



Escuela de Física Matemática Uniandes

Coupled Quantum Dots and Other Solid
State Physical Models for Quantum
Computing

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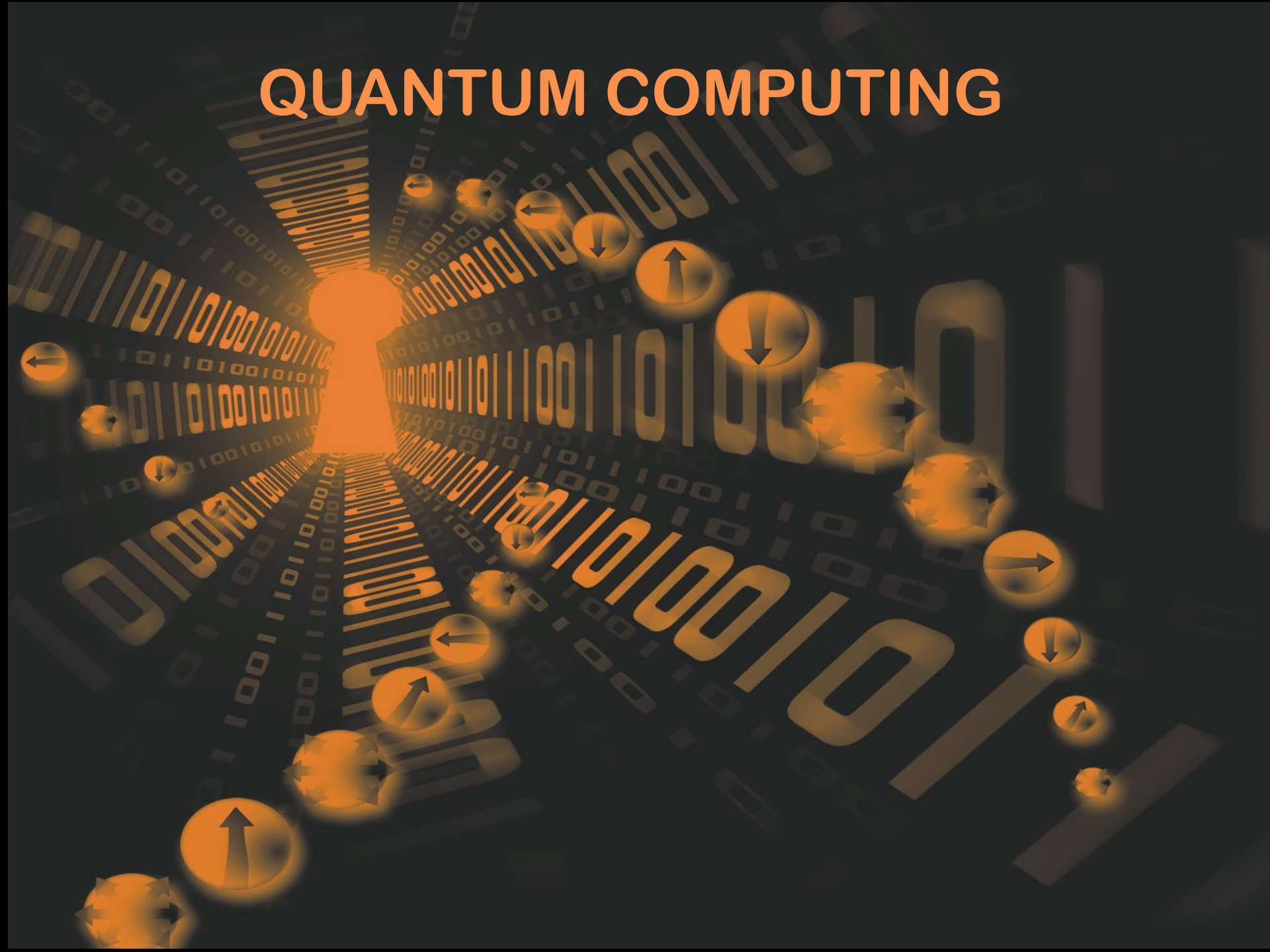
ABSTRACT

- In this work, the exchange of energy J for a system of **two laterally-coupled quantum dots**, each one with an electron, is calculated analytically and in a detailed form, considering them as hydrogen-like atoms, **under the Heitler-London approach**. The atomic orbitals, associated to each quantum dot, are obtained from translation relations, as functions of the Fock-Darwin status. Our results agree with the ones reported by Burkard, Loss and DiVincenzo in their model of quantum gates based on quantum dots, as well as with the recent experimental reports.
- On the other hand we have studied other models of **quantum tunneling effects** that include spin effects that are sources of the entanglement and that, based in solid state physics, contribute to the understanding and potential production of quantum mechanisms.

1. MOTIVACIÓN

Addressing and learning even more about a new branch of physics called quantum computation and its application of solid state prototypes for physical realization of quantum computers.

QUANTUM COMPUTING



2. QUANTUM COMPUTING

Definition: New model of computation in which the effects described by quantum mechanics for the subatomic world as superposition and entanglement are used as tools for information processing.



2. QUANTUM COMPUTING

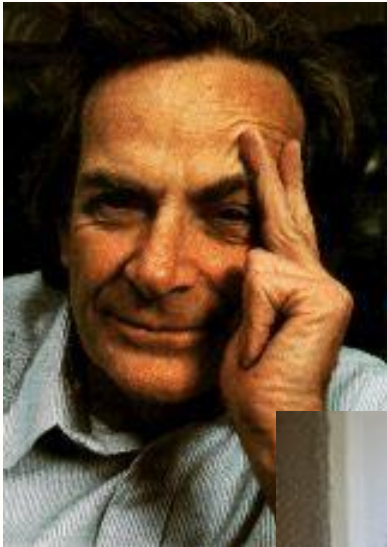
Features:

- The job scenario is not restricted to only two states
- Many states appear as a result of the states superposition
- This scheme of calculation allows us to evaluate all possibilities in one step = Quantum Parallelism
- Polynomial Processing time
- Exponential Processing Speed

2. QUANTUM COMPUTING

History:

1980s, Introduction of Quantum Computer Concept
by Richard Feynman and David Deutsch



International Journal of Theoretical Physics, Vol. 21, Nos. 6/7, 1982

Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

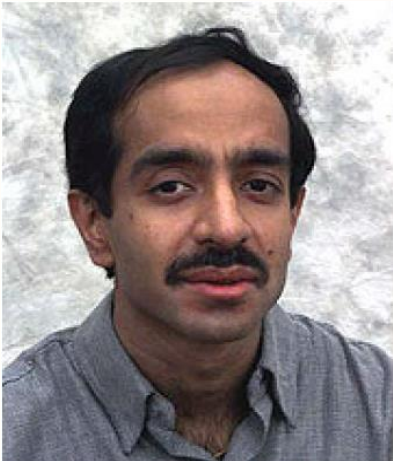
1. INTRODUCTION

On the program it says this is a keynote speech—and I don't know what a keynote speech is. I do not intend in any way to suggest what should be in this meeting as a keynote of the subjects or anything like that. I have my own things to say and to talk about and there's no implication that anybody needs to talk about the same thing or anything like it. So what I

2. QUANTUM COMPUTING



- 1994 Creation of the Factoring Algorithm by Peter Shor.
- 1994 Ignacio Cirac and Peter Zoller of the University of Innsbruck (Austria) proposed the first scheme for the implementing a quantum gate



- 1996 Creating of the Search Algorithm by Lov Grover.
- 1996 First implementation of the Cirac-Zoller gate by Christopher Monroe and David Wineland at NIST (USA).

2. QUANTUM COMPUTING

- 1998 Daniel Loss of the University of Basel (Switzerland) and David DiVincenzo of IBM (USA) proposed the first scheme for the quantum gate construction based on quantum dots.
- 2001 Isaac L. Chuang, develops early quantum computers of 2-qubit, 3-qubit, 5 and 7-qubit qubit using NMR techniques.



2015-2013



1. "Analysis of the Quantum Zeno Effect for Quantum Control and Computation", J. Phys. A: Math. Theor. 46, 075306 (2013), by J. Dominy, G. Paz-Silva, A.T. Rezakhani, and **D.A. Lidar.**
2. "Quantum Adiabatic Markovian Master Equations", New J. of Physics 14, 123016 (2012), by T. Albash, S. Boixo, D. Lidar, and P. Zanardi.
3. "Quantum Adiabatic Machine Learning", Quantum Info. Process. 12, 2027 (2013), by K. Pudenz and D. Lidar.
4. "Universality Proof and Analysis of Generalized Nested Uhrig Dynamical Decoupling", J. Math. Phys. 53, 122207 (2012), by W.J. Kuo, G. Quiroz, G. Paz Silva, D. Lidar.
5. "High-Fidelity Adiabatic Quantum Computation via Dynamical Decoupling", Phys. Rev. A 86, 042333 (2012), by G. Quiroz and D. Lidar. [pdf]

2013



1. Magnetically-Defined Qubits on 3D Topological Insulators. Gerson J. Ferreira and Daniel Loss. [arXiv:1305.5003](#)
2. Correlations between Majorana fermions through a superconductor. A.A. Zyuzin, Diego Rainis, Jelena Klinovaja, and Daniel Loss. [arXiv:1305.4187](#) .
3. Integer and Fractional Quantum Hall Effect in a Strip of Stripes. Jelena Klinovaja and Daniel Loss. [arXiv:1305.1569](#)
4. Topological Edge States and Fractional Quantum Hall Effect from Umklapp Scattering Jelena Klinovaja and Daniel Loss. [arXiv:1302.6132](#)

2.1. QUBIT

Definition: The smallest unit of information in a quantum mechanical calculating device that describes the quantum state of a two-level quantum system in a Bidimensional Hilbert space.

$$|\psi\rangle = a_0 |0\rangle + a_1 |1\rangle$$

The ket basis of the system are given by

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

2.1. QUBIT

Types:

1-qubit

$$|\psi\rangle = a_0 |0\rangle + a_1 |1\rangle$$

2-qubit

$$|\psi\rangle = a_{00} |00\rangle + a_{01} |01\rangle + a_{10} |10\rangle + a_{11} |11\rangle$$

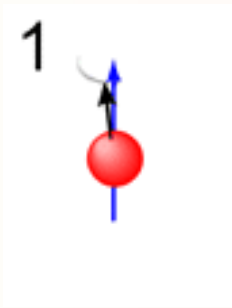
n-qubit

$$|\psi\rangle = \sum_{x=0}^{2^N-1} a_x |x\rangle$$

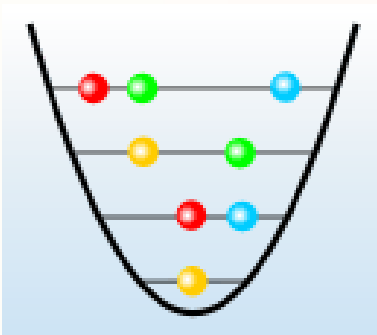
2.1. QUBIT

Implementation:

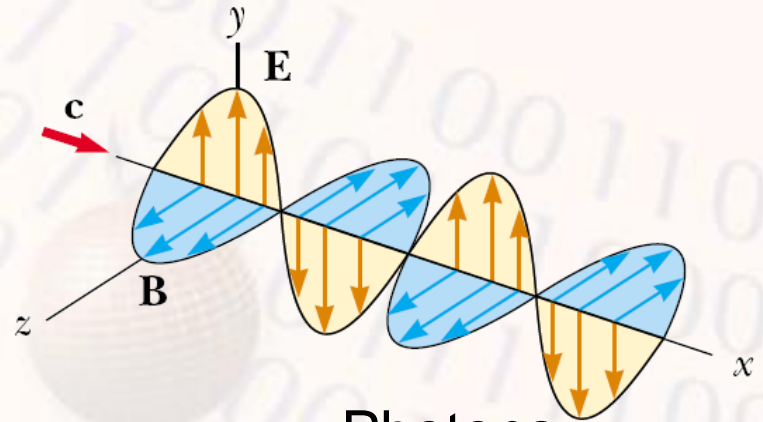
Electron spin



Nuclear spin

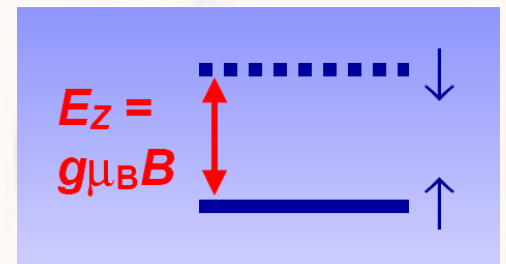


Polarized Light



Photons

Any two level quantum system!!



2.2. QUANTUM GATES

Definition: Linear processing unit that performs an operation on a selected set of qubits in a certain period of time.

$$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$



$$U_{\text{CNOT}} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$



2.2. QUANTUM GATES

Electronic Spin

✓ 1-qubit: Spin rotation

$$\hat{R} : (a_0 |0\rangle + a_1 |1\rangle) \longrightarrow a_0 |1\rangle + a_1 |0\rangle$$

✓ 2-qubit: Exchange Interaction

$$\hat{U}_{XOR} : |x\rangle |y\rangle \longrightarrow |x\rangle |x \oplus y\rangle$$

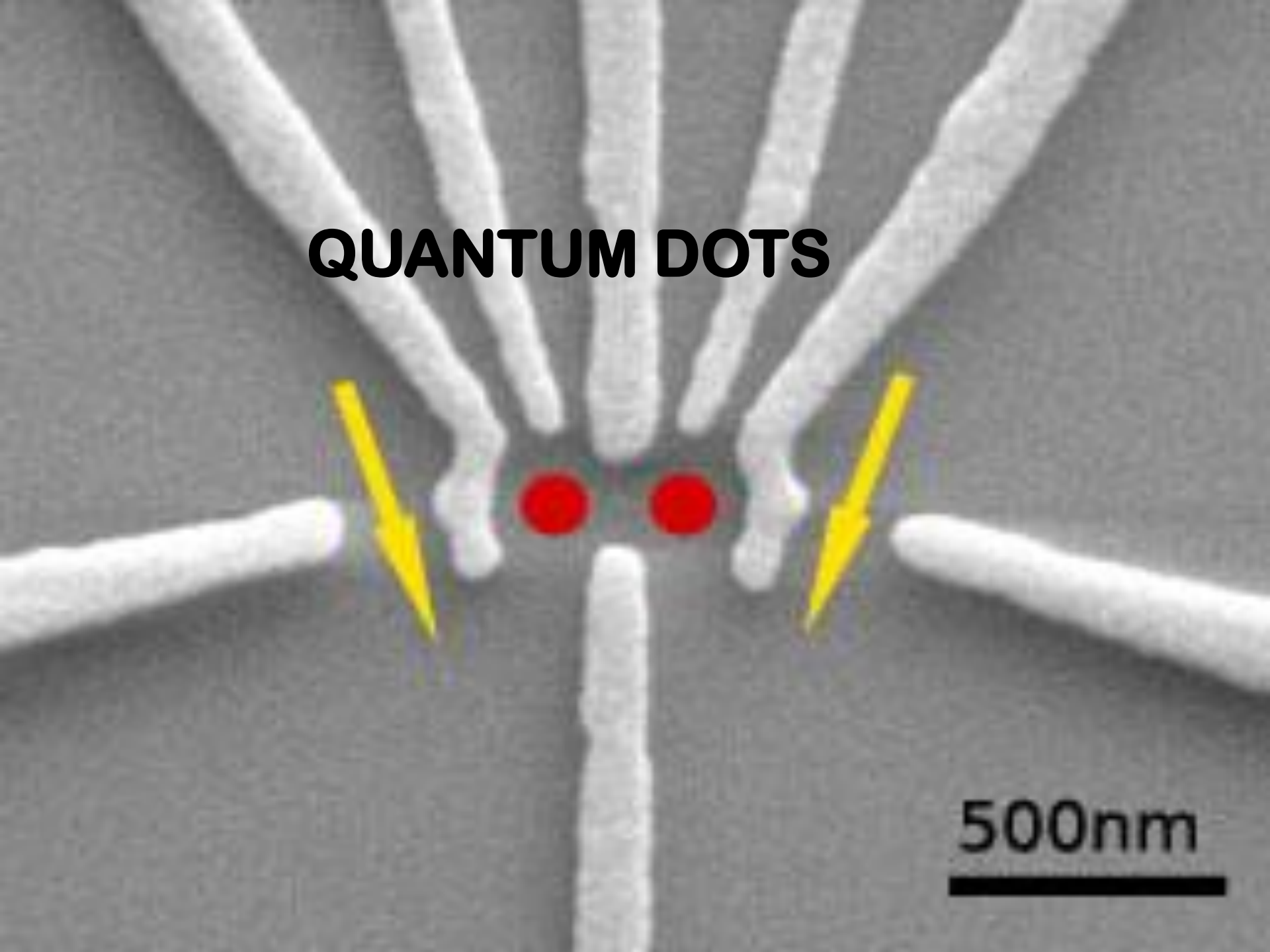
$$|x\rangle = |y\rangle = \frac{1}{\sqrt{2}} (|0\rangle - |1\rangle)$$

2.2. QUANTUM GATES

Features :

- Infinite number of gates
- Any unitary transformation on n qubits can be represented by a set of two quantum gates
- Allow reversible computing
- Increased thermodynamic efficiency = Minimum power consumption
- quantum Parallelism

QUANTUM DOTS

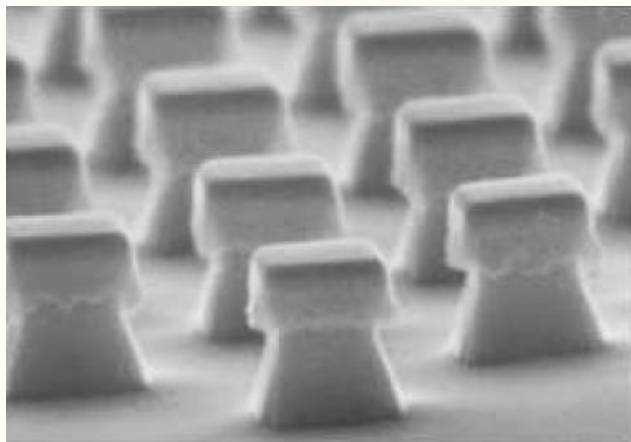
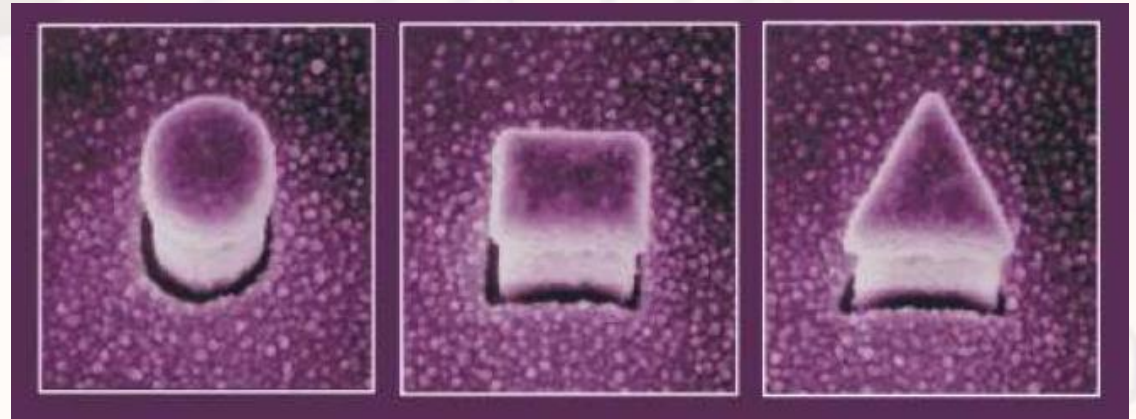


500nm

3. QUANTUM DOTS

Definition: nanoscale systems that act as confining box whether particles electrons, holes or excitons.

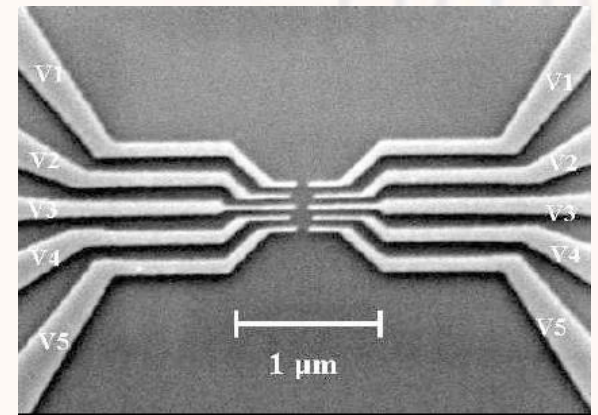
Different Geometries



Vertical Confinement

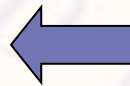


Lateral Confinement

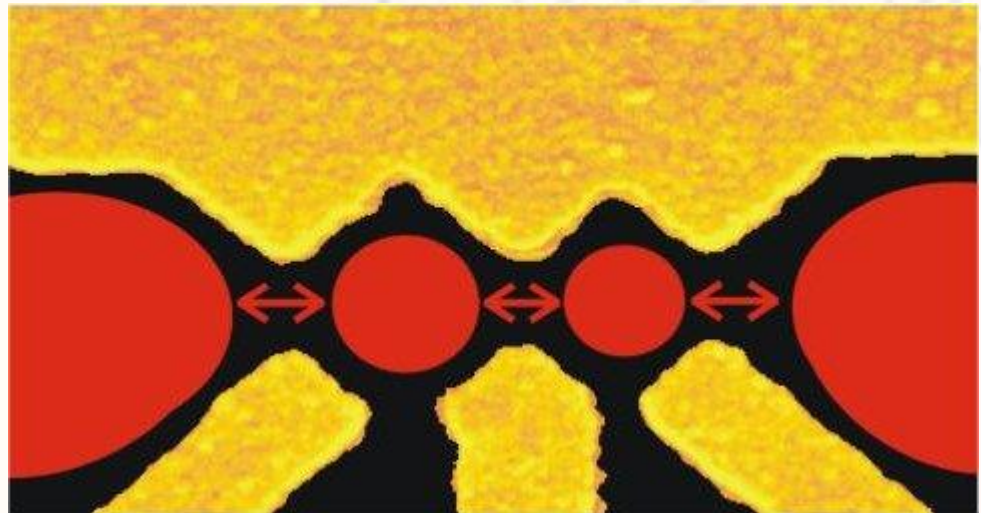
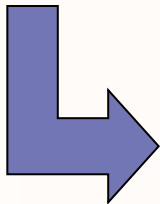


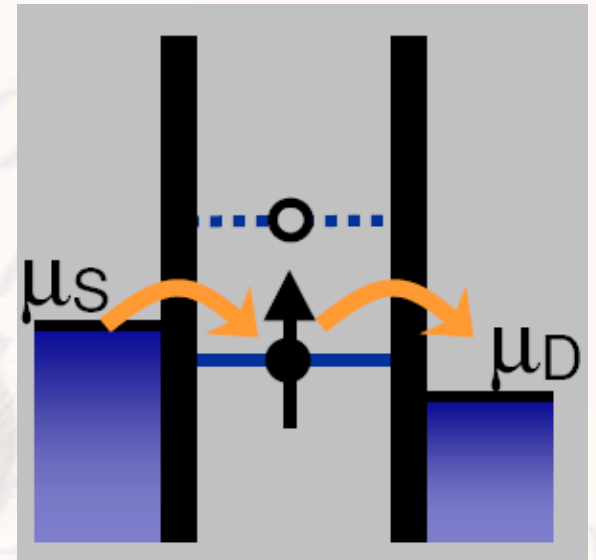
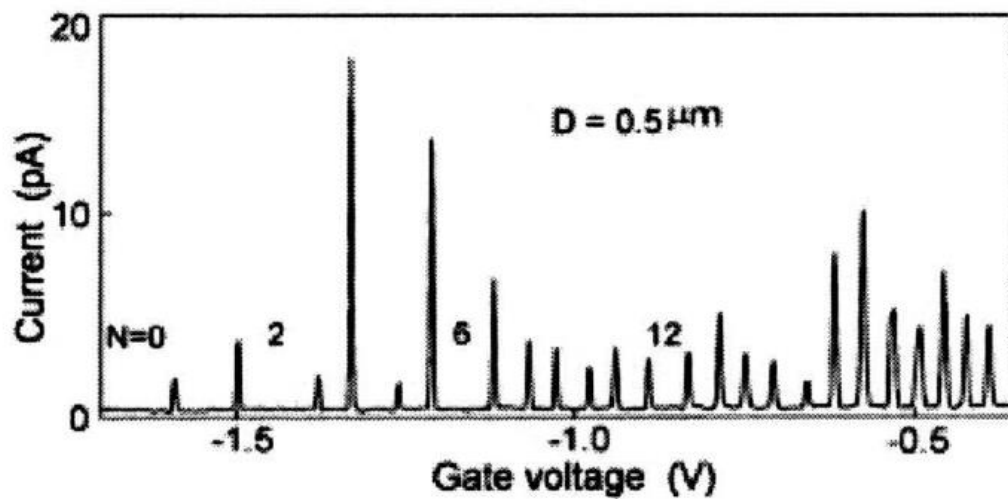
1980`s – Optical properties in QDs

Nanocrystals and Optical Processes



Lateral QDs





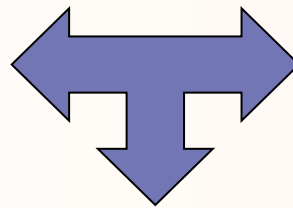
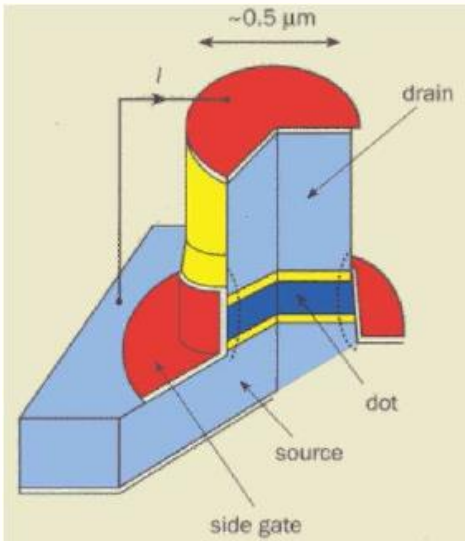
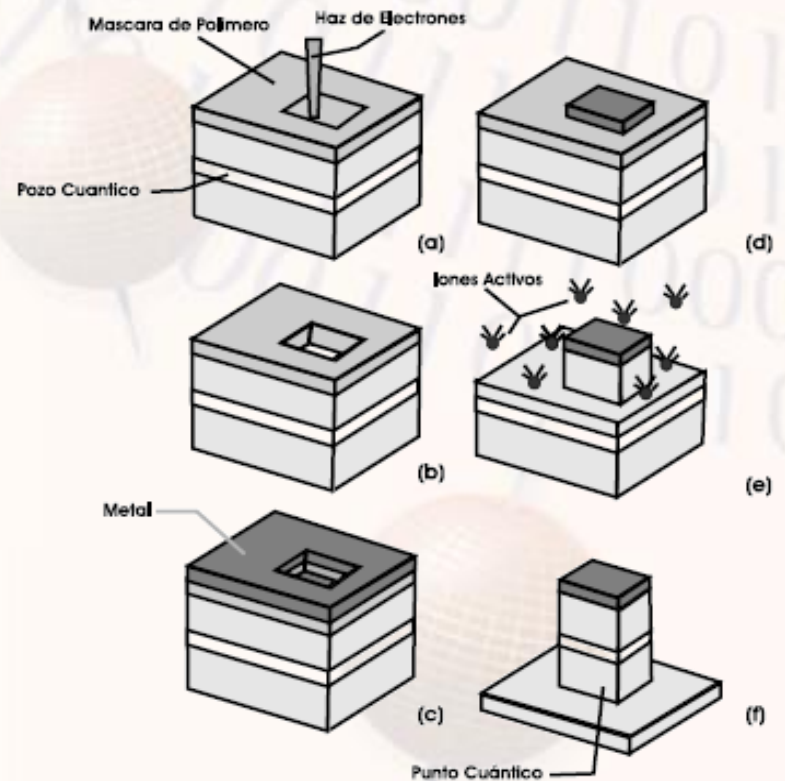
Tarucha, S. et al. Shell filling and spin effects in a few electron quantum dot.
Phys. Rev. Lett., 77:3613, 1996.

$$E_i = \frac{\hbar^2 n^2 \pi^2}{2\mu l_i^2},$$

3.1. FABRICACIÓN



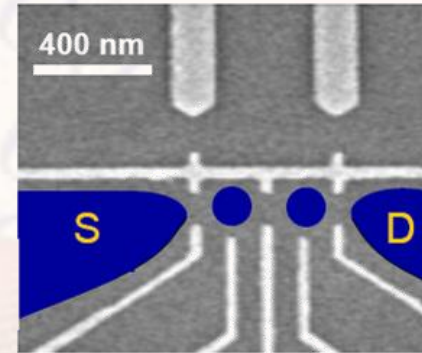
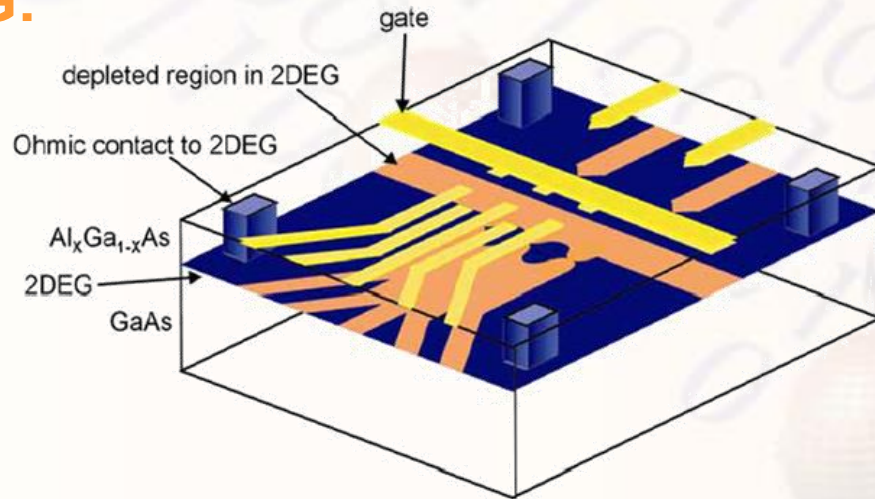
colloidal suspensions:
Louis E. Brus



Litografic: Mark
A. Reed

3.1. FABRICATION

2DEG:



Laurens Willems van Beveren and Ronald Hanson en NTT Basic Research Labs, Holland

