Quanteneffekte in Halbleiternanostrukturen

Rolf J. Haug

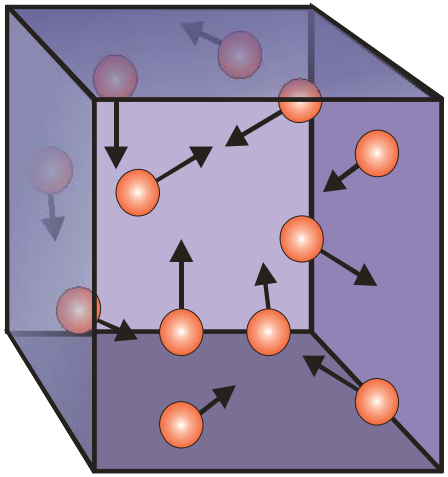
Abteilung Nanostrukturen
Institut für Festkörperphysik
Gottfried Wilhelm Leibniz Universität Hannover
Germany

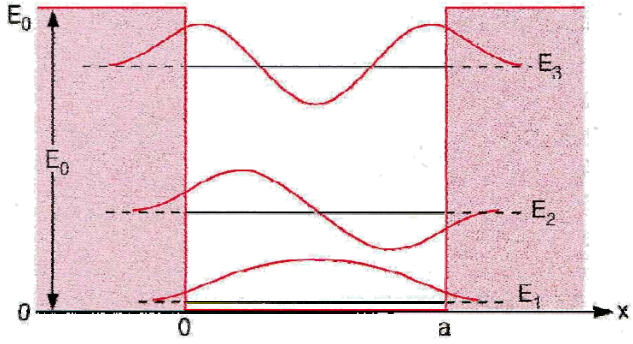
Quantum Mechanics:
Low-Dimensional Systems

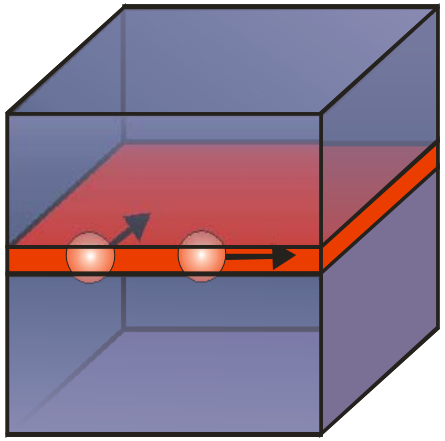
3d

2d

quantum size effect

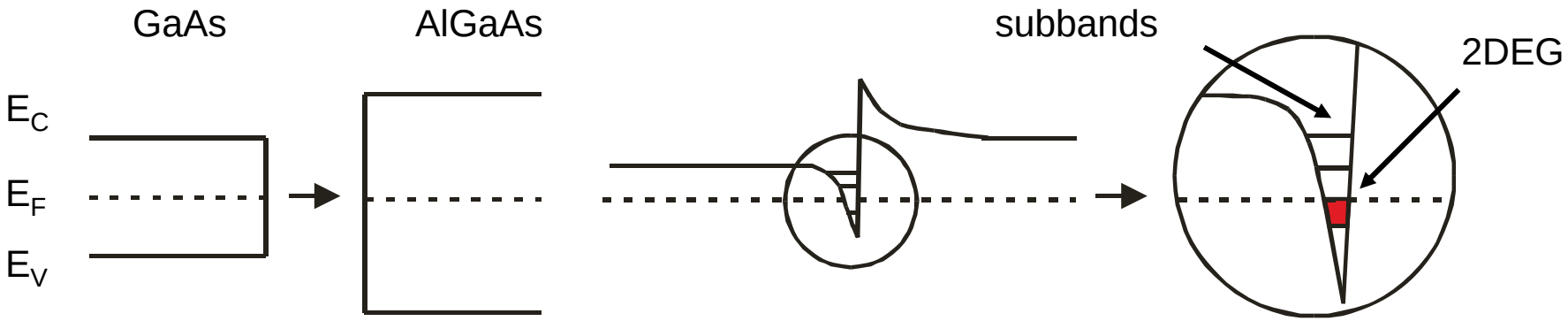




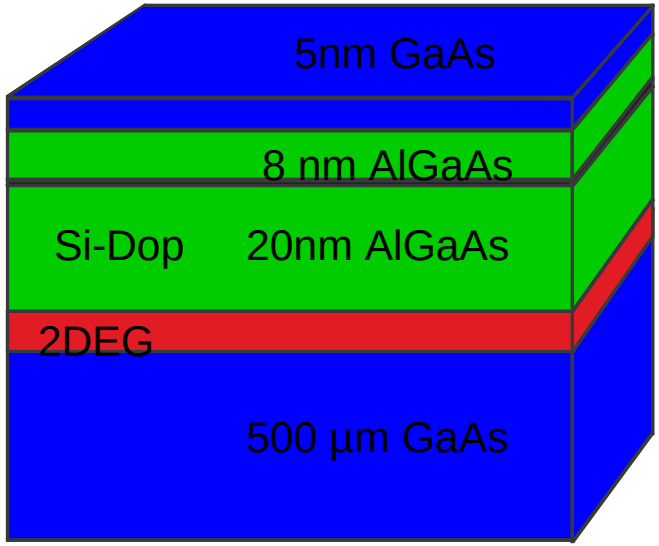


particles have signatures of waves

2D in Semiconducting Heterostructures



2d



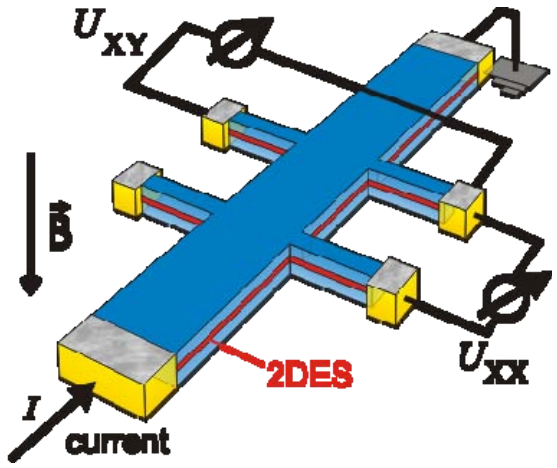
- **band-edge discontinuity produces triangular well** ➡ **2DEG**

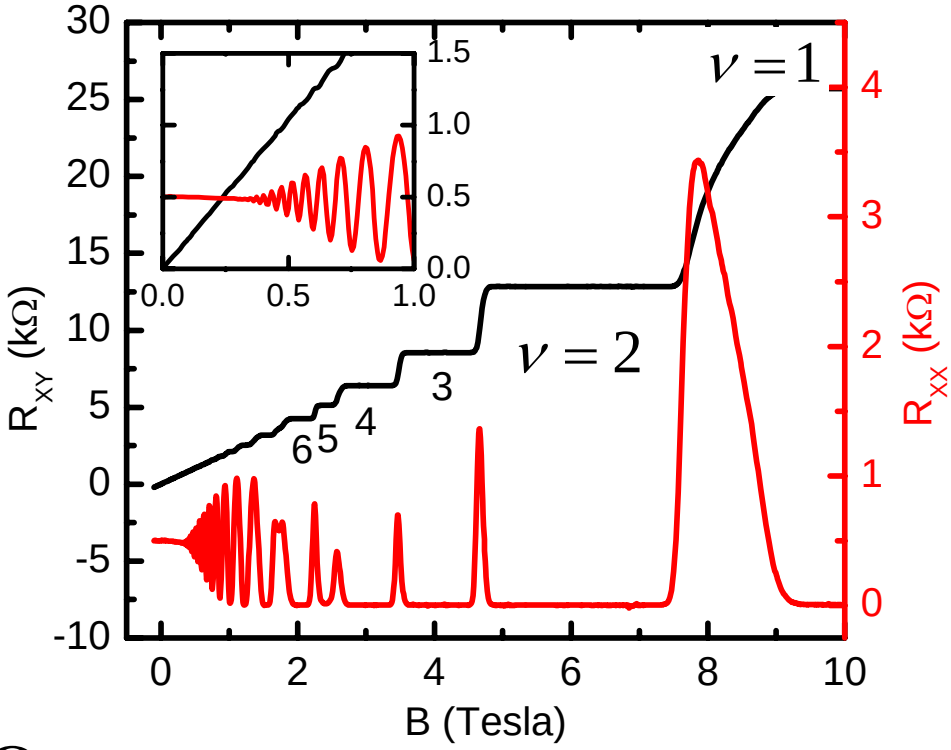
used in

made by molecular beam epitaxy

2d Physics: Quantum Hall Effect

DFG Priority Program: 2000 - 2006

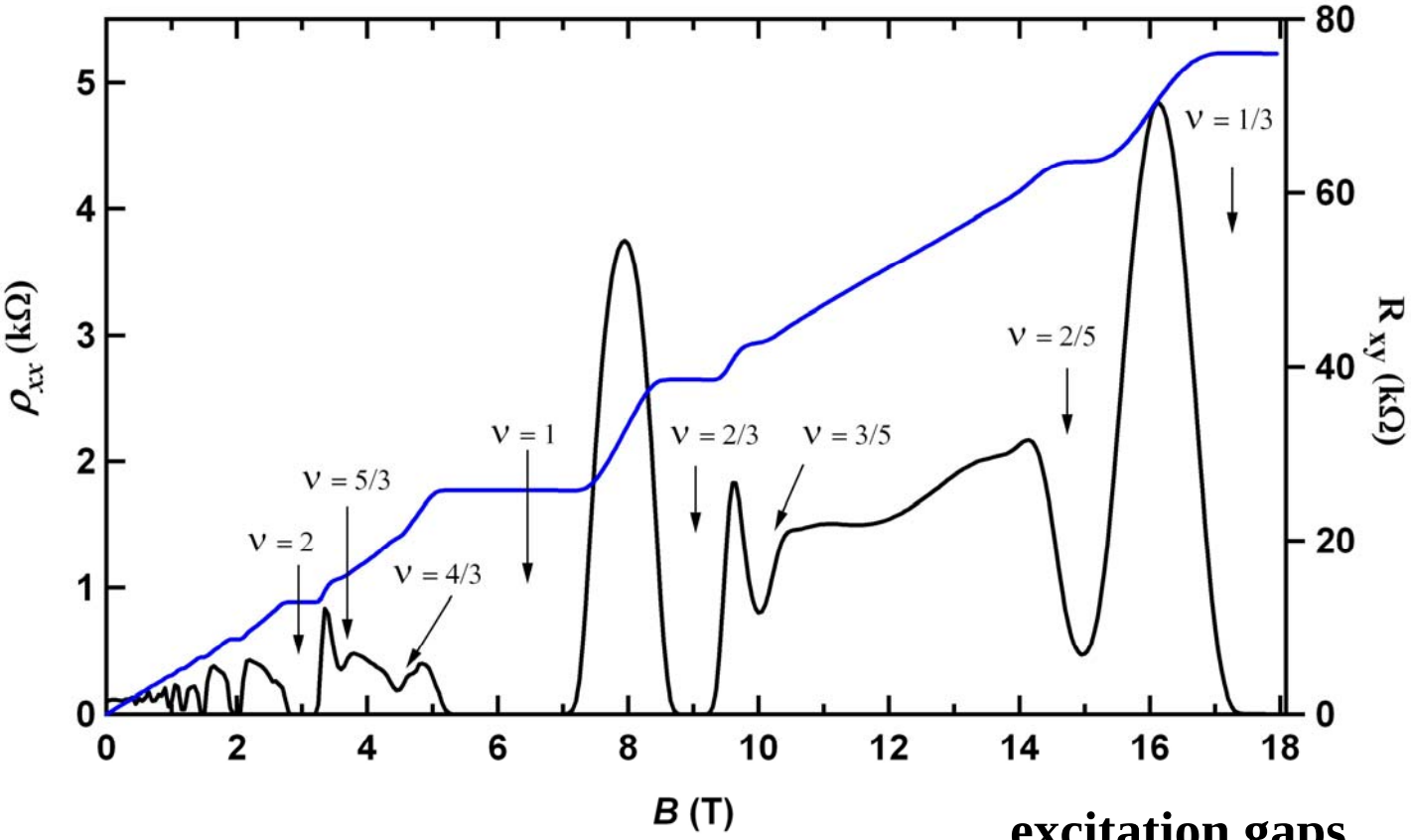




$$R_{XY} = \frac{U_{XY}}{I} = \frac{h}{\nu e^2} = \frac{1}{\nu} 25812{,}807\Omega$$

Phys. Rev. Lett. 93, 196801 (2004)
Phys. Rev. Lett. 89, 276801 (2002)
Phys. Rev. Lett. 88, 036802 (2002)
Phys. Rev. Lett. 86, 5124 (2001)

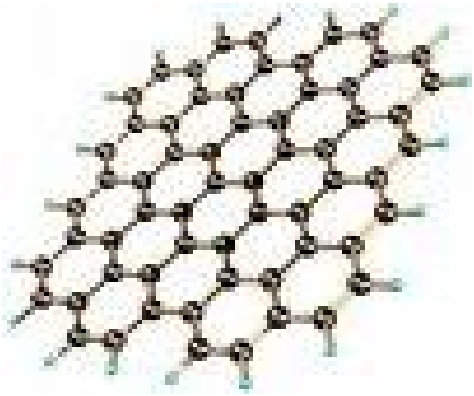
Fractional Quantum Hall Effect



cond-mat/0607167
Phys. Rev. B 74, 165325 (2006)
Phys. Rev. B 74, 195324 (2006)
Phys. Rev. Lett. 92, 156401 (2004)
Phys. Rev. Lett. 93, 026801 (2004)

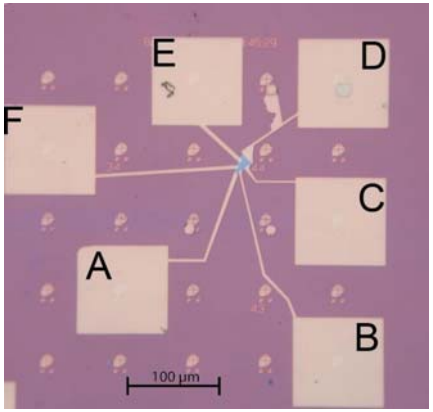
excitation gaps
effects of spin,
specific heat,
electrons versus holes

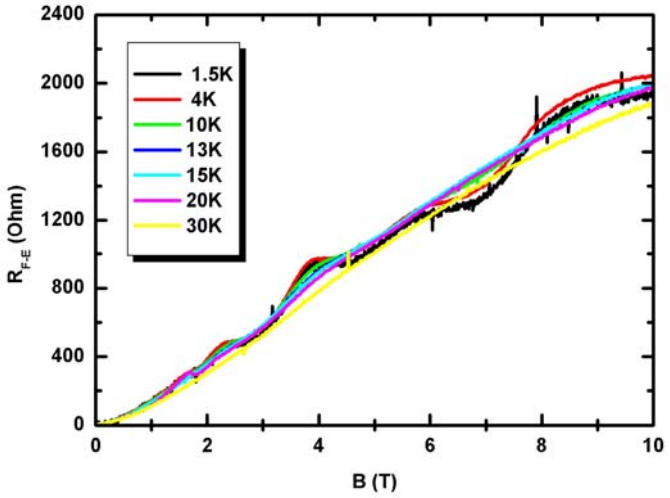
Quantum Hall Effect at Room Temperature
Novel Material: Graphene



Novoselov et al., Science 315 (2007)

our measurements:
not yet as good

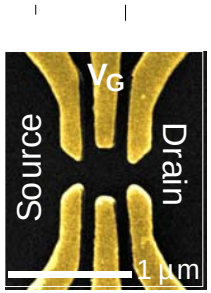


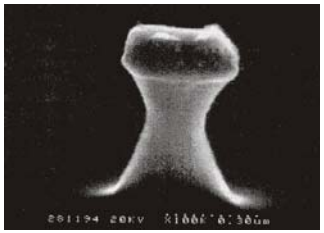


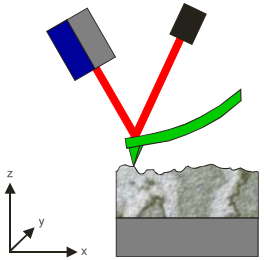
Low-Dimensional Structures: 1d, 0d

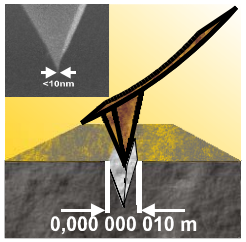
- **lithography**

1. optical lithography
2. electron beam lithography
3. direct writing with
   atomic force microscope (AFM)



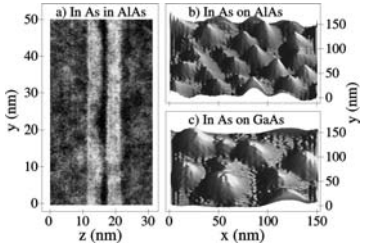






- **self-organized growth**

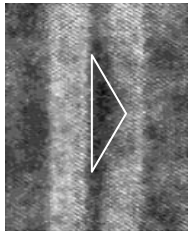
quantum dots (InAs, Si, Ge)



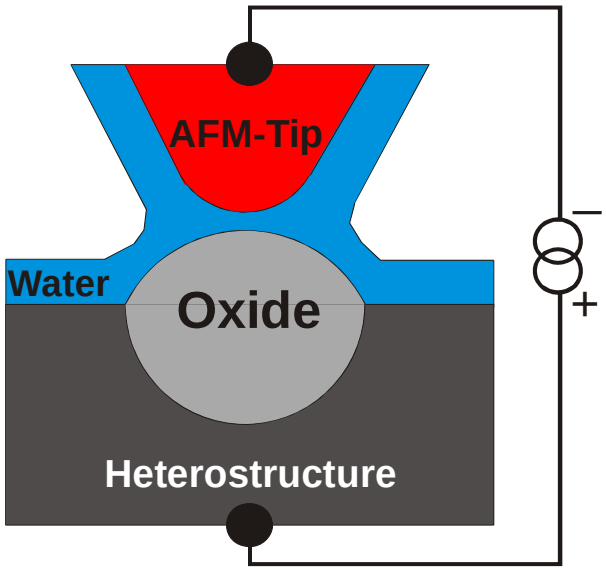
lattice mismatch between InAs and AlAs (GaAs): 7%

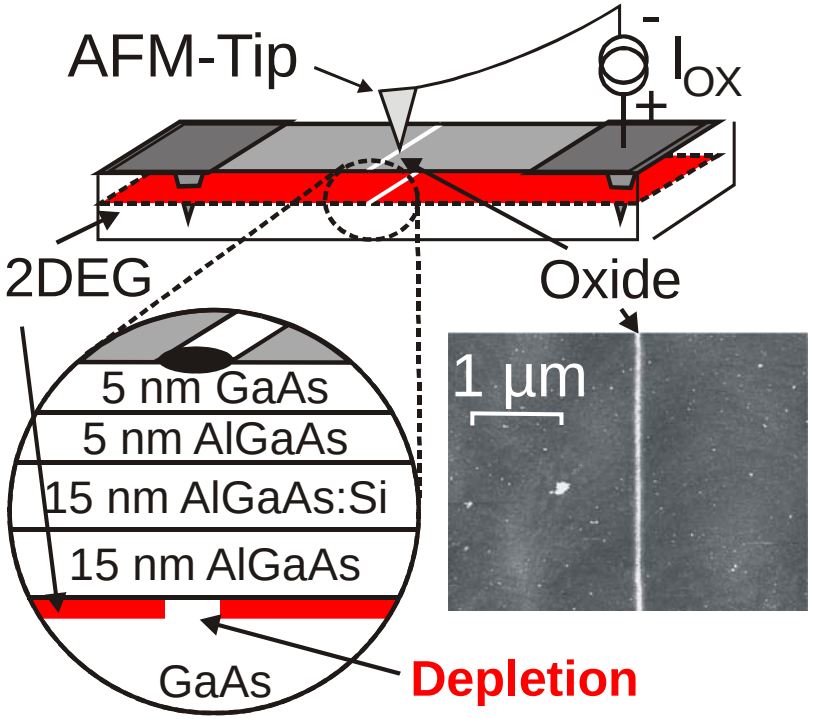
Stranski Krastanov growth

Appl. Phys. Lett. 82, 1209 (2003)

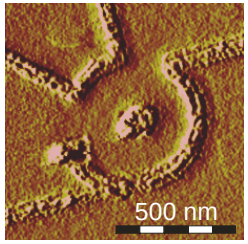


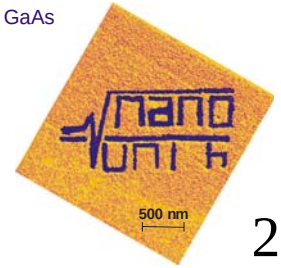
Local Oxidation with AFM





Appl. Phys. Lett. 76, 457 (2000)



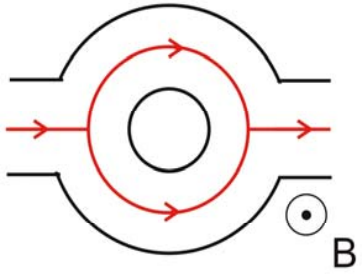


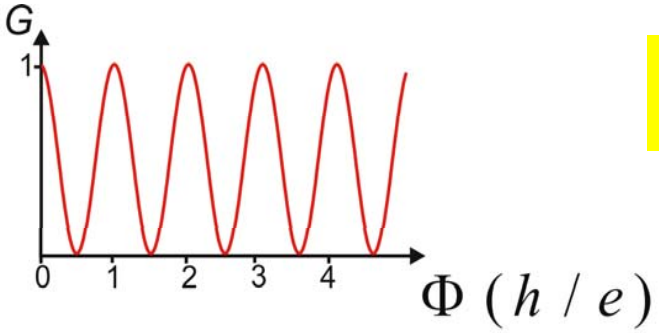
Ishii, Matsumoto (1995)

chemistry:

$$2GaAs + 12p^{+} + 10OH^{-} \rightarrow Ga_2O_3 + As_2O_3 + 4H_2O + 2H^{+}$$

Interference Effects in Quantum Rings

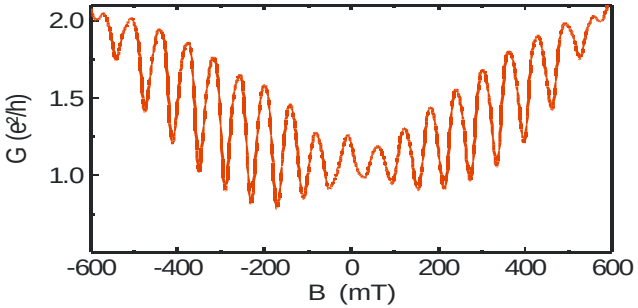




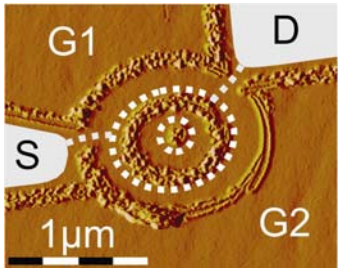
$$G \propto \cos(2\pi\ \Phi/\Phi_0)$$

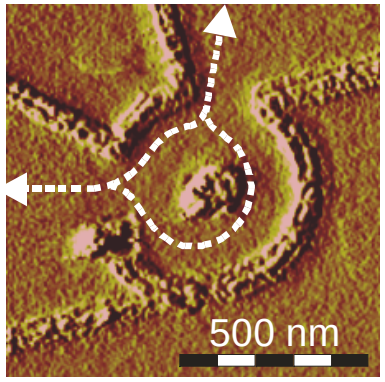
flux quant.: $\Phi_0 = h/e$

Aharonov-Bohm effect

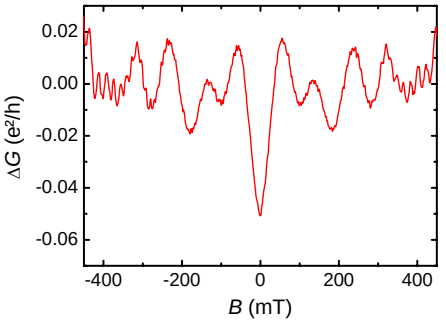


2 rings:





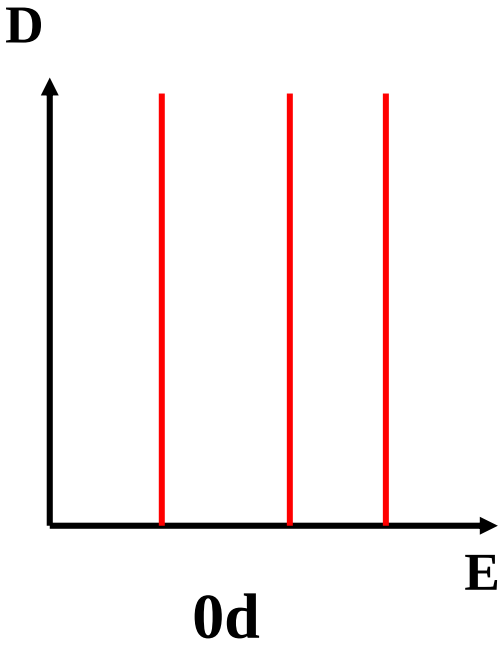
up to 50% modulation of the conduct. periodicity
58mT: R=150nm



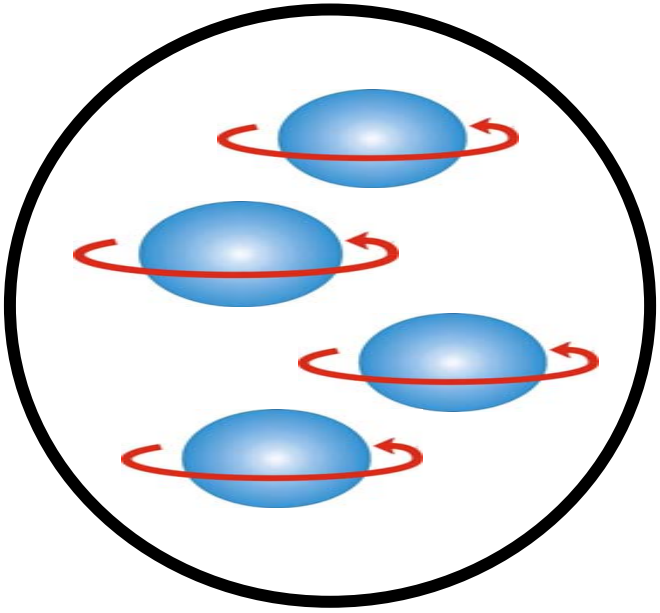
Phys. Rev. Lett. 90, 196601 (2003)

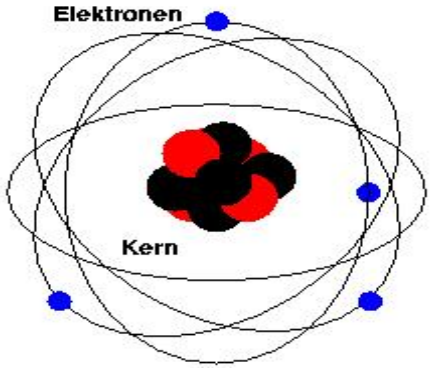
Quantum Dot:
quasi-zerodimensional system in a semiconductor

artificial atom?!



0d



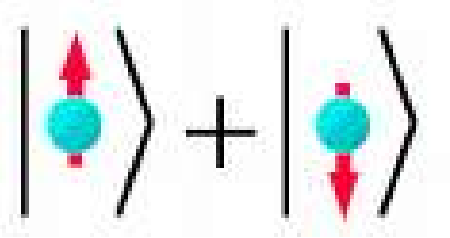


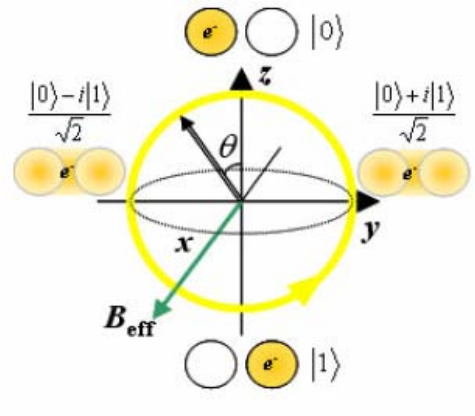
Bohr radius

$$a_B = \frac{4\pi\hbar^2 \varepsilon\varepsilon_0}{me^2}$$

charge, spin,
interaction effects,
quantum information processing

Quantum Information Processing: Calculating with Quantum Mechanics





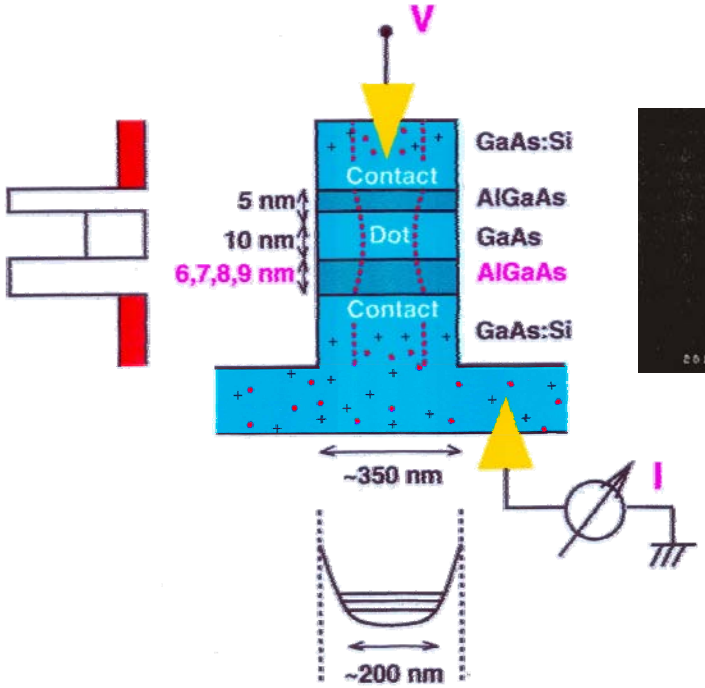
two-level systems in quantum dots:

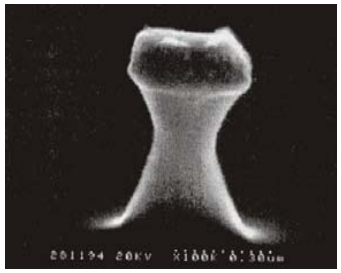
- **charge**
- **spin**

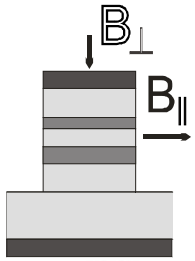
Bundesministerium für Bildung und Forschung

nanoQUIT

Spin Effects in Single Dots

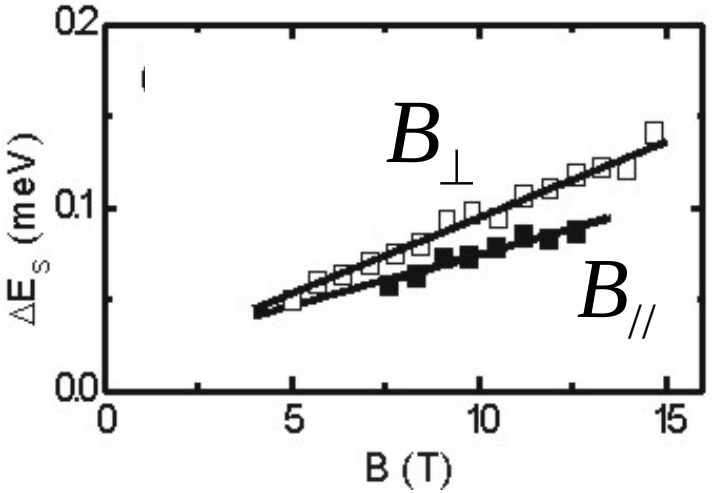


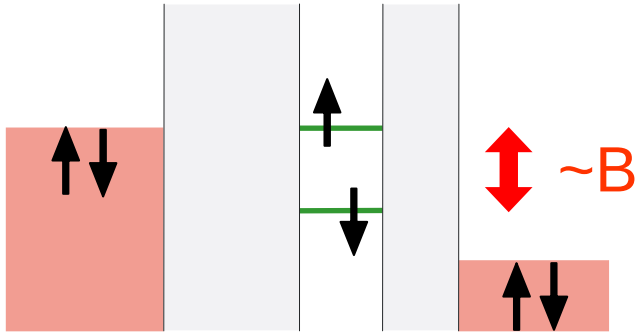




disc-like quantum dot

spin splitting





differences due to spin-orbit effects

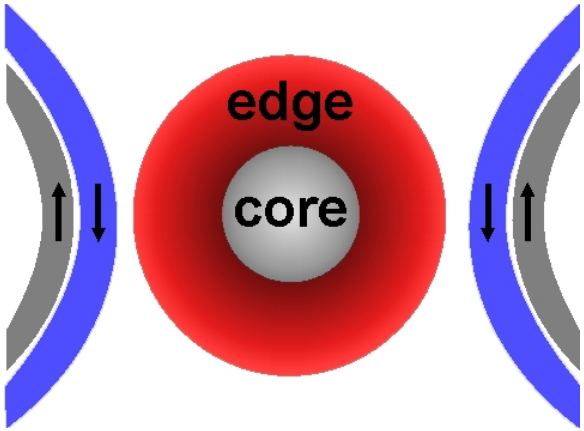
Phys. Rev. Lett. 94, 226404 (2005)

extreme anisotropy: holes in SiGe/Ge structure
g=6.2 ⟶ 0

Phys. Rev. Lett. 96, 086403 (2006)

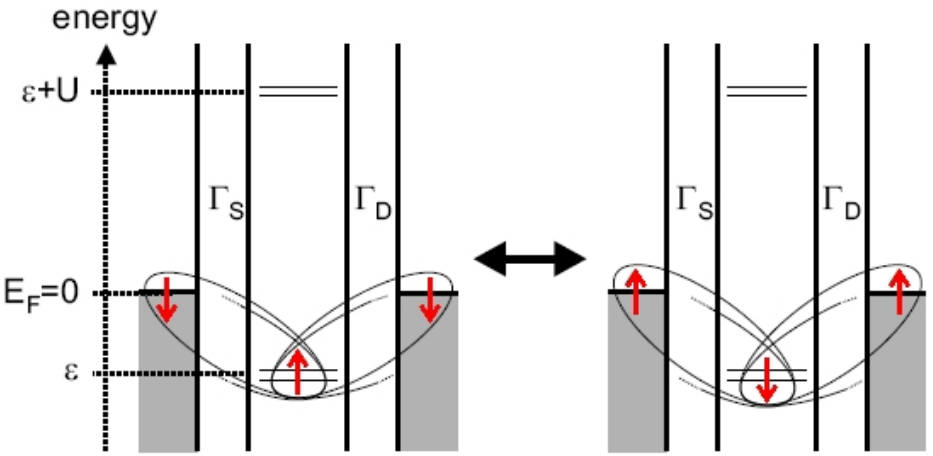
Interaction Effects in Single Dots: Kondo Effect versus Spin Blockade

spin blockade



spin-polarized leads necessary

Kondo effect

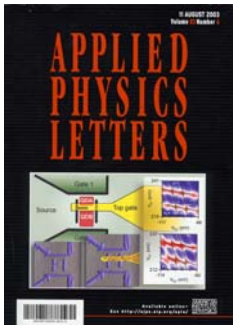


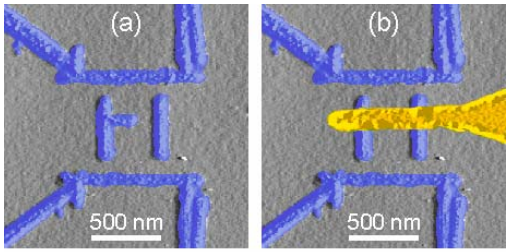
both spins in the leads necessary

➡ **spin structure of many-electrons quantum dots**

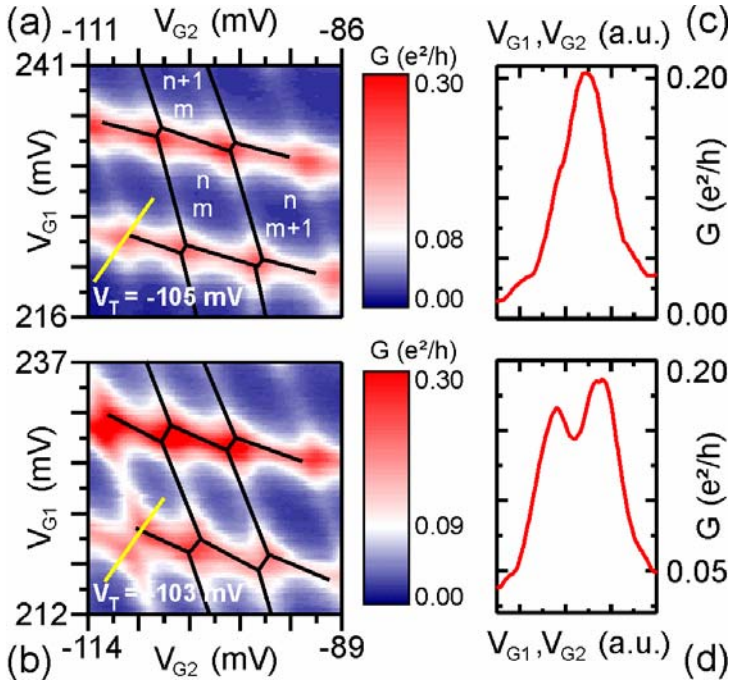
Phys. Rev. Lett. 96, 046802 (2006)
Phys. Rev. Lett. 96, 176801 (2006)

Coupling between Quantum Dots: Artificial Molecule





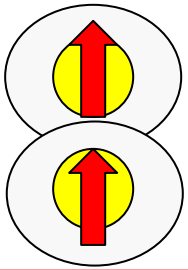
Appl. Phys. Lett. 83, 1163 (2003)
Appl. Phys. Lett. 85, 806 (2004)



weak coupling

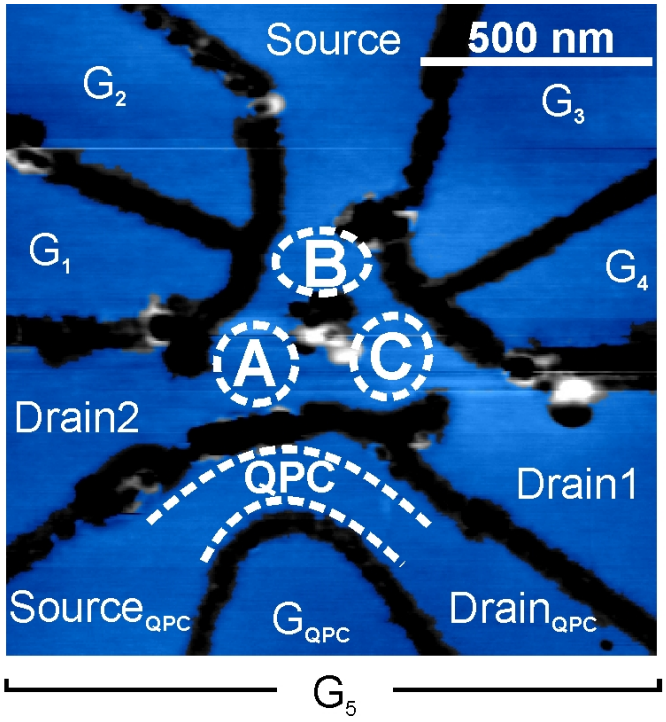
strong coupling

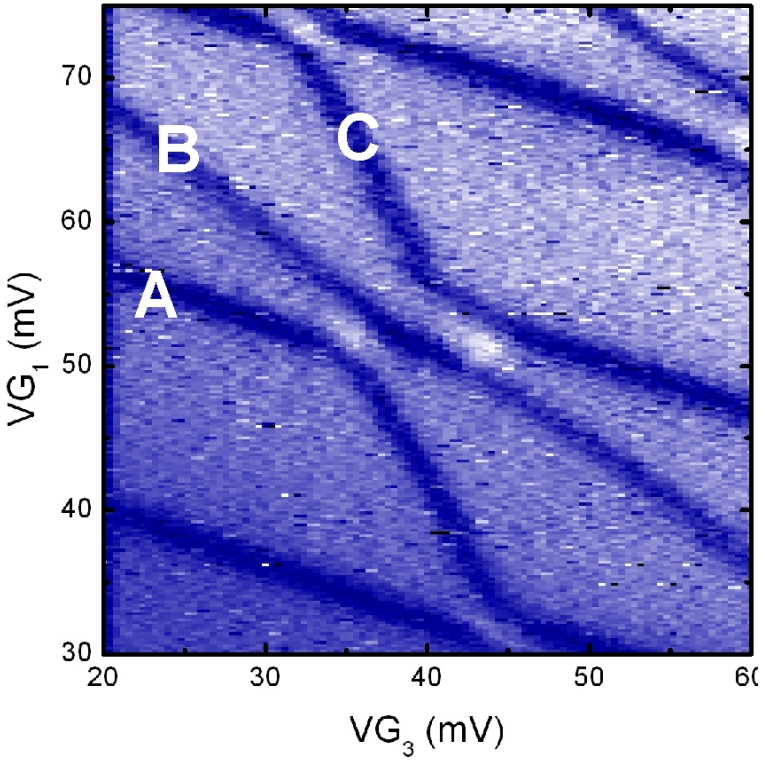
Phys. Rev. Lett. 96, 246803 (2006)
Phys. Rev. Lett. 80, 4032 (1998)
Phys. Rev. Lett. 81, 689 (1998)



coupled quantum dots: building blocks of quantum comp.

Triple Quantum Dot



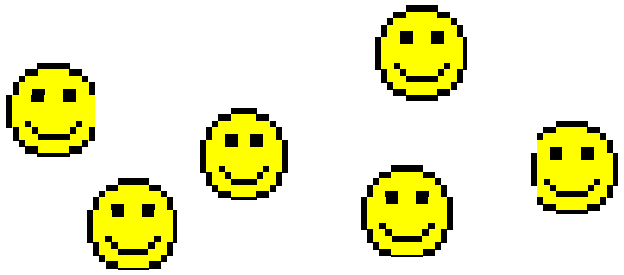


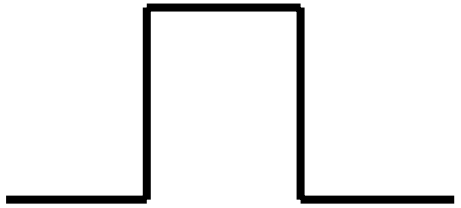
- **triple quantum dot made with local anodic oxidation**
- **charge detection with quantum point contact**

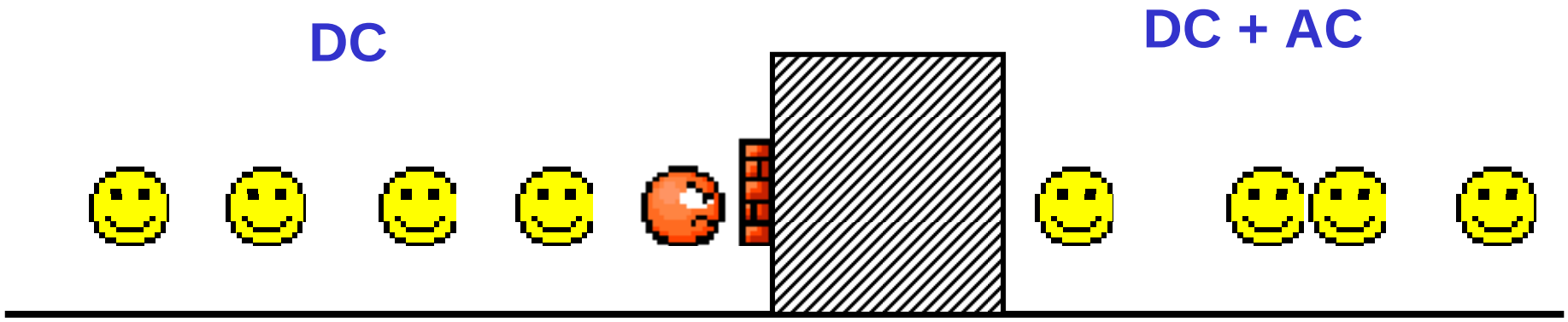
Shot Noise

- **electrical current**

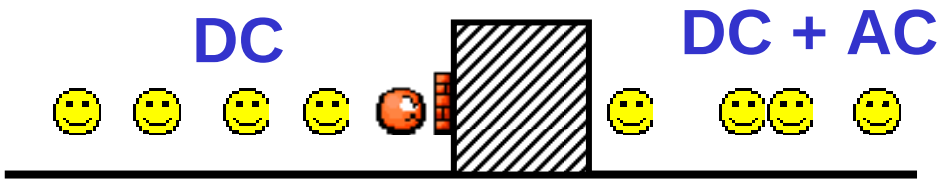
barrier







Shot Noise Suppression

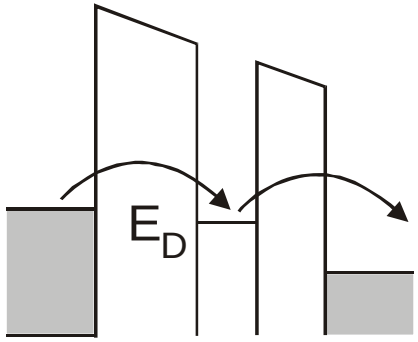


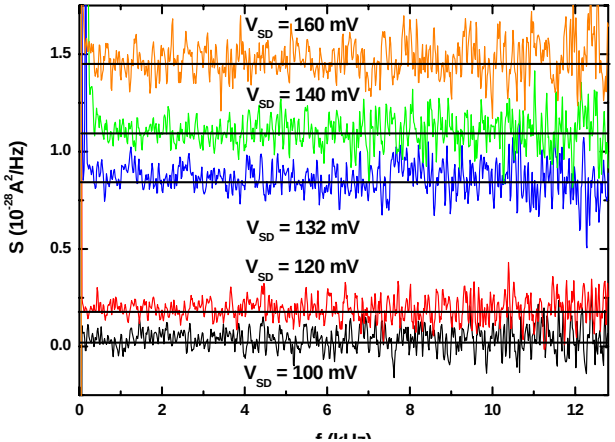
$S_{Poisson} = 2eI$ **(single barrier)**

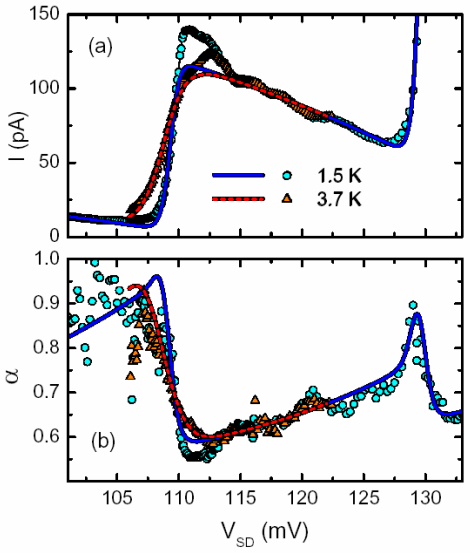
correlations can suppress noise

$$S = \alpha 2eI$$

Fano factor



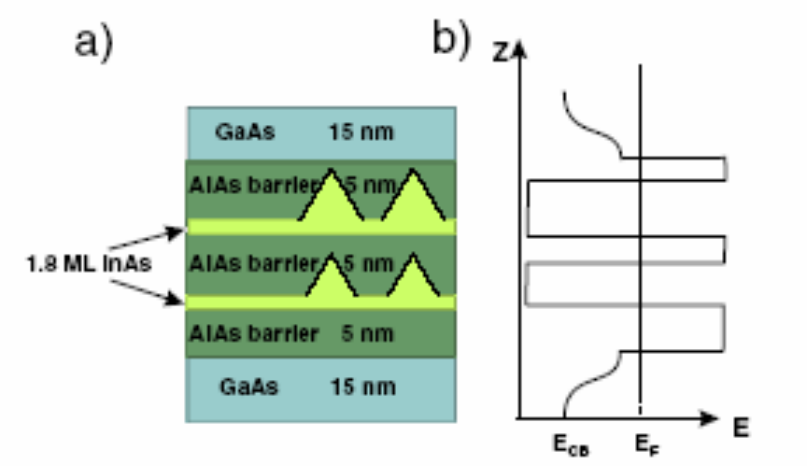


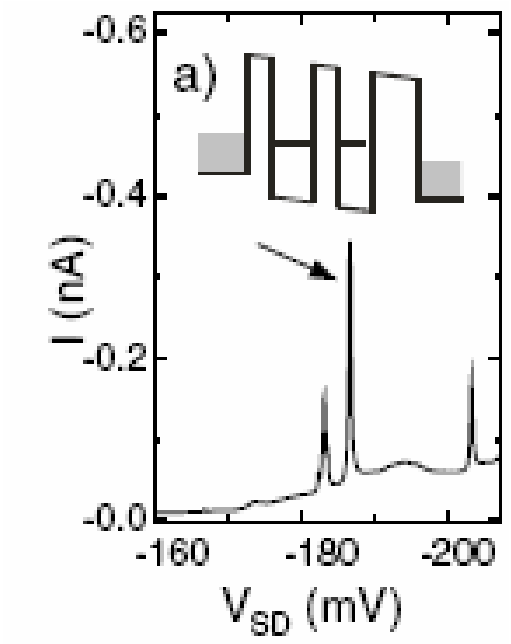


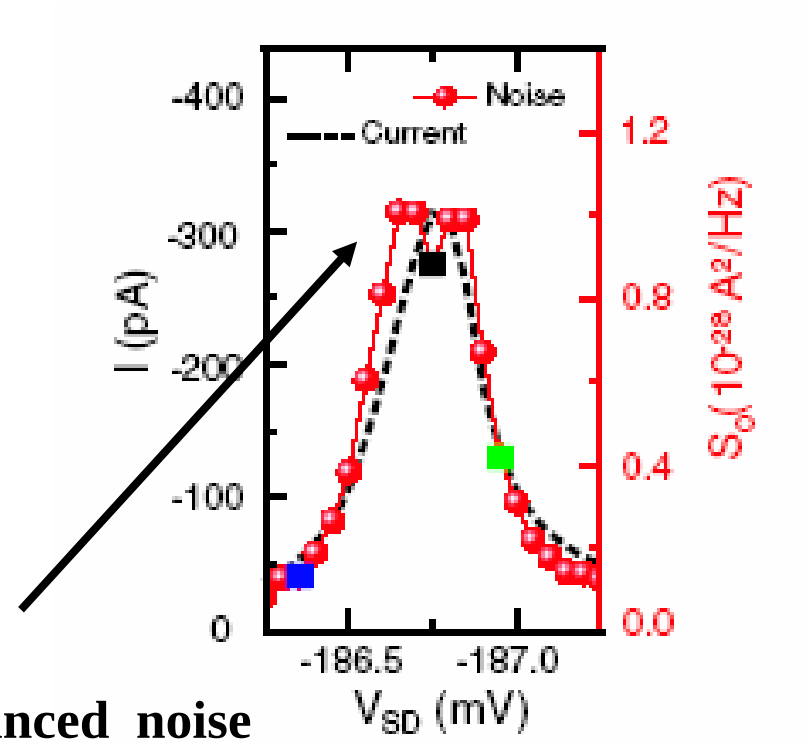
Phys. Rev. B 66,161303 (2002)

Phys. Rev. B 69, 113316 (2004)

Shot Noise in Coupled Quantum Dots



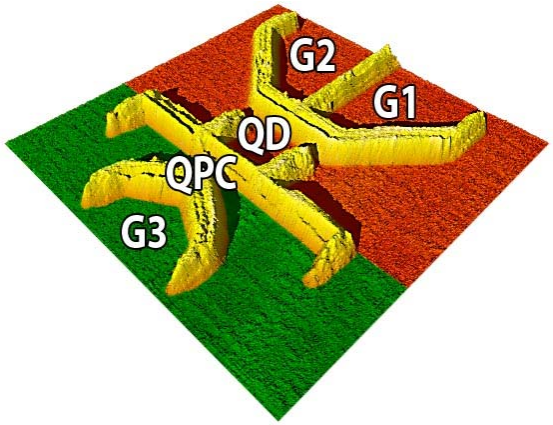


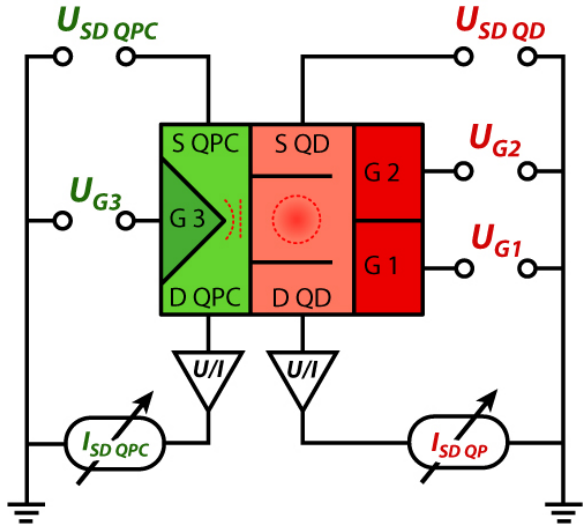


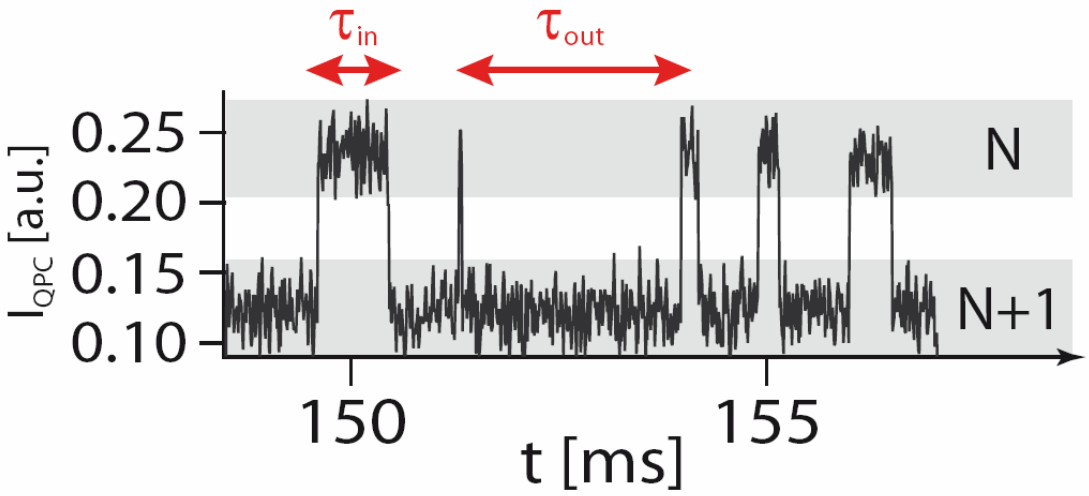
enhanced noise
due to ??
coupling effects, interactions, …

Phys. Rev. Lett. 96, 246803 (2006)

Real Time Detection of Single Electrons







direct analysis of tunneling properties

tunneling times, distribution,
counting statistics
Fano factor, …

Phys. Rev. B 72, 193302 (2005)
Phys. Rev. B 72, 233402 (2005)

N. Maire

D. Tutuc

Dr. F. Hohls

A. Hadzibrahimovic

O. Agafonov

P. Barthold

M. Rogge

N. Ubbelohde

T. Ridder

Q. Ahmad

F. Luque

C. Fricke

A. Mühle

H. Schmidt