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From Discovery to Innovation...

NANOSCIENCE IN SEMICONDUCTORS

IUPAP NANOSCIENCE WORKING GROUP COMMISSION ON SEMICONDUCTORS C8

**PAWEL HAWRYLAK
INSTITUTE FOR MICROSTRUCTURAL SCIENCES
NATIONAL RESEARCH COUNCIL OF CANADA
OTTAWA, K1A0R6, CANADA**



National Research
Council Canada

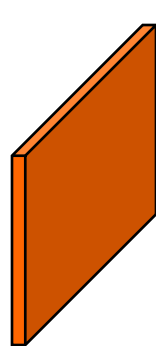
Conseil national
de recherches Canada

Canada

NANOSCIENCE IN SEMICONDUCTORS

VOCABULARY

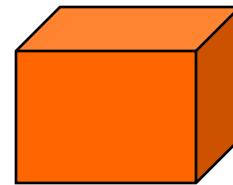
SEMICONDUCTOR NANOSTRUCTURES
AT LEAST ONE DIMENSION \sim nm
QUANTUM DOT \sim 3dim \sim nm



2D



1D



0D

COMMISSION ON SEMICONDUCTORS C8

Chair: SAKAKI, HIROYUKI (2005)

**Institute of Industrial Science University of Tokyo,
Tokyo, JAPAN**

NANOSCALE (QDOT) LASER 1982

Vice Chair: VAN DE WALL, CHRIS (2005)

**Materials Department, University of California
Santa Barbara, USA**

ATOMISTIC STRUCTURE OF MATERIALS

Secretary: HAWRYLAK, PAWEL (2005) (2002)

**Institute for Microstructural Sciences
National Research Council of Canada,
Ottawa, CANADA**

NANOSCALE SEMICONDUCTOR STRUCTURES

COMMISSION ON SEMICONDUCTORS C8

BLOCH, JACQUELINE (2005)

**Laboratoire de Photonique et de Nanostructures,
LPN/CNRS, MARCOUSSIS
FRANCE**

CALLEJA, JOSE M (2005)

**Departamento de Fisica de Materiales
C-IV Universidad Autonoma de Madrid, Cantoblanco
SPAIN**

GERSHONI, DAVID (2005)

**The Physics Department Technion Haifa
Israel**

KLITZING, KLAUS VON (2005) (2002)

**Max-Planck-Institut, Stuttgart
GERMANY**

KUKUSHKIN, IGOR (2005)

**Institute of Solid State Physics,
Russian Academy of Sciences
Chernogolovka, RUSSIA**

LEE, SEUNG JOO (2005)

**QSRC, Dongguk University,
Jung-Gu, Seoul 100-715
KOREA**

MEDEIROS-RIBEIRO, GILBERTO (2005)

**Laboratorio Nacional de Luz Sincrotron-LNLS
Campinas, SP BRAZIL**

NICHOLAS, ROBIN (2005)

**University of Oxford Clarendon Lab.
Physics Department, Oxford, UK**

ROSSI, FAUSTO (2005)

**Dipartimento di Fisica, Politecnico di Torino
10129 Torino
ITALY**

SAMUELSON, LARS (2005)

**Lund University,
NanoStructure Consortium
SWEDEN**

Mandate

To promote the exchange of information and views among the members of the international scientific community in the general field of **Semiconductor Physics** including:

- **electronic states, lattice dynamics and properties of matter in bulk at surfaces and interfaces, and in systems of reduced dimensionality**
(in collaboration with other commissions as appropriate);
- **defects, imperfections, impurities and amorphous semiconductors;**
- **application of semiconductor physics to technology.**

COMMISSION ON SEMICONDUCTORS MEETINGS

Meetings

2006 28th International Conference on the Physics of Semiconductors
4th International Conference on Semiconductor Quantum Dots

2005 12th International Conference on Modulated Semiconductor Structures
12th International Conference on HVI Semiconductors
21th International Conference on Amorphous and Nanocrystalline Semiconductors

2004 3rd Int. Conf. on the Physics and Chemistry of Quantum Dots QD2004
27th Int. Conf. on the Physics of Semiconductors - ICPS2004
13th Int. Conf. on Nonequilibrium Carrier Dynamics in Semiconductors/ Hot Carriers
20th Int. Conf. on Amorphous and Microcrystalline Semiconductors - ICAMS 20

2002 26th Int. Conf. on the Physics of Semiconductors

2001 C8.1 Electronic Properties of Two-Dimensional Systems

2000 C8.1 25th Int'l. Conf. on the Physics of Semiconductors

COMMISSION ON SEMICONDUCTORS MEETINGS

Meetings

2006 28th International Conference on the Physics of Semiconductors

80% devoted to Nanoscale Semiconductor Structures


Other meetings:

STM+NANO – Basel2006

- ~1500 participants

- Merging

- Support IUVSTA (Intl Union of Vacuum S&T)



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NANOSCIENCE IN SEMICONDUCTORS



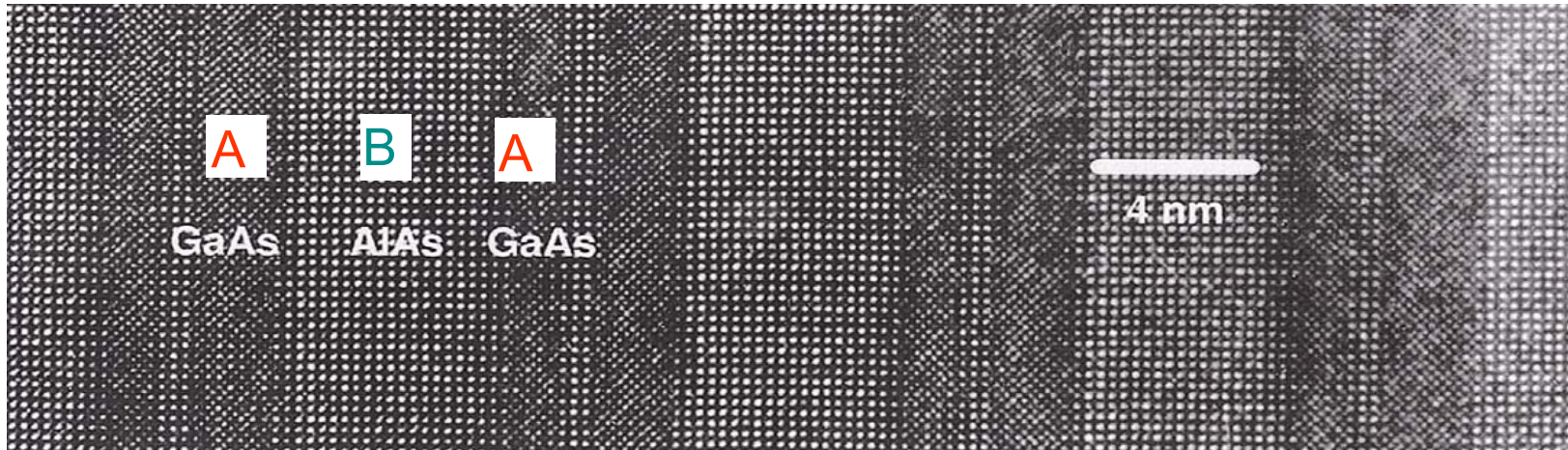
National Research
Council Canada

Conseil national
de recherches Canada

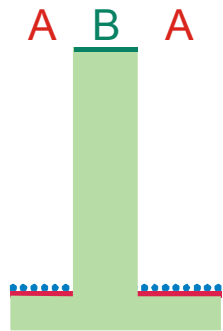
Canada

DIFFERENT LAYER SEQUENCES

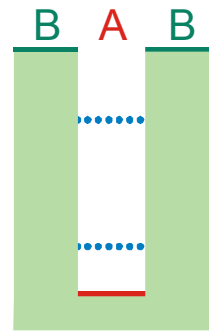
DIFFERENT DEVICES



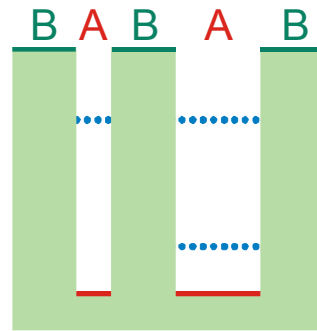
tunnel barrier



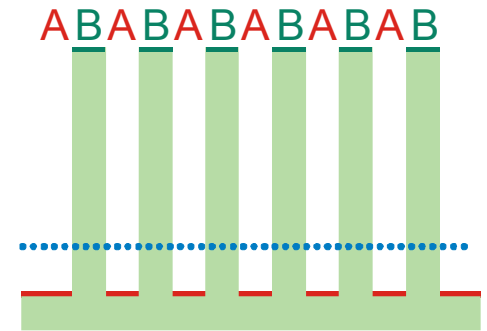
quantum well



cascade laser



superlattice, Bragg mirror



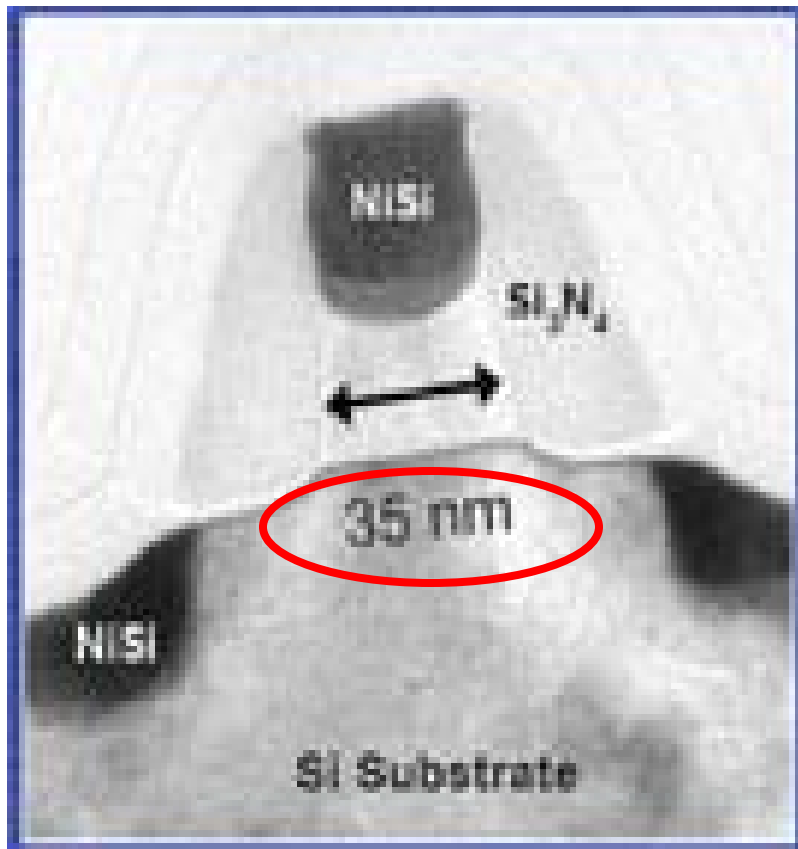
"forbidden region" for electrons



allowed electron states

NANOSCALE SEMICONDUCTOR STRUCTURES

INTEL-Si transistor

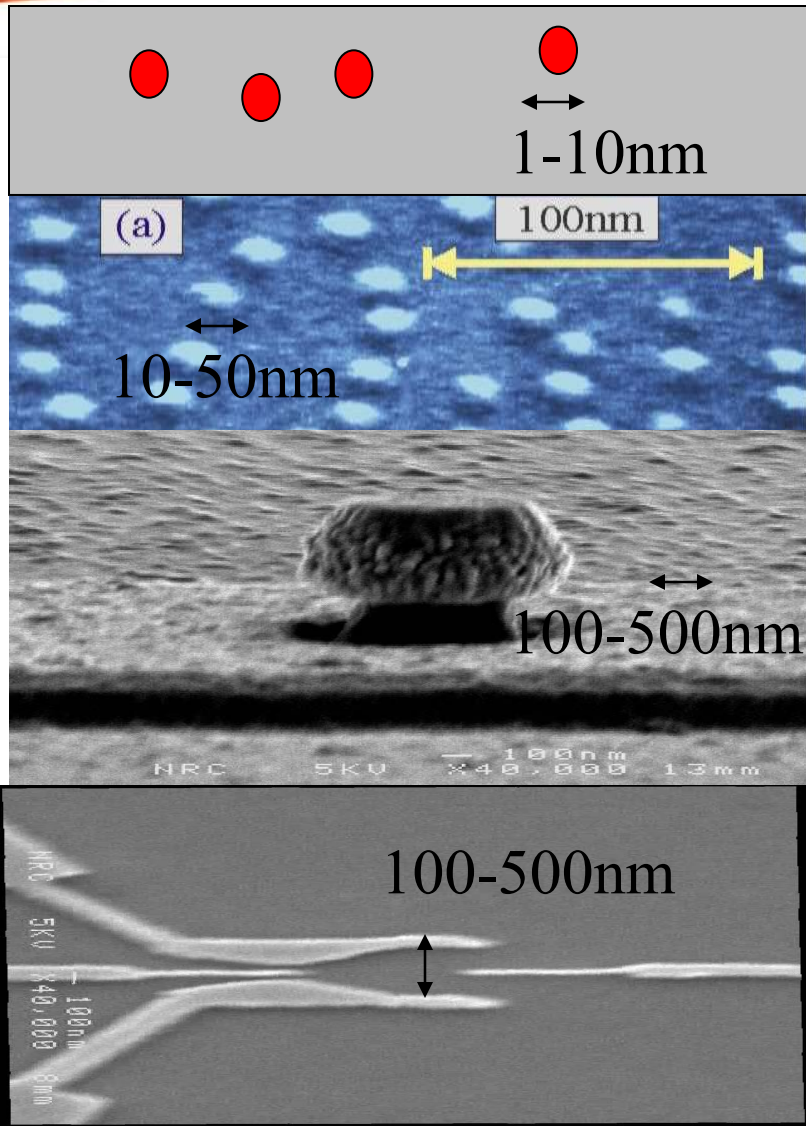


**Top down technology:
etching/strain,
complex geometry,
complex materials**

nano-electronics?

**SEMICONDUCTOR INDUSTRY
GOES NANO**

NANOSCALE SEMICONDUCTOR STRUCTURES



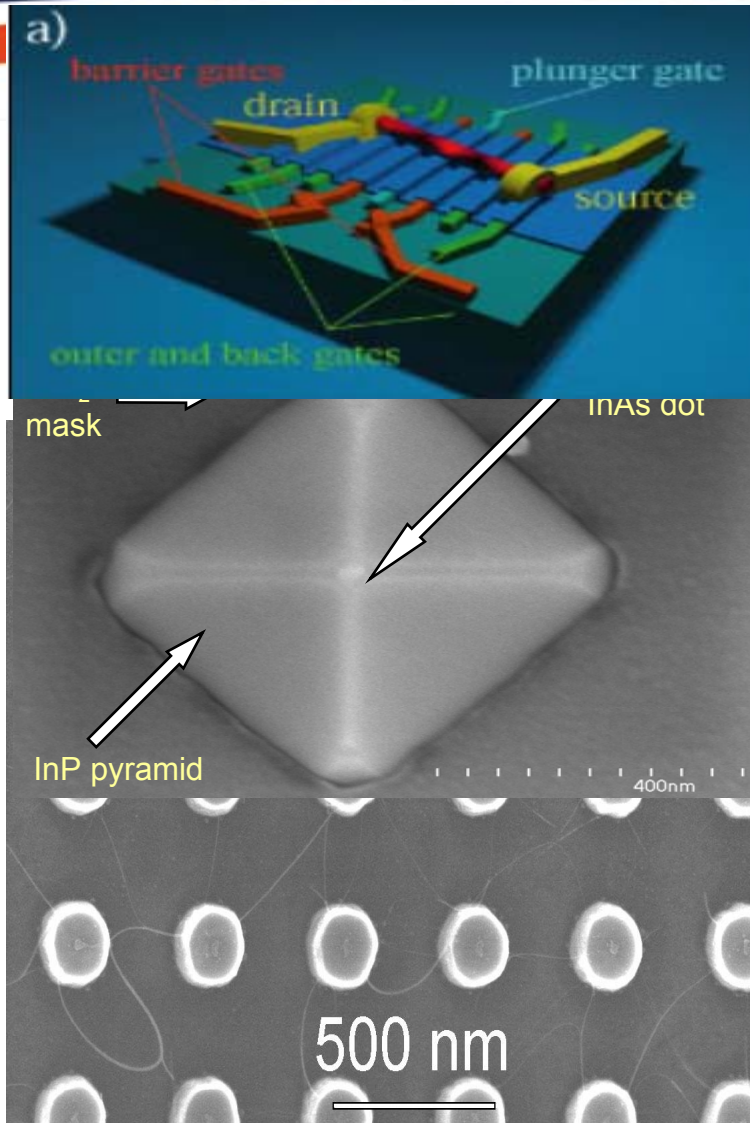
Nanocrystals-chemically driven self-assembly: excitons, nano-biology

Atom by atom strain driven self-assembly(IMS,...):
excitons, nano-photonics

Etching/electrostatically assembled electron droplet (IMS,Tokyo):
nano-electronics, quantum information

One electron at a time electrostatically assembled electron droplet, spin polarised injection/detection:electrons,
IMS,Harvard,MIT,Delft,Munich,MPI Stuttgart,...nano-spintronics

NANOSCALE SEMICONDUCTOR STRUCTURES

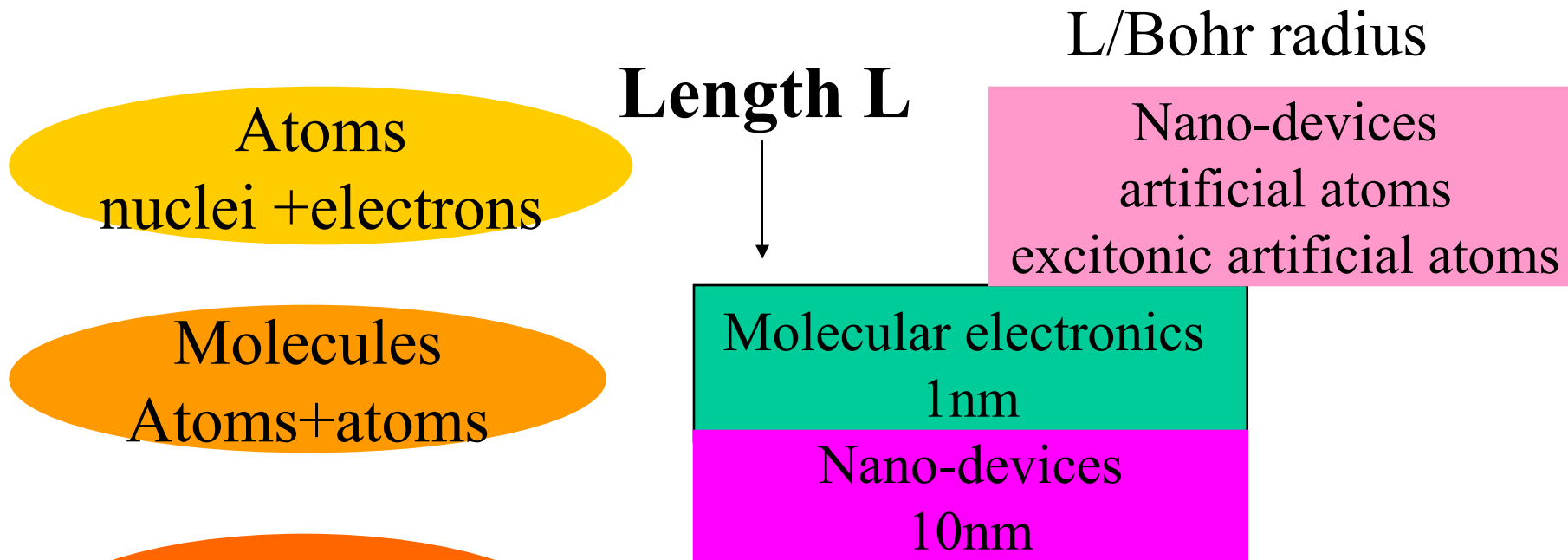


Seeded self-assembly-nanorods (Lund)
nano-electronics

Directed self-assembly (IMS)
nano-electronics, nano-photonics,
quantum information

Carbon nanotubes (IMS)
Nano-photonics

NANOSCALE SEMICONDUCTOR STRUCTURES

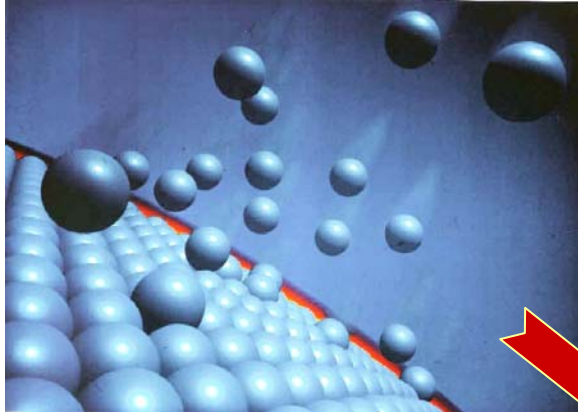


Design quantum systems at many-particle level

Quantum Hardware on a chip?

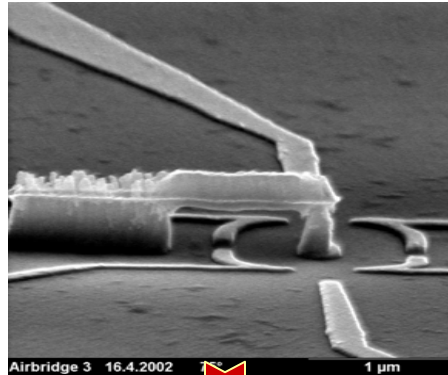
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atomically precise growth (MBE)



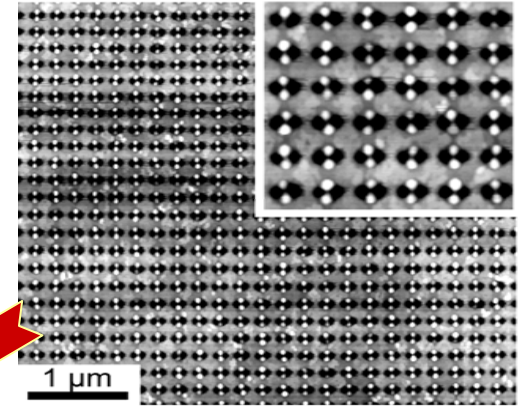
lithography

e-beam down to few nm

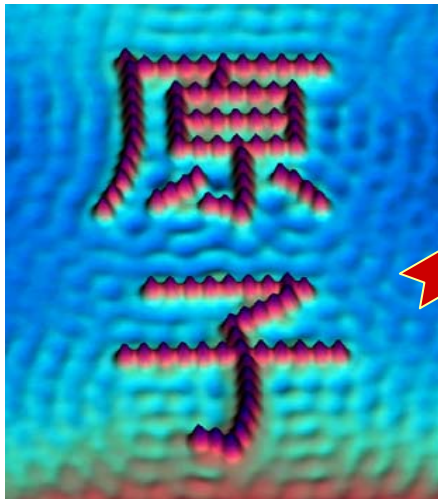


self-organized growth

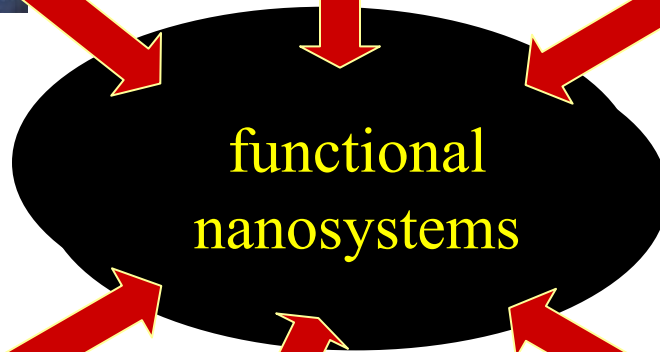
quantum molecules



K.von Klitzing

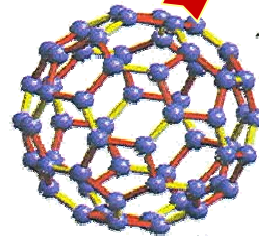


atom manipulation

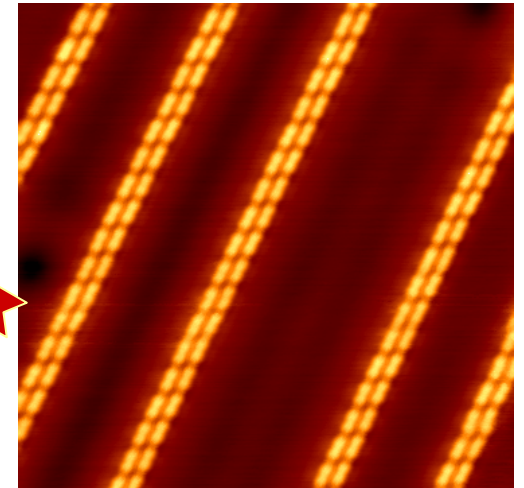


top-down

bottom-up

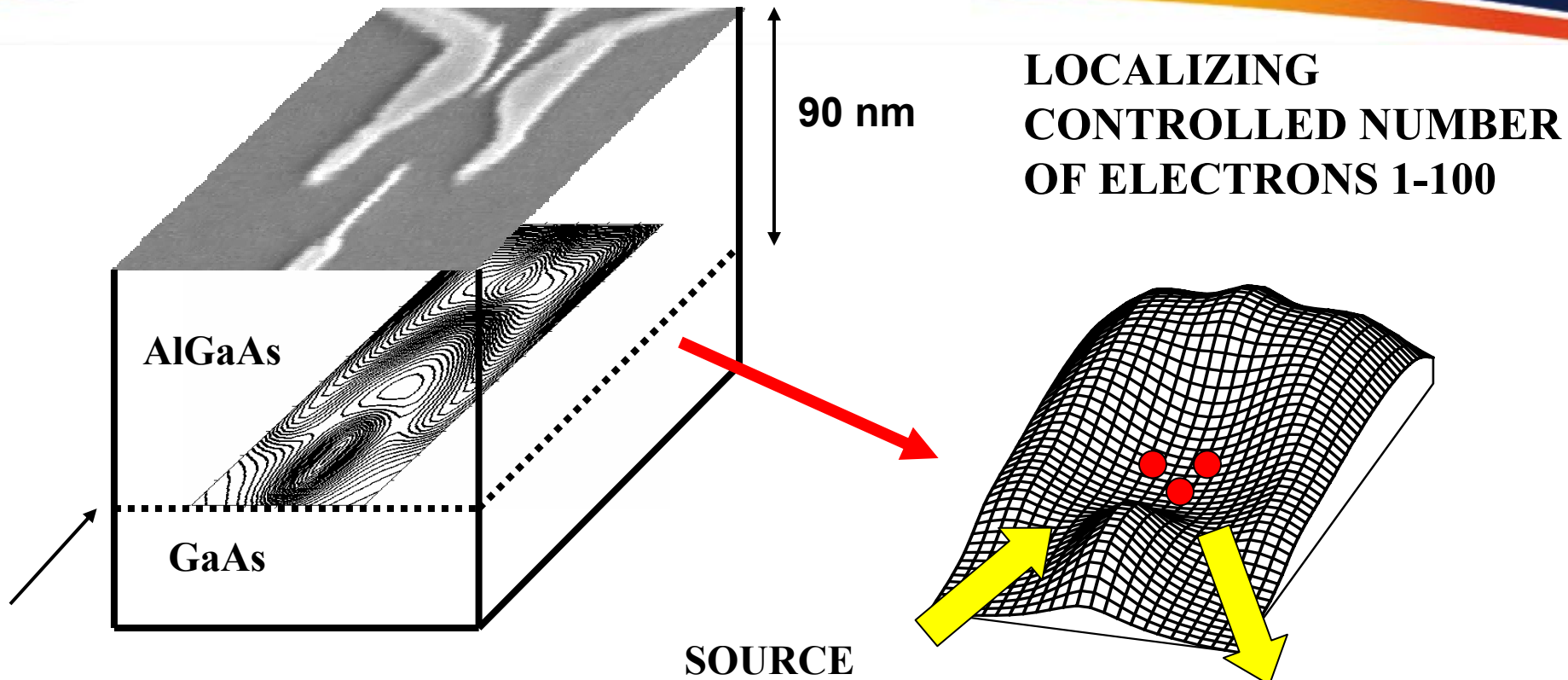


molecular systems



self-assembly

CONTROLLING ELECTRON IN NANOSCALE SEMICONDUCTORS-ARTIFICIAL ATOMS (C15)



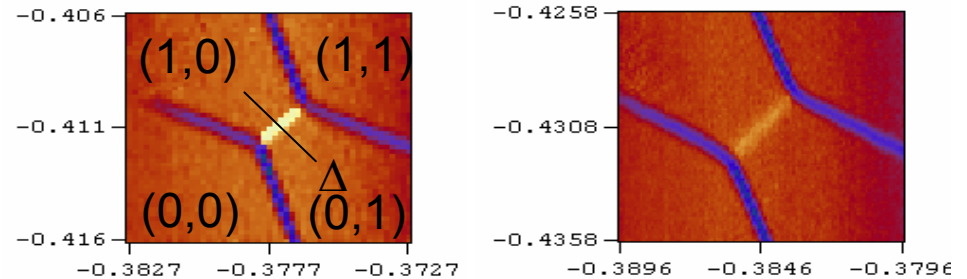
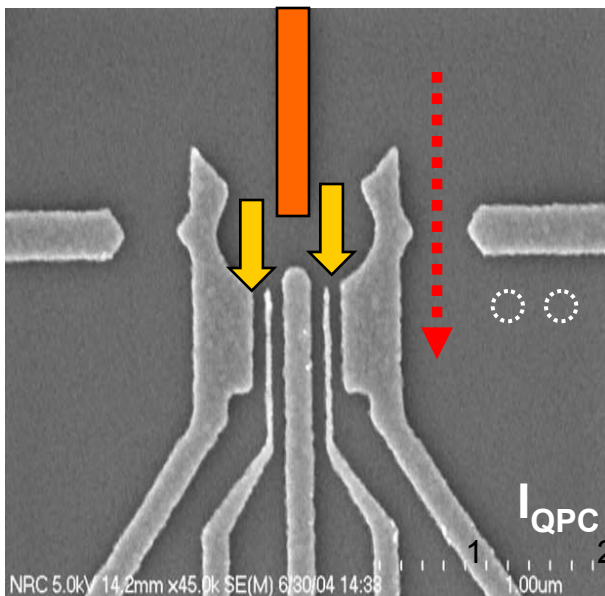
2D electron gas at GaAs/AlGaAs

A.Sachrajda, M.Ciorga, ...PH
Phys.Rev.B 1999, 2000

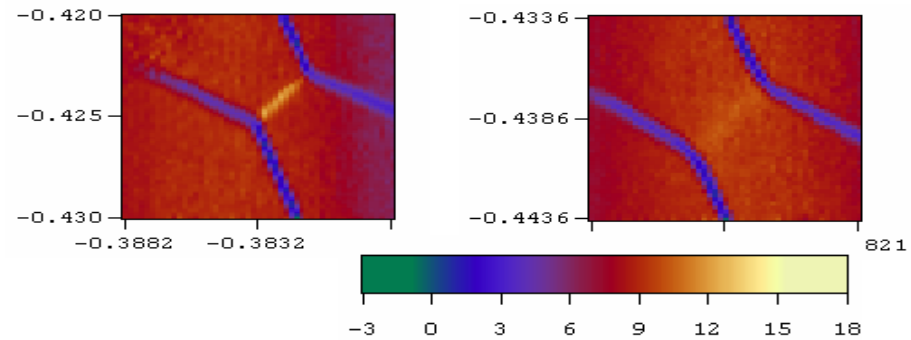
POTENTIAL ENERGY LANDSCAPE
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CONTROLLING ELECTRON IN NANOSCALE SEMICONDUCTORS-ARTIFICIAL H⁺ MOLECULE (C15)

mK - LOW TEMPERATURE MEASUREMENTS



TUNING TUNELING BARRIER

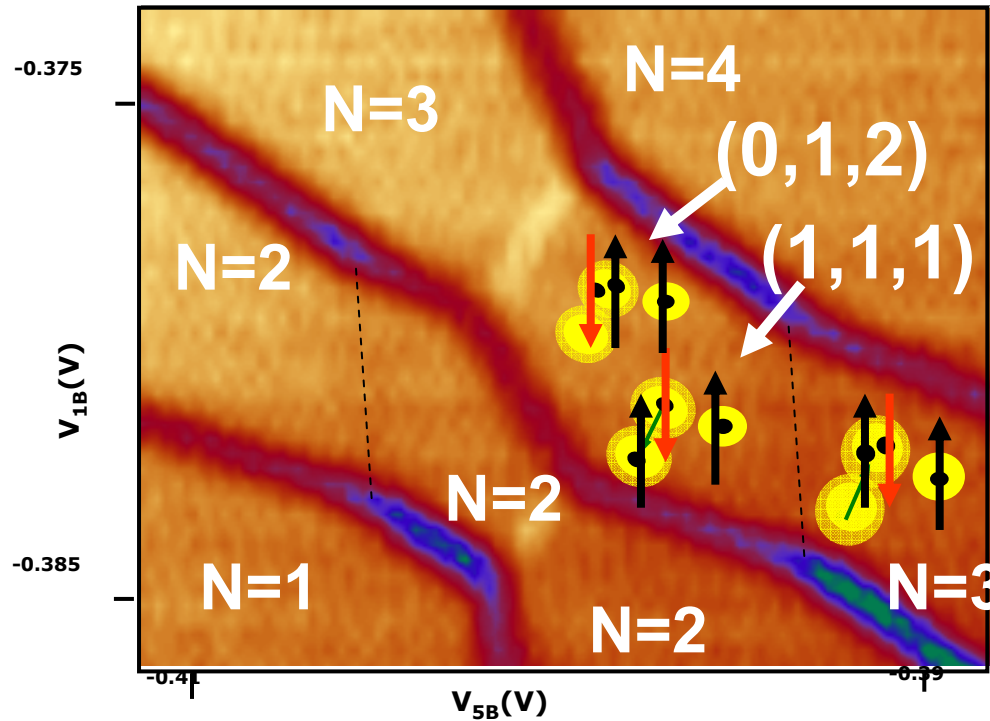
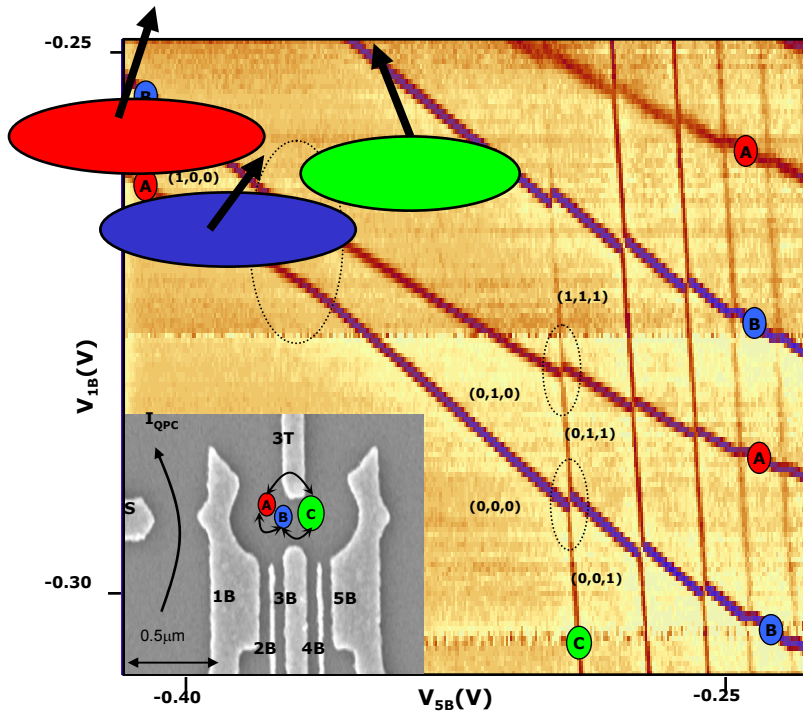


L.Kouwenhoven et al, Delft
S.Tarucha et al Tokyo
C.Marcus et al, Harvard
M.Heiblum et al, Weizman

A.Sachrajda, M.Pioro-Ladriere, PH, Ottawa

TOWARDS ARTIFICIAL SOLID TRIPLE QUANTUM DOT

Hubbard Model – building artificial solids



BUILDING ELECTRON SPIN BASED QUANTUM COMPUTER ONE ELECTRON AT A TIME

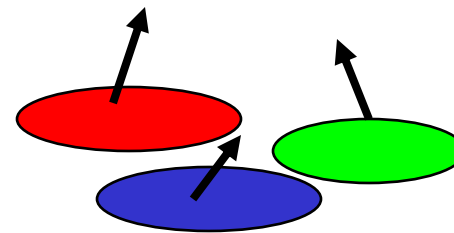
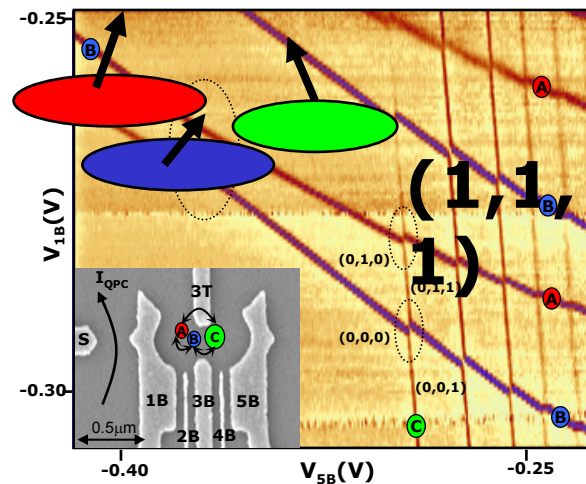
Model of QComputer : interacting qubits S

$$H = \sum \vec{S}_i \vec{B}_i + \sum \vec{S}_i J_{ij} \vec{S}_j$$

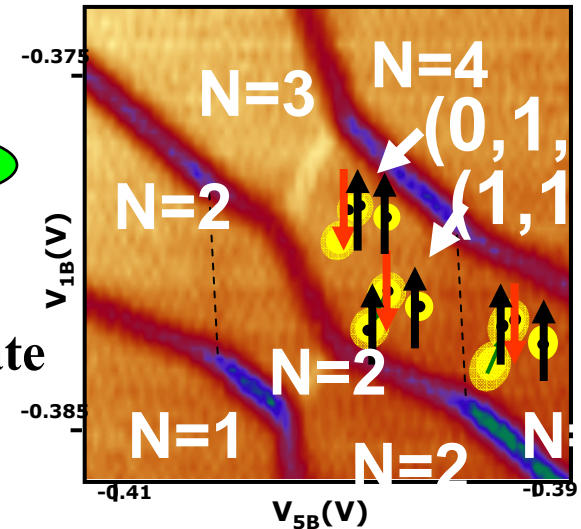
Effective qubit

local field

tunable entanglement J



GHZ entangled state
QTeleportation



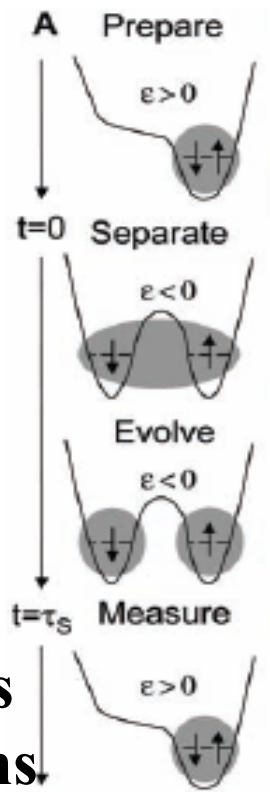
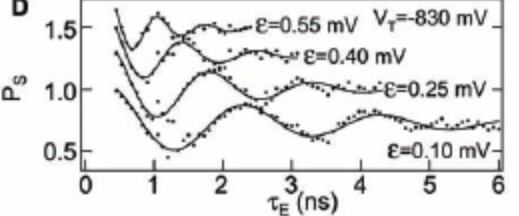
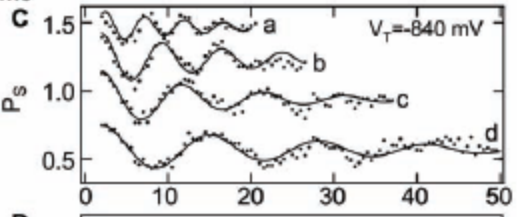
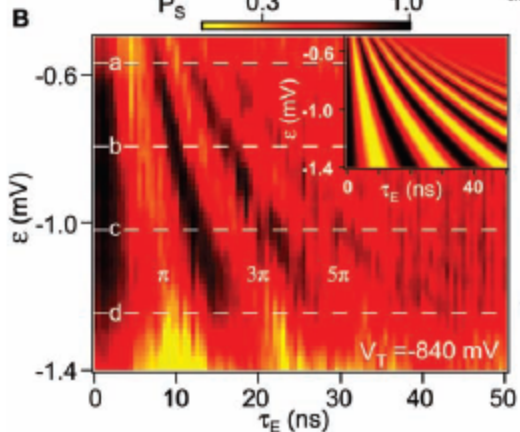
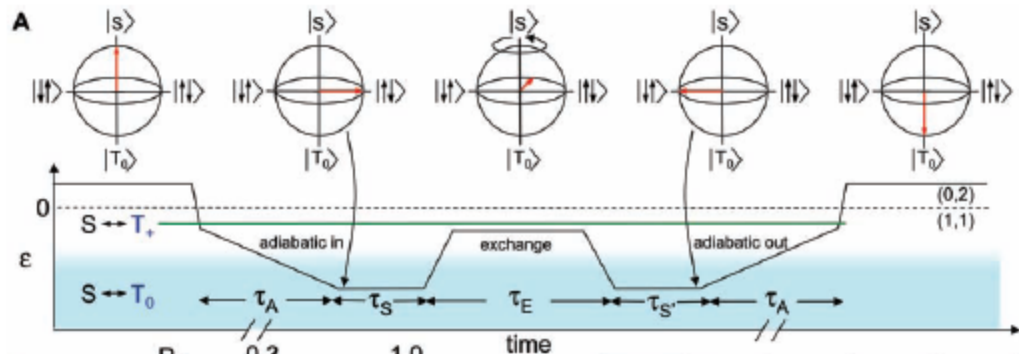
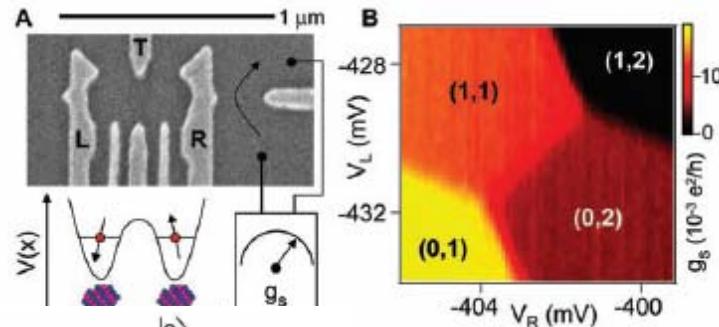
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QUANTUM OPTICS ON A CHIP

30 SEPTEMBER 2005 VOL 309 SCIENCE

Coherent Manipulation of Coupled Electron Spins in Semiconductor Quantum Dots

J. R. Petta,¹ A. C. Johnson,¹ J. M. Taylor,¹ E. A. Laird,¹ A. Yacoby,² M. D. Lukin,¹ C. M. Marcus,¹ M. P. Hanson,³ A. C. Gossard³



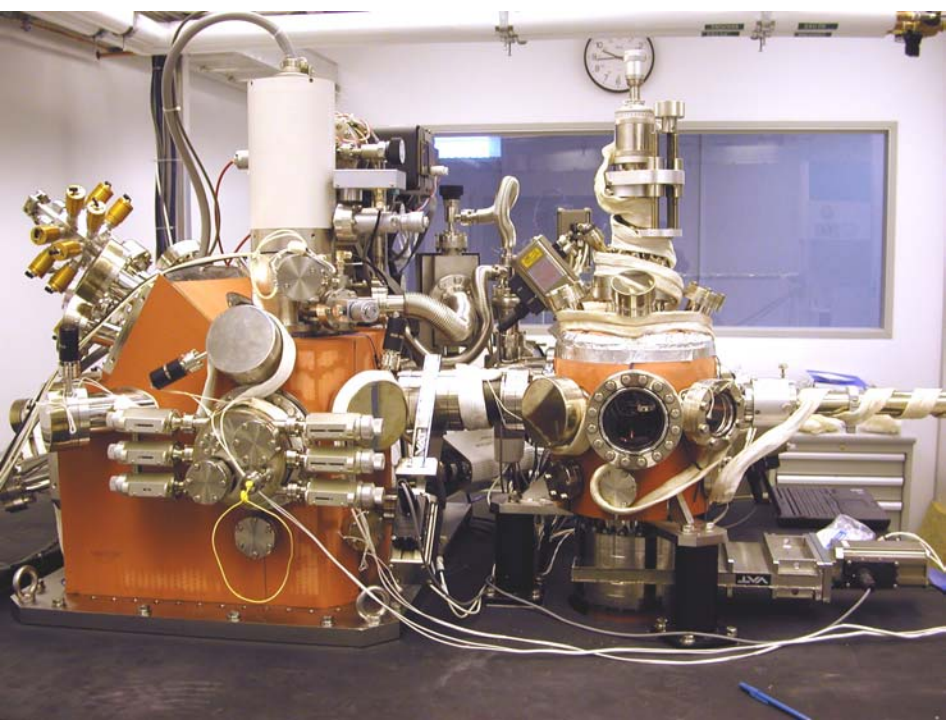
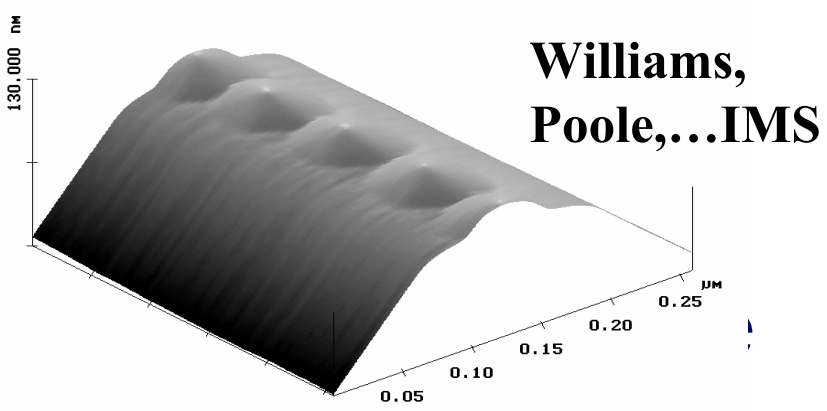
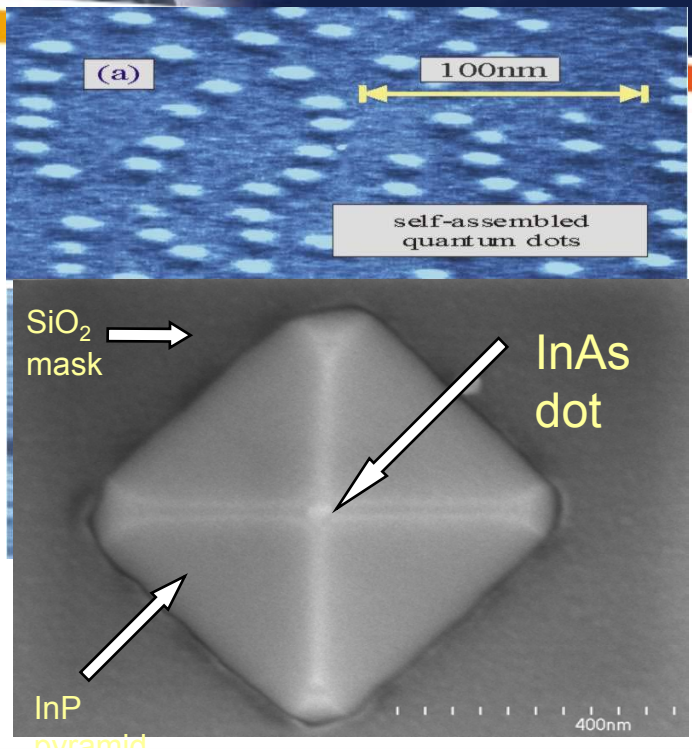
Swapping spins
Rabi oscillations
Quantum Optics
on a chip

GROWTH AND POSITIONING OF QDOTS EMITTING AT TELECOM WAVELENGTH

STRAIN DRIVEN
SELF-ASSEMBLY: InAs/GaAs

DIRECTED SELF-ASSEMBLY VIA
LITHOGRAPHY: InAs/InP at 1.5 μ m

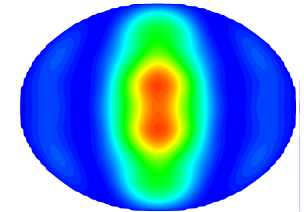
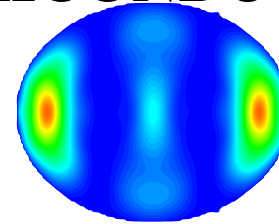
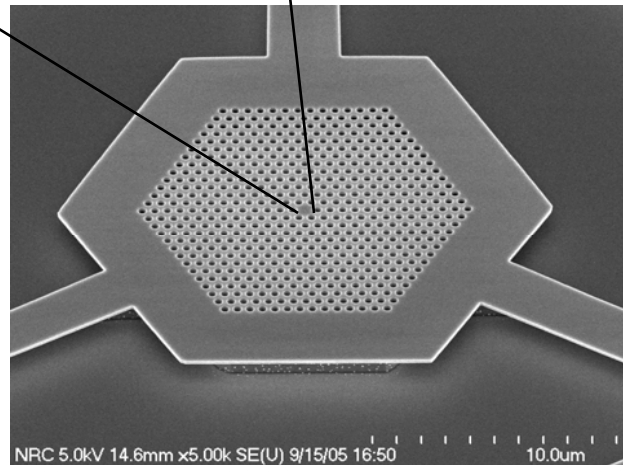
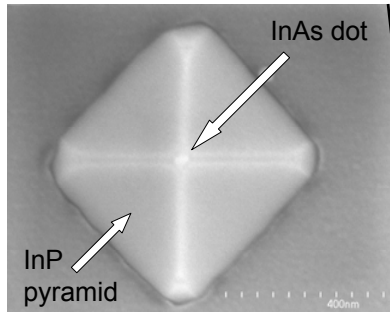
ARTIFICIAL ATOM FACTORY



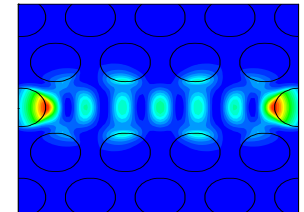
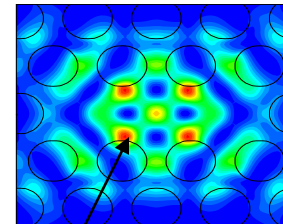
CONTROLLING LIGHT MATTER INTERACTION SINGLE QUANTUM DOT IN A CAVITY

Dalacu, Aers, Williams, Poole

QUANTUM OPTICS IN SEMICONDUCTORS



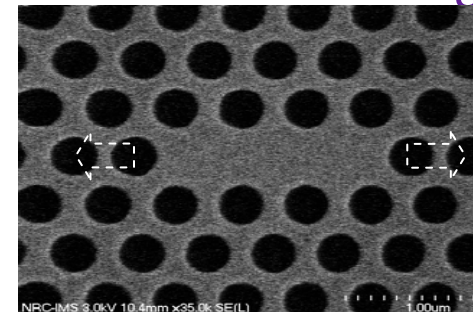
Tuning
Photon
Field
Inside
cavity



$Q > 8000$

sa

sa



**POSITIONING DOTS IN
E-FIELD MAXIMA**

MAGNETISM IN SEMICONDUCTORS SPINTRONICS DOWN TO ONE Mn ION

VOLUME 93, NUMBER 20

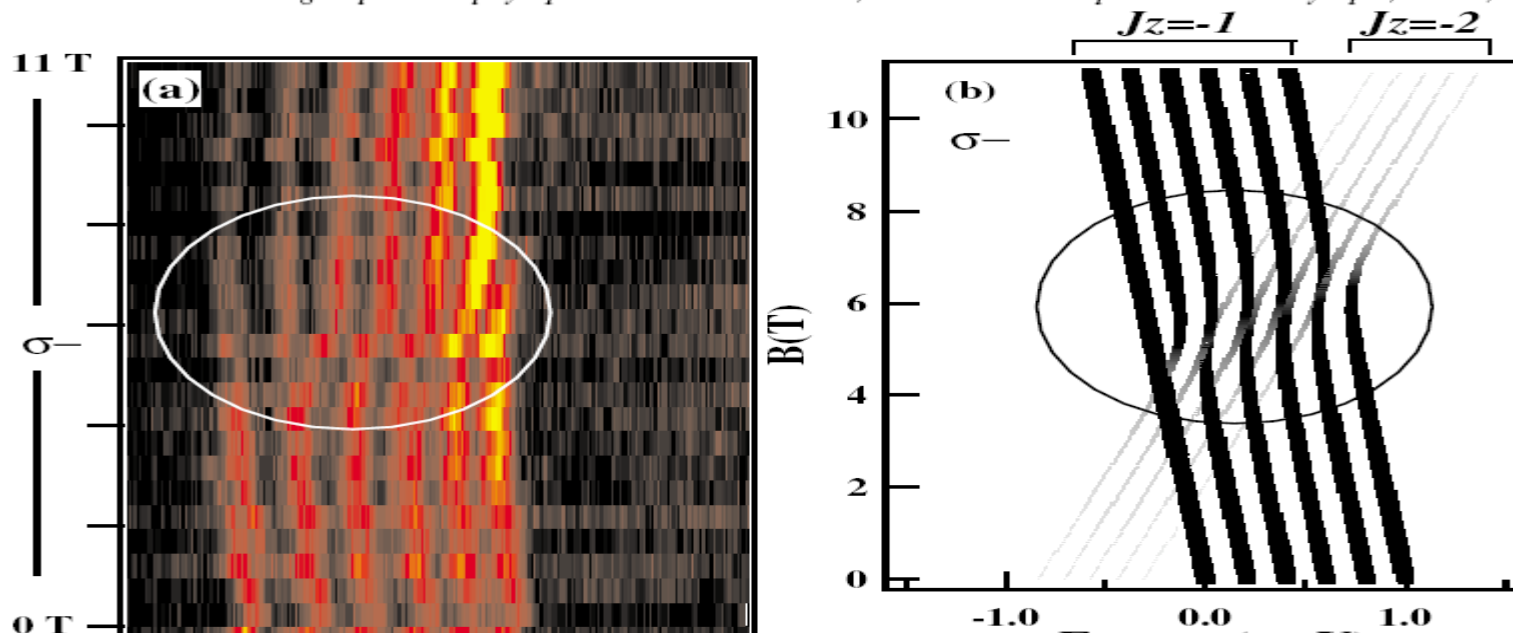
PHYSICAL REVIEW LETTERS

week ending
12 NOVEMBER 2004

Probing the Spin State of a Single Magnetic Ion in an Individual Quantum Dot

L. Besombes,* Y. Léger, L. Maingault, D. Ferrand, and H. Mariette

CEA-CNRS group "Nanophysique et Semiconducteurs", Laboratoire de Spectrométrie Physique, CNRS,



Mn ion $M=5/2$ 6 states

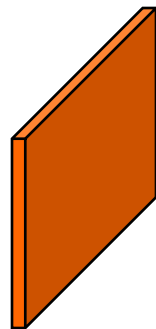
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NANOSCIENCE IN SEMICONDUCTORS

INTERDISCIPLINARY AND RIPE FOR INTER-COMMISSION COLLABORATION:

LOW TEMPERATURE
SOLIDS STATE
ATOMIC AND OPTICAL
MAGNETISM
BIOLOGICAL

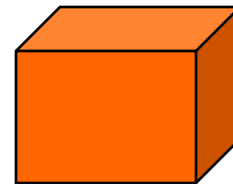
.....



2D



1D



0D