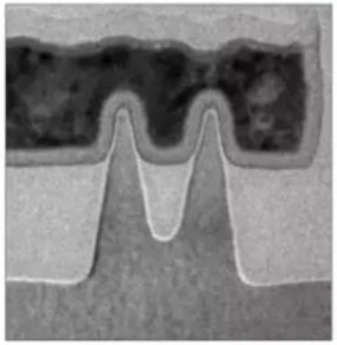
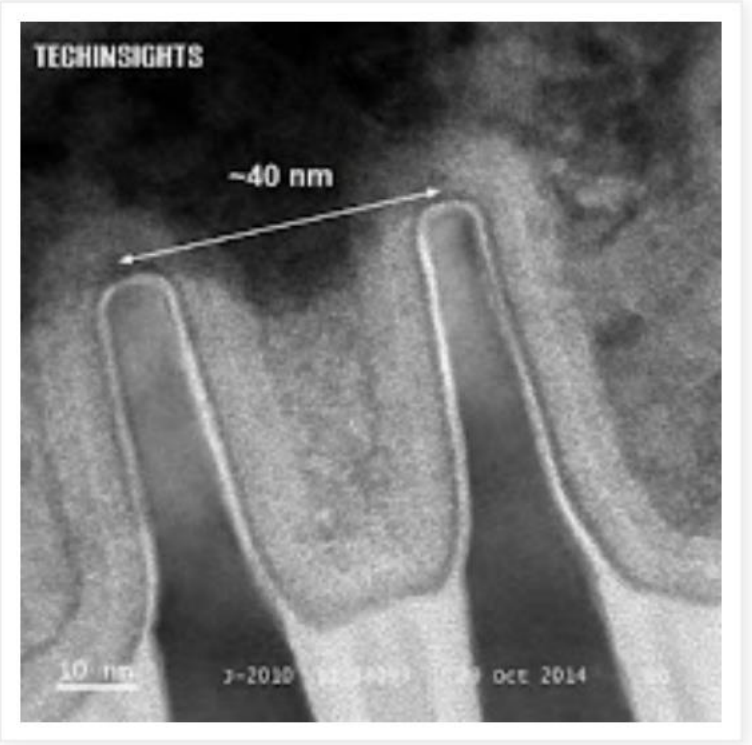
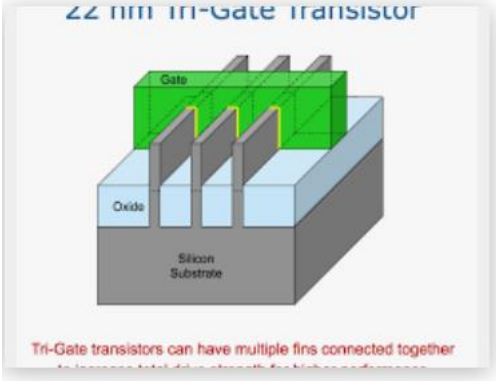


22 nm 1st Generation
Tri-gate Transistor

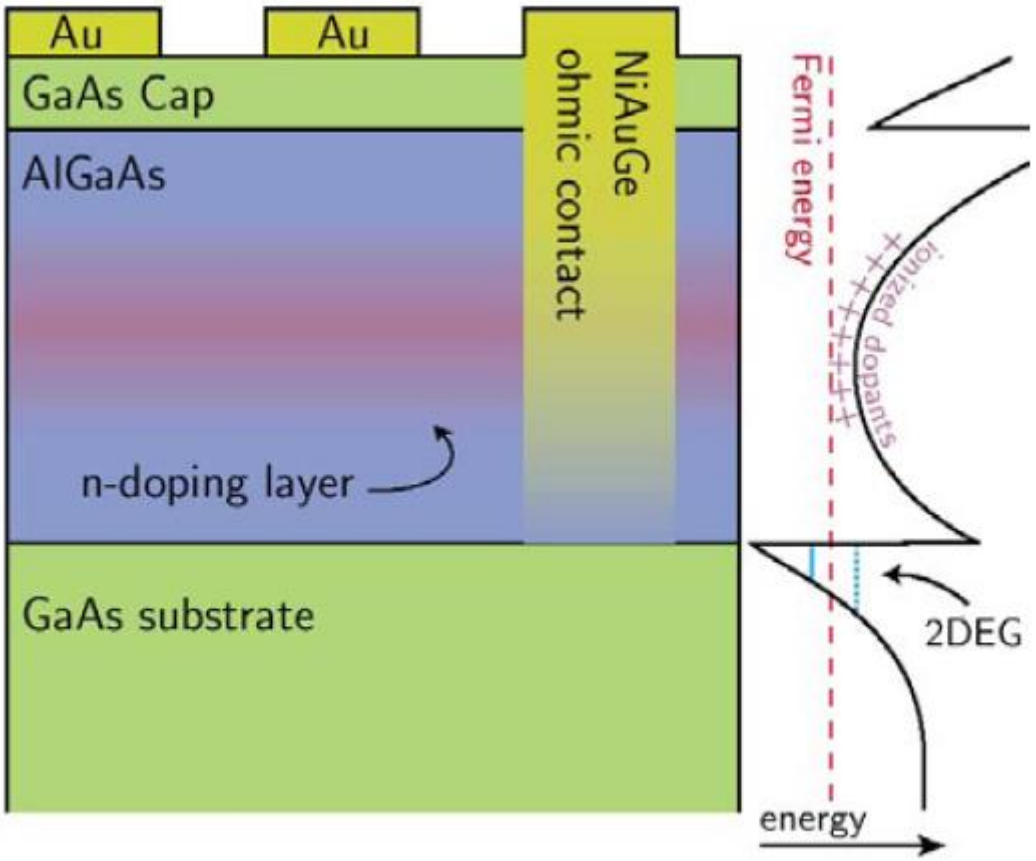


[nanoscale views: What do IBM's 7 nm transistors mean?]

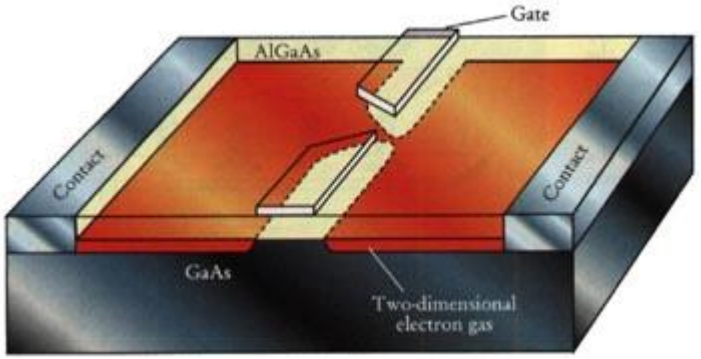


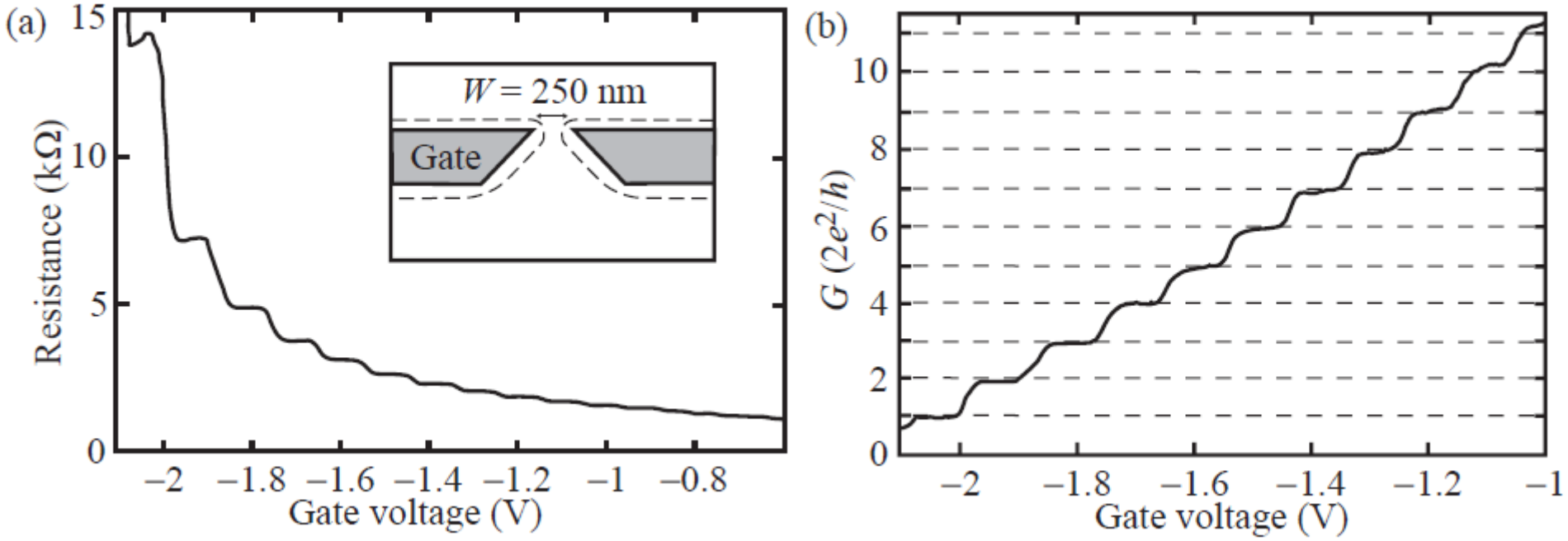
Photolitography : 193 nm –
10nm,14nm tehnologija
13.5 nm – extreme ultraviolet 2nm

2DEG



doktorat Sara Cronewett

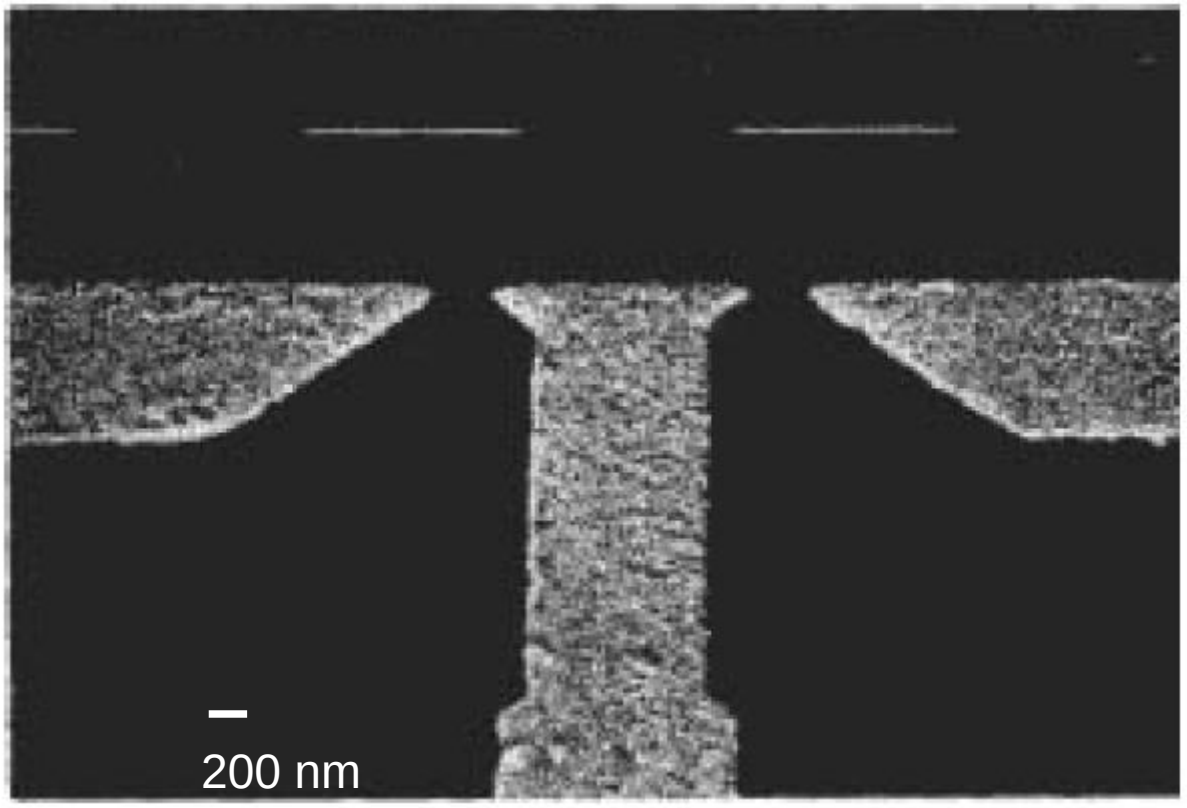

Gate
AlGaAs
Contact
Contact
GaAs
Two-dimensional
electron gas



van Wees et al, 1988

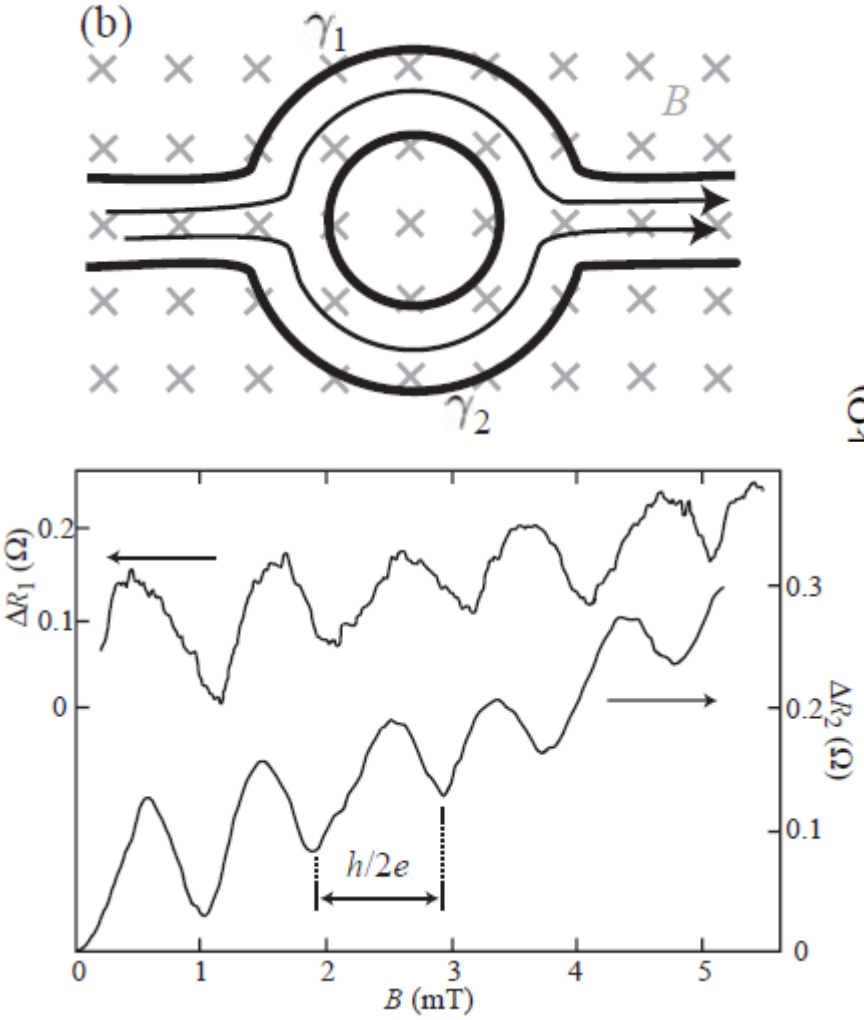
QPC (kvantni točkovni stik)

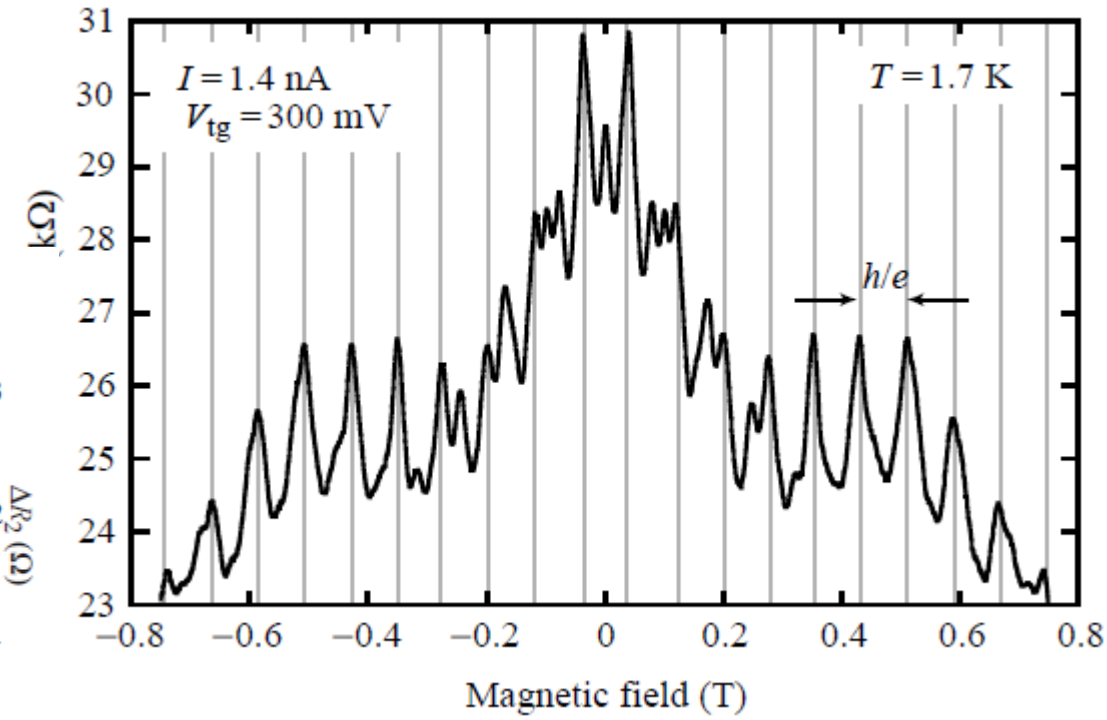
- par kvantnih točkovnih stikov



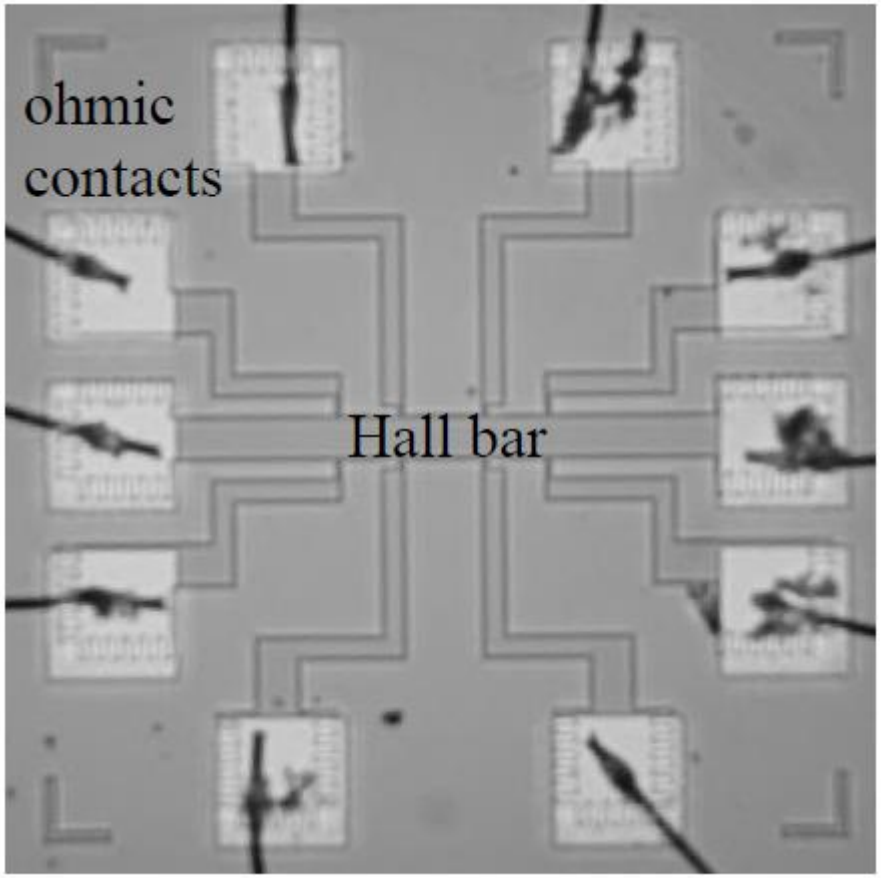
Aharonov-Bohm

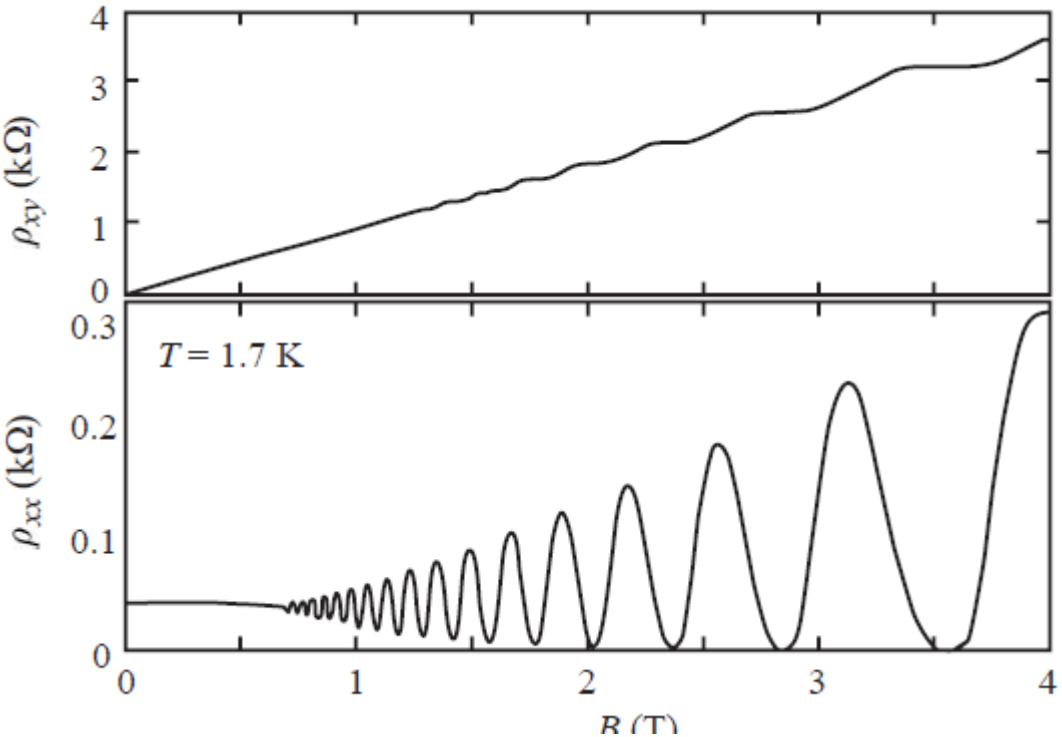
meritve 1980-1985





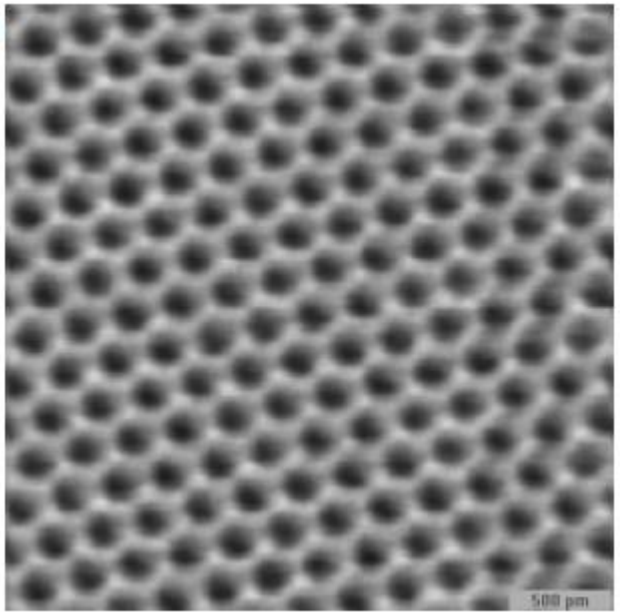
Meritev Hallove napetosti

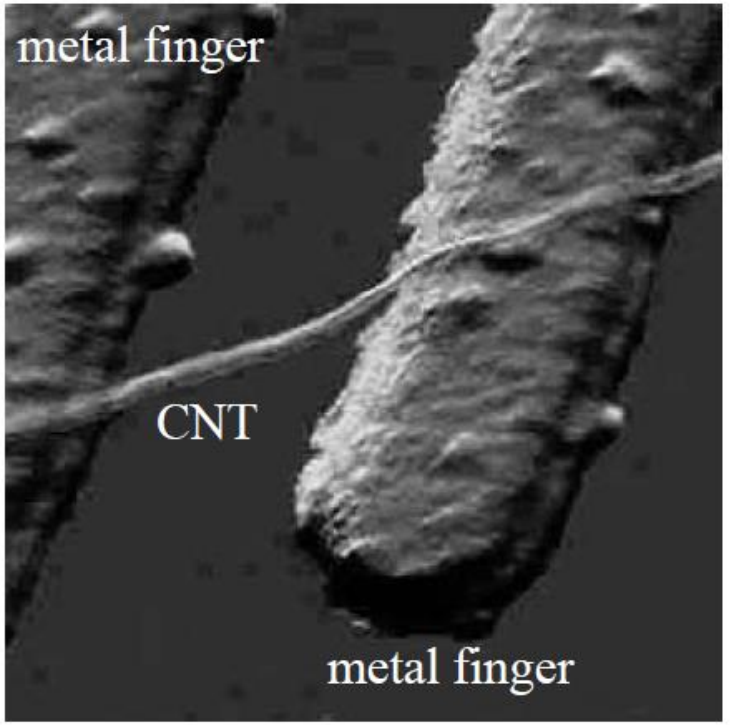




Grafen

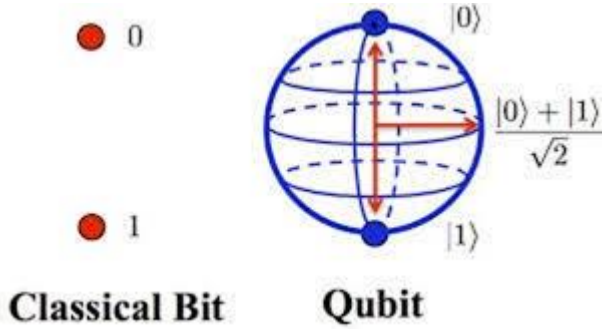
- grafen 2d snov (odkrito 2004)



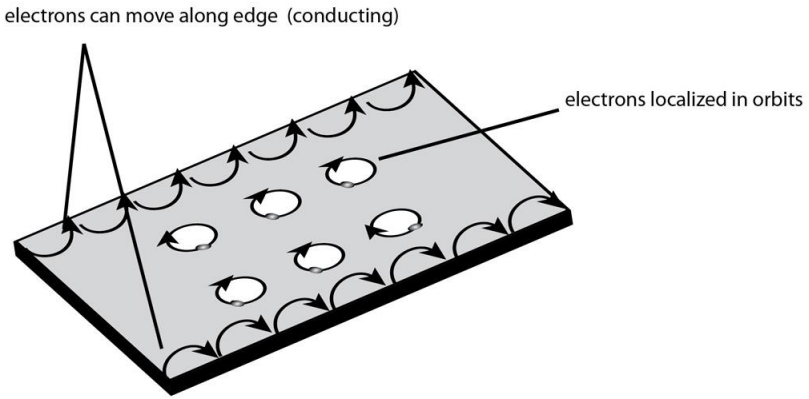


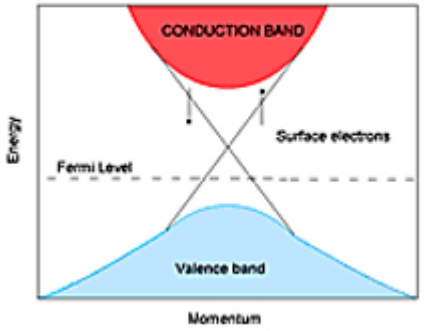
- nanocevke

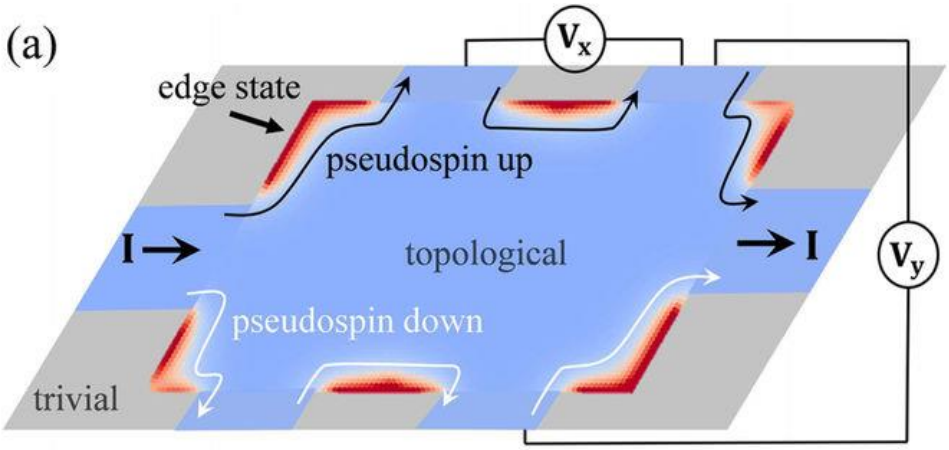
Kvantno računanje

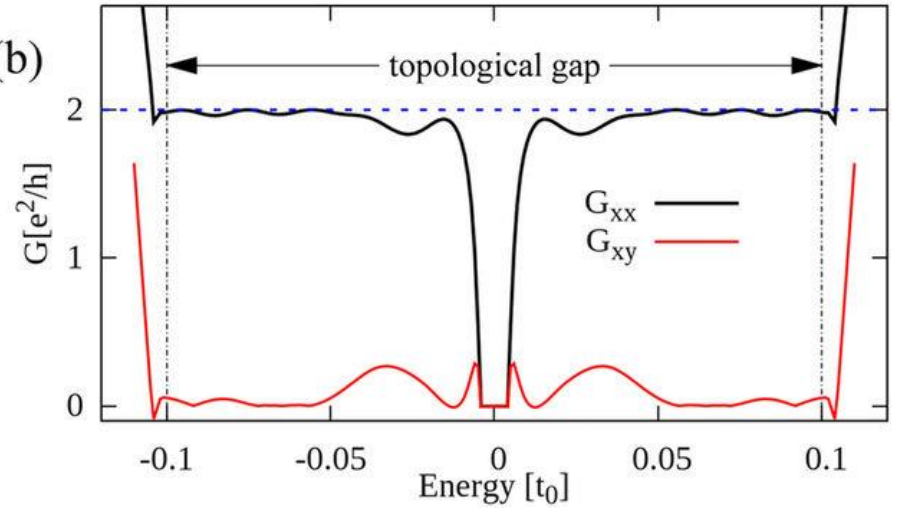


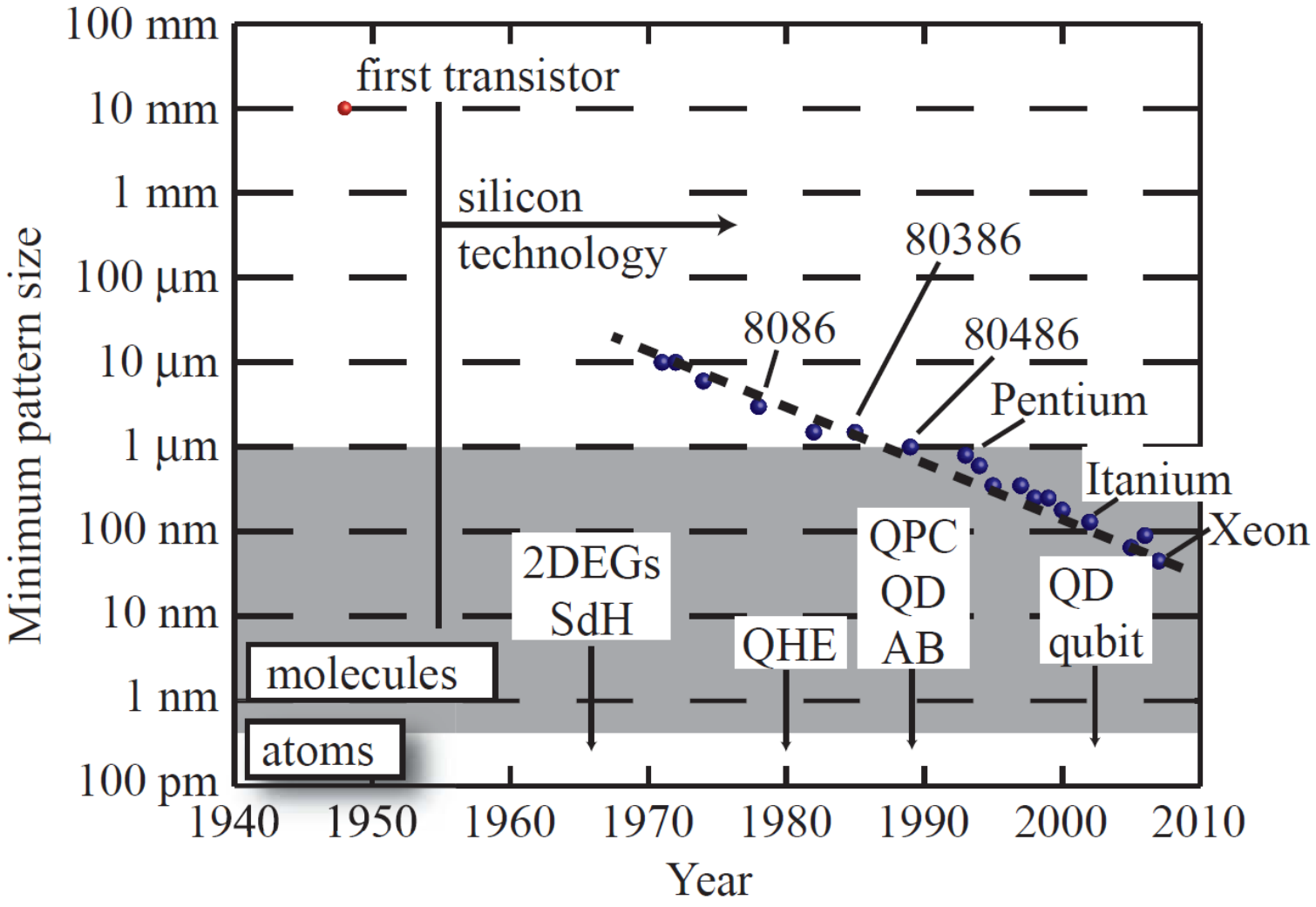
Robna stanja top. izolatorjev (2005)







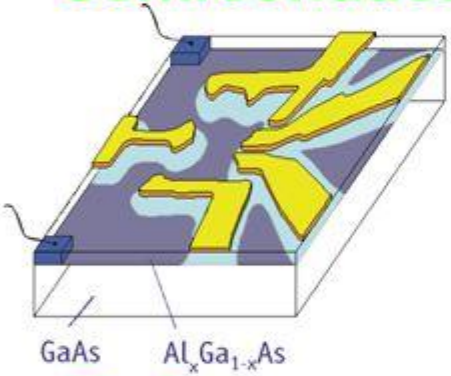


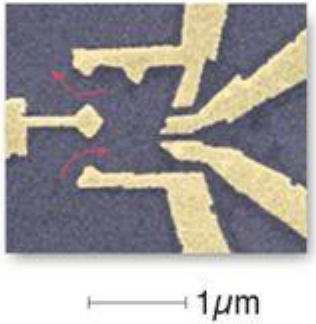

100 mm
10 mm
1 mm
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
100 pm
Minimum pattern size
1940
1950
1960
1970
1980
1990
2000
2010
Year
first transistor
silicon
technology
8086
80386
80486
Pentium
Itanium
Xeon
2DEGs
SdH
QHE
QPC
QD
AB
QD
qubit
molecules
atoms

Quantum dots

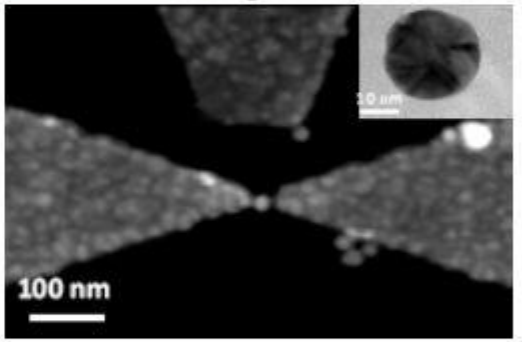
- "**0D**" systems:
  - Artificial atoms
  - Single electron transistors

- **Realizations**:
  - **Semiconductor** heterostructures

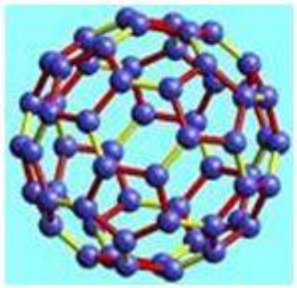


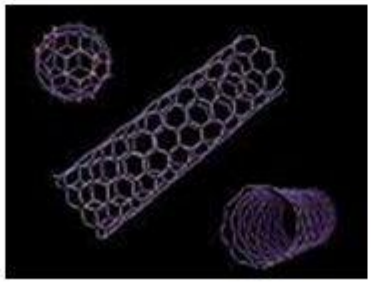


  - **Metallic** grains

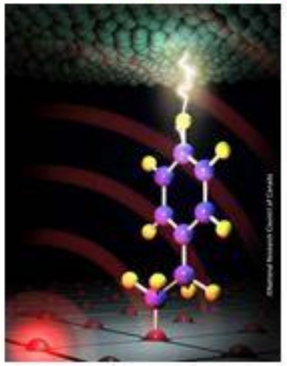


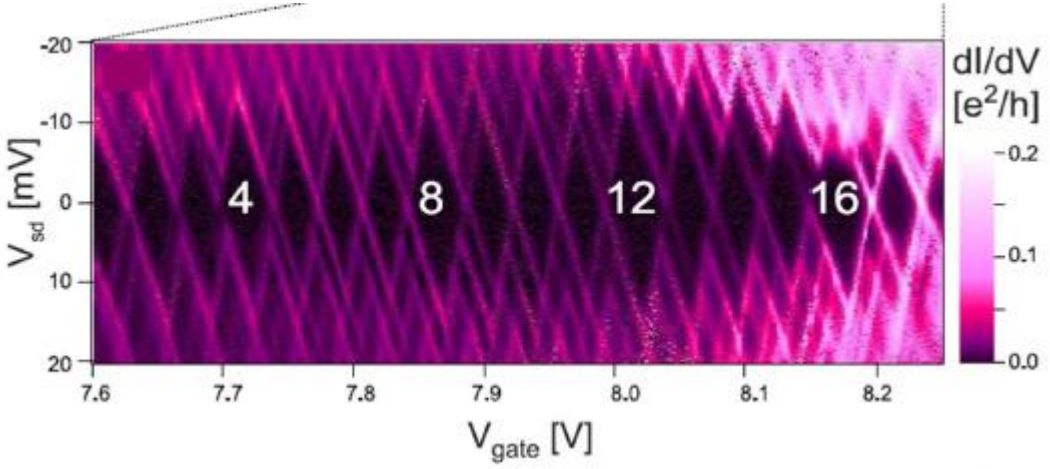
  - **Carbon** buckyballs & nanotubes

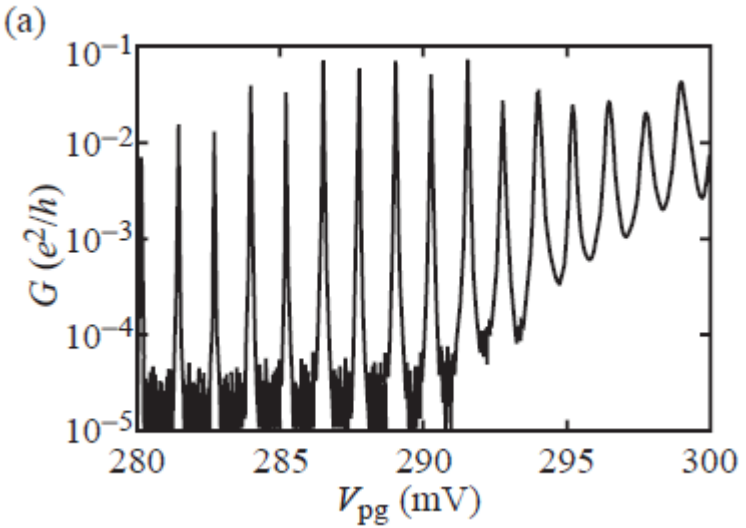


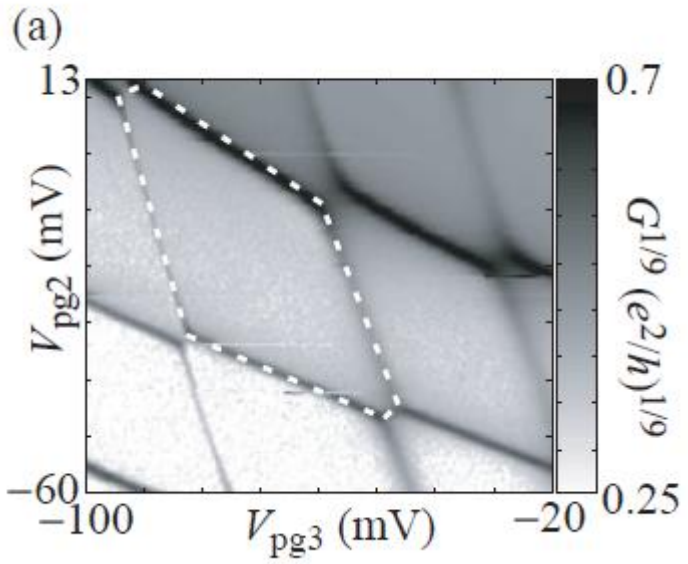


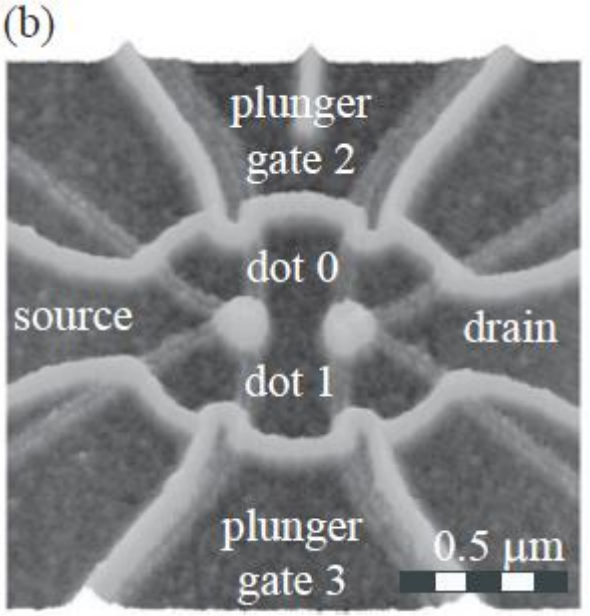
  - Single **molecules**

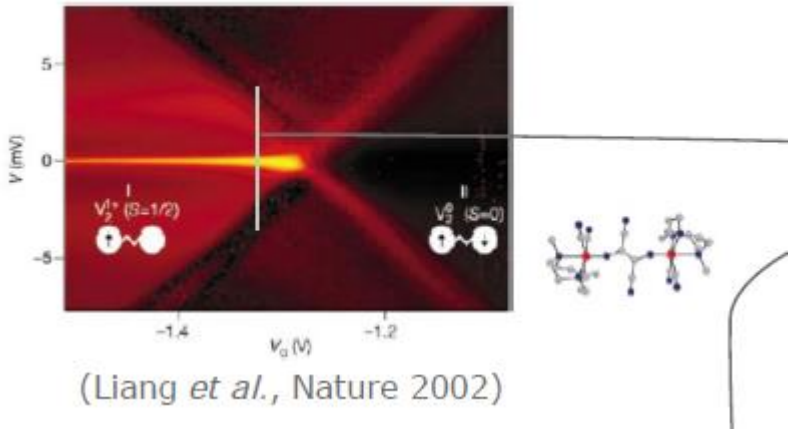



-20
-10
0
10
20
V_sd [mV]
4
8
12
16
7.6
7.7
7.8
7.9
8.0
8.1
8.2
V_gate [V]
dI/dV
[e²/h]
0.2
0.1
0.0

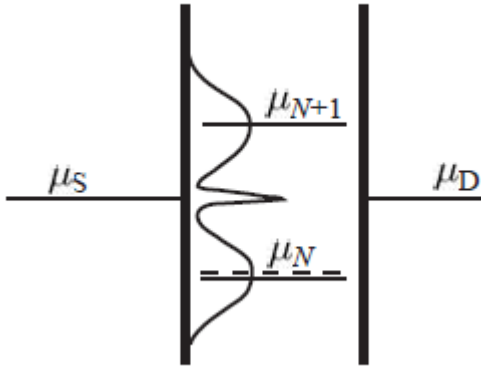

(a)
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
G (e²/h)
280
285
290
295
300
V_pg (mV)

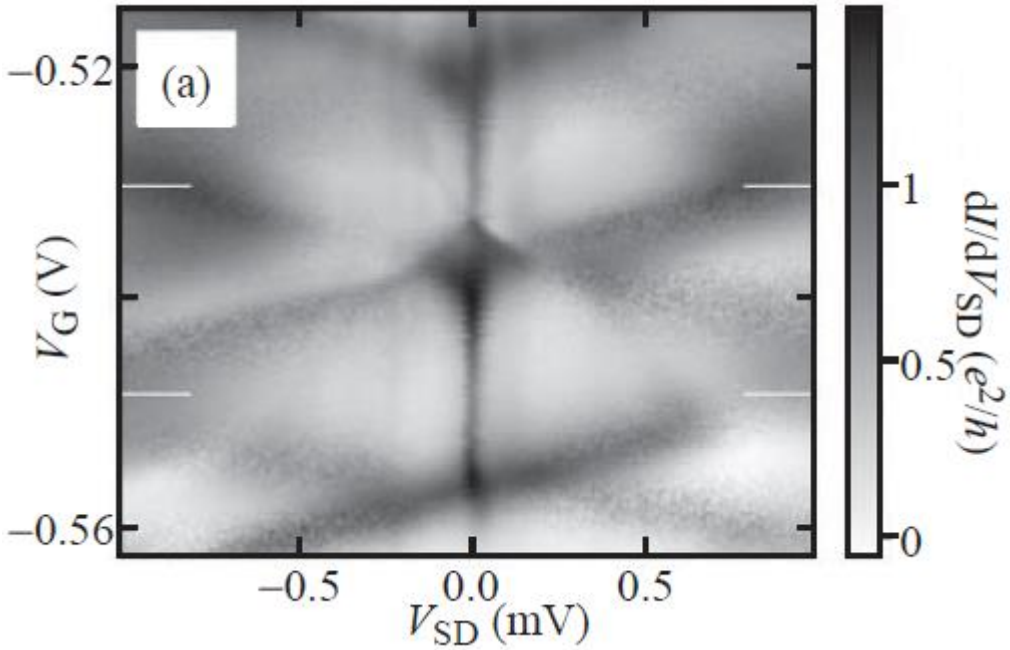

(a)
13
−60
−100
−20
V_{pg2} (mV)
V_{pg3} (mV)
0.7
0.25
$G^{1/9}$ $(e^2/h)^{1/9}$

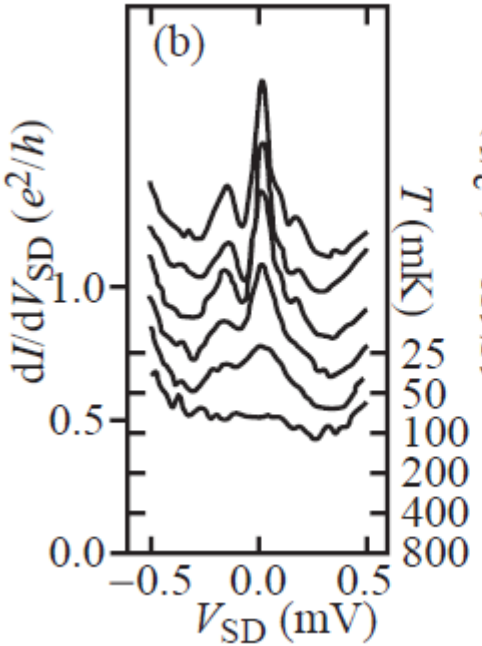

(b)
plunger
gate 2
dot 0
source
drain
dot 1
plunger
gate 3
0.5 μm

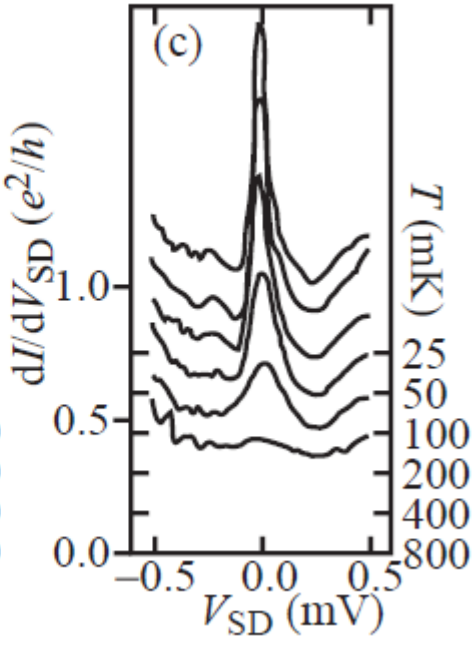


(Liang *et al.*, Nature 2002)



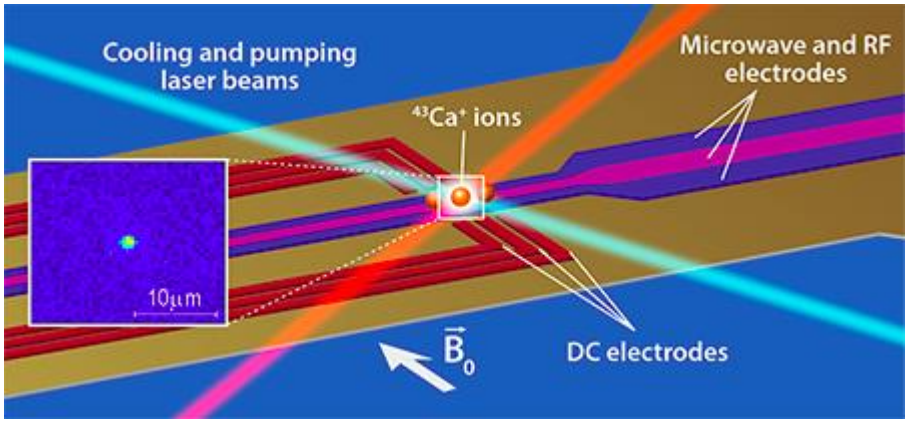




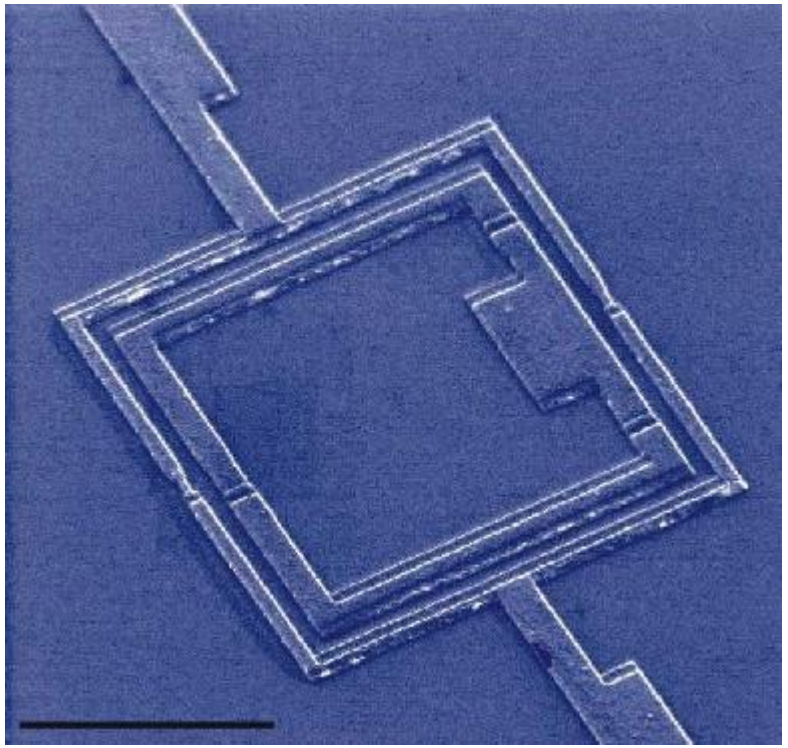


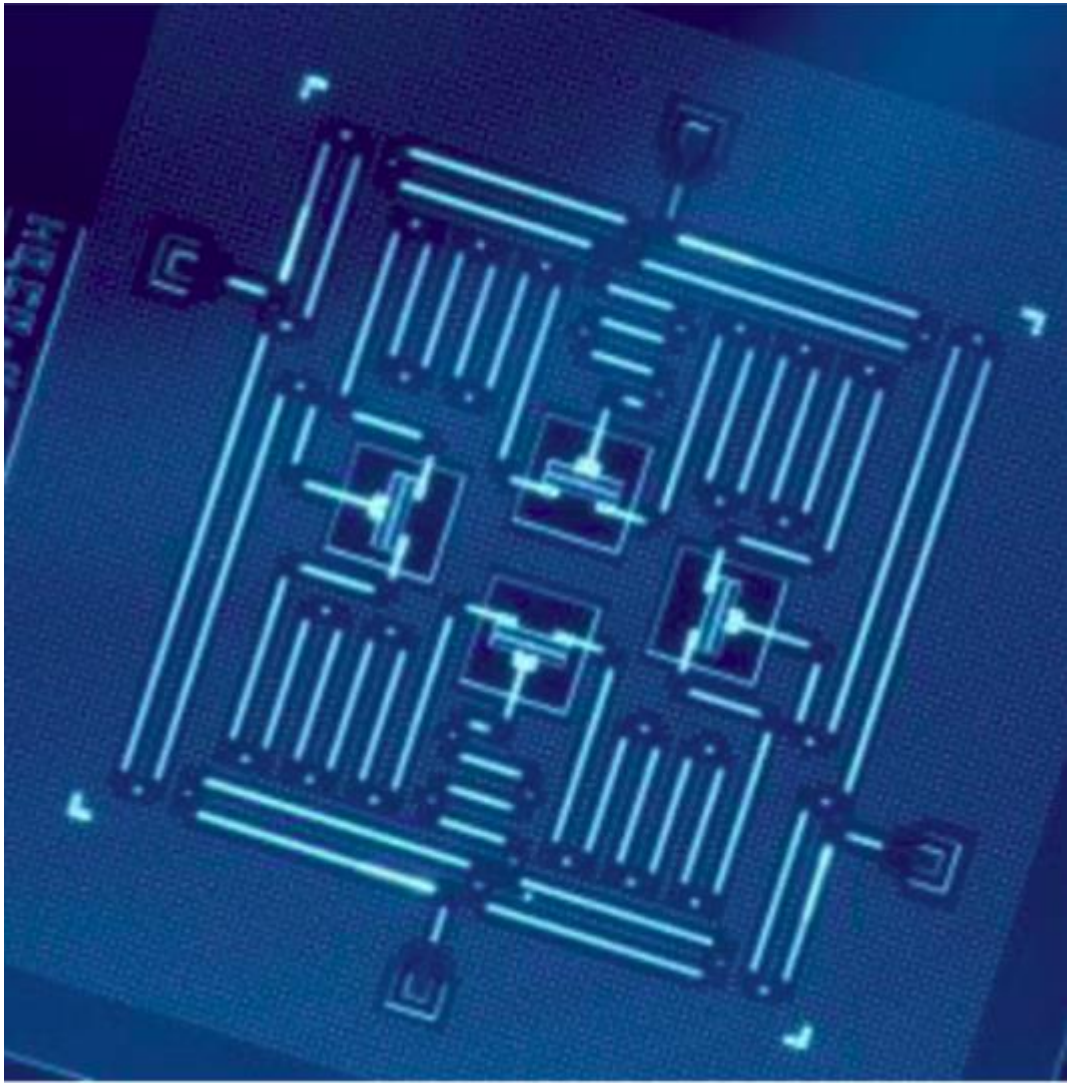
Trapped Ion

(a)
Laser
Laser


Cooling and pumping laser beams
$^{43}Ca^{+}$ ions
Microwave and RF electrodes
10μm
$\vec{B}_0$
DC electrodes

Josephsonovi kubiti

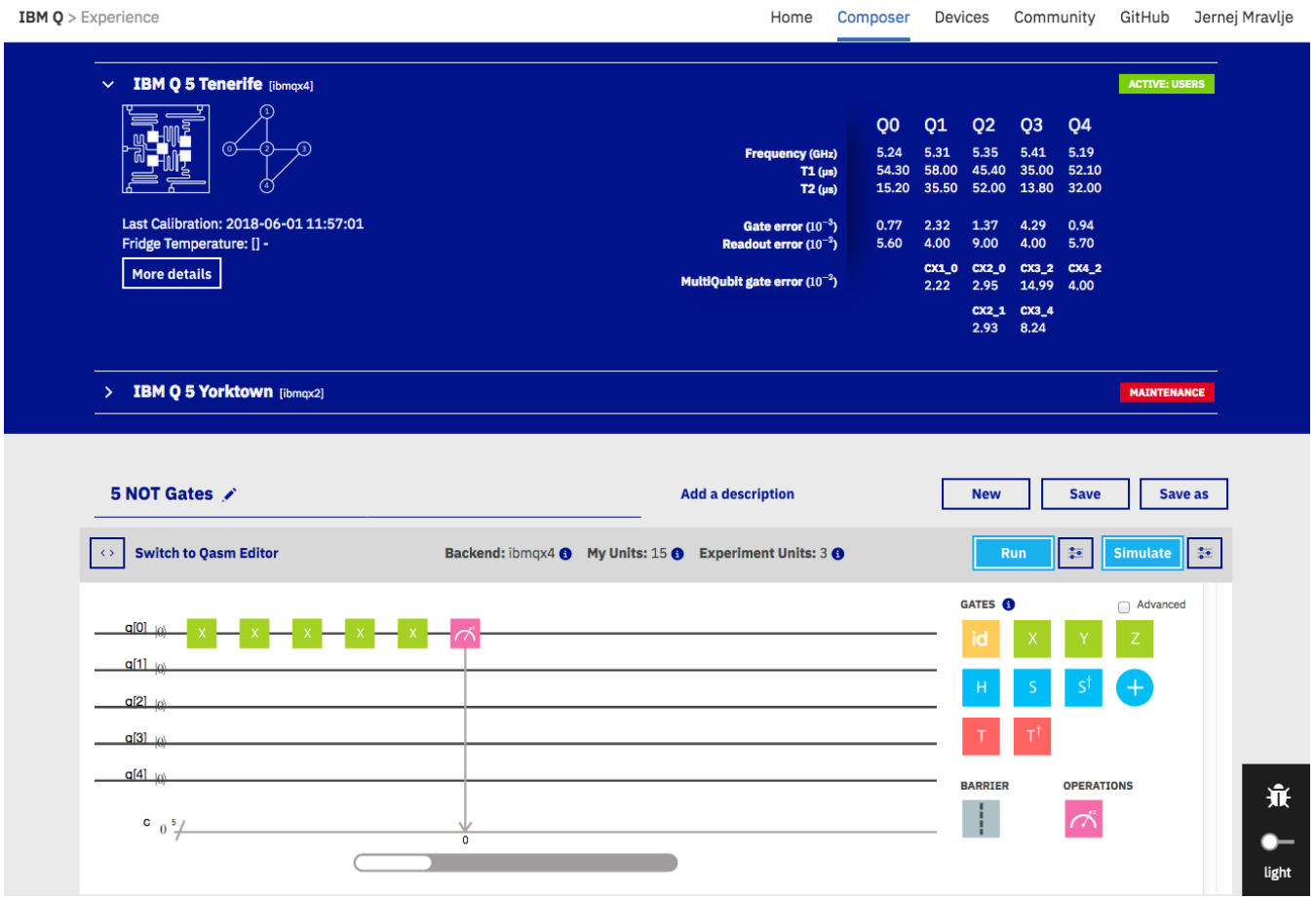




Ali so kvantni računalniki računalniki prihodnosti?

- Josephsonovi kvantni račun. so sedanjost!
- Aktivno tekmovanje med velikani:
  - IBM Quantum Experience (online platforma, odprta! 5 kubit 2016, 20 kubit 2017), 50 kubitov (konec 2017)
  - Google Bristlecone: 72 Josephsonovih kubitov (Marec 18)
  - Microsoft : topological quantum computing, Majoranini kubiti

IBM Quantum Experience

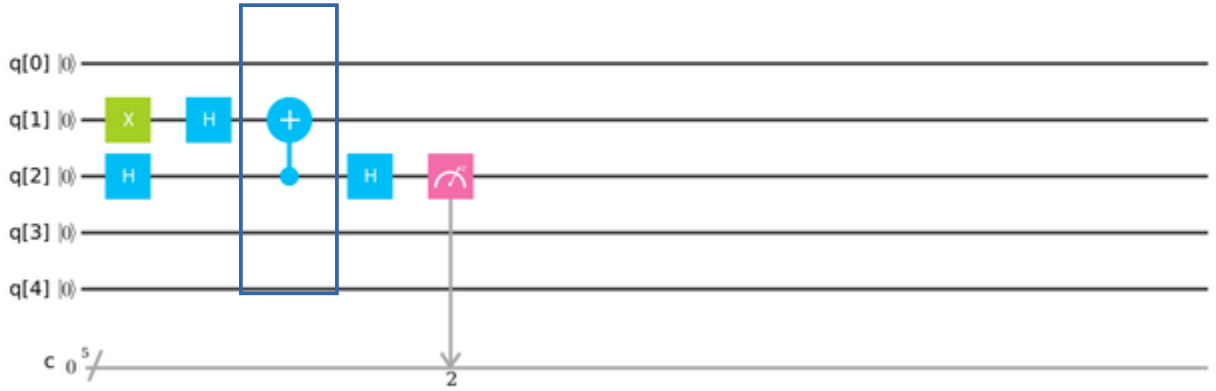


Device: ibmqx4

Quantum State: Computation Basis

Download CSV

Quantum Circuit

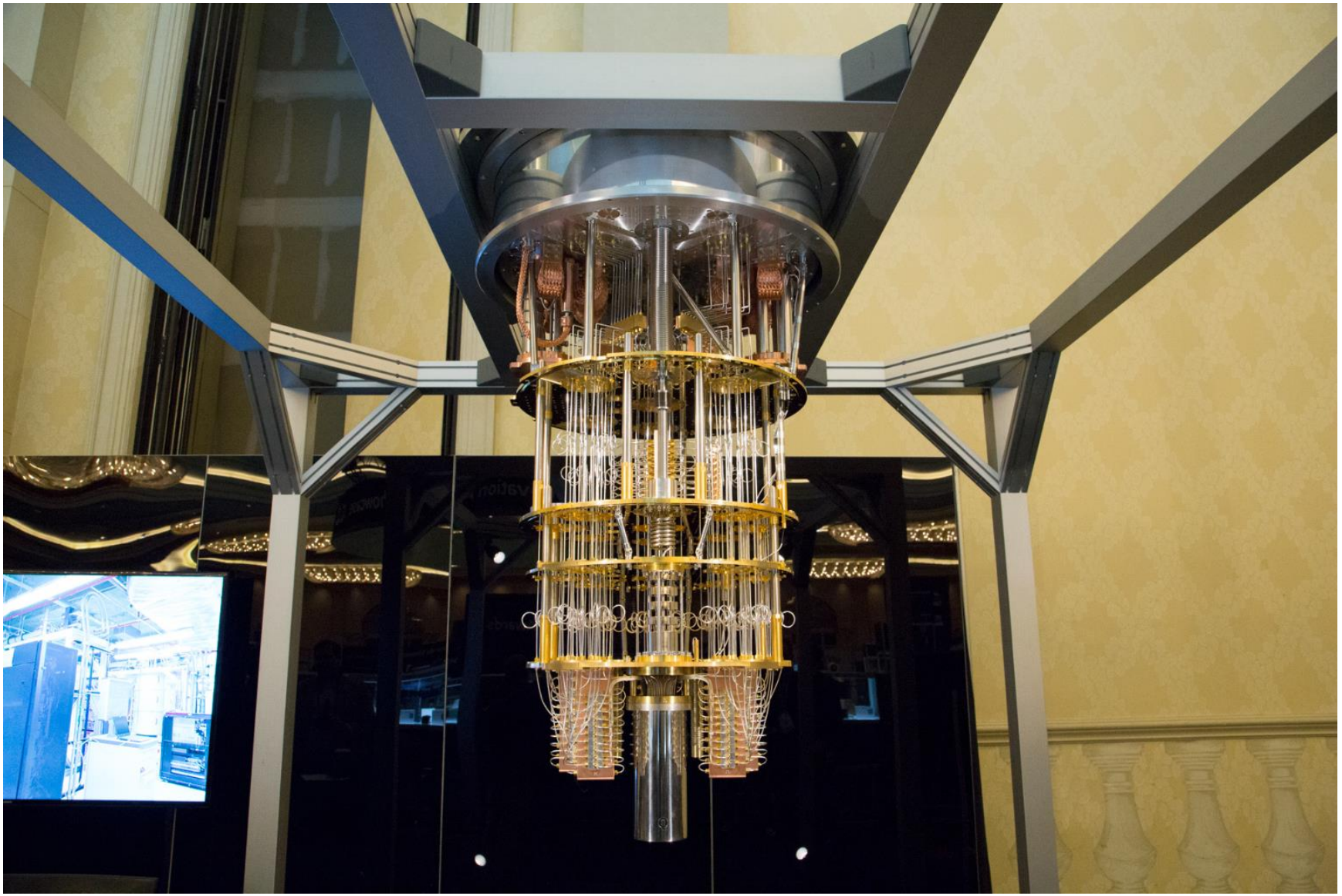


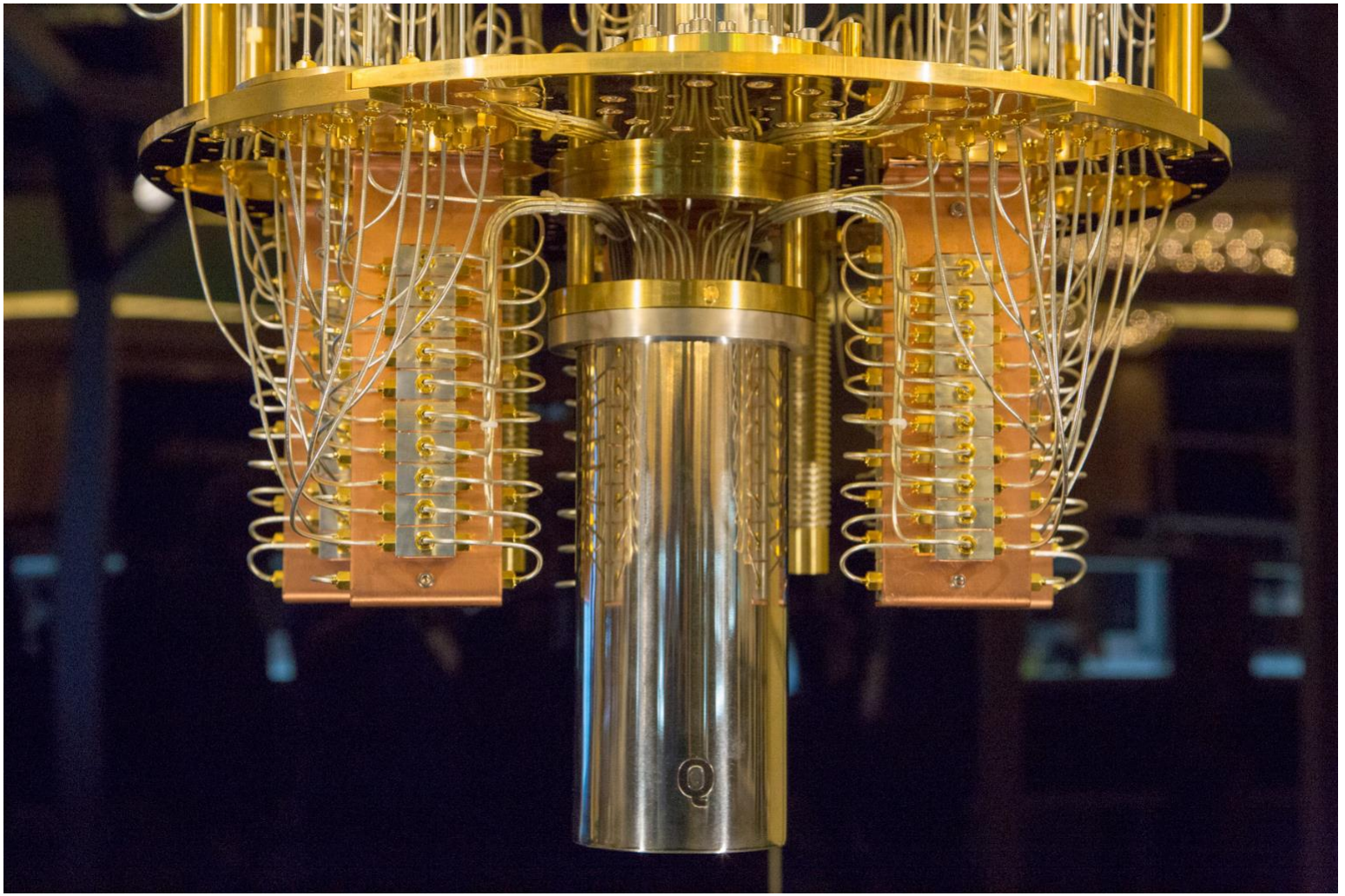
OPENQASM 2.0

```
1  include "qelib1.inc";
2
3  qreg q[5];
4  creg c[5];
5
6  x q[1];
7  h q[2];
8  h q[1];
```

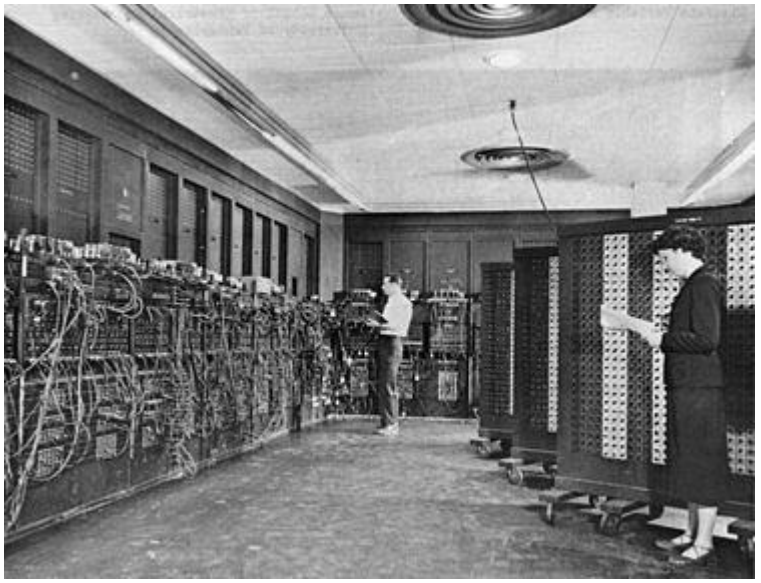
Open in Composer

IBM Nov 2017 50kubitov

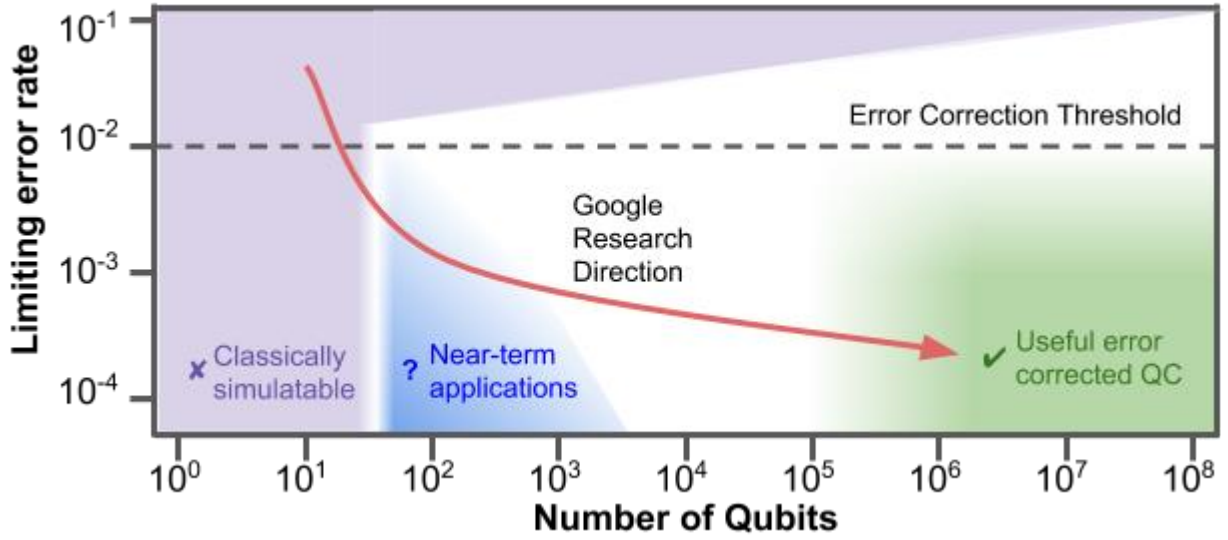




ENIAC 1945



Google Bristlecone 72 Josephsonovih kubitov



Microsoft : topološki kubiti (“1 naš kubit toliko kot 1000 njihovih”)

Microsoft Quantum labs and locations

Redmond

The Quantum Architectures and Computation (QuArC) group works to make quantum computers accessible to developers by creating a software stack.

Santa Barbara

Station Q at the University of California, Santa Barbara is working to understand how topological phases of matter can be used in quantum architecture.

Delft

The team in Delft is finding ways to suppress quantum decoherence through topological protection through a quantum-gate operation.

Copenhagen

The Center for Quantum Devices looks for ways to control and study the properties of Majorana fermions.

Sydney

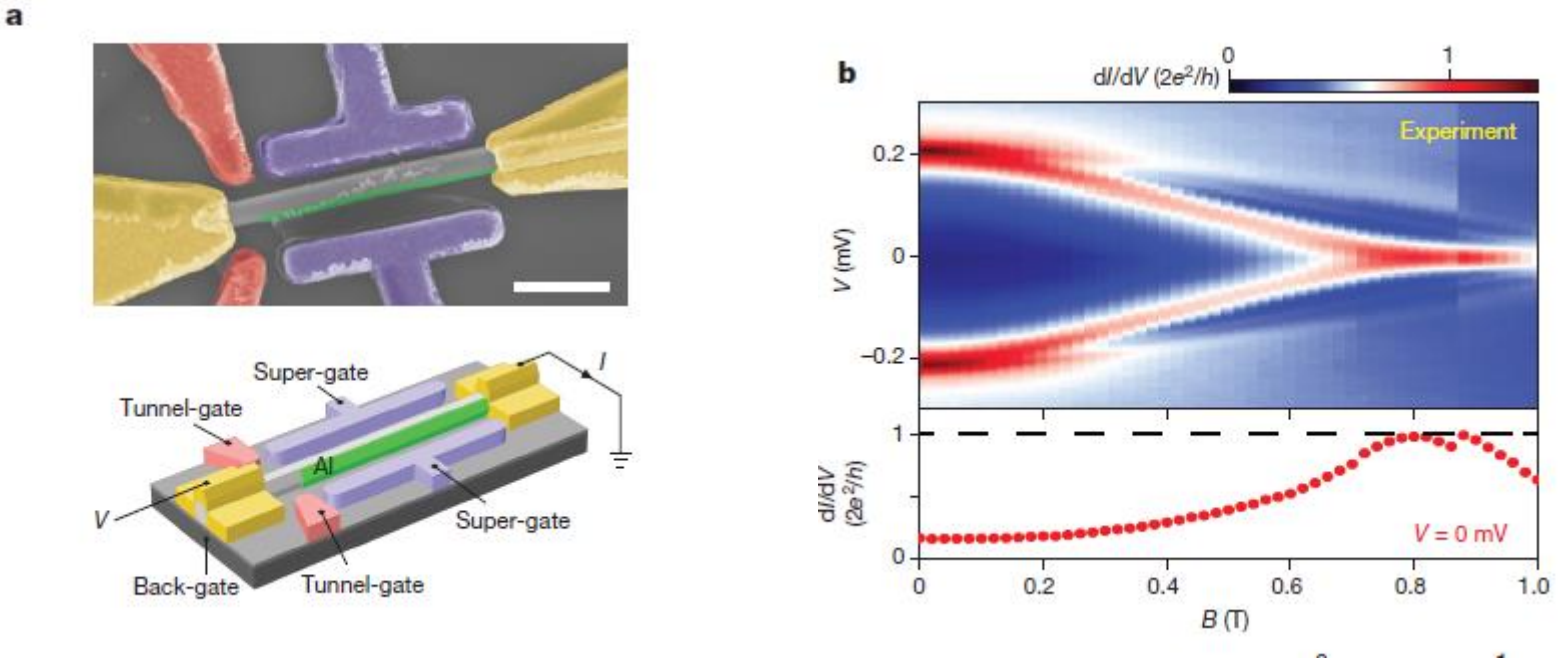
The team in Sydney is exploring the engineering challenges for reading out and controlling qubits in scaled-up architectures.

Lafayette

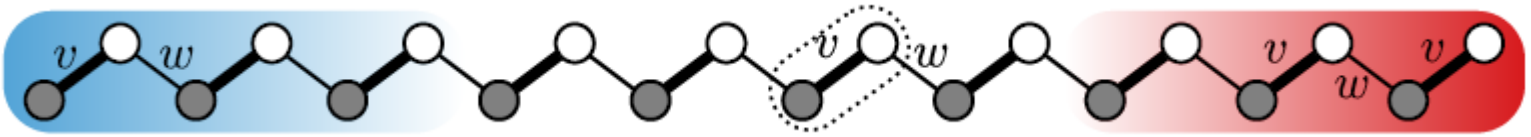
Station Q at Purdue University focuses on the quantum-mechanical properties of electrons in ultra-high purity III-V semiconductor devices.

Quantized Majorana conductance

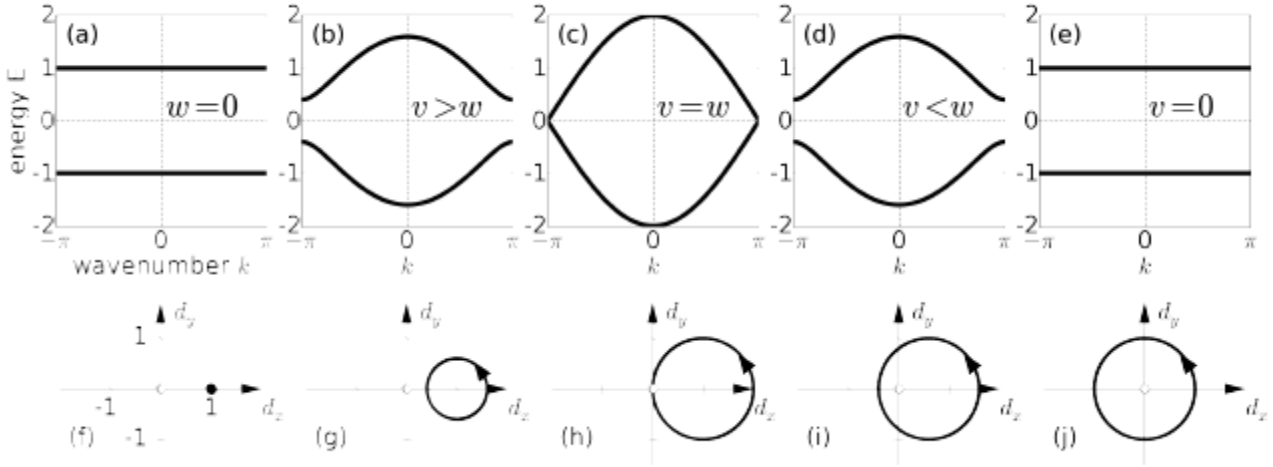
InSb nanozicka

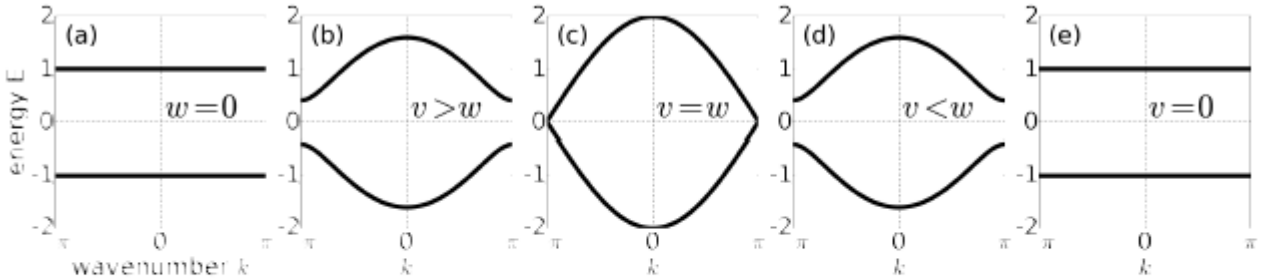


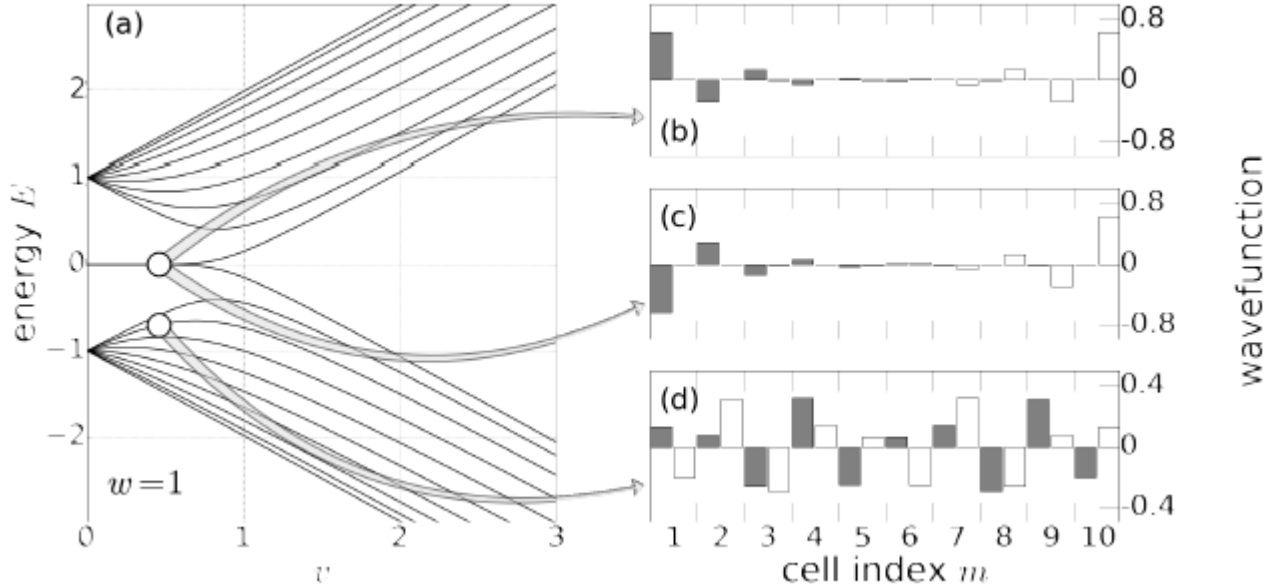
2. Mourik, V. *et al.* Signatures of Majorana fermions in hybrid superconductor-semiconductor nanowire devices. *Science* **336**, 1003–1007 (2012).



$$\hat{H} = v \sum_{m=1}^{N} \left(|m,B\rangle \langle m,A| + h.c. \right) + w \sum_{m=1}^{N-1} \left(|m+1,A\rangle \langle m,B| + h.c. \right)$$







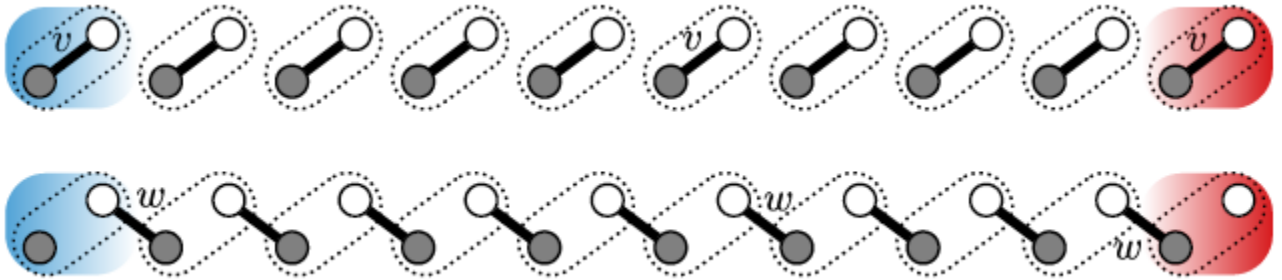
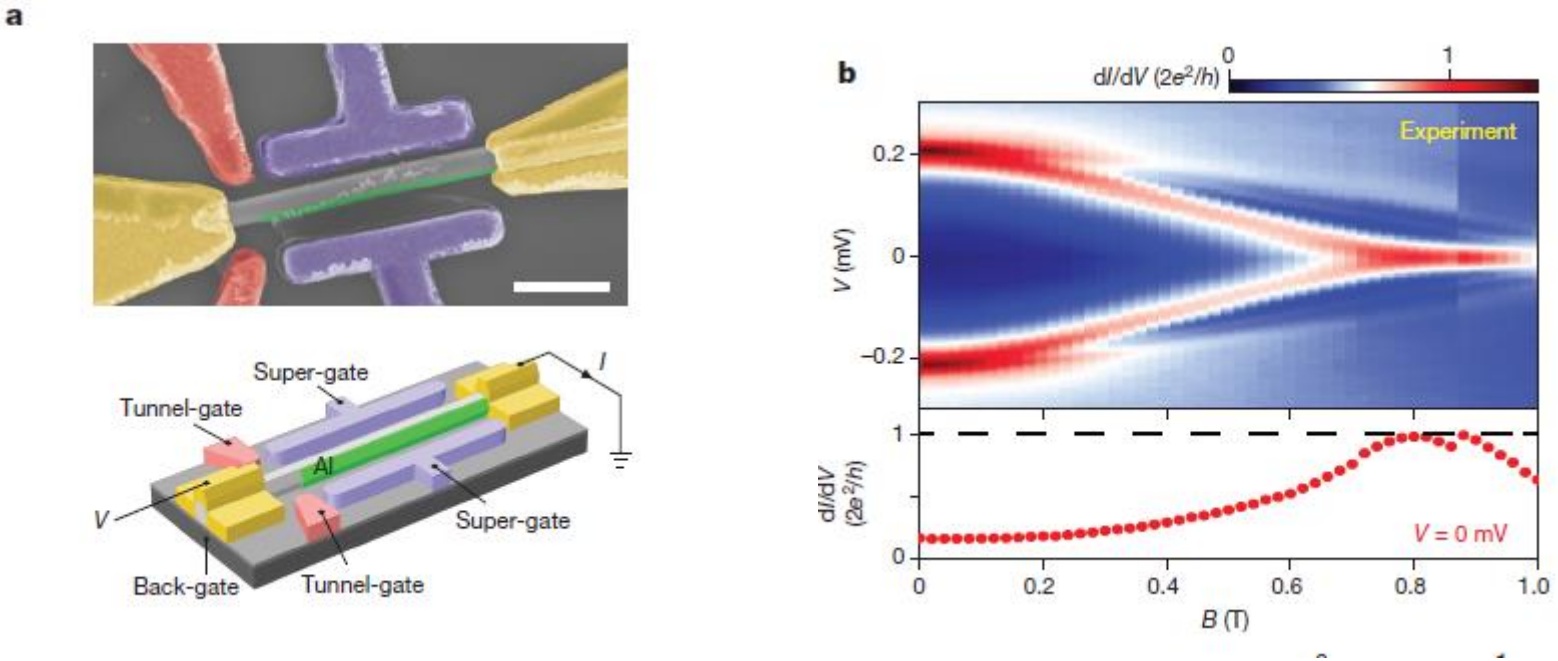


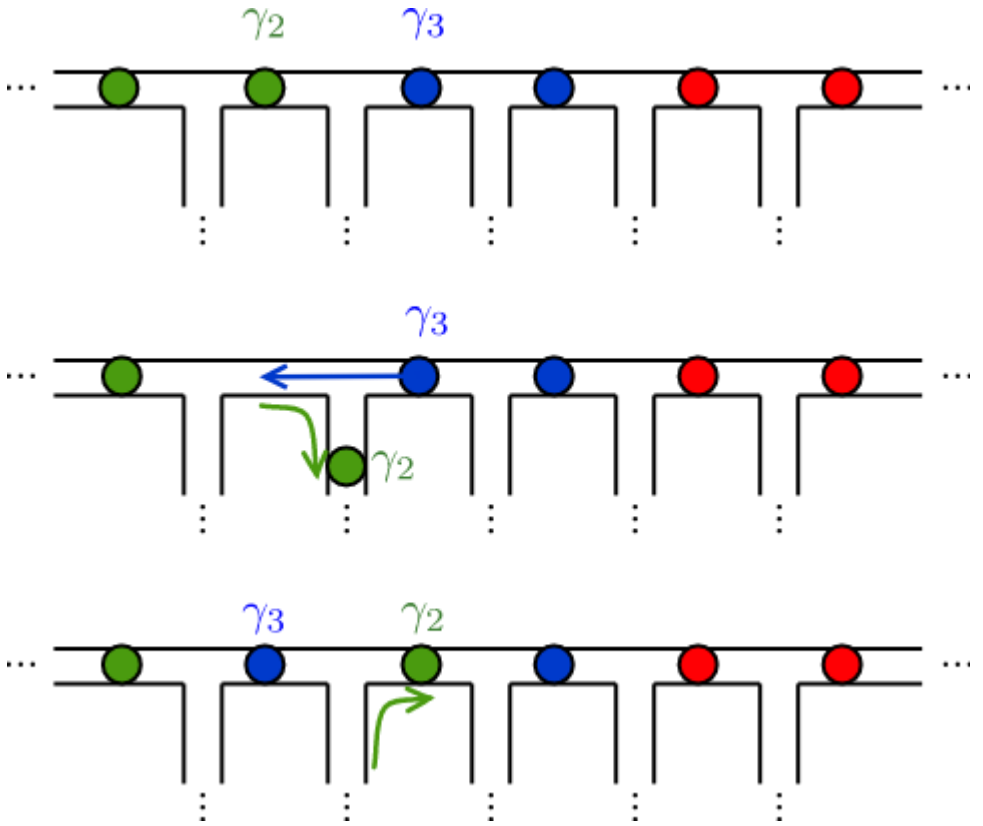
Fig. 1.3 Fully dimerized limits of the SSH model, where the chain has fallen apart to disconnected

Quantized Majorana conductance

InSb nanozicka



2. Mourik, V. *et al.* Signatures of Majorana fermions in hybrid superconductor-semiconductor nanowire devices. *Science* **336**, 1003–1007 (2012).

Eksitacije z energijo 0: degenerirano osnovno stanje

- 2^N, kjer je $N=N_{majorana}/2$. Vsak par Majoraninih fermionov kubit.