

Title: Introduction to Spin Qubits in Lateral Quantum Dots

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Abstract: A quantum computer is a computer fabricated using quantum bits (qubits) that uses the quantum properties of matter (entanglement, superposition of states, etc.). Such a computer would allow certain calculations to be done exponentially more quickly than with a classical computer. An electron in a quantum box constitutes a perfect two-level system and can thus be used as a qubit. In my talk, I will give an introduction to lateral quantum dots, their fabrication process and how they can be used as qubits.

Introduction to lateral quantum dots

Chloé BUREAU-OXTON

L. P. Kouwenhoven *et al.* 1997



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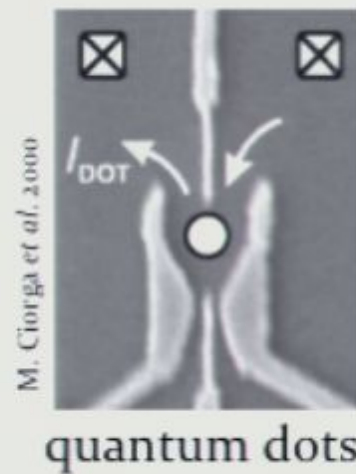
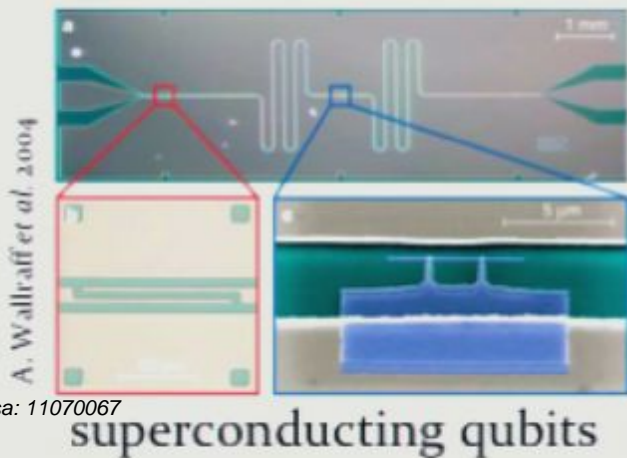
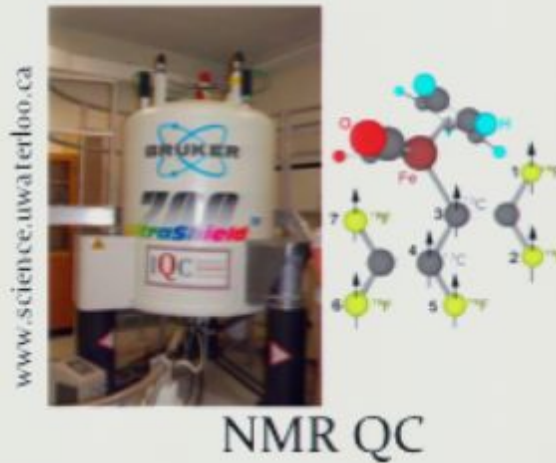
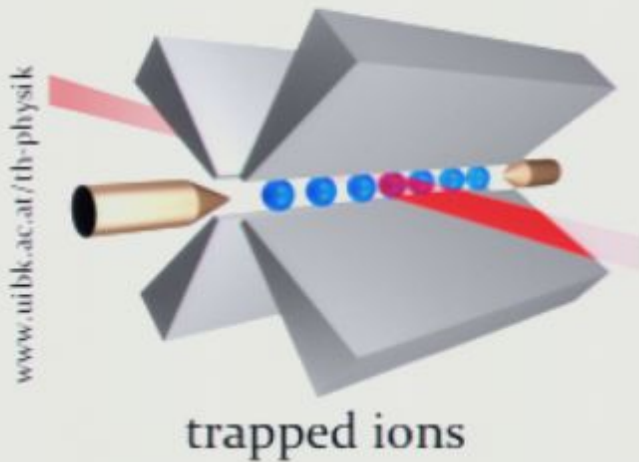
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Introduction

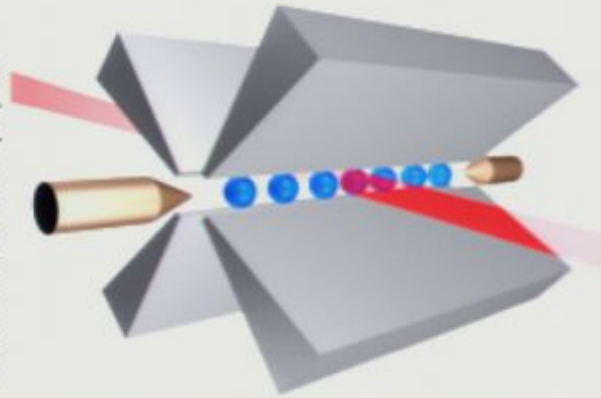
- What is a quantum dot?
- Fabrication of a lateral quantum dot.
- Role of the different gates on the structure.
- Controlling the number of electrons on the dot.
- Measuring the spin of an electron on the dot.
- Conclusion

Varieties of qubits



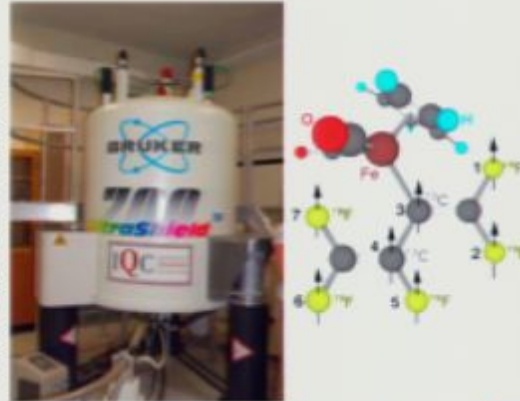
Varieties of qubits

www.uibk.ac.at/th-physik



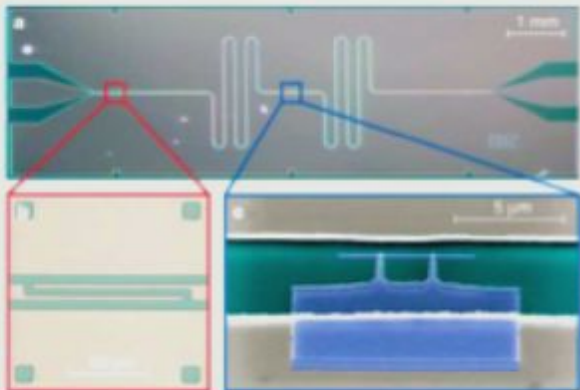
trapped ions

www.science.uwaterloo.ca



NMR QC

A. Wallraff et al. 2004



superconducting qubits

M. Giorga et al. 2000

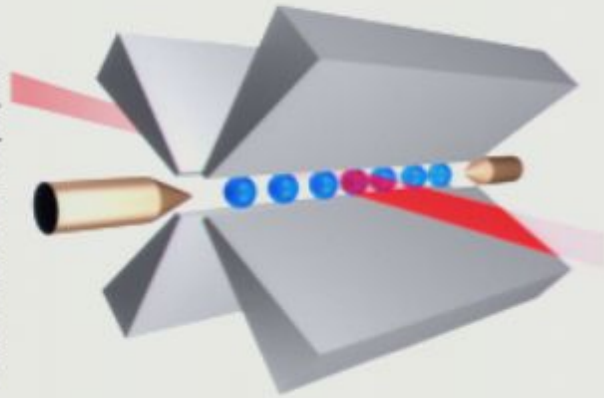


quantum dots



Varieties of qubits

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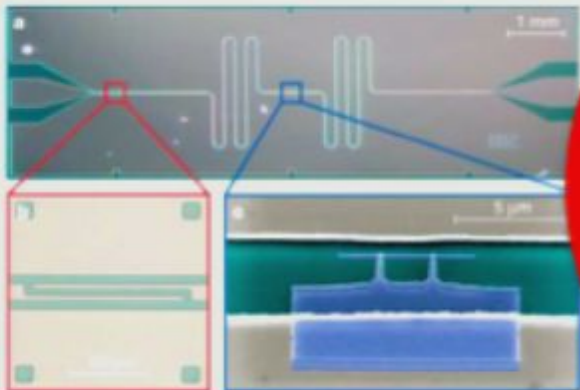


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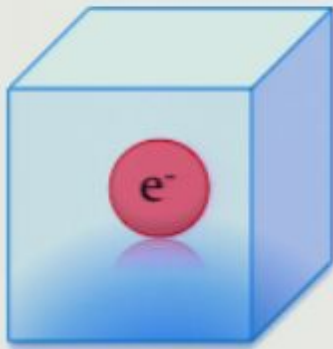


quantum dots



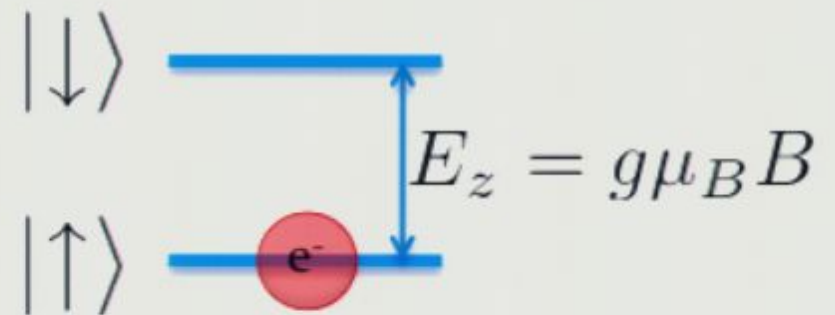
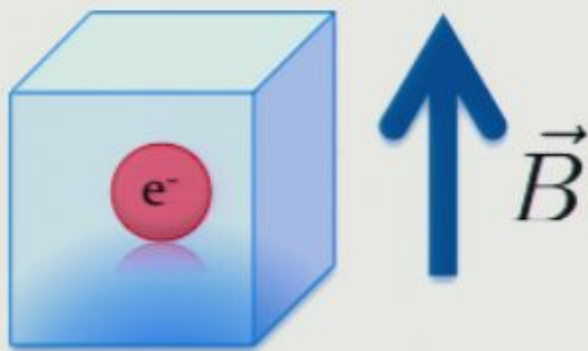
What is a quantum dot?

- Single electron confined in all three spatial directions
- Use of its spin (perfect 2-level system) as a qubit



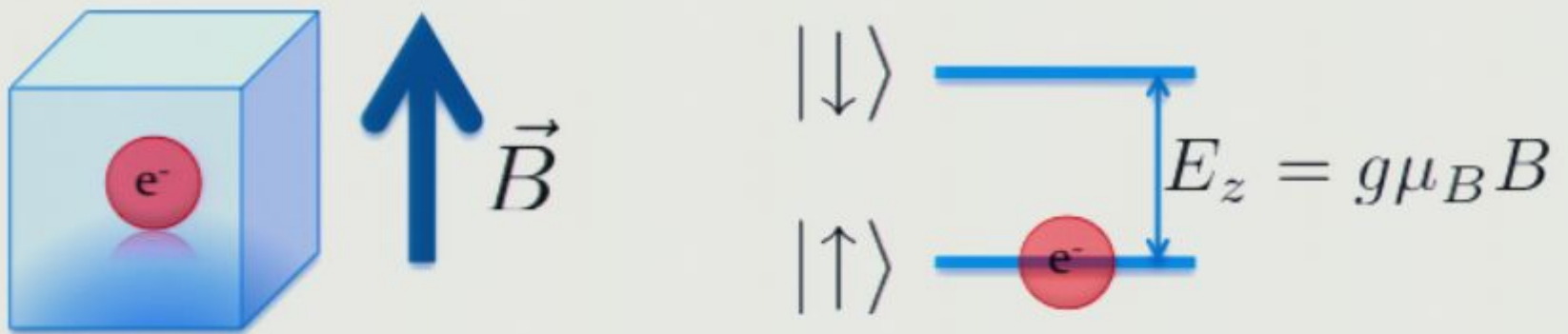
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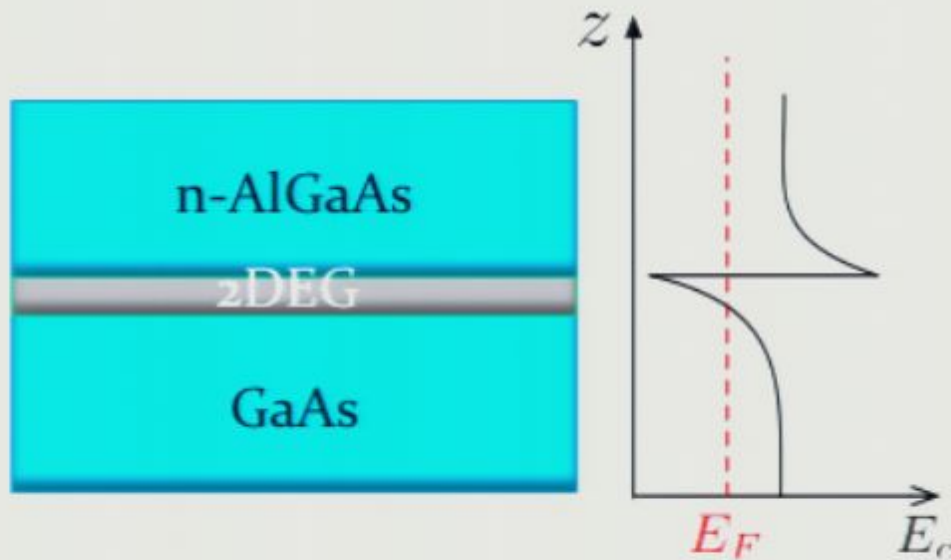
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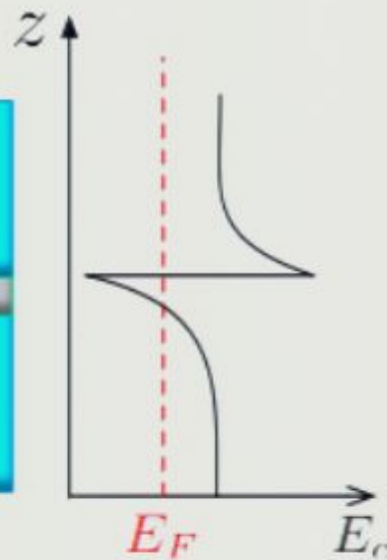
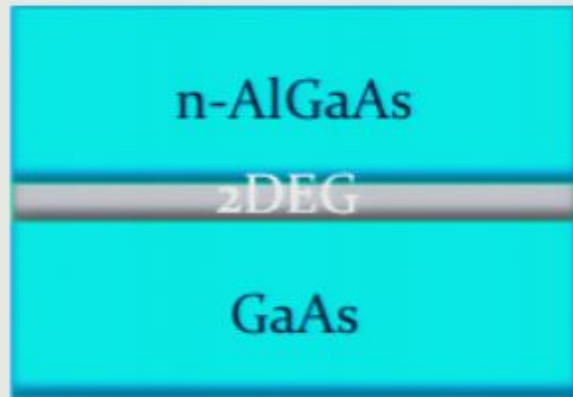
How do you spatially confine an electron?

Confinement in the z direction : Choose a proper substrate

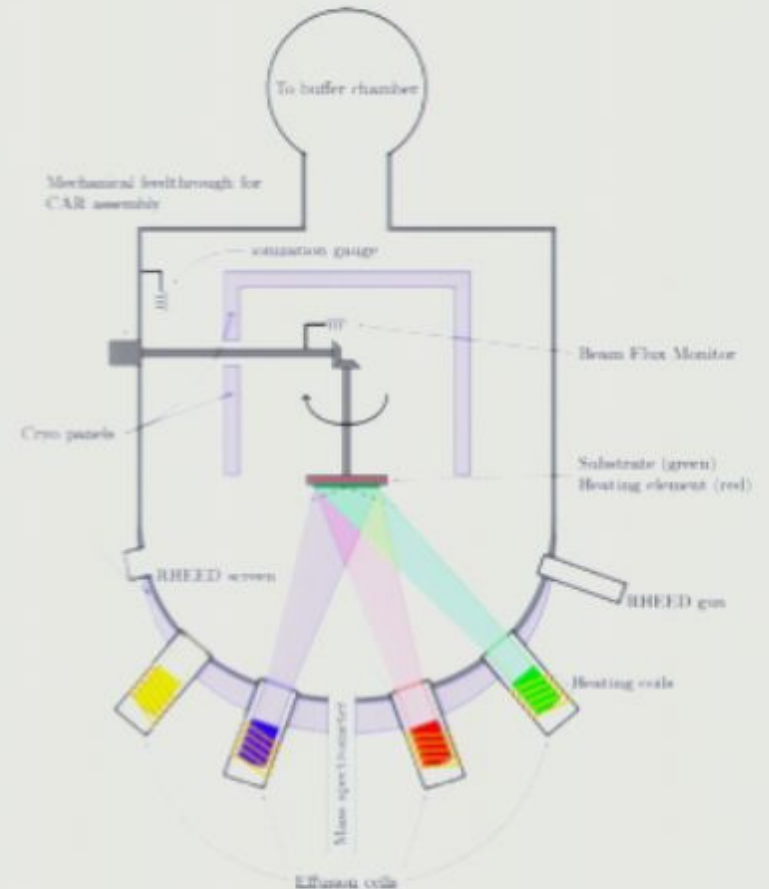


GaAs/AlGaAs
heterostructure

Confinement in the z direction : Choose a proper substrate

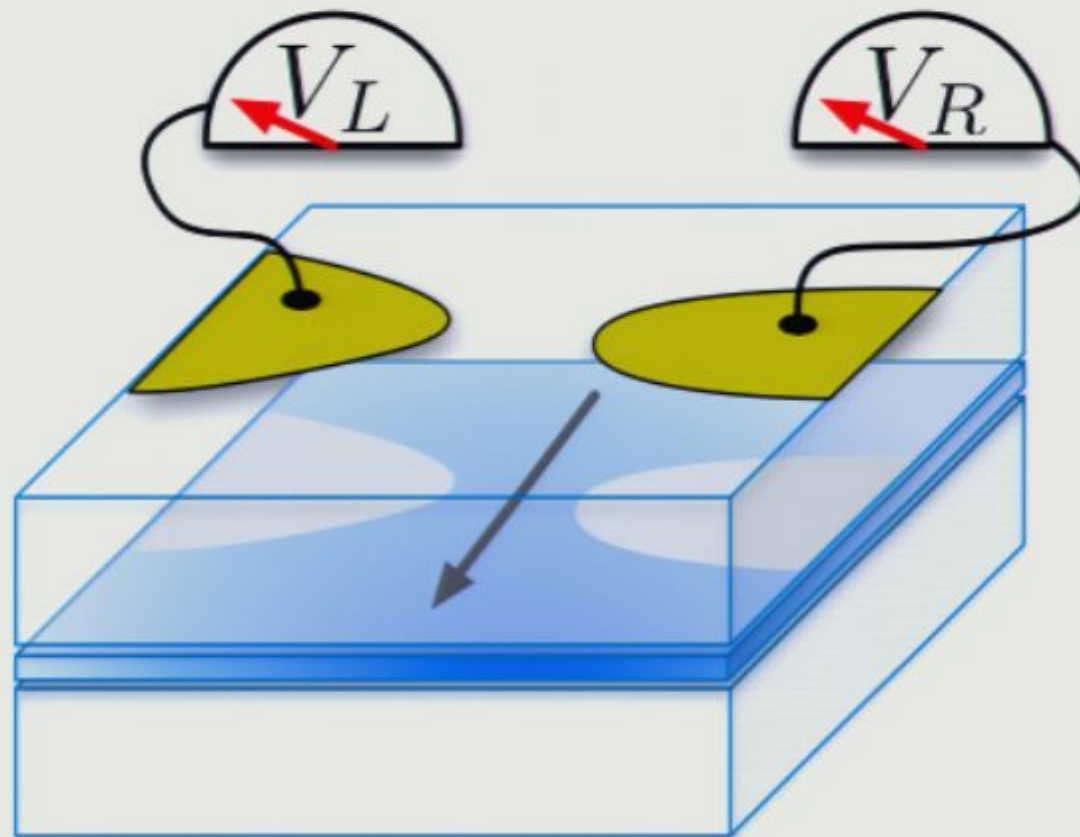


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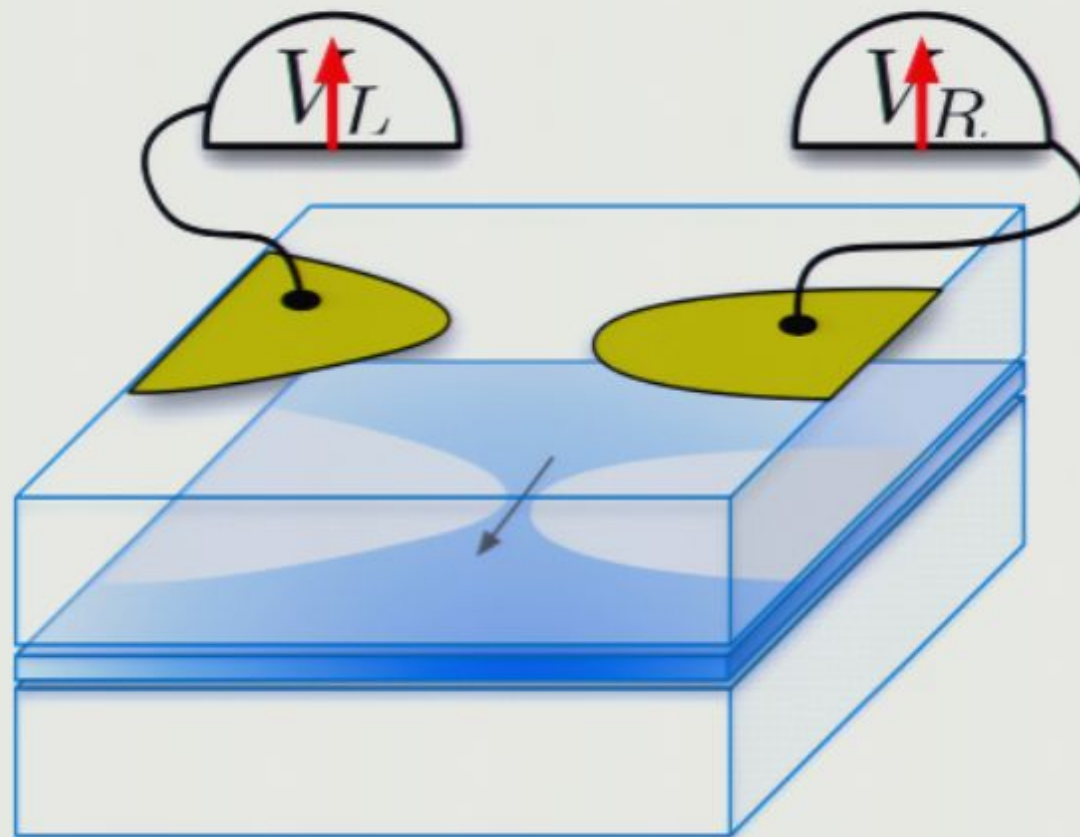


molecular beam epitaxy

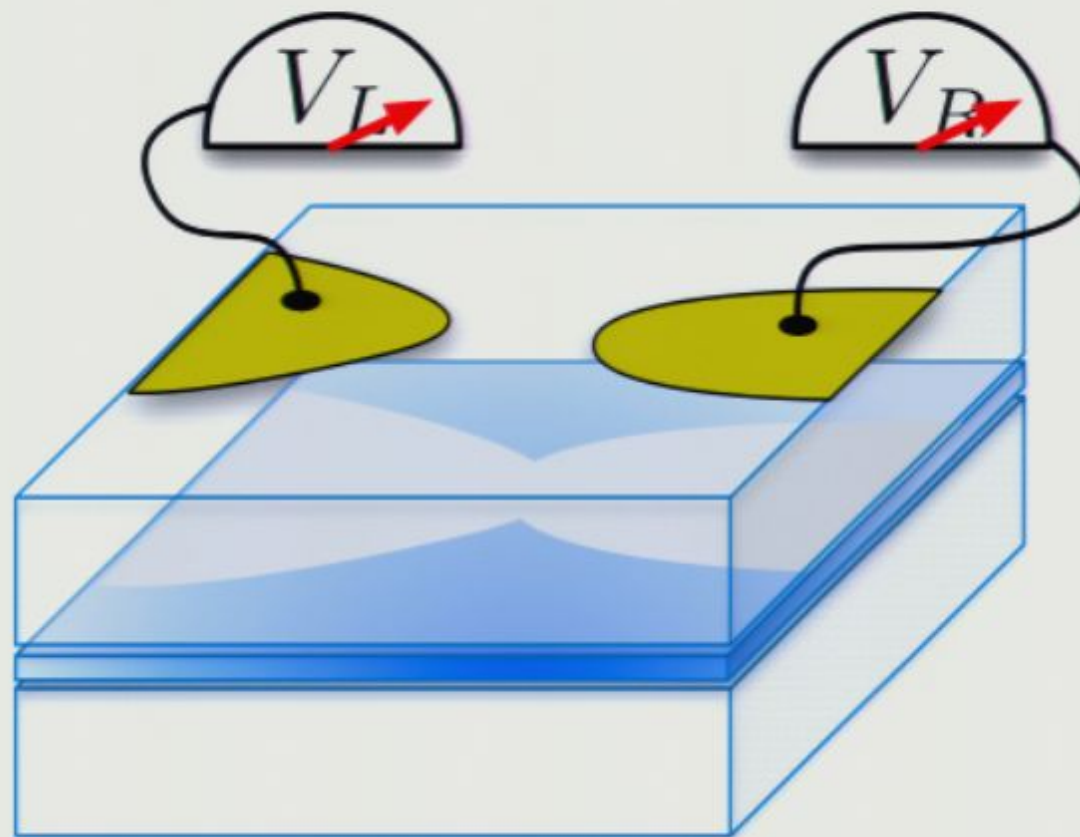
Confinement in the x and y directions : Use gates



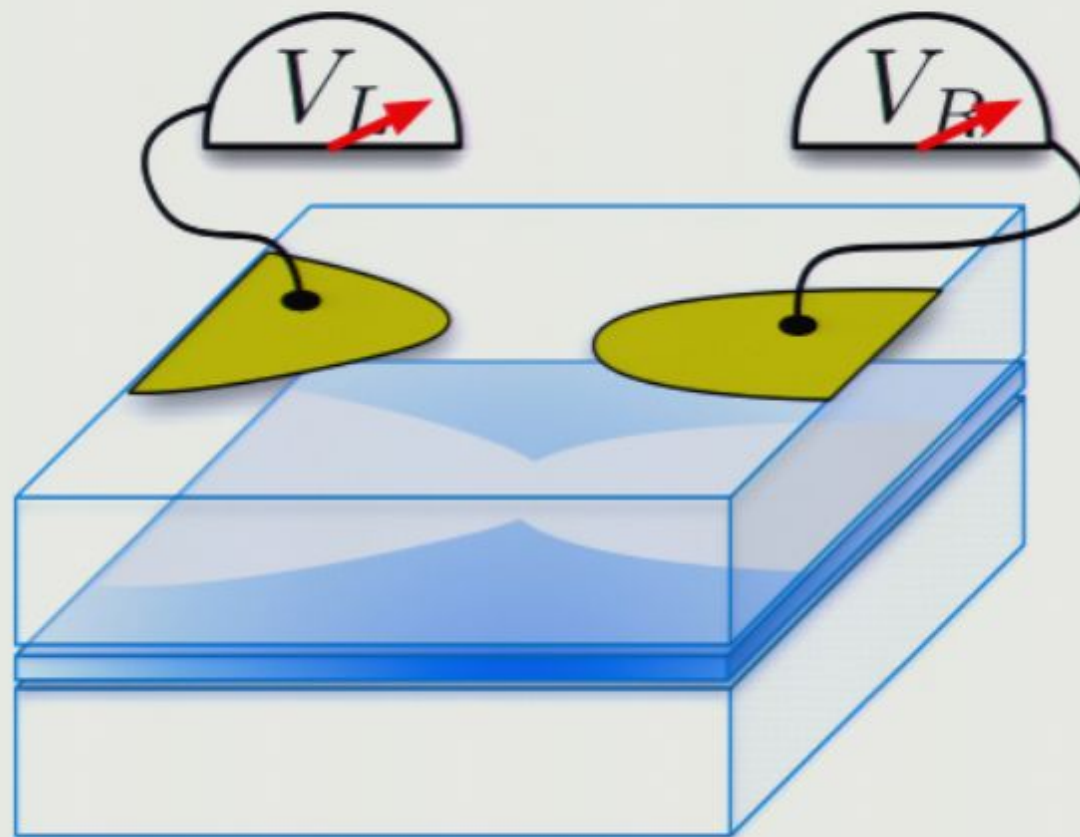
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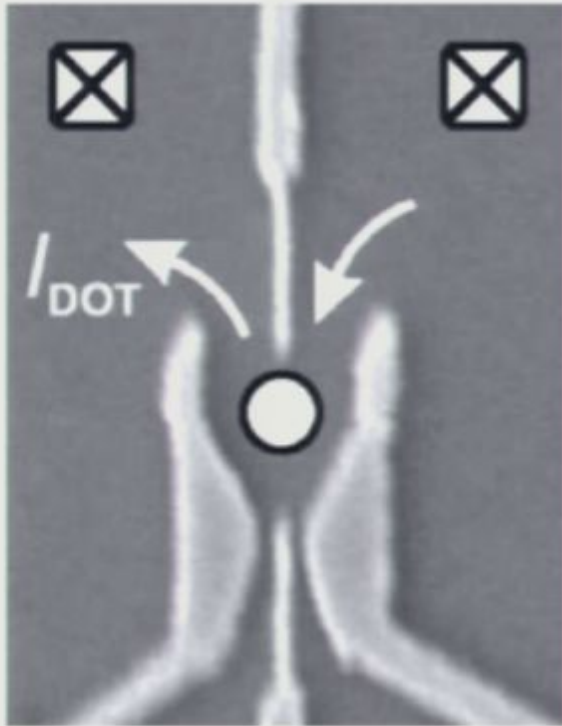
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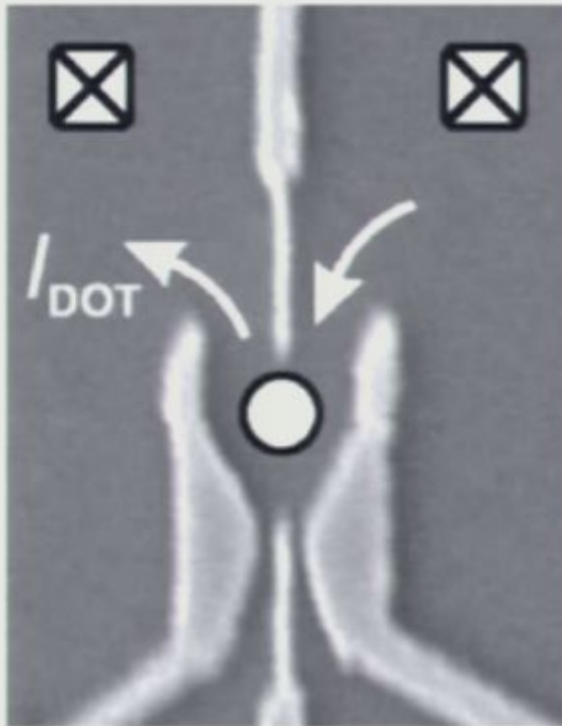
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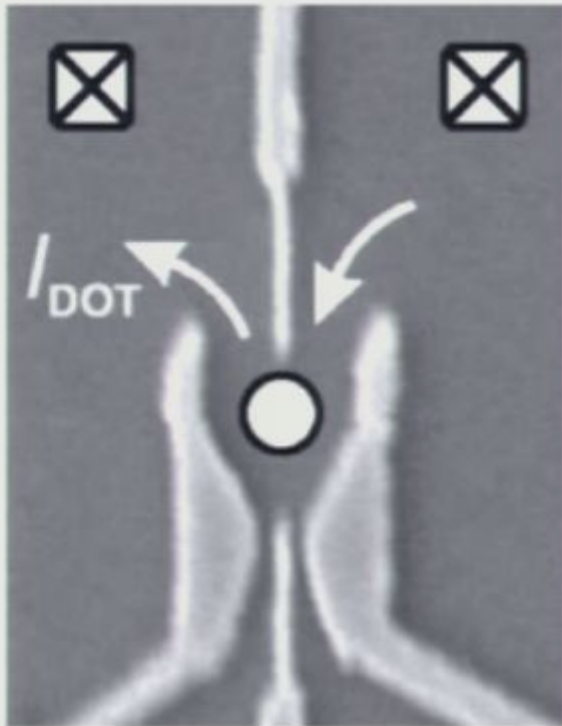
Fabrication of the gates by e-beam lithography



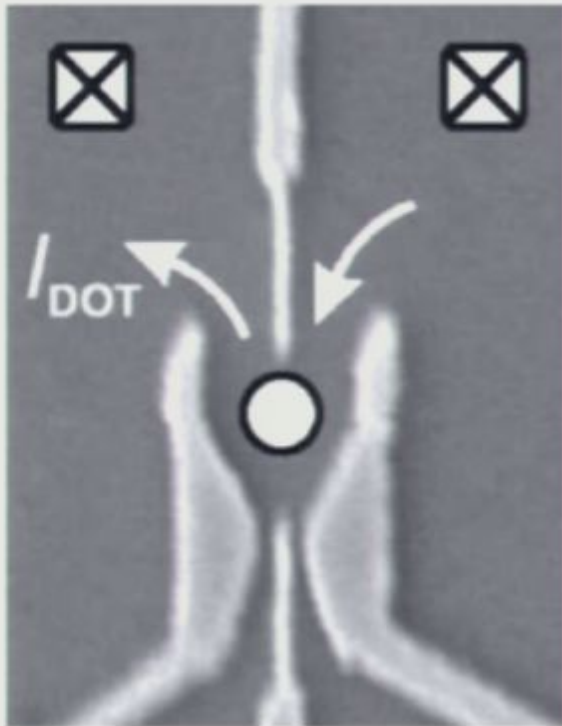
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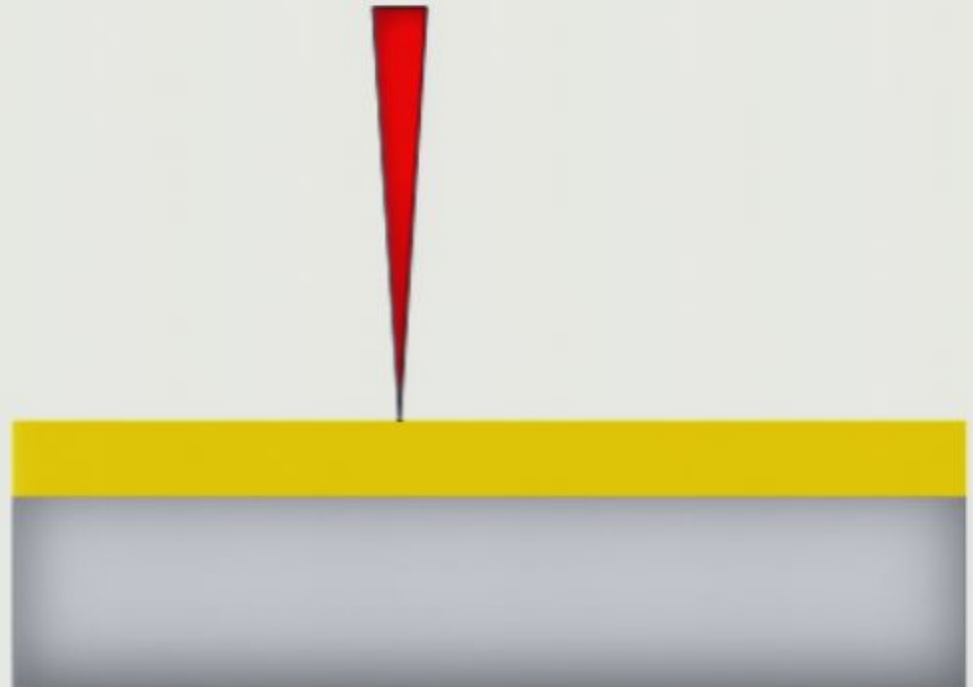
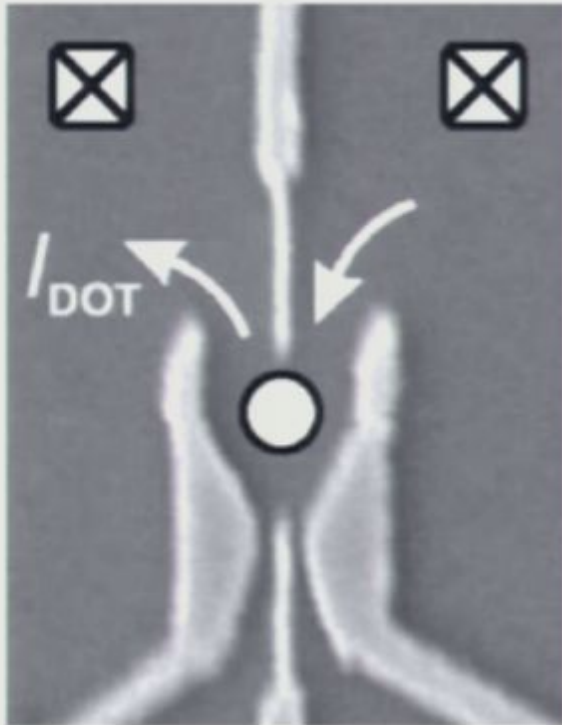
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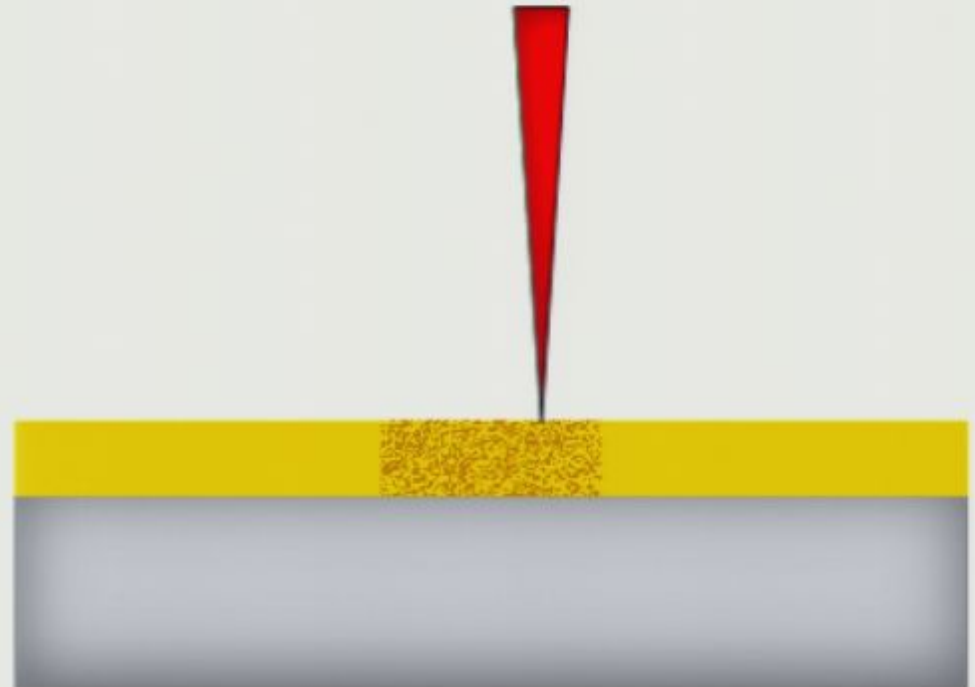
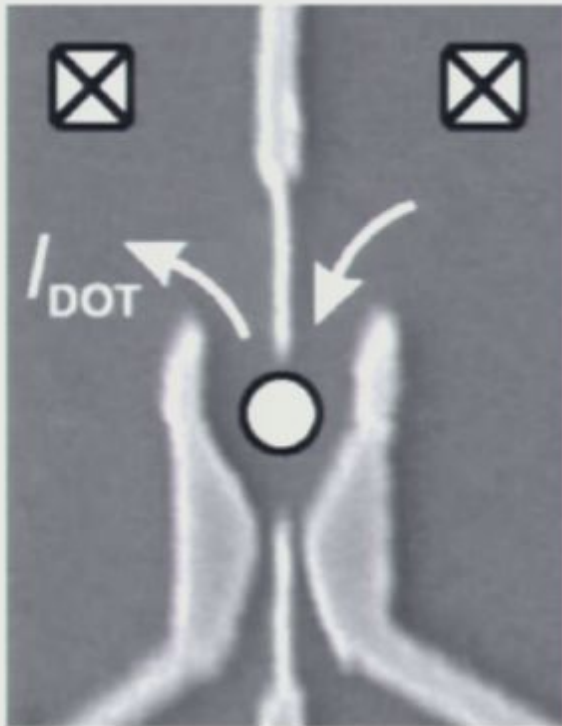
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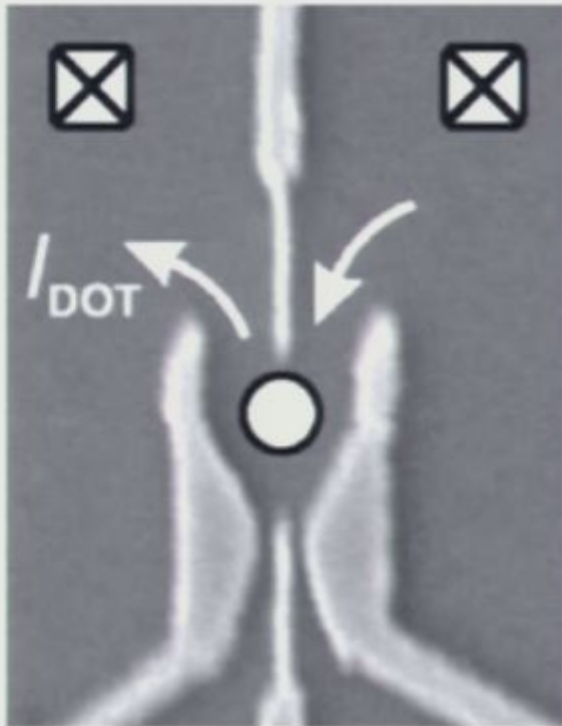
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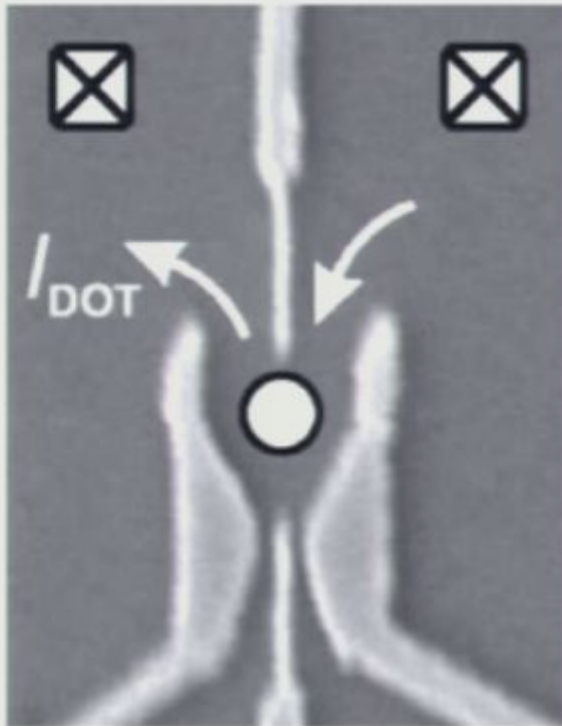
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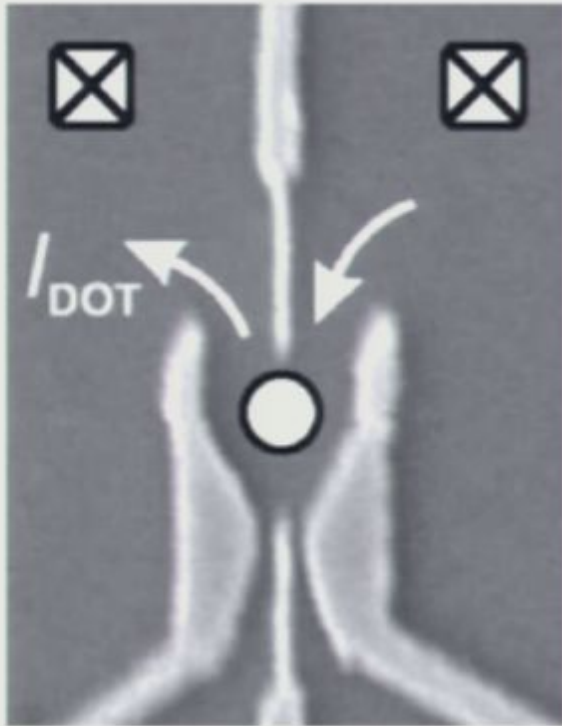
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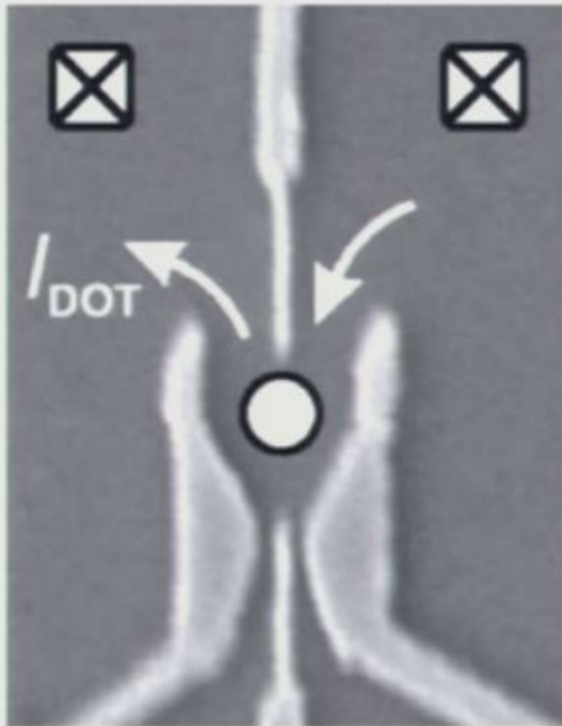
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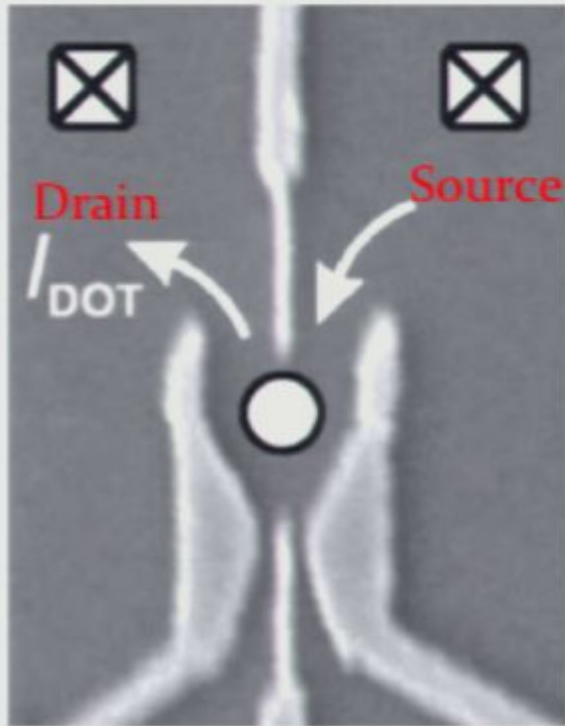
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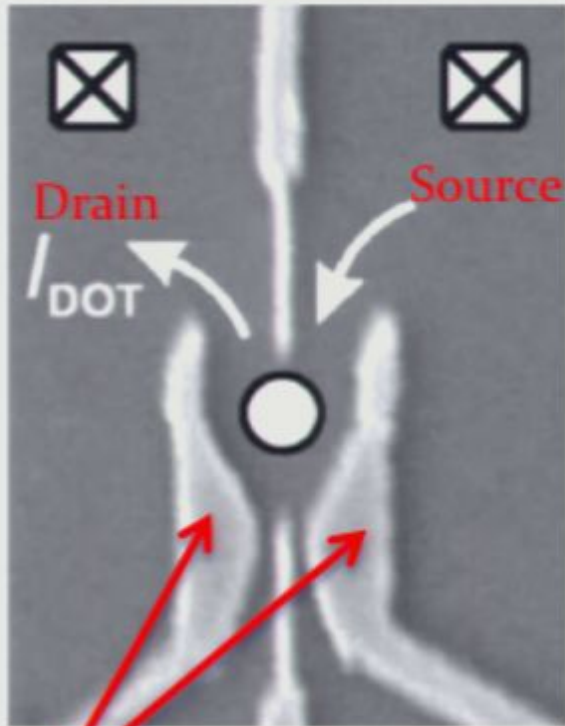
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Quantum dot gate structure

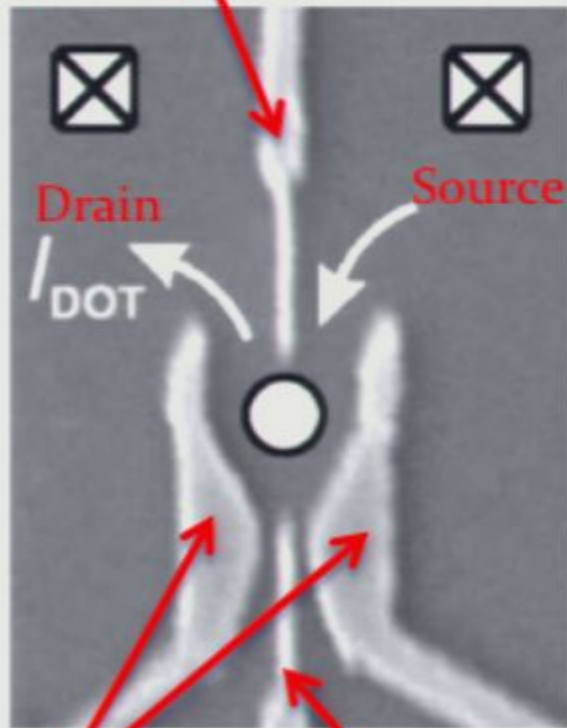


Quantum dot gate structure



Quantum dot gate structure

Control of R_S and R_D



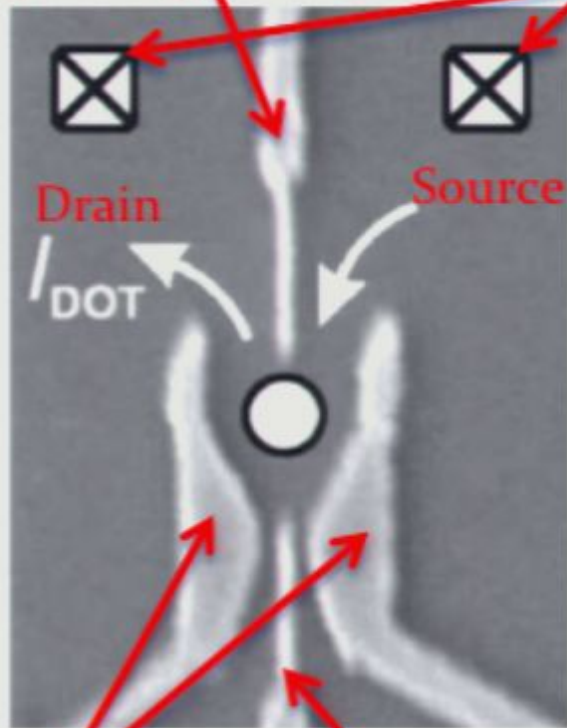
Define dot

Control of the # of e^- on the dot

Quantum dot gate structure

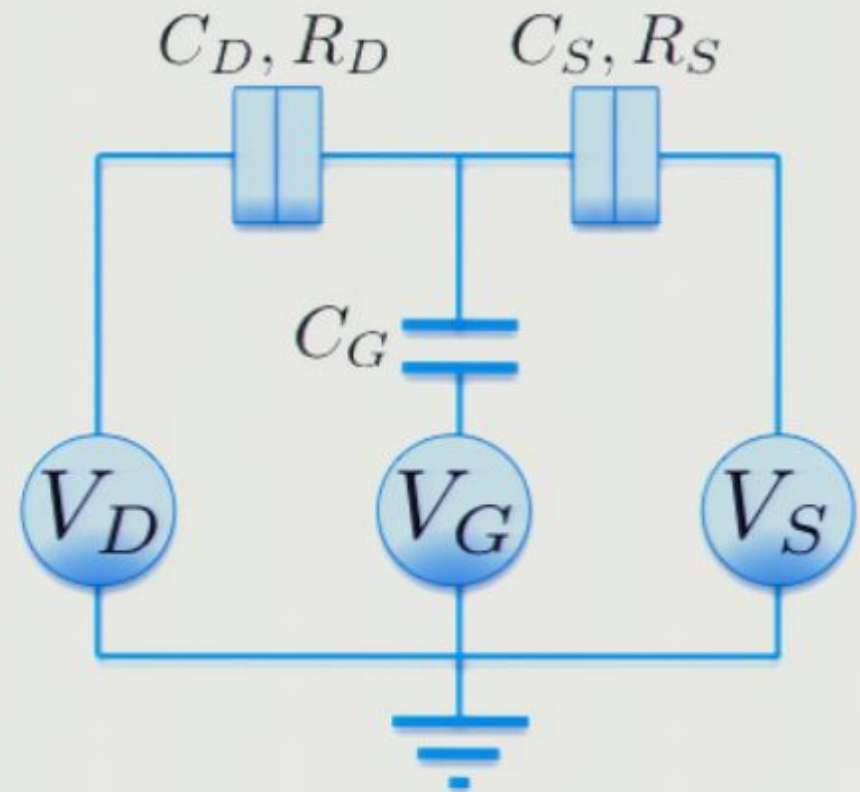
Control of R_S and R_D

Ohmic contacts



Define dot

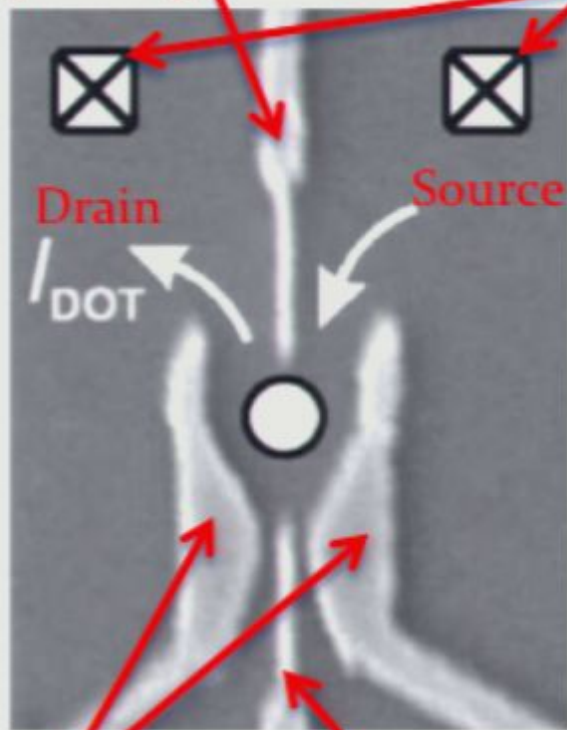
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Quantum dot gate structure

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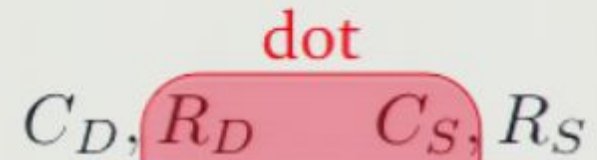
Ohmic contacts



Drain

Source

DOT

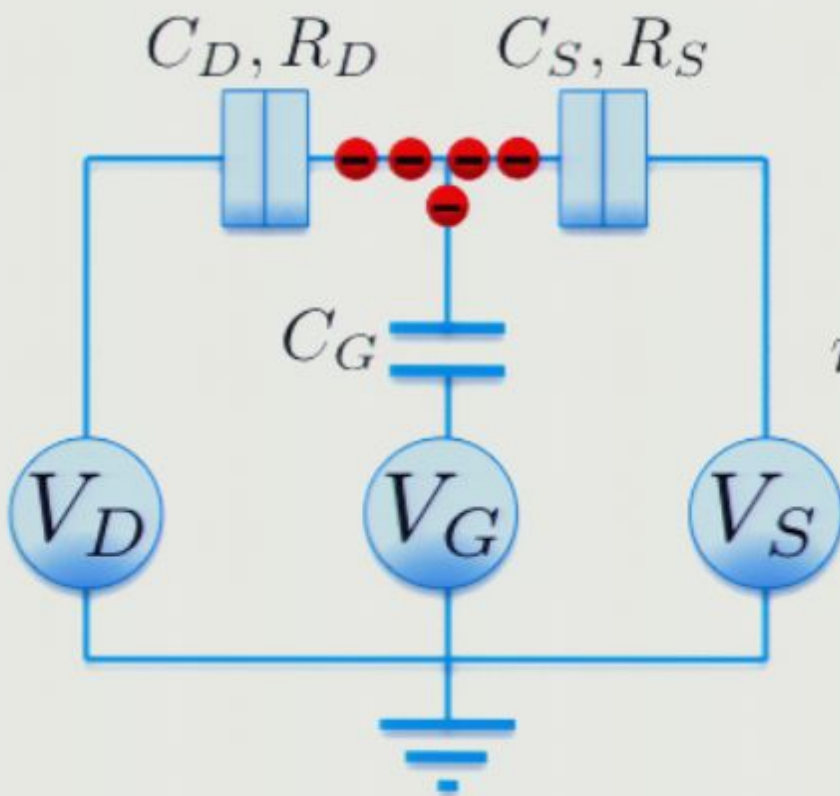


V_D

V_G

V_S

Using the gates

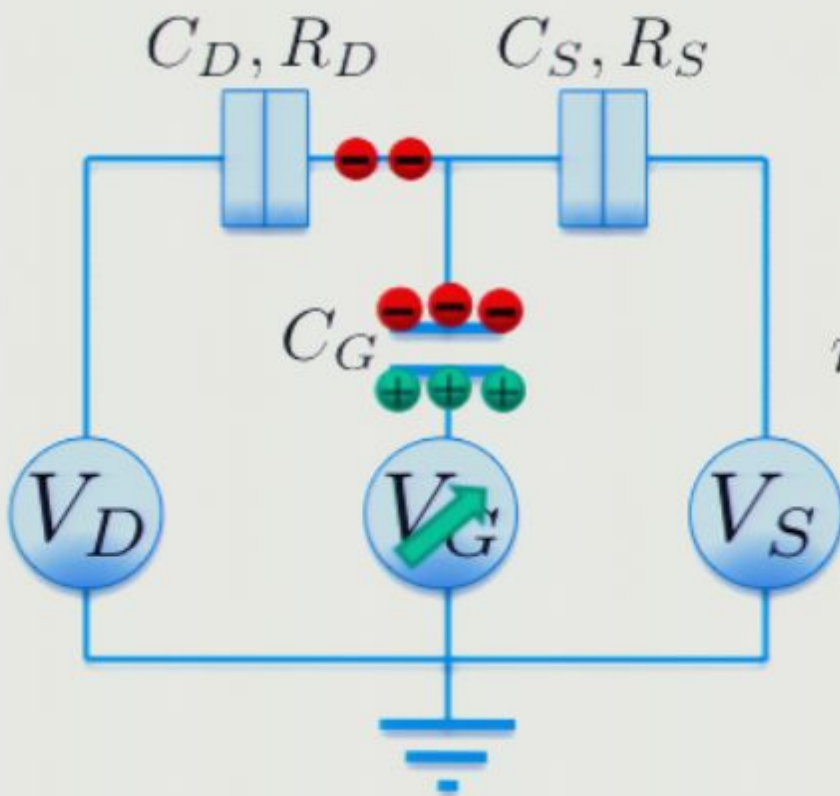


$$E_{el} = E_C(n - n_g)^2$$

$$E_C = \frac{e^2}{2(C_S + C_D + C_G)}$$

$$n_g = (C_S V_S + C_D V_D + C_G V_G) / e$$

Using the gates

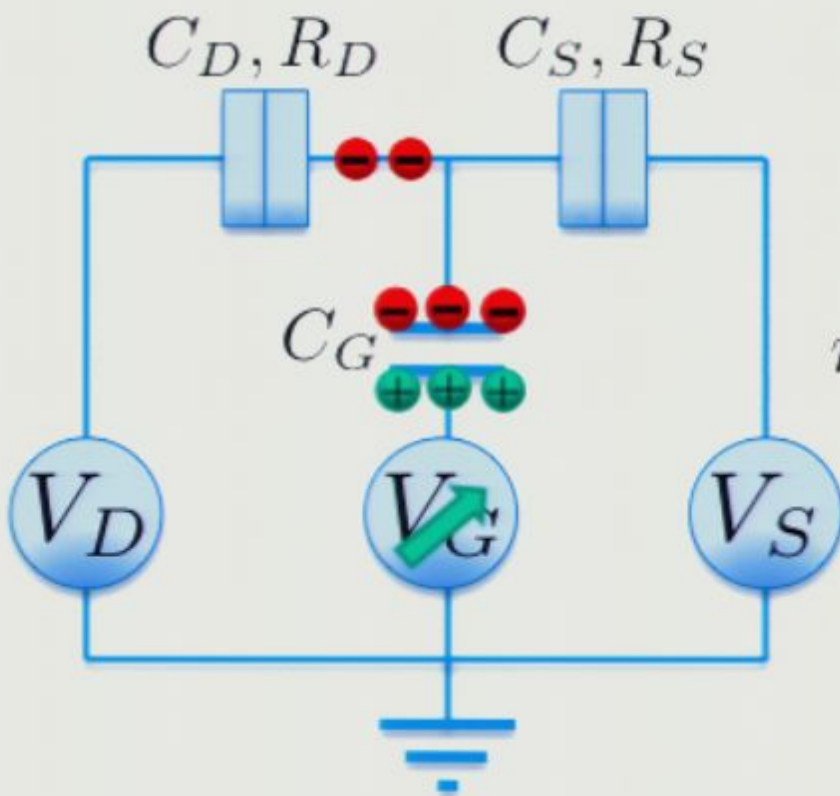


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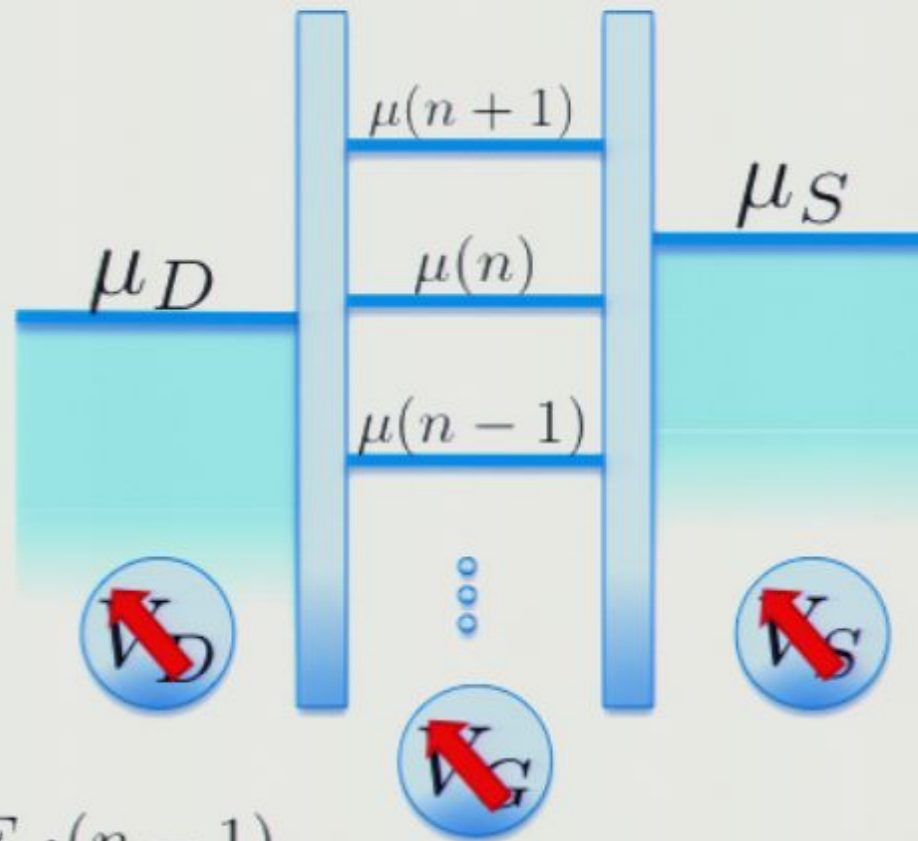


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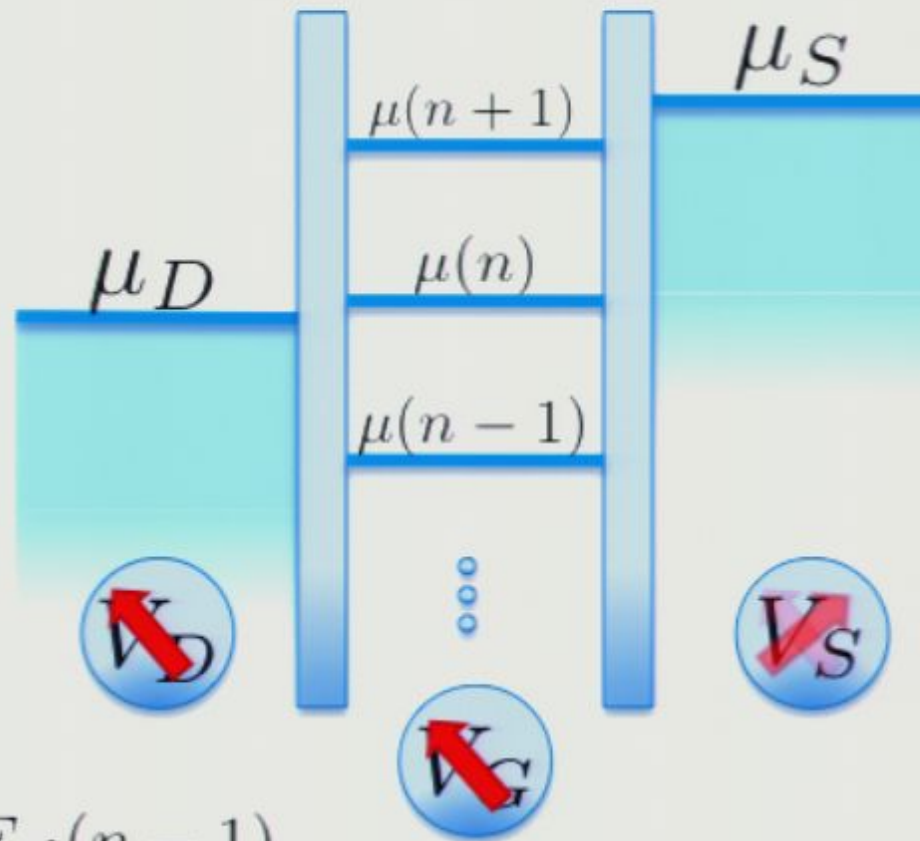
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More practical way to view the dot



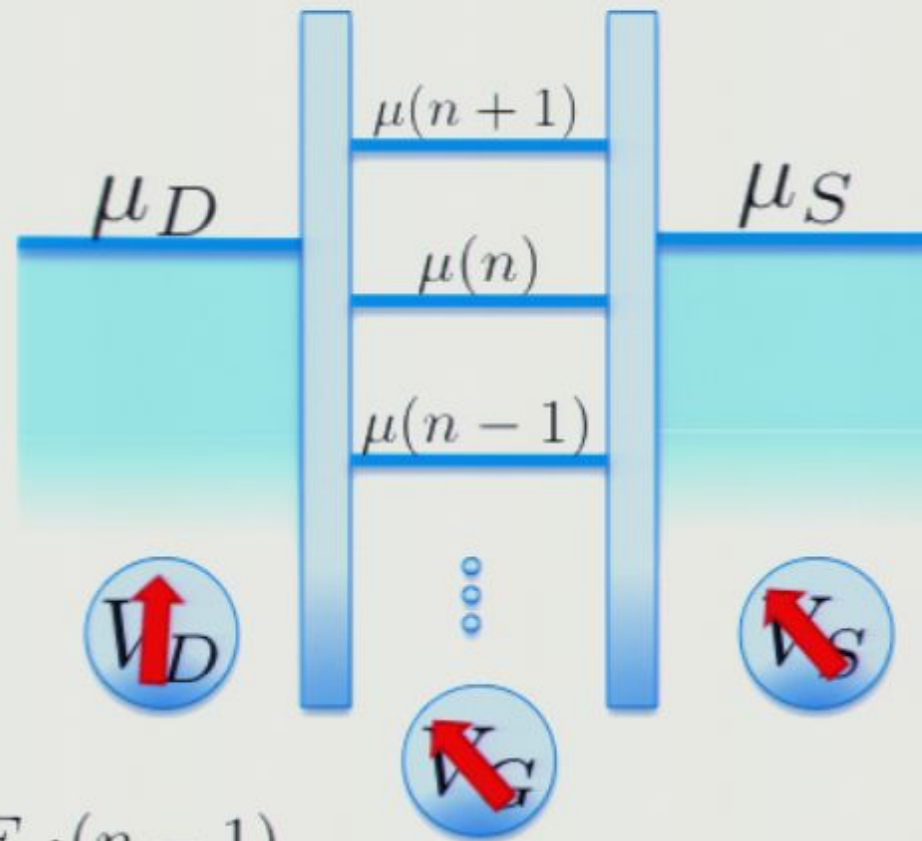
$$\begin{aligned} \mu(n) &= E_{el}(n) - E_{el}(n-1) \\ &= 2E_C[n - n_g - 1/2] \end{aligned}$$

More practical way to view the dot



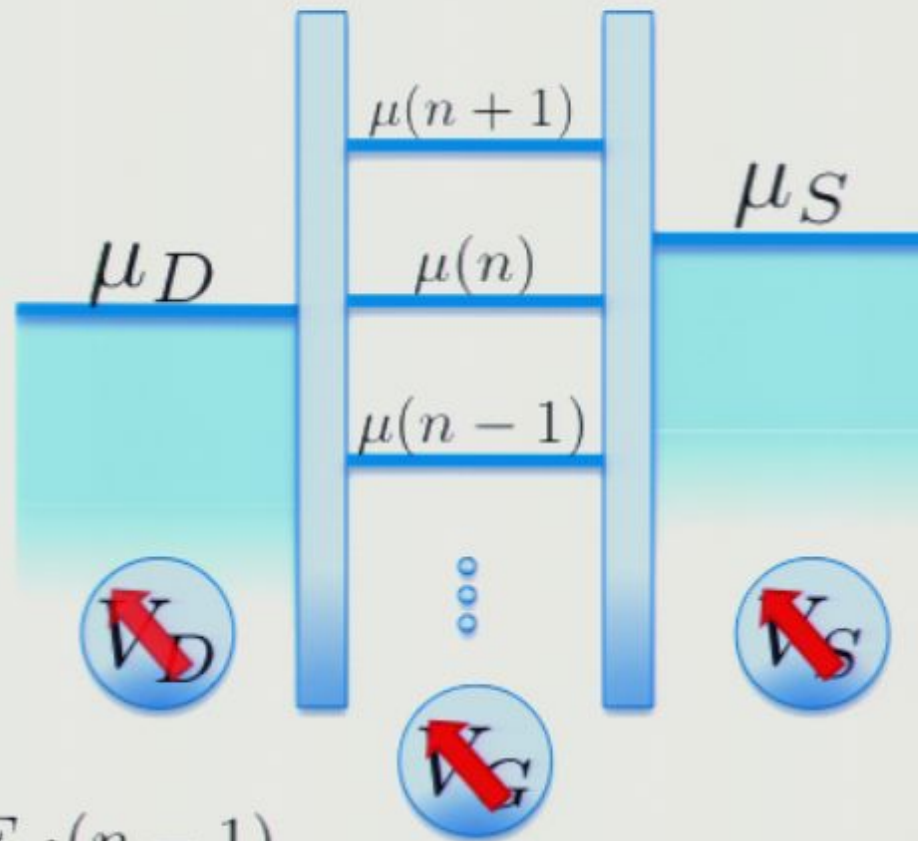
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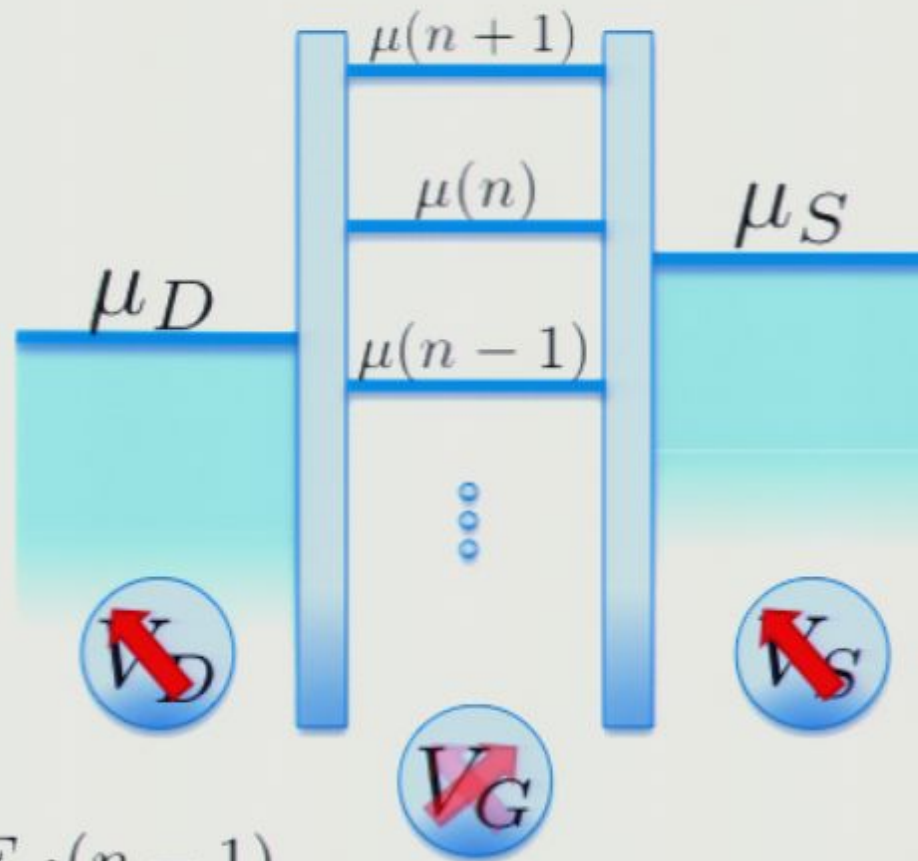
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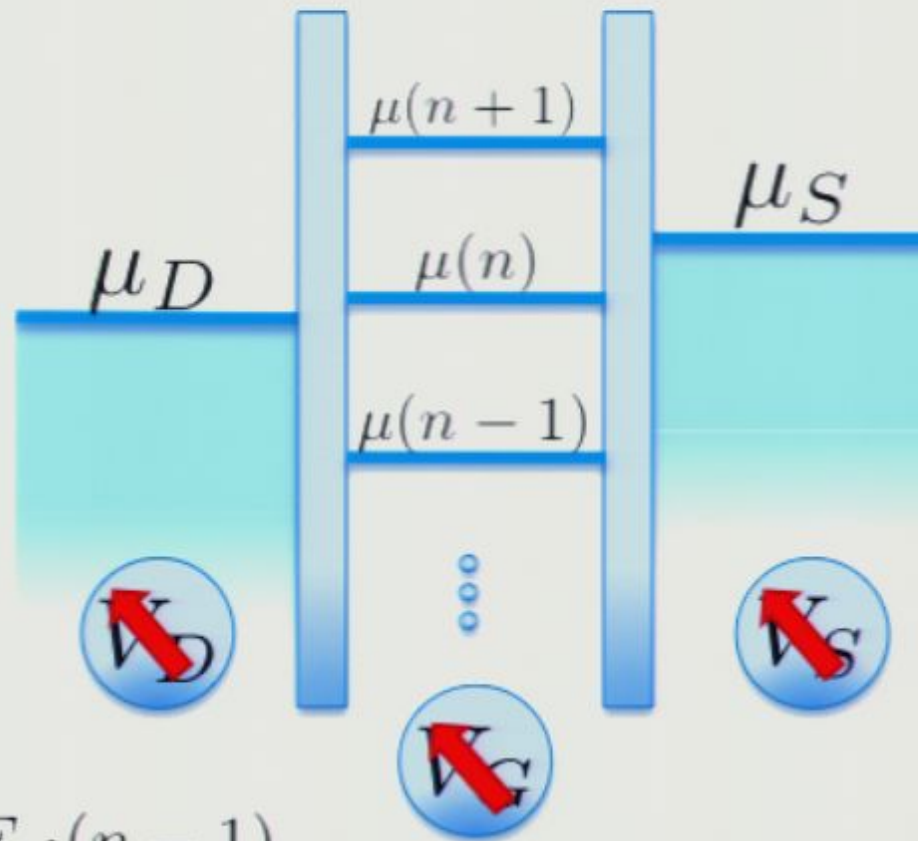
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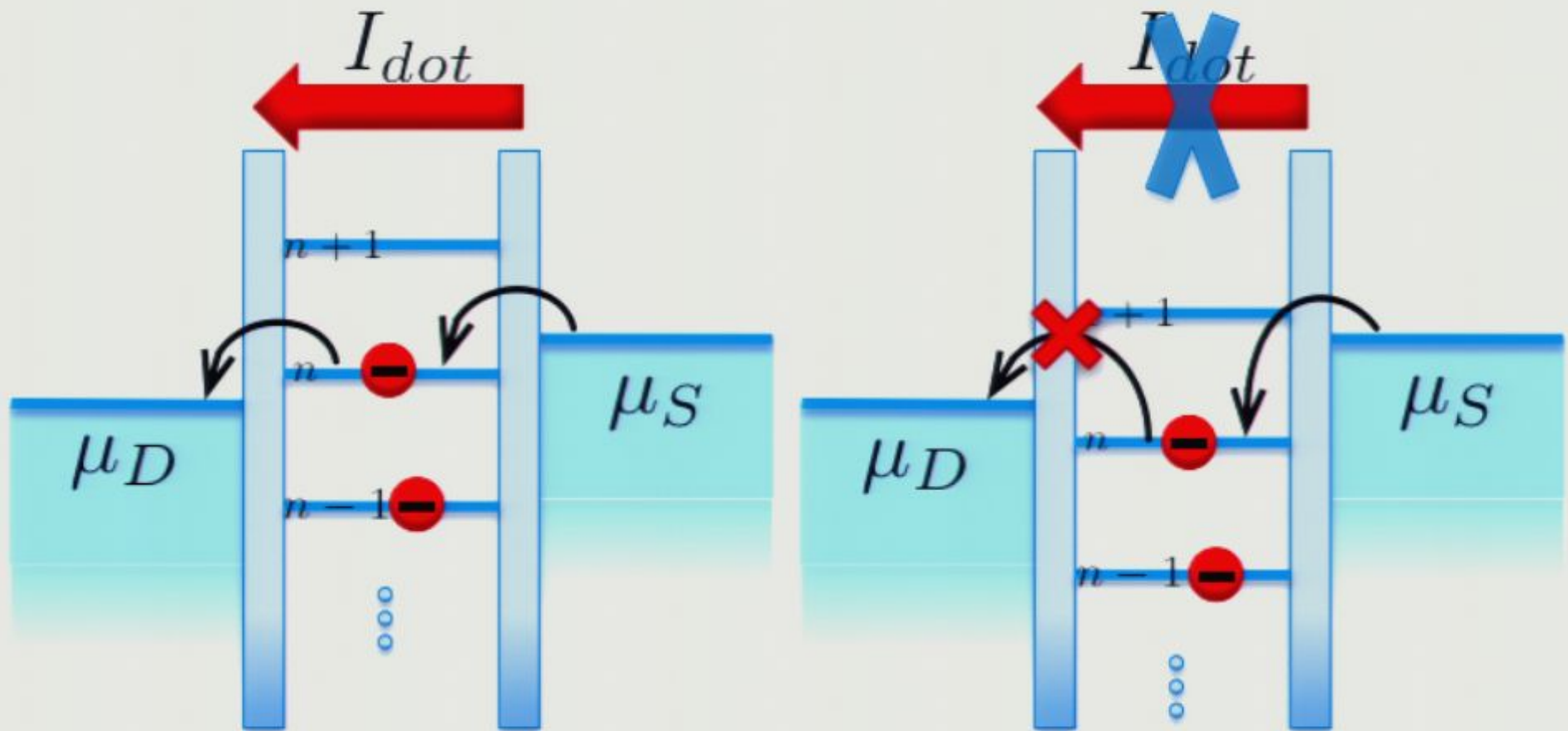
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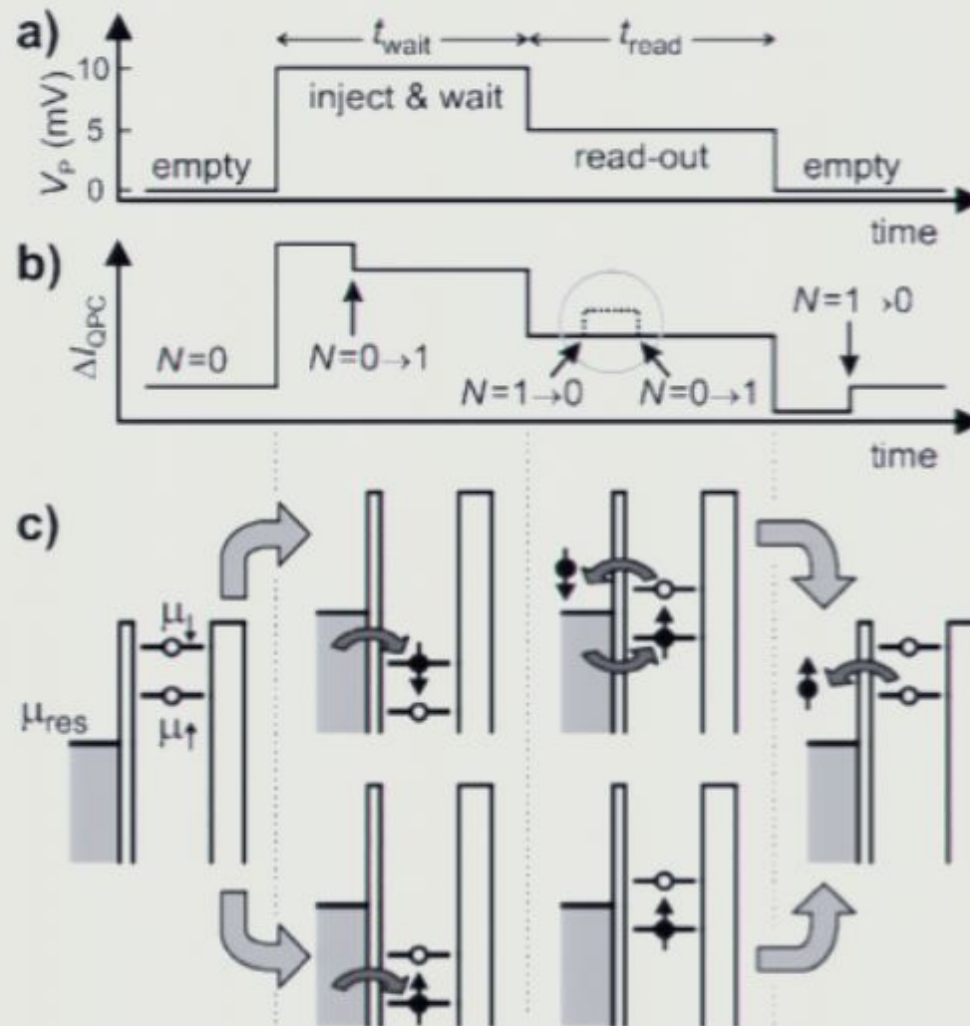


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Controlling the current through the dot



Reading the spin



Conclusion

- Lateral quantum dots can spatially confine a single electron.
- The spin of the electron on the dot can be determined.
- The spin of the electron on the dot can be controlled using a magnetic field gradient (Sophie's presentation).
- Two qubit interactions can be done using a double quantum dot.
- Challenges include scaling and controlling or eliminating decoherence due to nuclear spins in the substrate.

Thank you

Questions?