Transport in Mesoscopic Systems with Broken Symmetry

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Ratchets, pumps, Brownian motors

particle transport in
asymmetric channels

Zur Anzeige wird der QuickTime™ Dekompressor „Video“ benötigt.

Feynman
ratchet

molecular motor

Zur Anzeige wird der QuickTime™ Dekompressor „Video“ benötigt.

Zur Anzeige wird der QuickTime™ Dekompressor „Video“ benötigt.

MPI Halle

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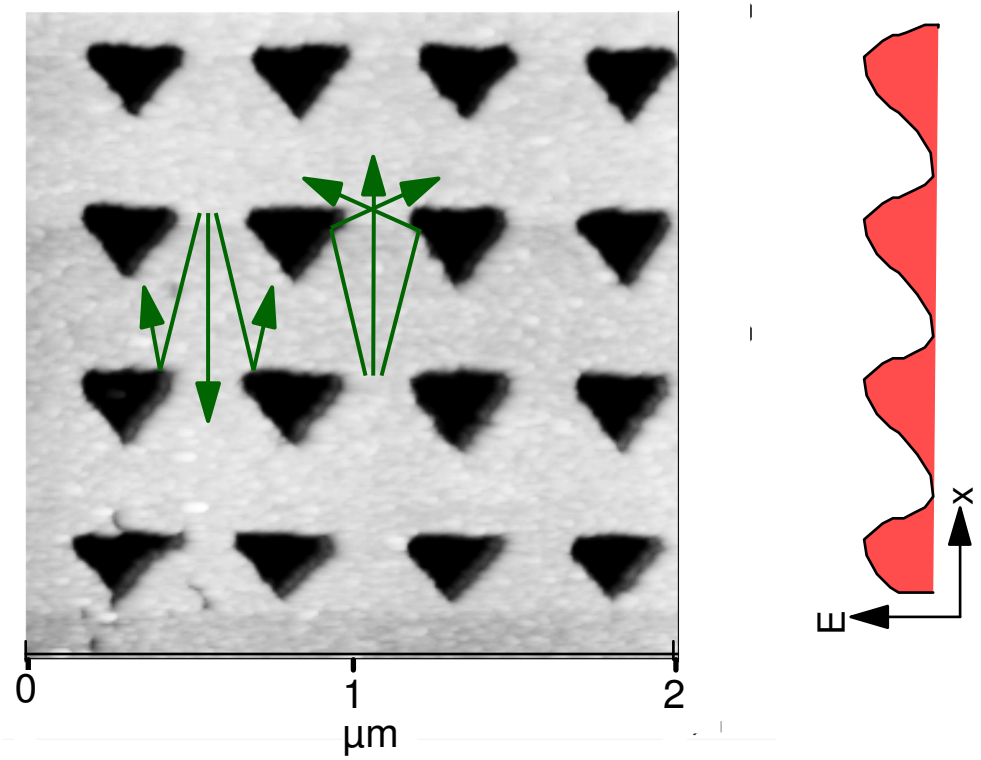
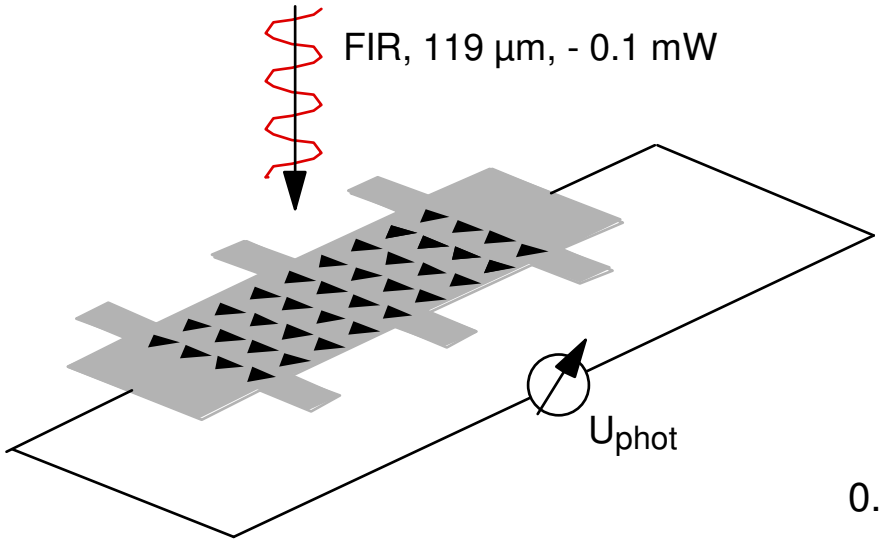
Why electrons?

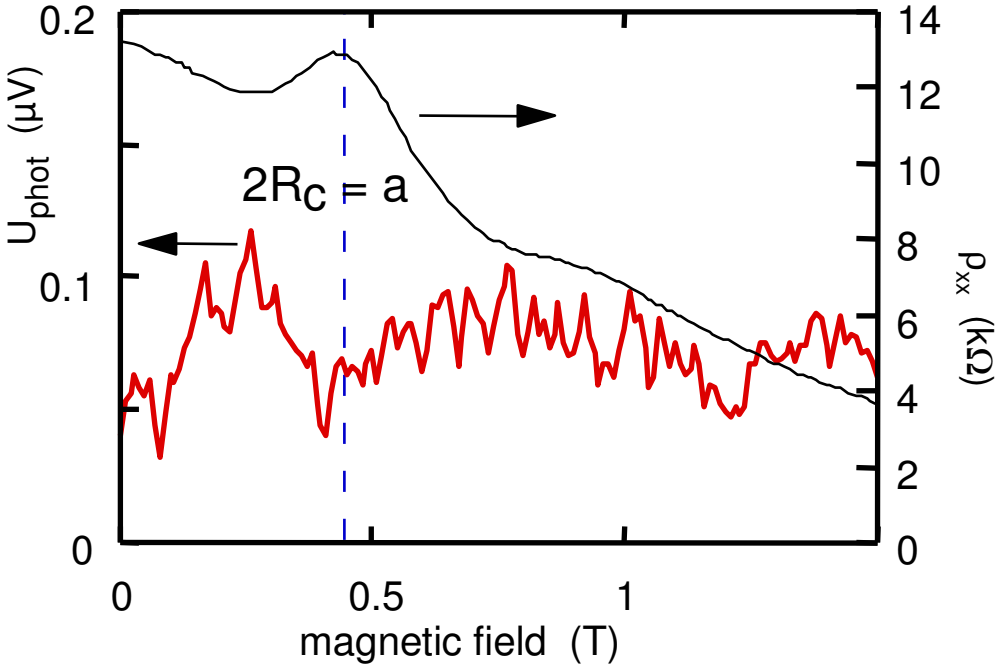
- ✓ flexibility: confinement can be (almost) arbitrarily shaped and tuned
- ✓ currents are determined relatively easy
- ✓ 3 regimes
  - classical diffusive
  - semiclassical ballistic
  - quantum mechanical

Electron billiard in structures with broken symmetry



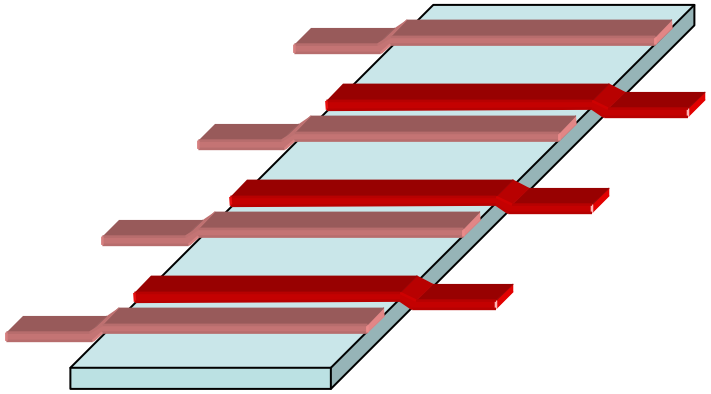
A driven ratchet: Detection of THz radiation

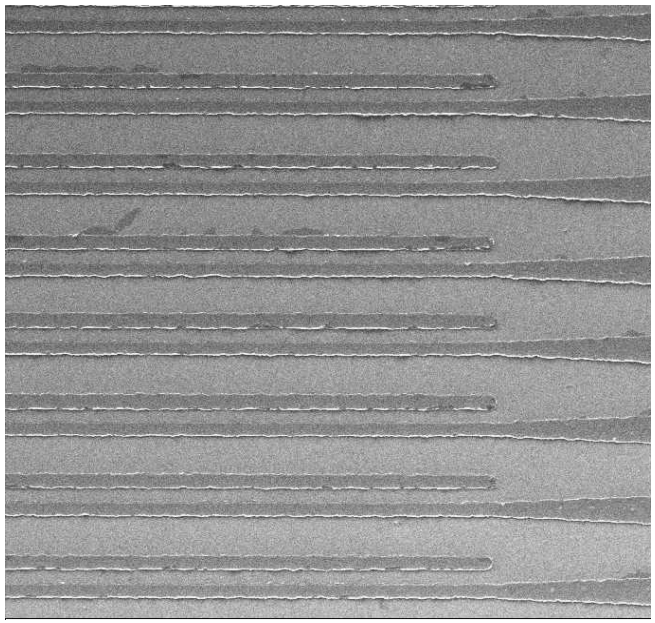


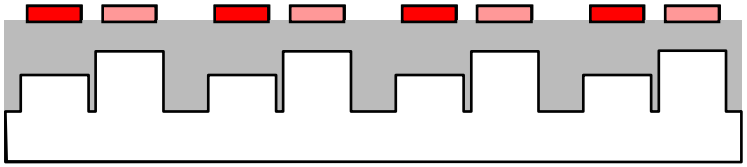


S. Wimmer et al.
Physica B **249**, 312 (1998)

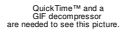
Tunable ratchets



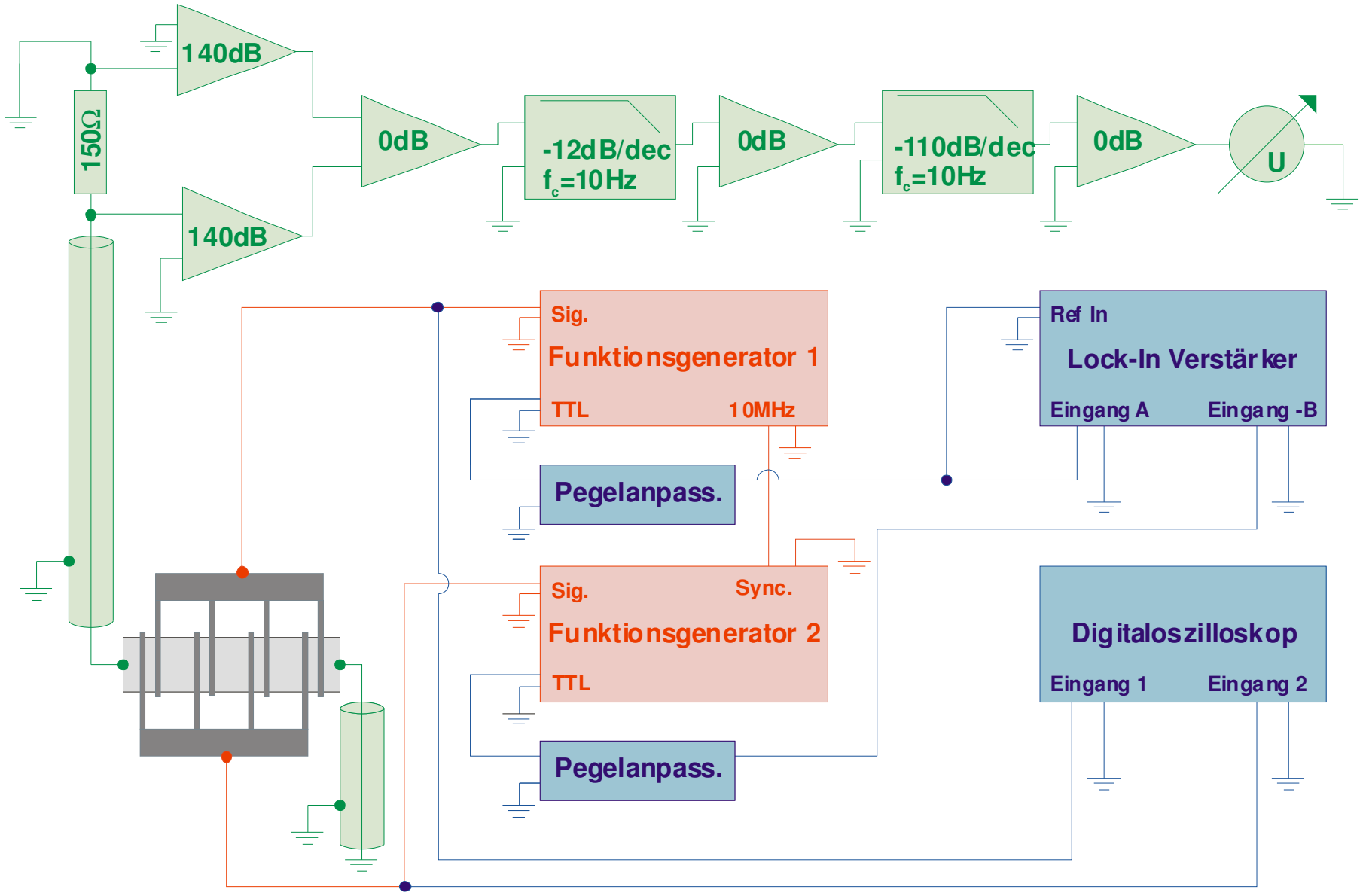




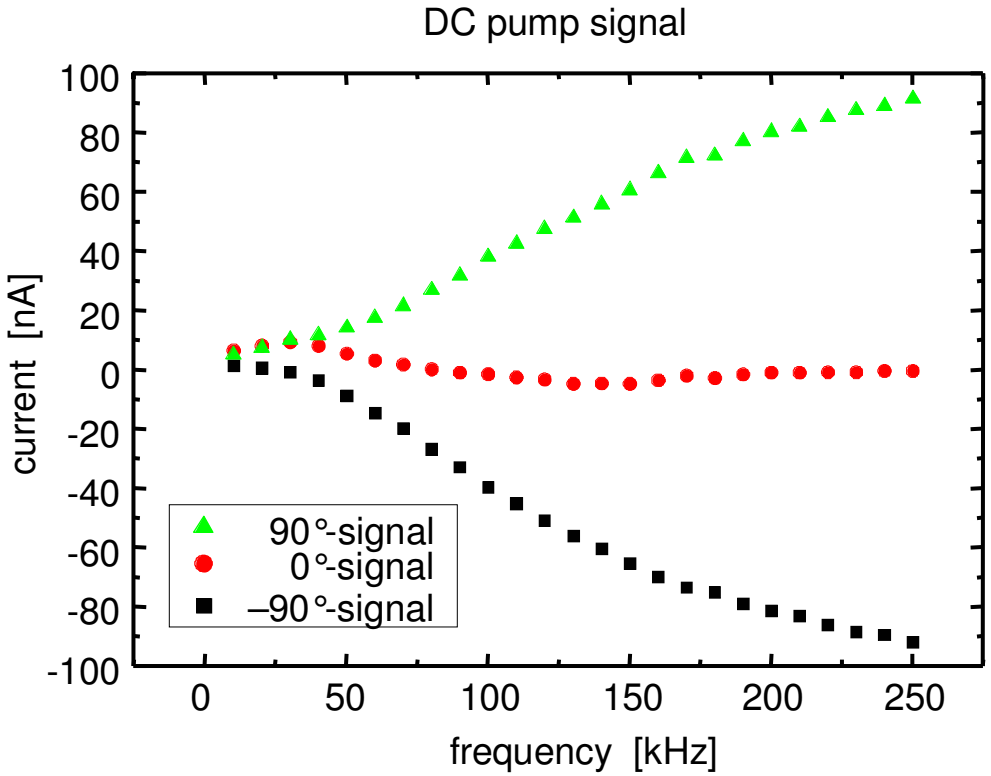
Pumping with ratchets



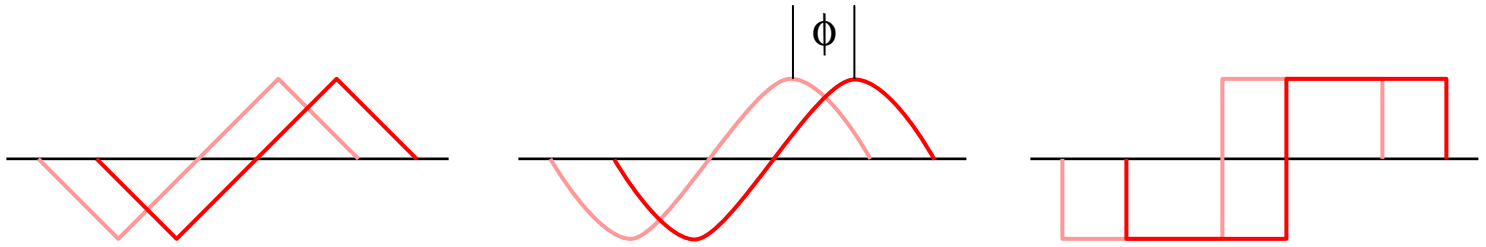
Pumping with ratchets

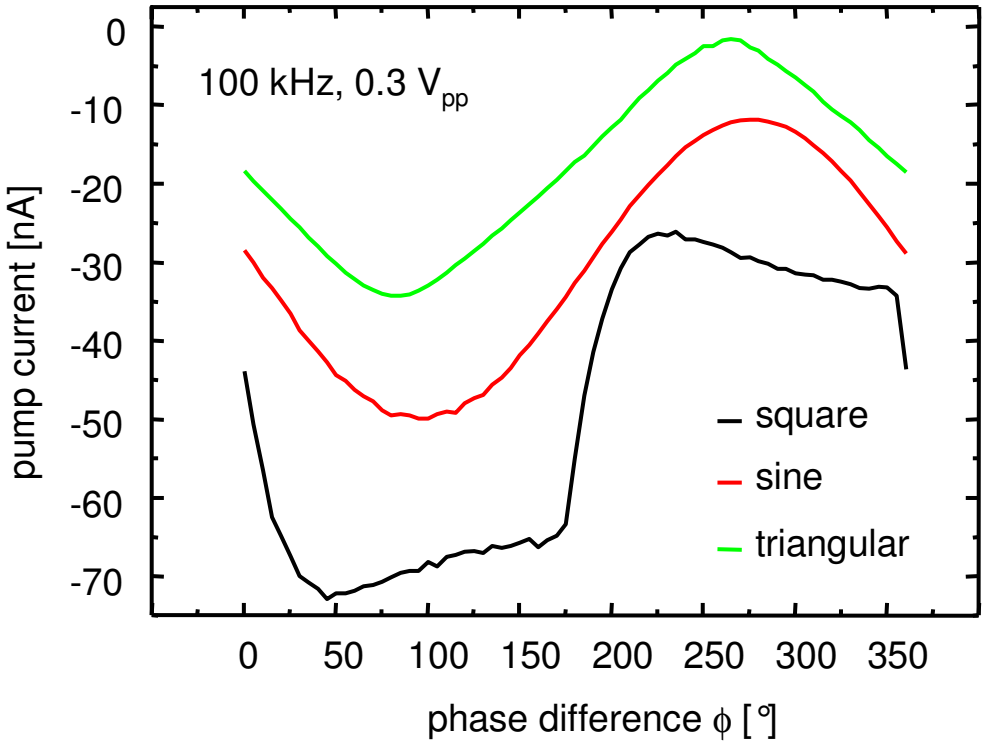


Pumping with ratchets

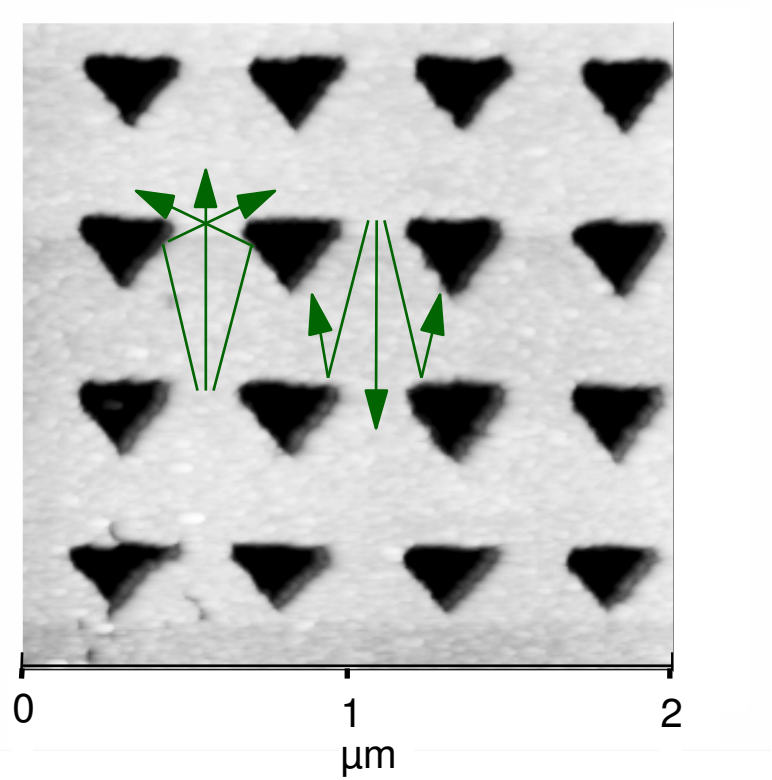


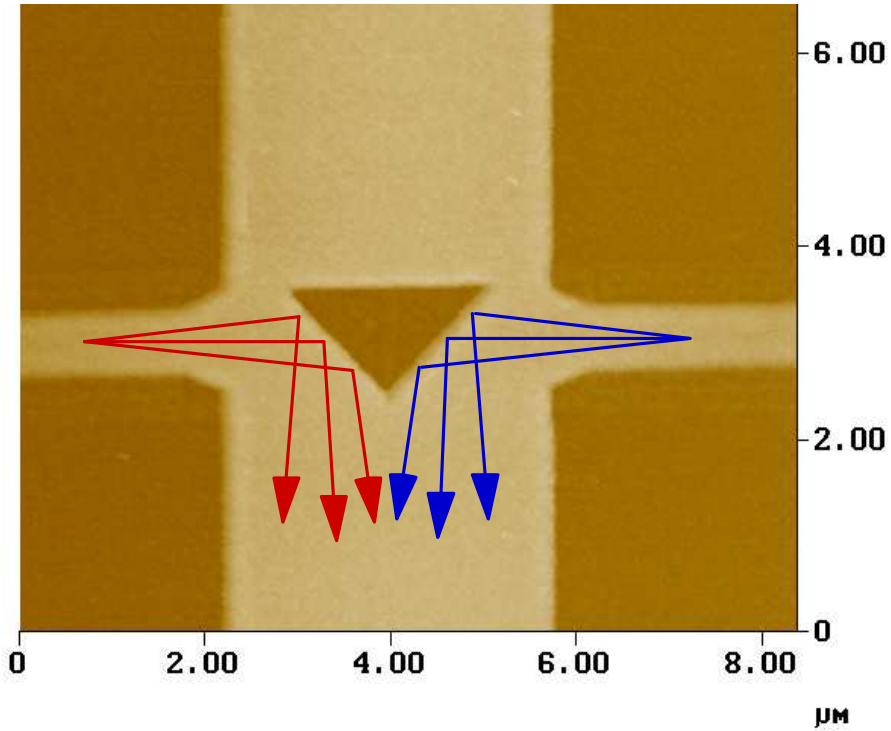
Pumping with ratchets





Electron scattering from asymmetric barriers





rectification possible?

Symmetry relations

linearer transport:

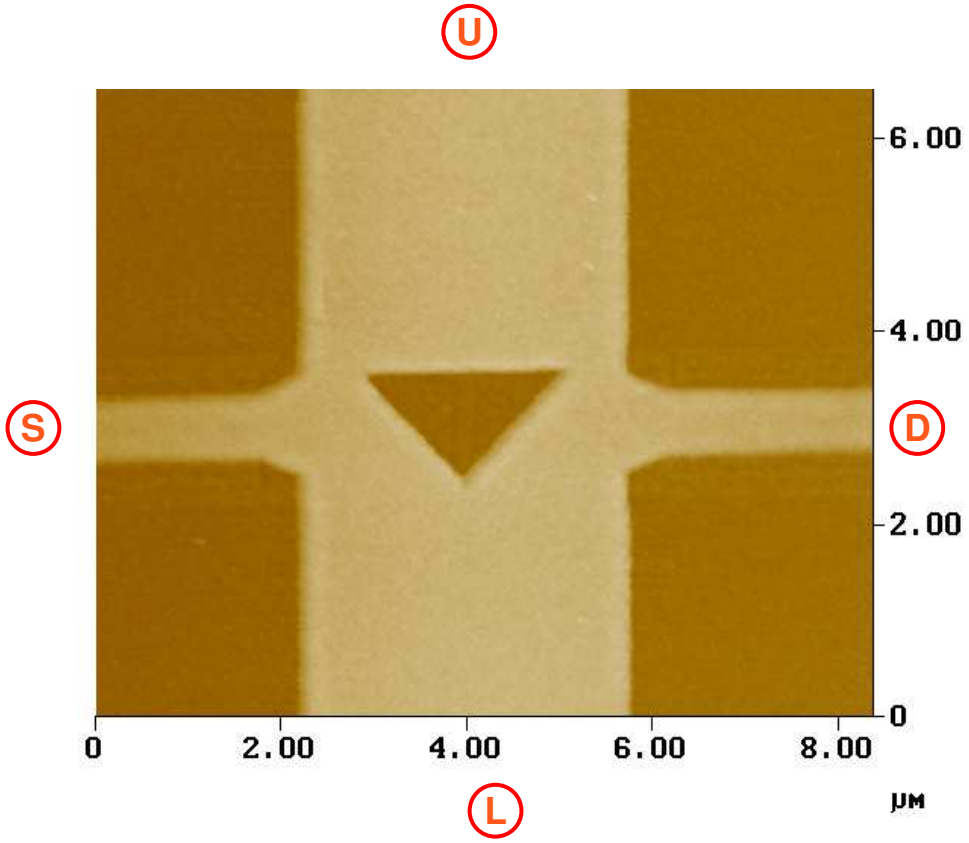
$U_{LU}(I_{SD}) = -U_{LU}(-I_{SD})$

symmetry

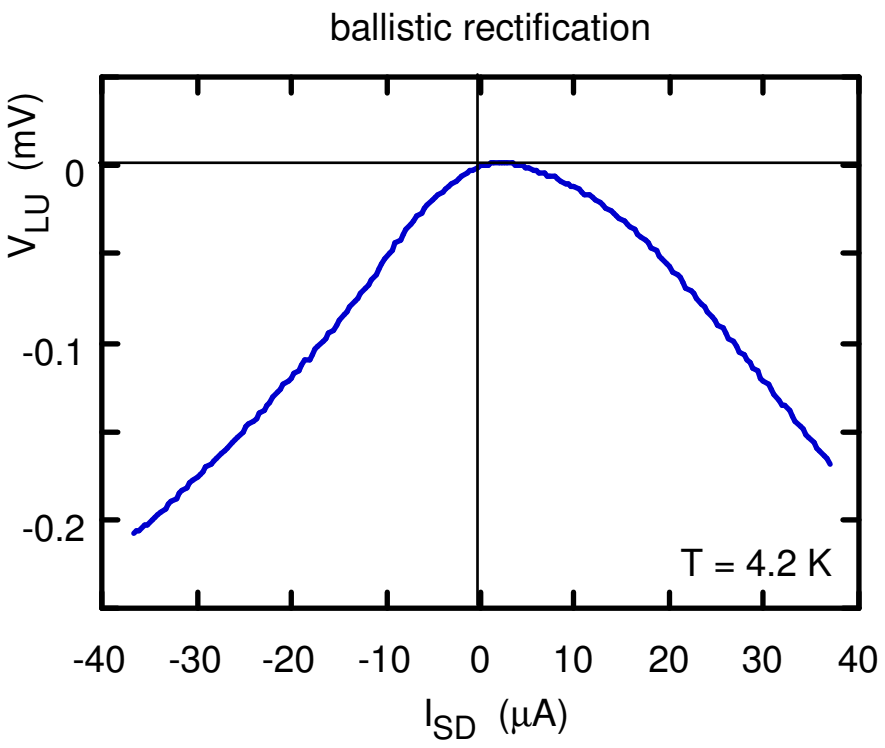
$U_{LU}(I_{SD}) = +U_{LU}(-I_{SD})$

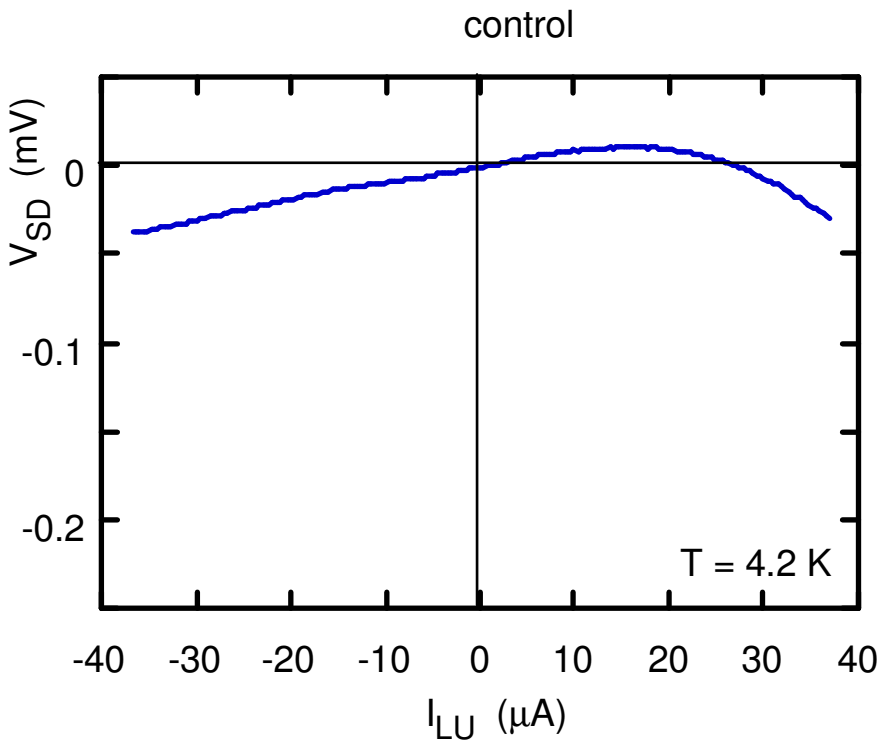
$U_{LU} = 0$

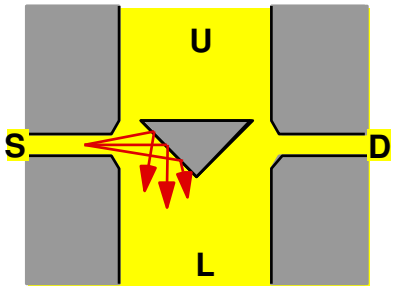
„filter“ for non-linear effects



Non-linear ballistic transport: experiment

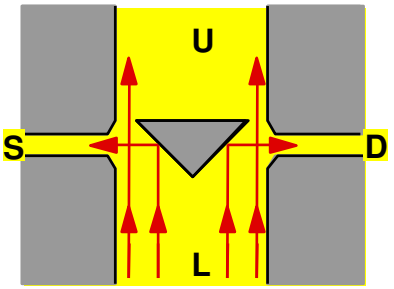






violation of Onsager-Casimir-relation

$$U_{LU,SD} \neq U_{SD,LU}$$



A-M. Song et al.
Phys. Rev. Lett. **80** 3831 (1998)

Ballistic rectifiers, the quantum mechanical picture

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Mesoscopic Rectifiers Based on Ballistic Transport

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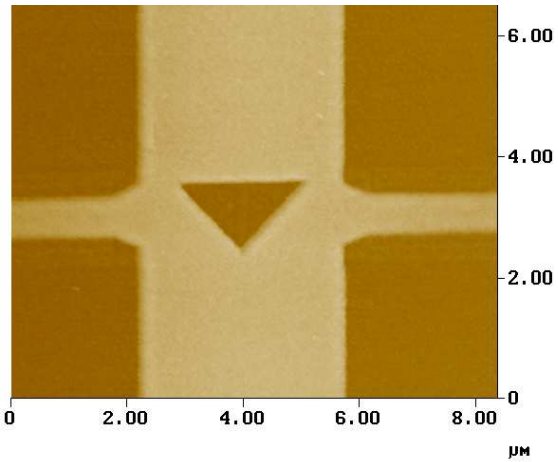
Recent experiments on symmetry-broken mesoscopic semiconductor structures have exhibited an amazing rectifying effect in the transverse current-voltage characteristics with promising prospects for future applications. We present a simple microscopic model, which takes into account the energy dependence of current-carrying modes and explains the rectifying effect by an interplay of fully quantized and quasiclassical transport channels in the system. It also suggests the design of a ballistic rectifier with an optimized rectifying signal and predicts voltage oscillations which may provide an experimental test for the mechanism considered here.

Ballistic rectifiers, the quantum mechanical picture



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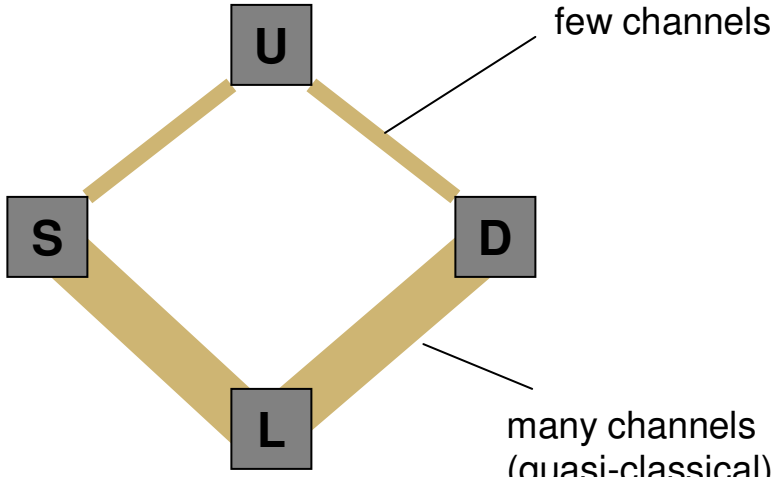
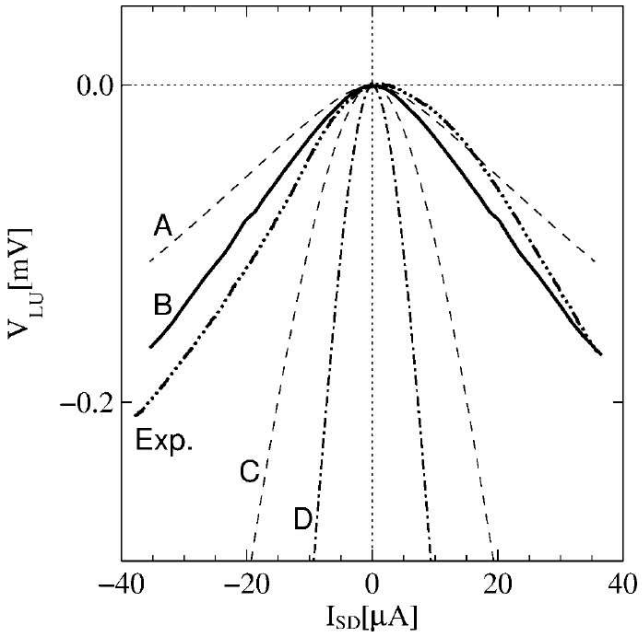
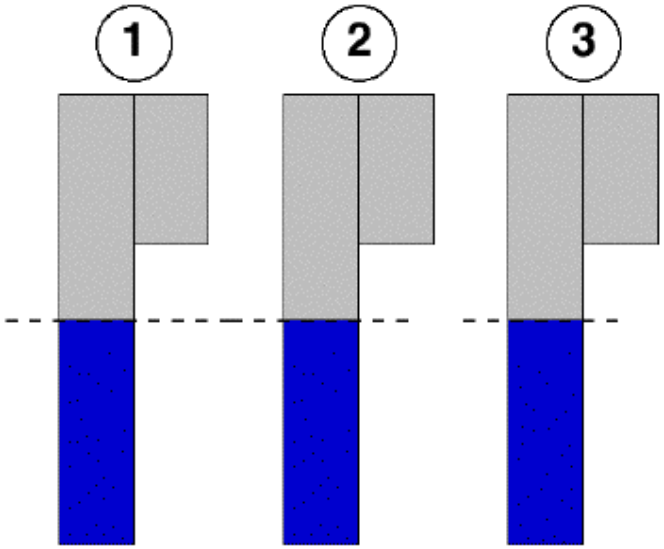
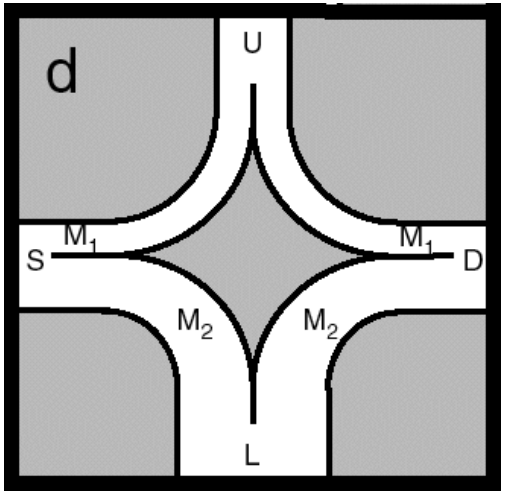
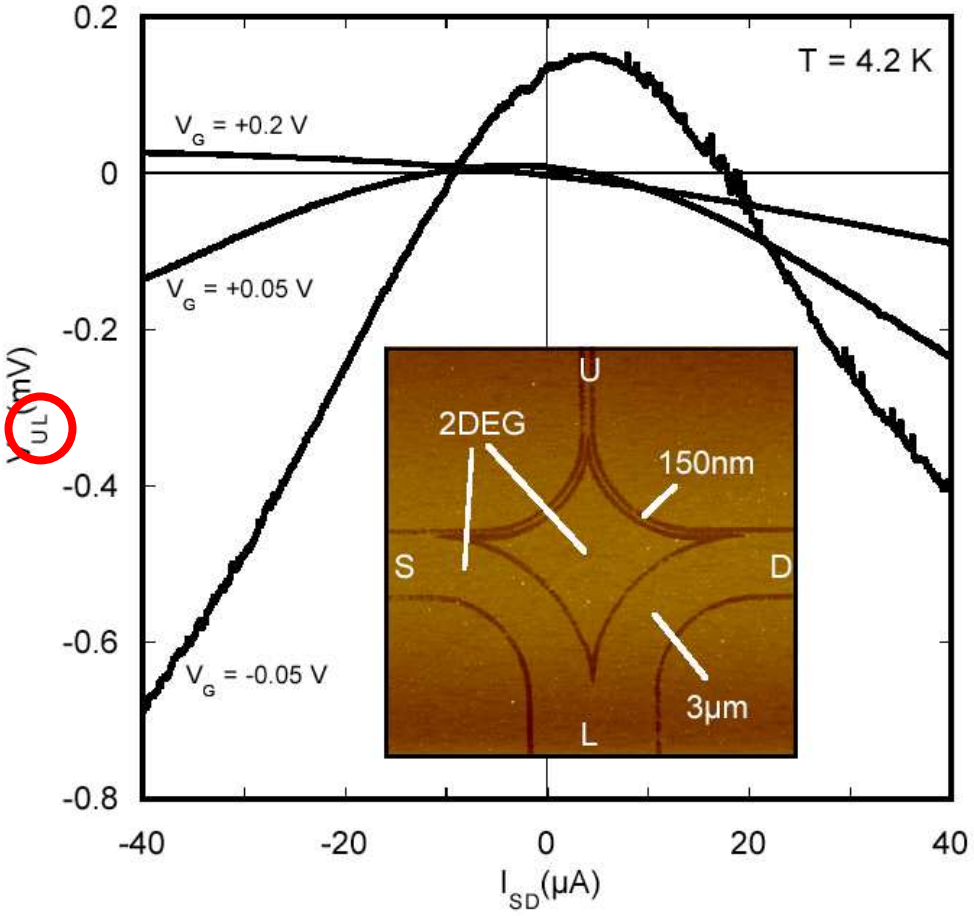






A proposal and its realization

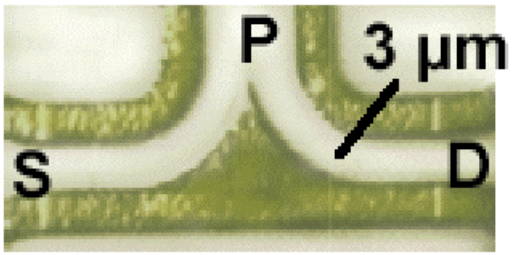


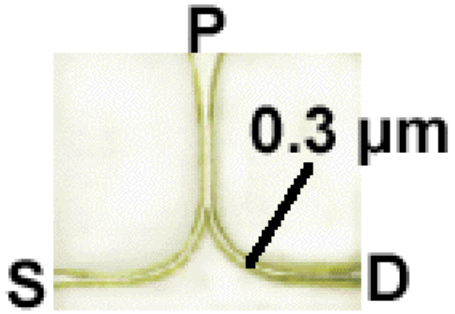


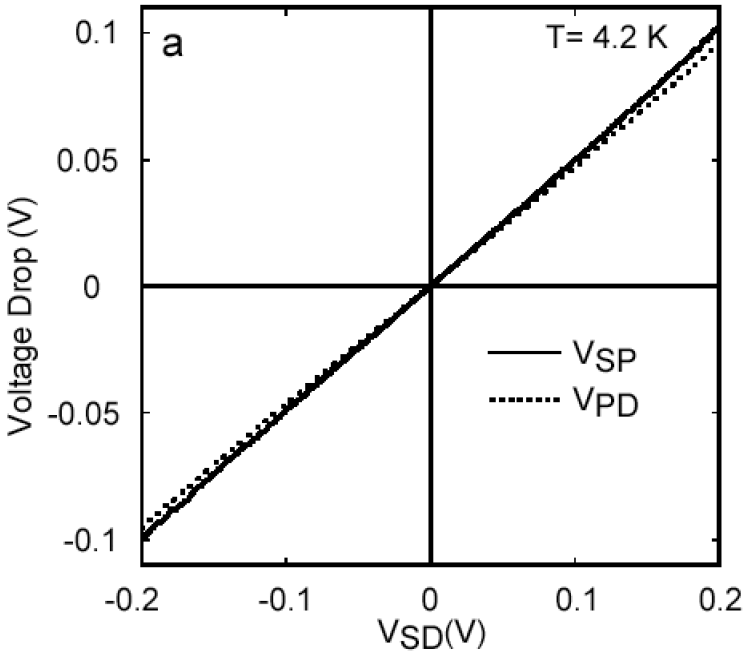
rectification works …

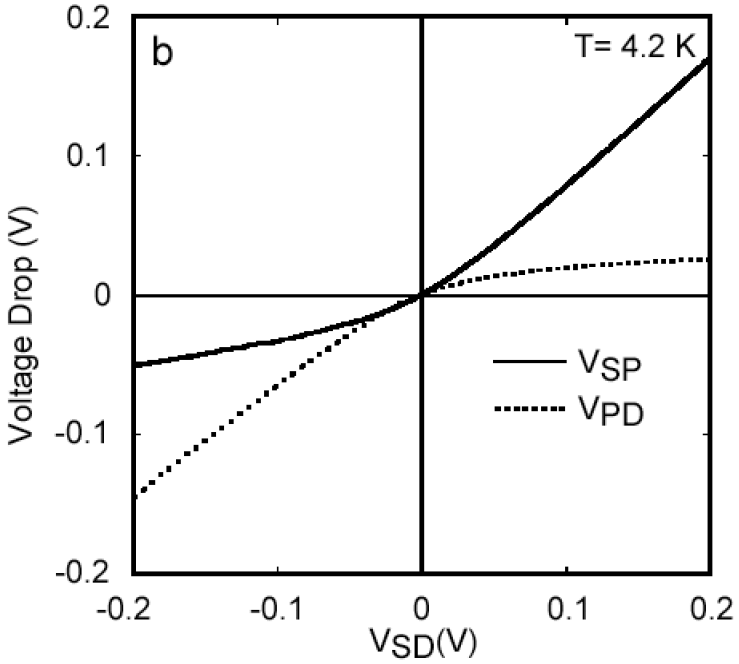
... but with the wrong polarity!

Which path becomes asymmetric?



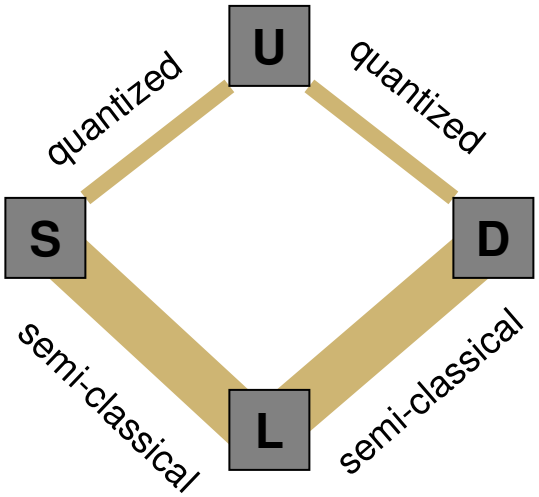


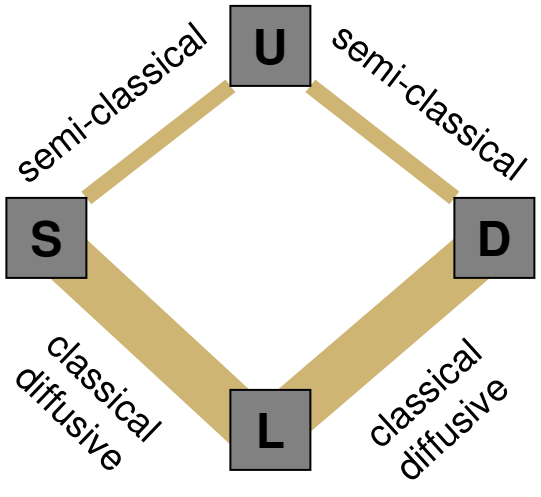


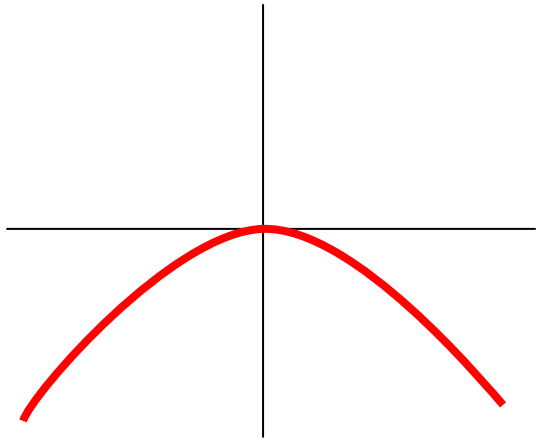


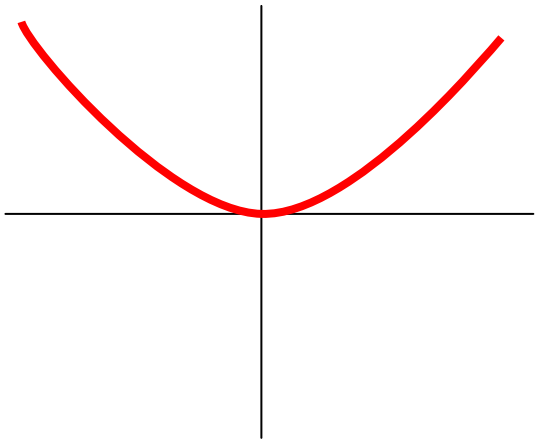
Extended model

... also takes into account the influence of **classical diffusive transport**

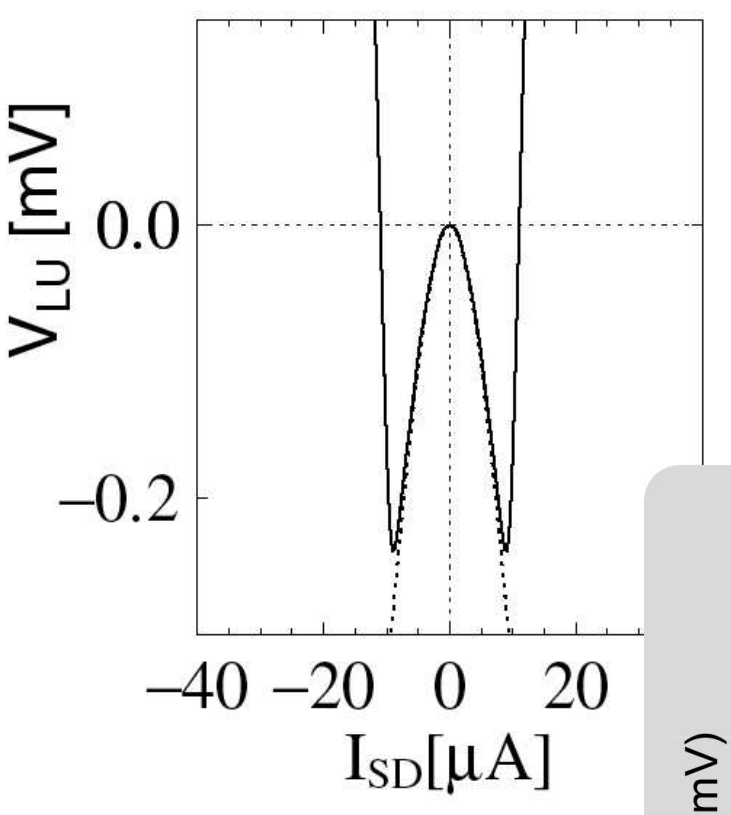


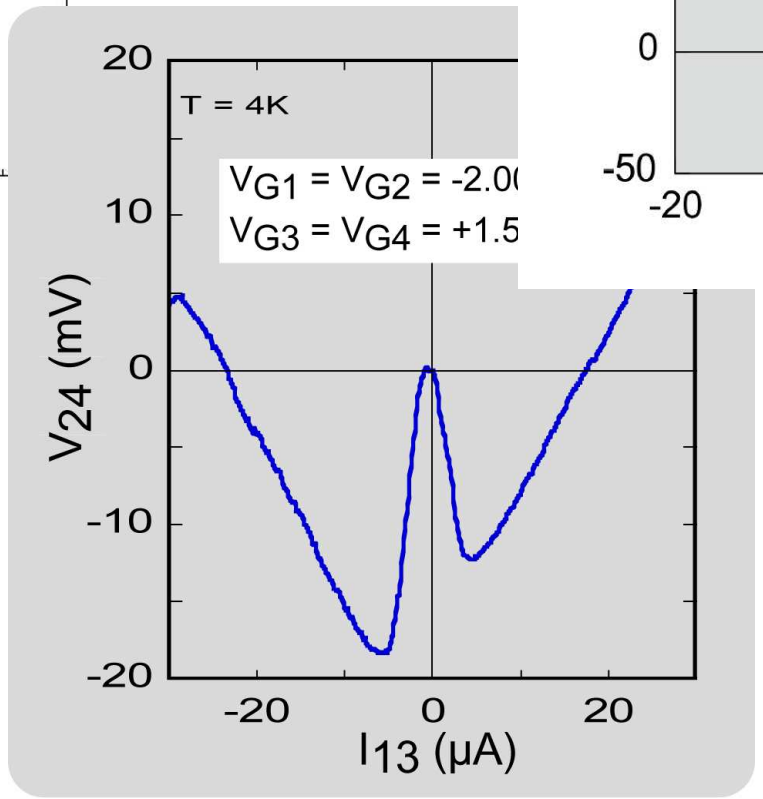


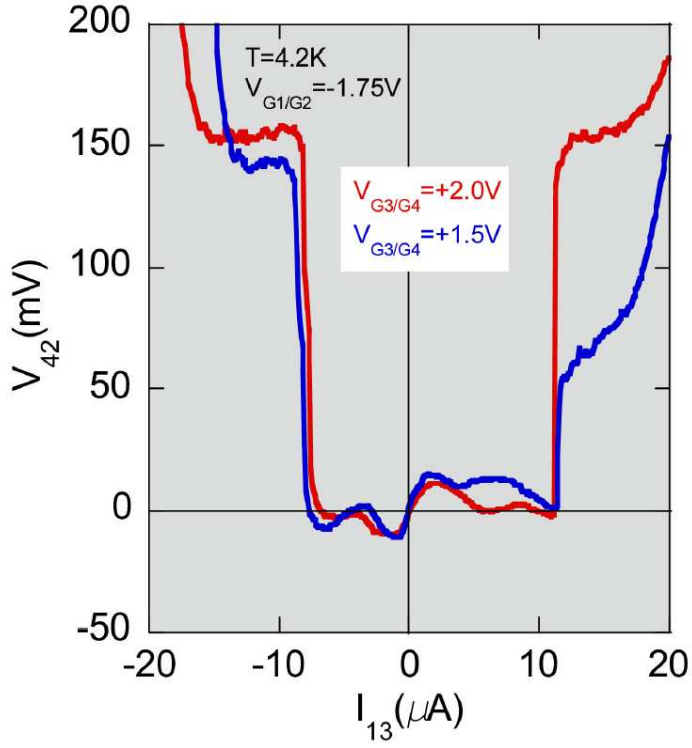




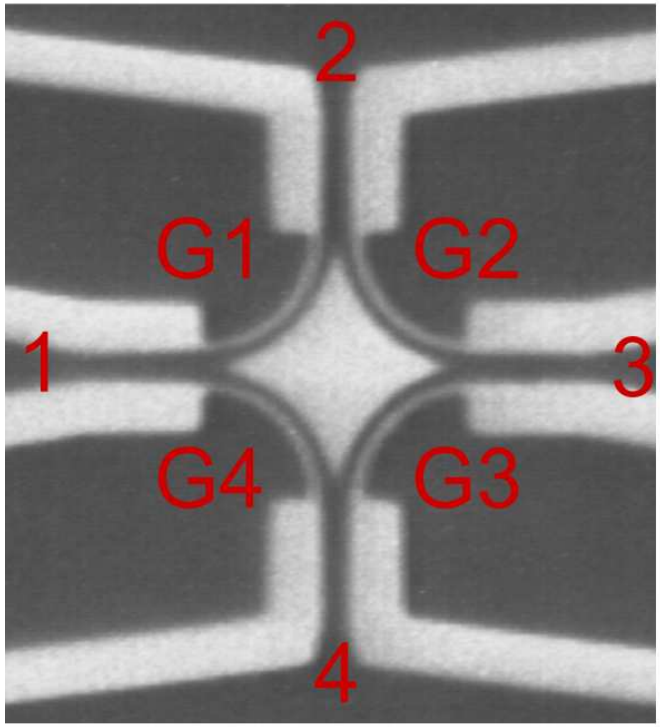
Further examples



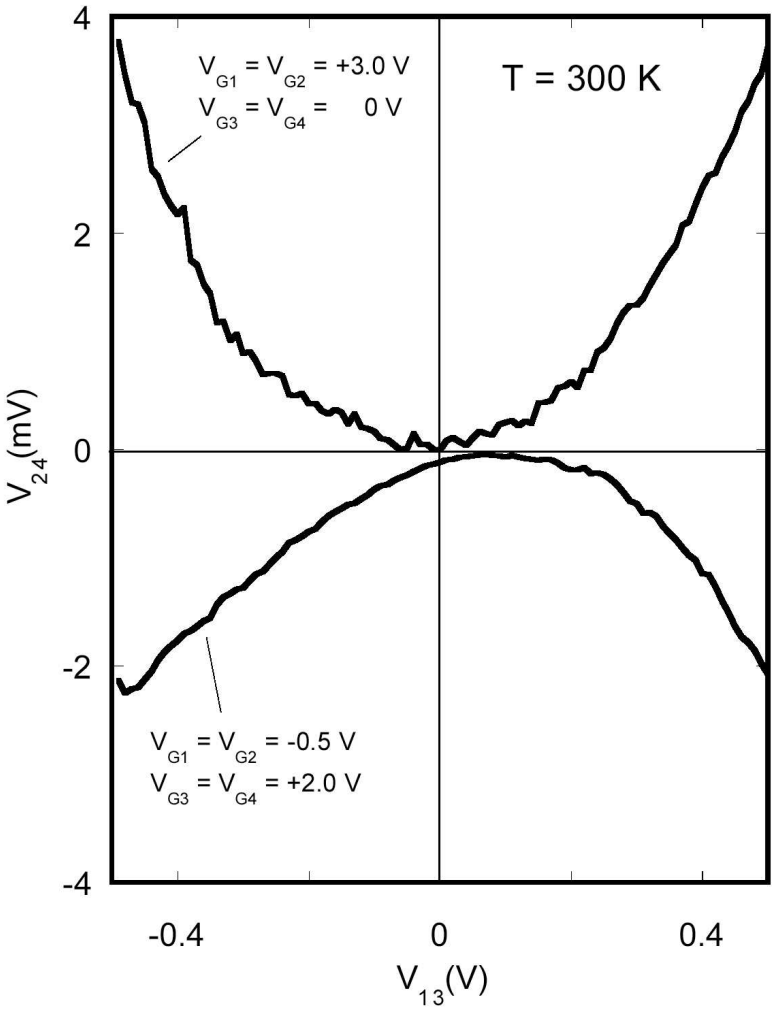




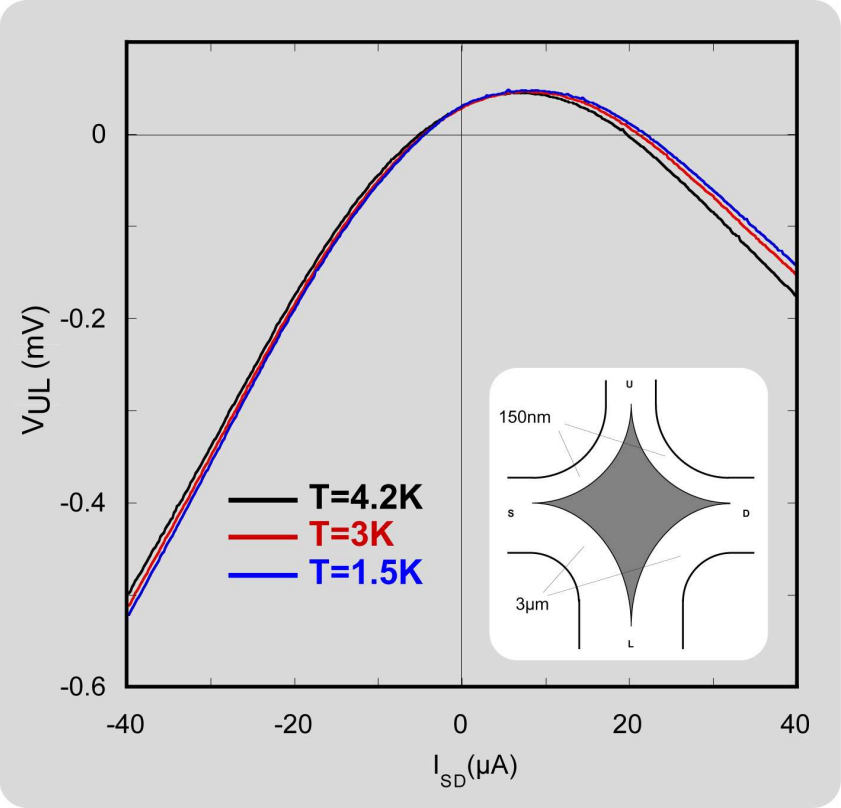
Tunable asymmetry



Phys. Rev. Lett. **92** 056806 (2004)



Could this effect be useful?



\+ suitable characteristics for mixing, SHG

\+ no intrinsic threshold

\+ small, low capacitance – fast ?

– low efficiency, low power

– room temperature?

- a new concept that does not require a change of material
- not material properties but geometry determines performance

„Function follows Form“

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Ludwig-Maximilians-Universität

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Applied Physics Letters **78**, 2905 (2001)

Phys. Rev. Lett. **92** 056806 (2004)

Physica E **21** 916 (2004)