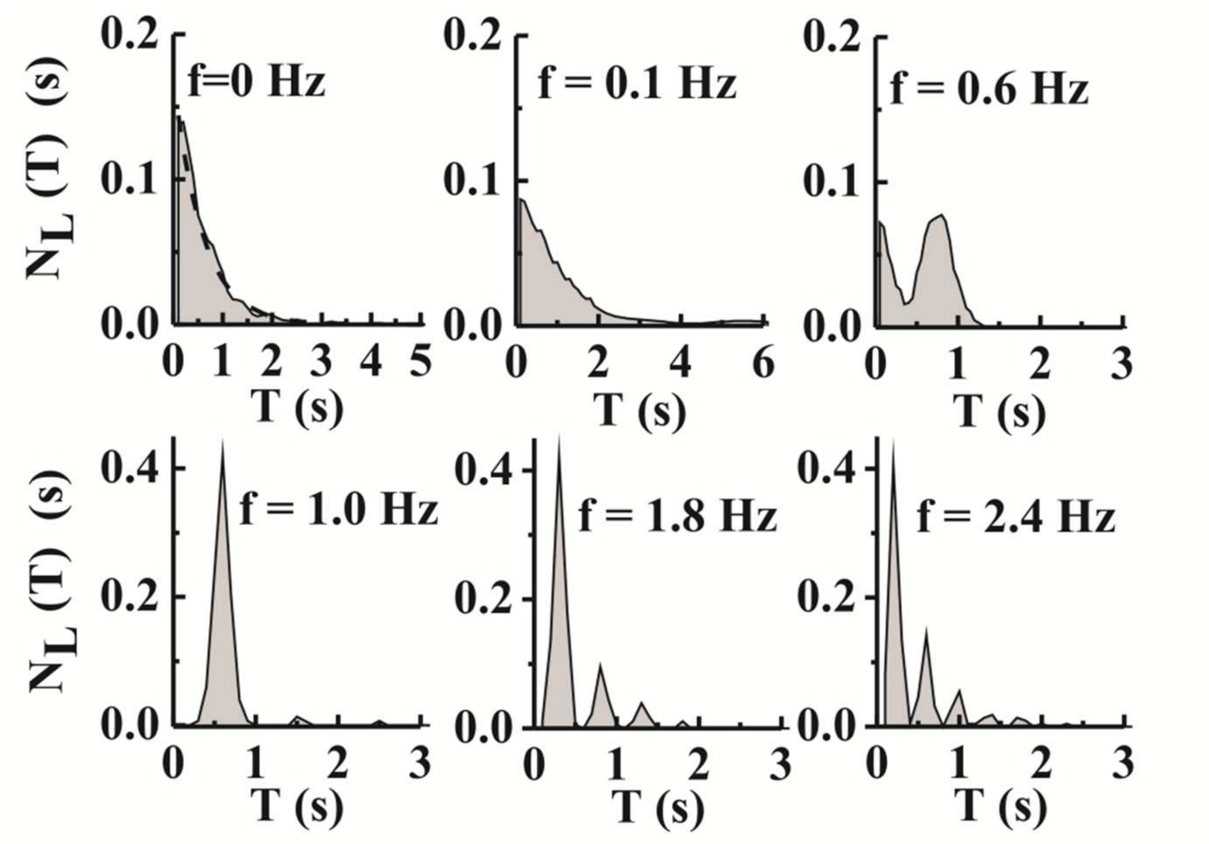
$$V_g(t) = V_{g,0} + \delta V_g \bullet \sin(\omega t)$$

Weak periodic signal:

$$\delta V_g = 1.3mV$$

# Recording SR: Residence Time





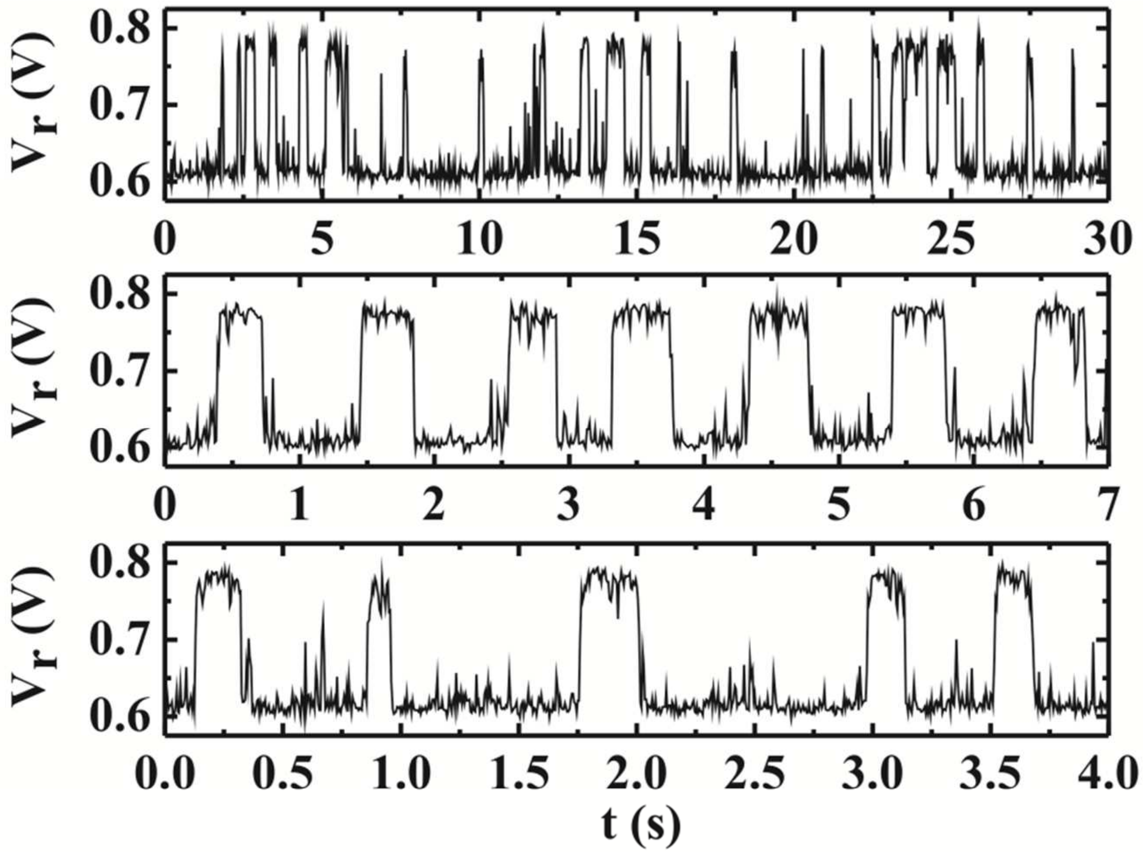

- For $f < f_{SR}$ the residence time distribution is strongly controlled by the noise
- For $f > f_{SR}$ odd multiples of the periodic forcing $T_\omega$ occur:

$$T_n = (2n-1)T_\omega / 2$$

At the optimum frequency f = 1 Hz the residence time distribution is almost perfectly restricted to the first peak.

# SR: Time Trace






f = 0.1 Hz

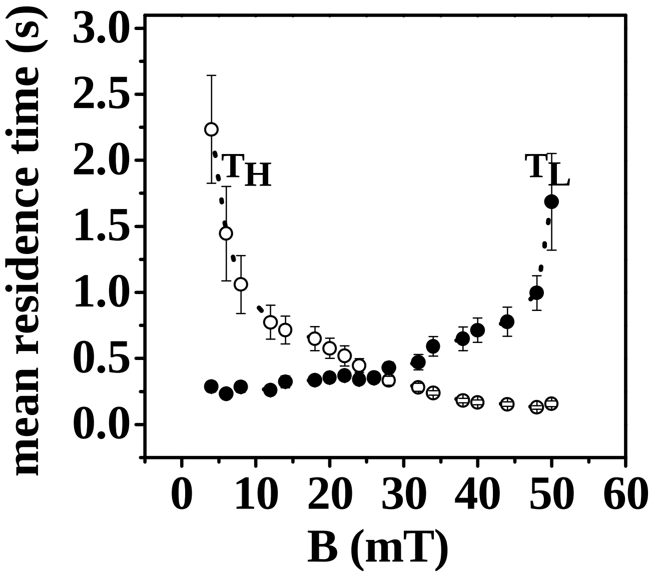
f = 1 Hz

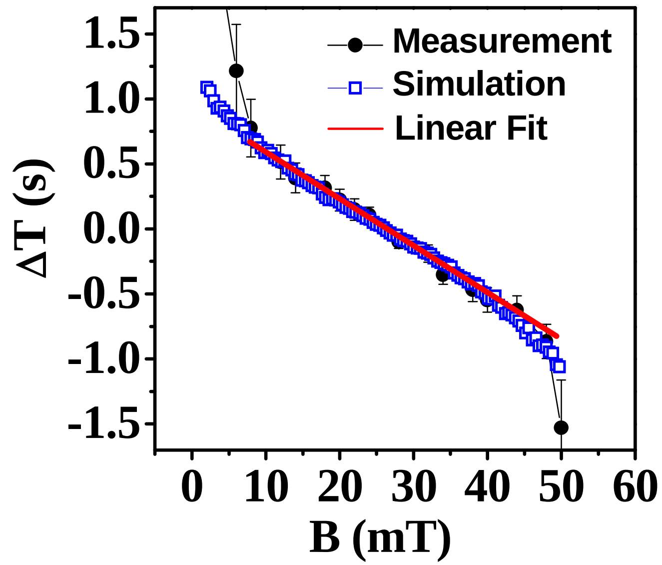
f = 1.8 Hz

At f = 1 Hz the noise dynamics follow directly the frequency of the external input forcing and a maximum synchronization is found.

# Application: Magnetic field sensor






- Output is a linear function of B around ΔT = 0 s

$$\Delta T(B) = T_0 - cB$$

- Target signal independent sensitivity

$$S(B) = \frac{\partial \Delta T}{\partial B} = c$$

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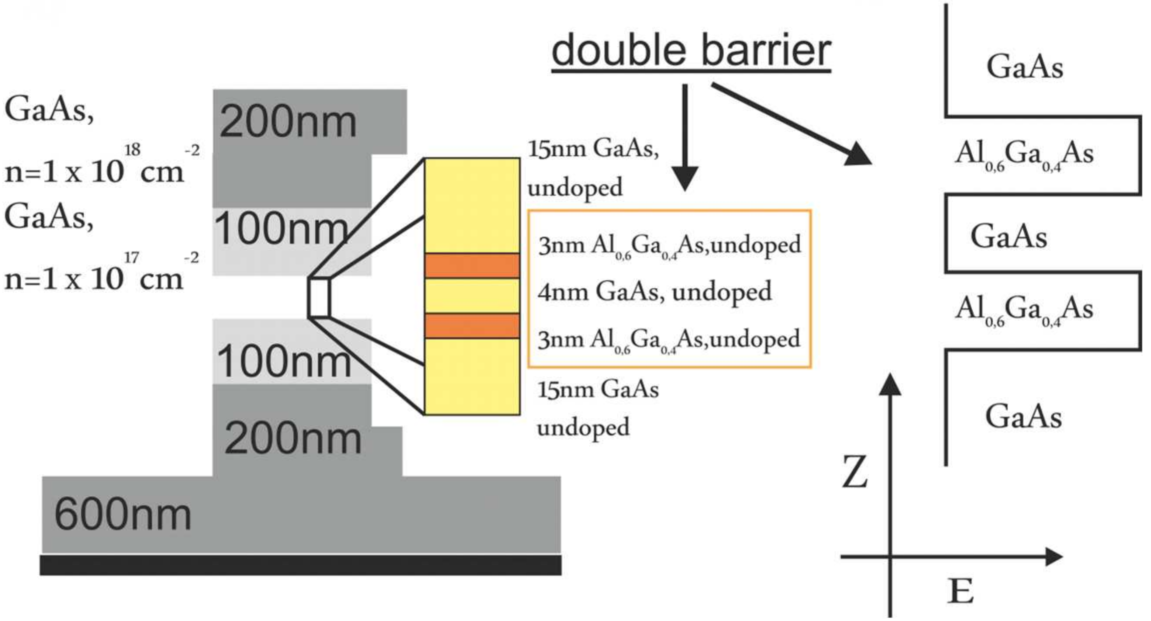
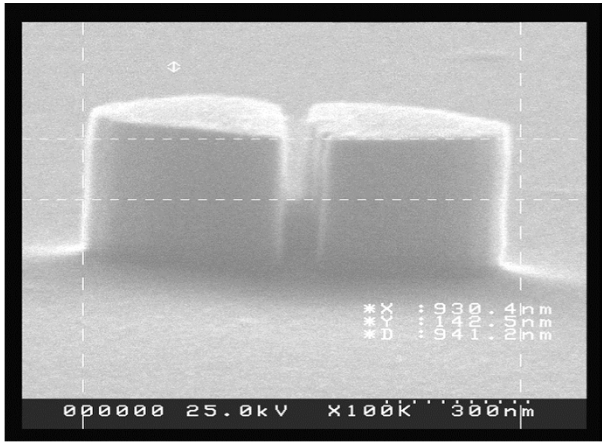
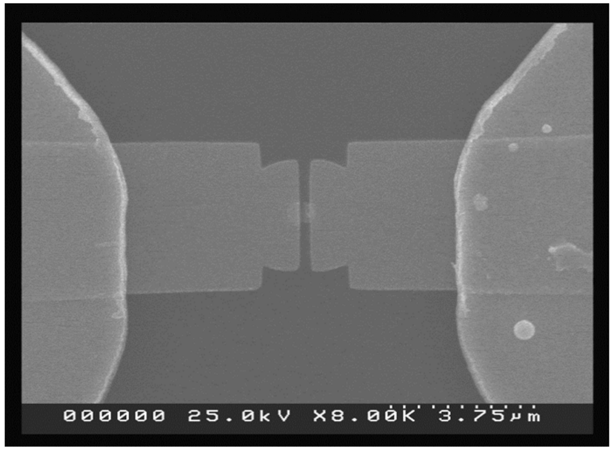
# Growth and fabrication of RTDs



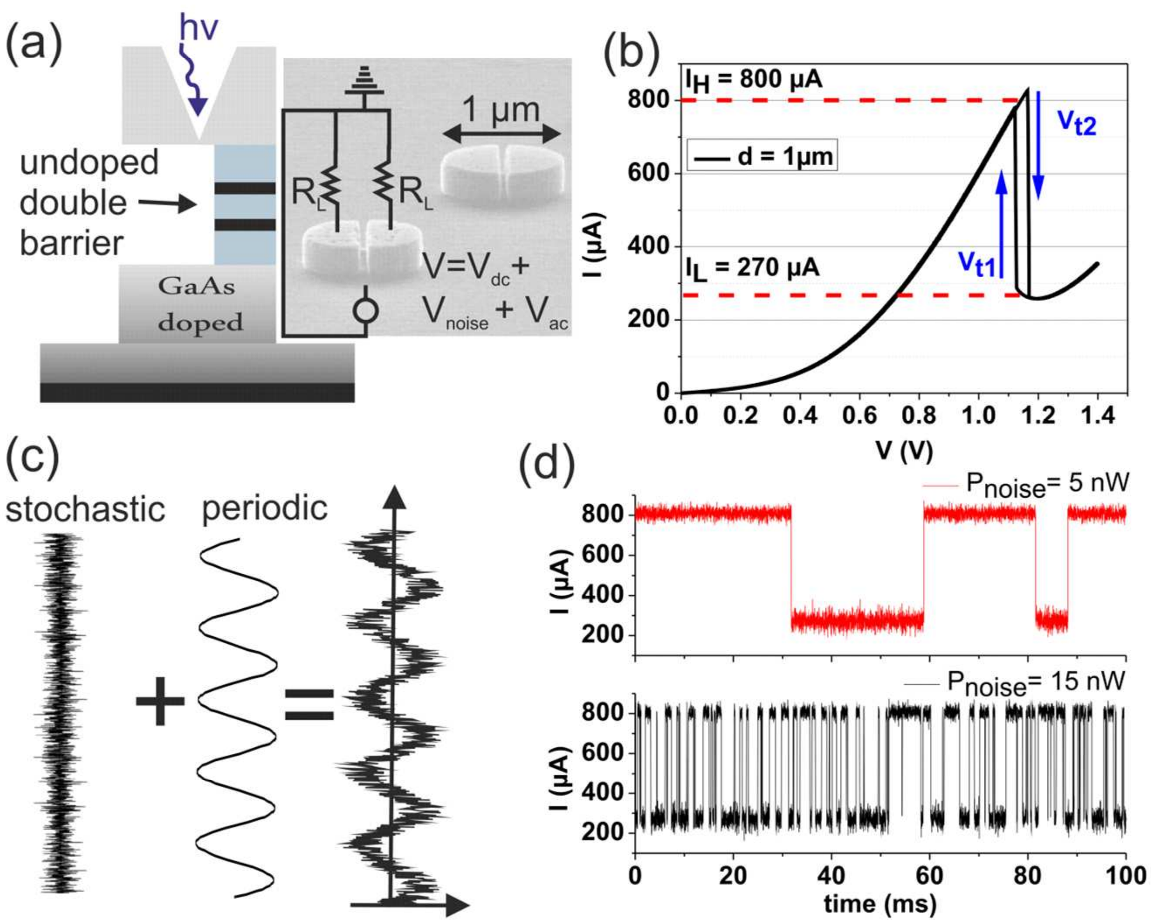




- RTDs AlGaAs/GaAs/AlGaAs DBS
- Dry chemical etching to define mesa from 1 µm down to 50 nm
- BCB (polymer) for mesa isolation
- Top Au/Ti/Ni contact

# Noise activated switching in RTDs

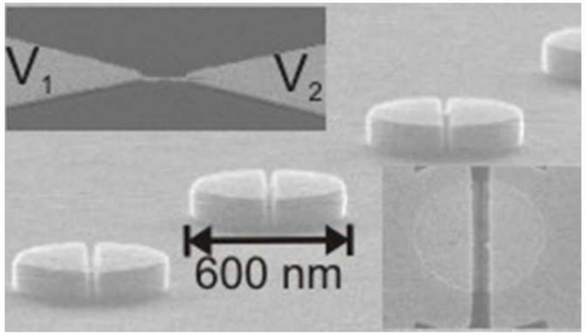


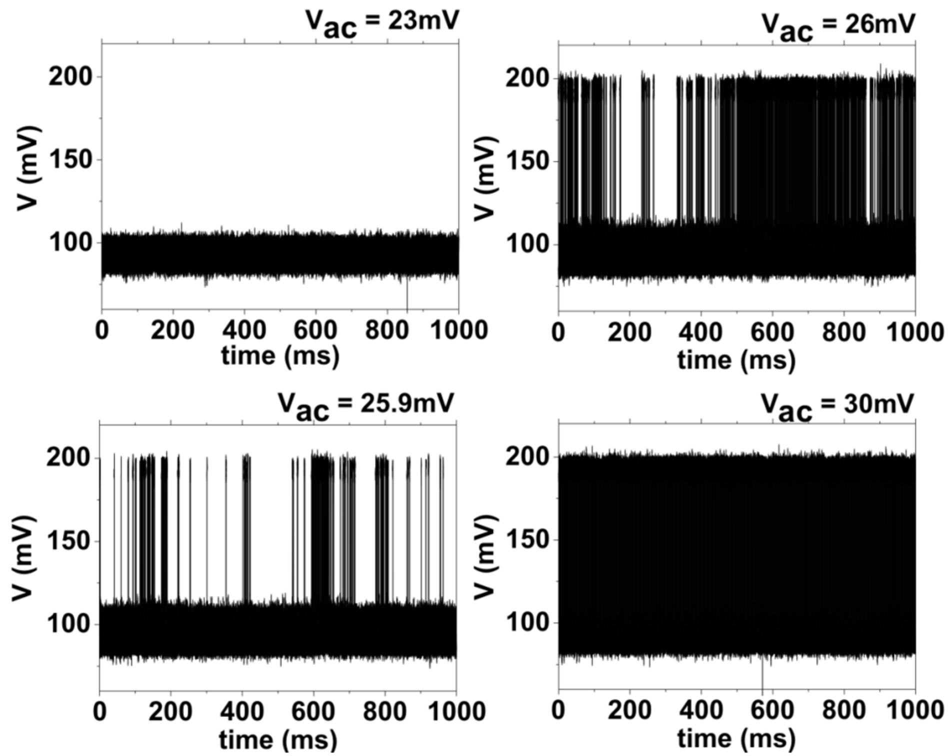



- RTD is bistable with stable outputs $I_H$ = 800 µA and $I_L$ = 270 µA
- Works @ RT
- PVR ~ 3
- Noise induced switching from one stable state appear
- Time scale is given by the inverse of the Kramer's rate

# Noise activated switching in RTDs



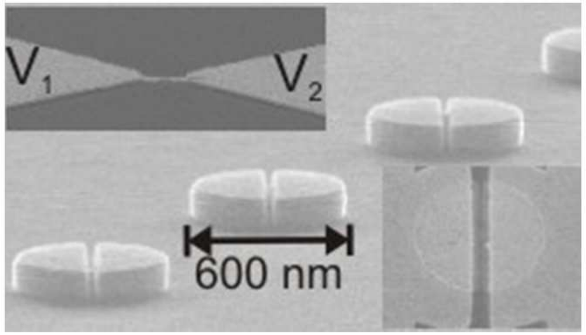


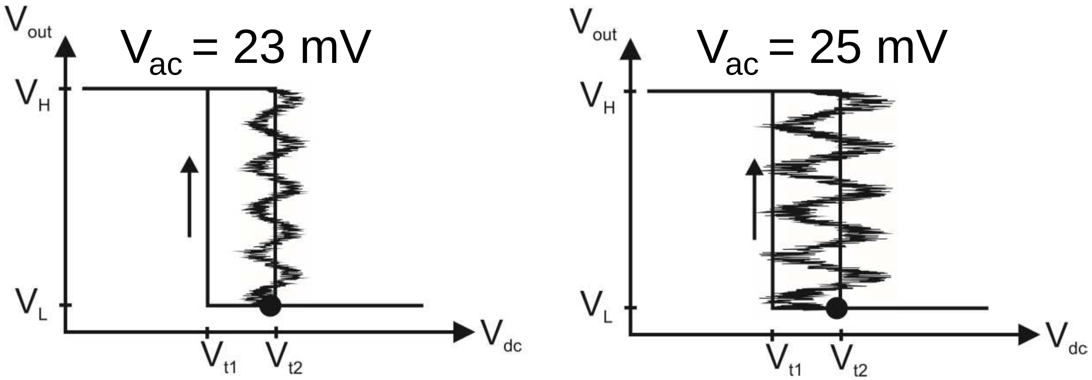




- Noise induced signal trains
- Mean value is efficiently controlled by input signals
- Can be integrated to arrays
- No classical kT limit of transconductance

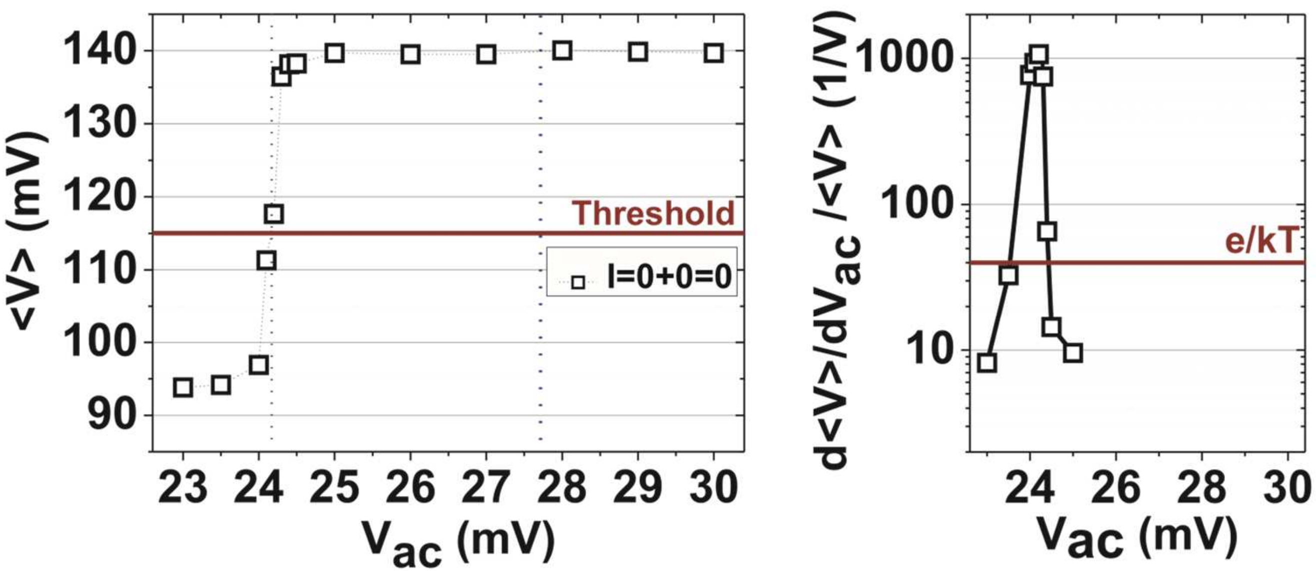
# Reconfigurable logic universal gates






Switching voltages: $V_1 = V_2 = 0mV$



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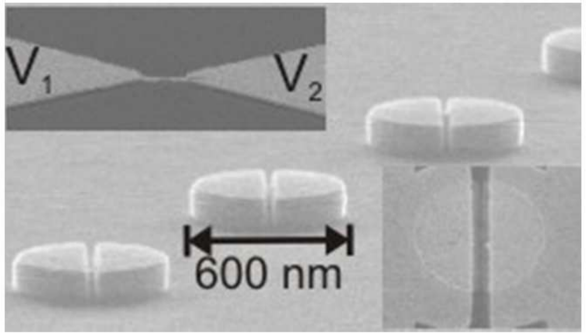
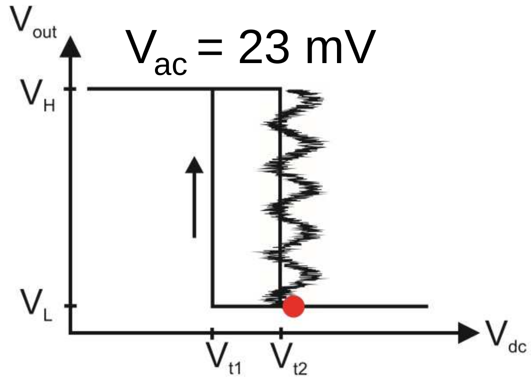
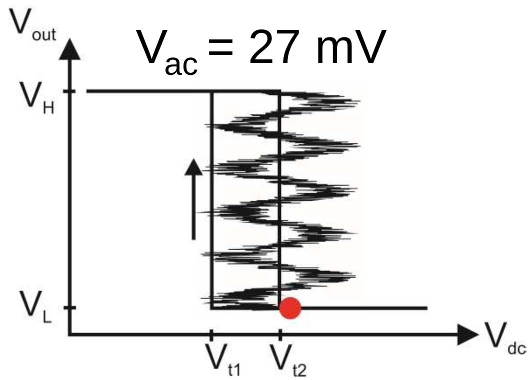
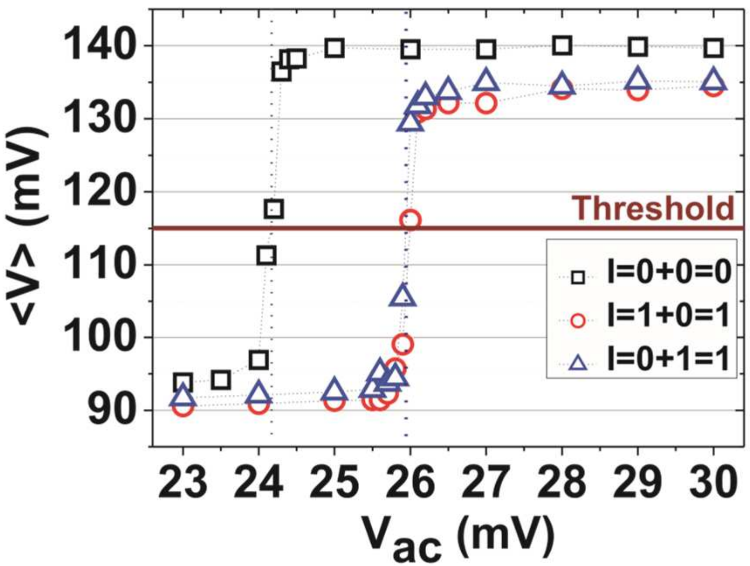
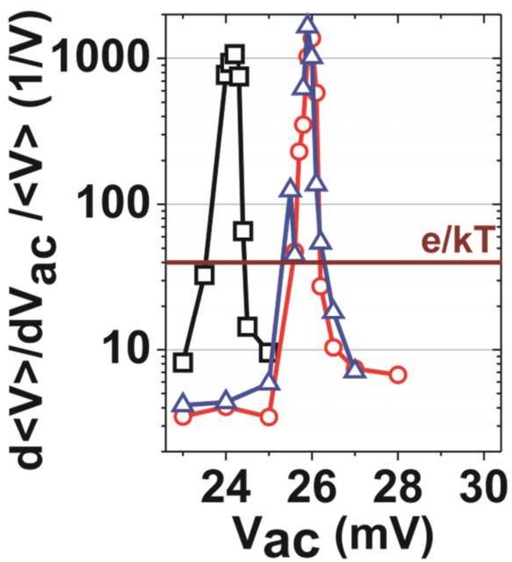


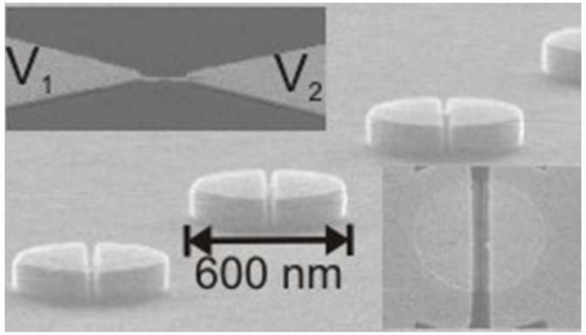



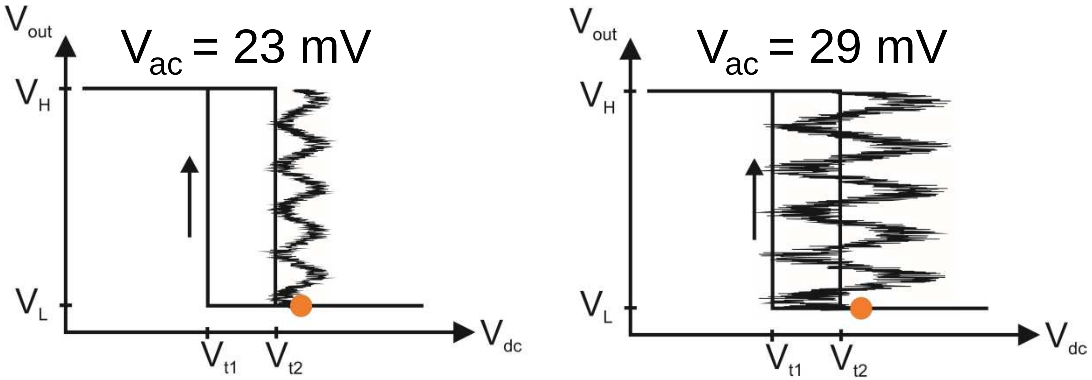

Switching voltages: $V_1$ = 0, 2 mV $V_2$ = 2, 0 mV



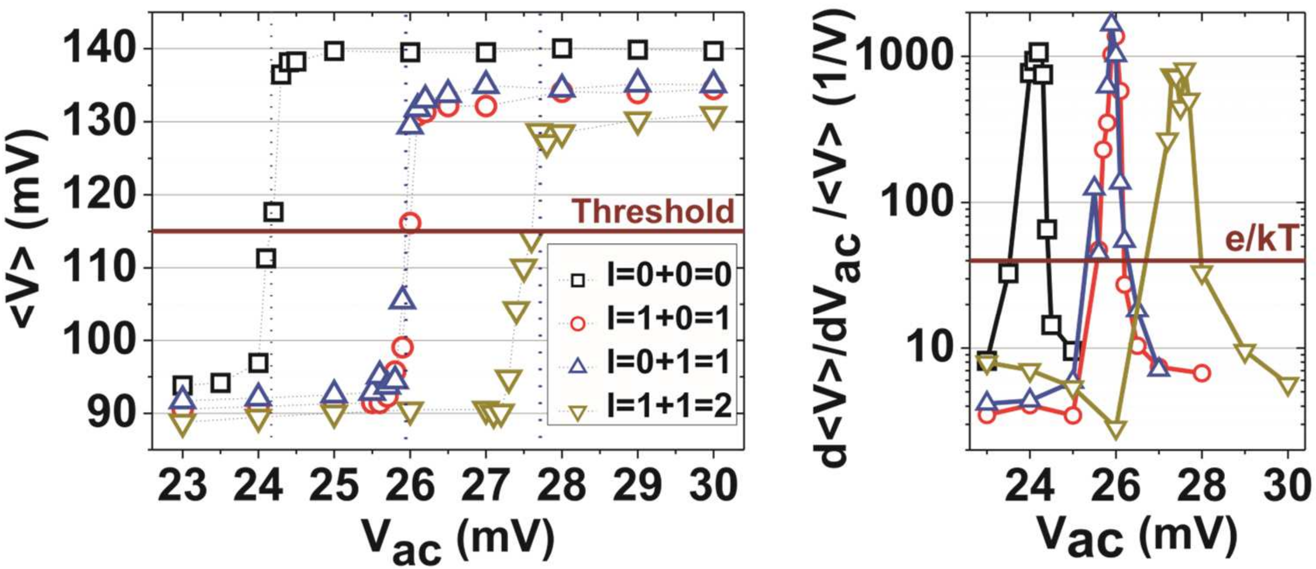



# Reconfigurable logic universal gates



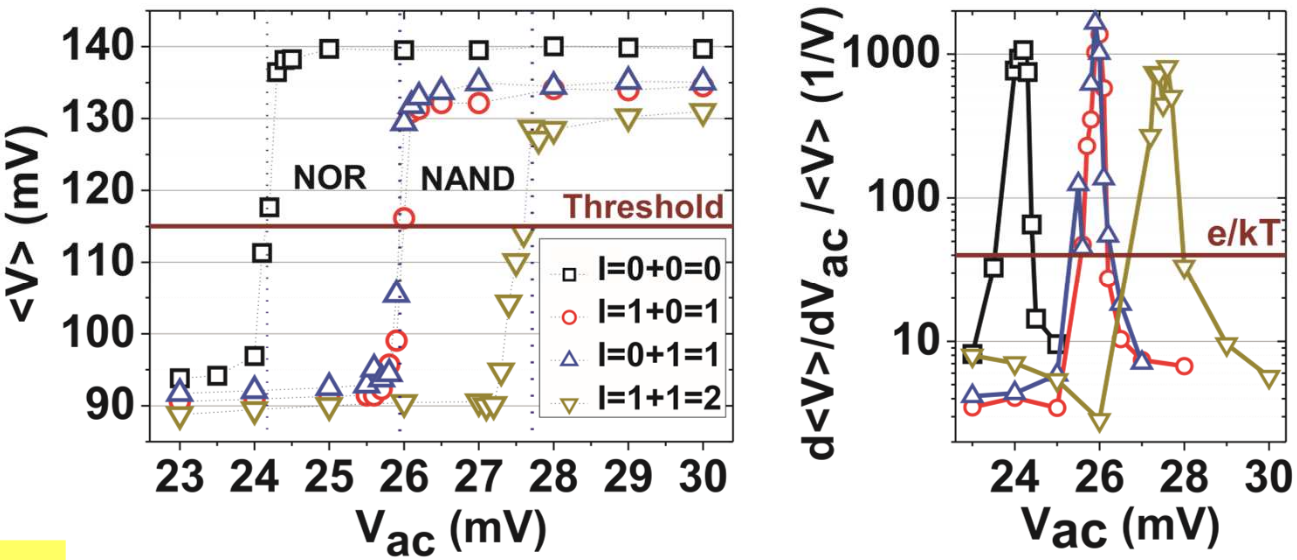




Switching voltages: $V_1 = V_2 = 2$ mV



# Reconfigurable logic universal gates






NOR

| | | |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 1 | 0 |

NAND

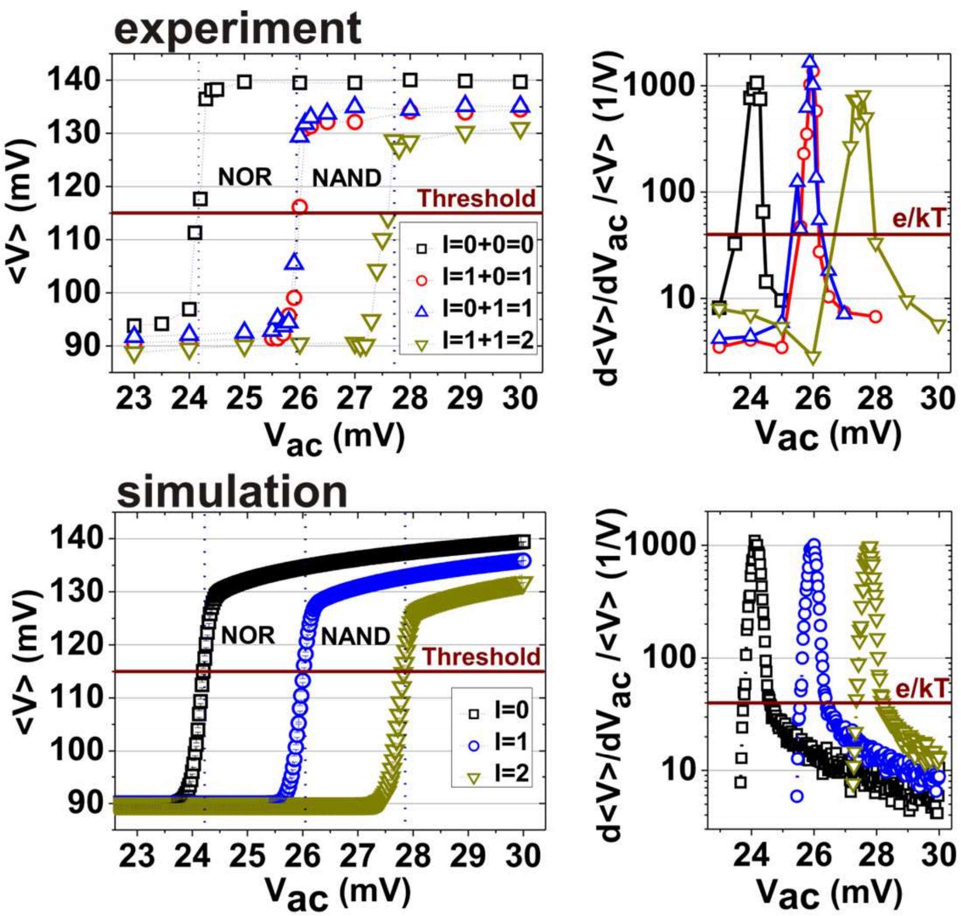
| | | |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 1 | 0 |

- Switch from NOR to NAND for $\Delta V_{ac} < 1$ mV with a logic input voltage 2 mV

# Reconfigurable logic universal gates



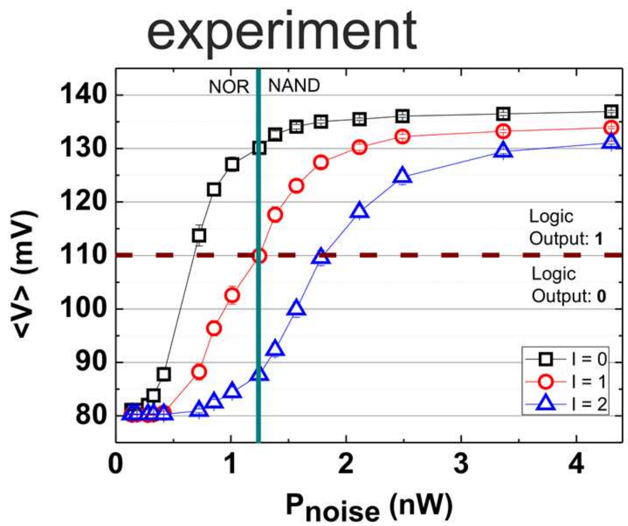
- ❒ Schmitt-Trigger simulation
- ❒ All Parameters from the experiment
- ❒ Excellent agreement !!

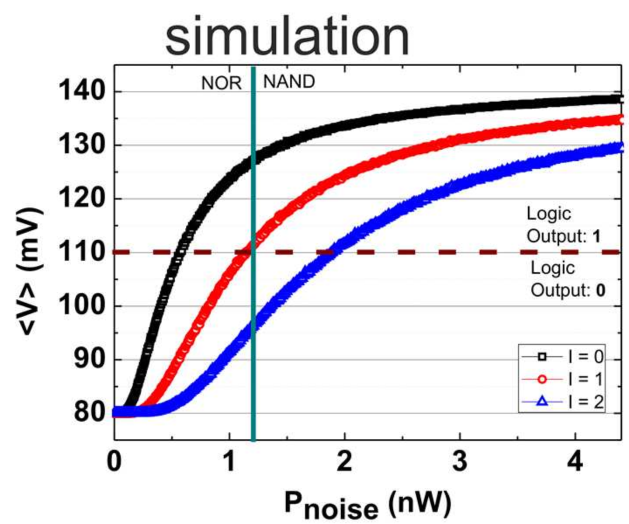



Parameter:
- b = 15 mV
- f = 1 kHz
- ΔT = 50ms
- Δx = 2 mV

# Logic Stochastic Resonance (LSR)





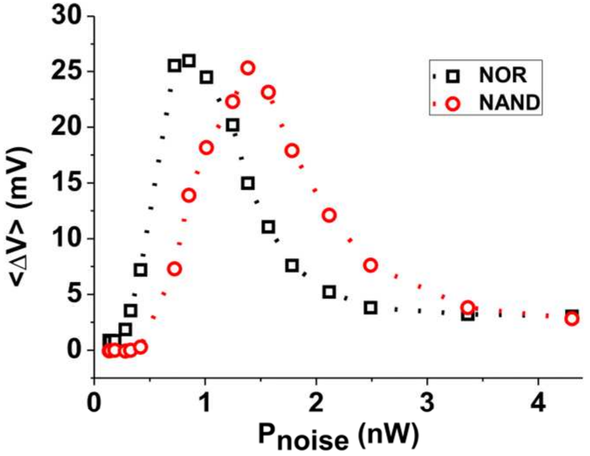




- Universal logic gate switching solely controlled by noise.
- Two universal logic gates: NOR/NAND
- Switching between the gates only as a function of noise power.

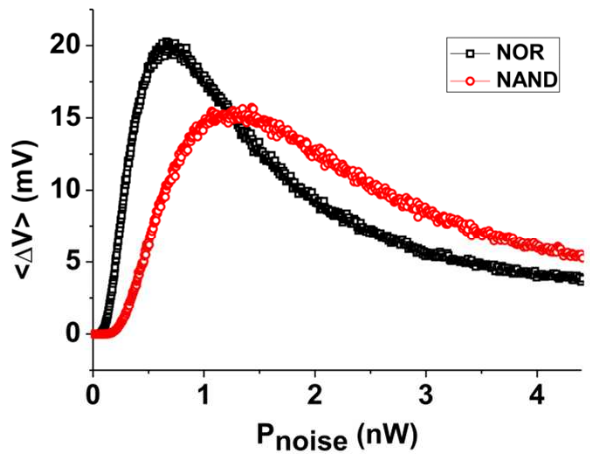
# Logic Stochastic Resonance (LSR)



experiment




simulation




- For the logic NOR gate:

The mean value difference is defined as
<V>=V(I=0)−V(I=1)

$P_{noise}$=0.9 nW the maximum corresponds to the logic NOR

- For the logic NAND gate:

The mean value difference is defined as
<V>=V(I=1)−V(I=2)

$P_{noise}$ = 1.4 nW the maximum corresponds to the logic NAND

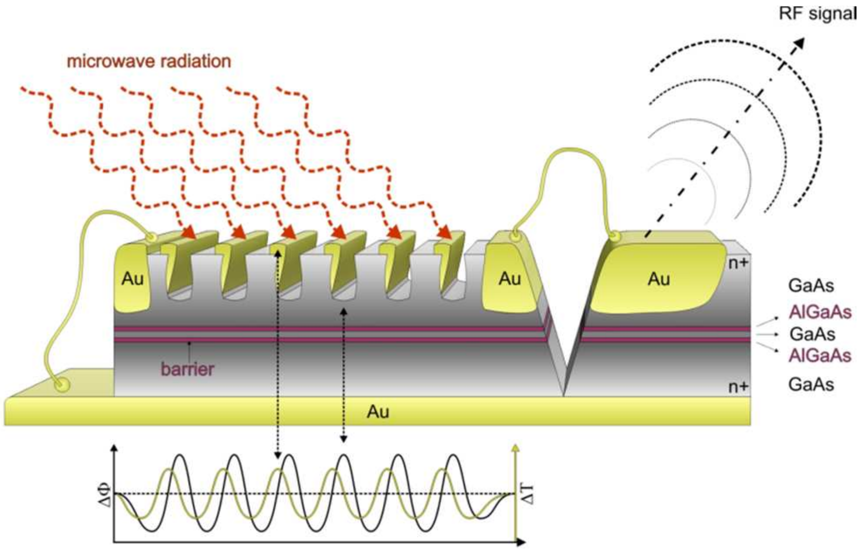
# Summary



- **Noise enhanced transport in Y-branch junctions**
  - Bistable transfer characteristic due to self-gating with noise activated switching
  - Synchronization of the internal noise floor with a weak periodic signal at 1 Hz: Stochastic resonance
  - Noise activated nonlinear magnetic field sensor
- **Noise enhanced logic gate switching in RTDs**
  - Universal logic gate switching with switching voltages of only 2mV
  - Logic Stochastic resonance with nW noise powers
  - Maximum logic gate operation at different noise inputs

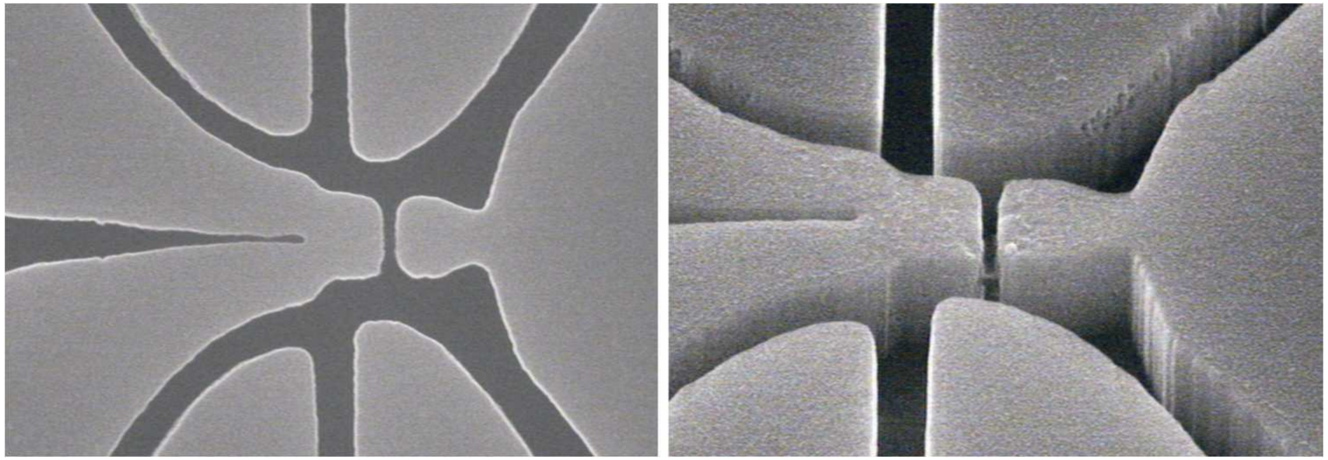
# Quantum harvester: UNIWUE






**Quantum harvester 1:**
- Autonomous ICT device
- Büttiker-Landauer motor

**Quantum harvester 2:**
- Heat to current conversion proposed by R. Sanchez and M. Büttiker



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NANO POWER


**Many thanks for your attention!**