Overview of Nanoscience at the CEA

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Nano-science and Nanotechnologies @ CEA

- *Nano* as enabling technology for the technologies
  Bio – Info – Cogno and Energy and their convergence
  is central to CEA Strategic Objectives

Information technologies
Electronics industry

New technologies
For Energy

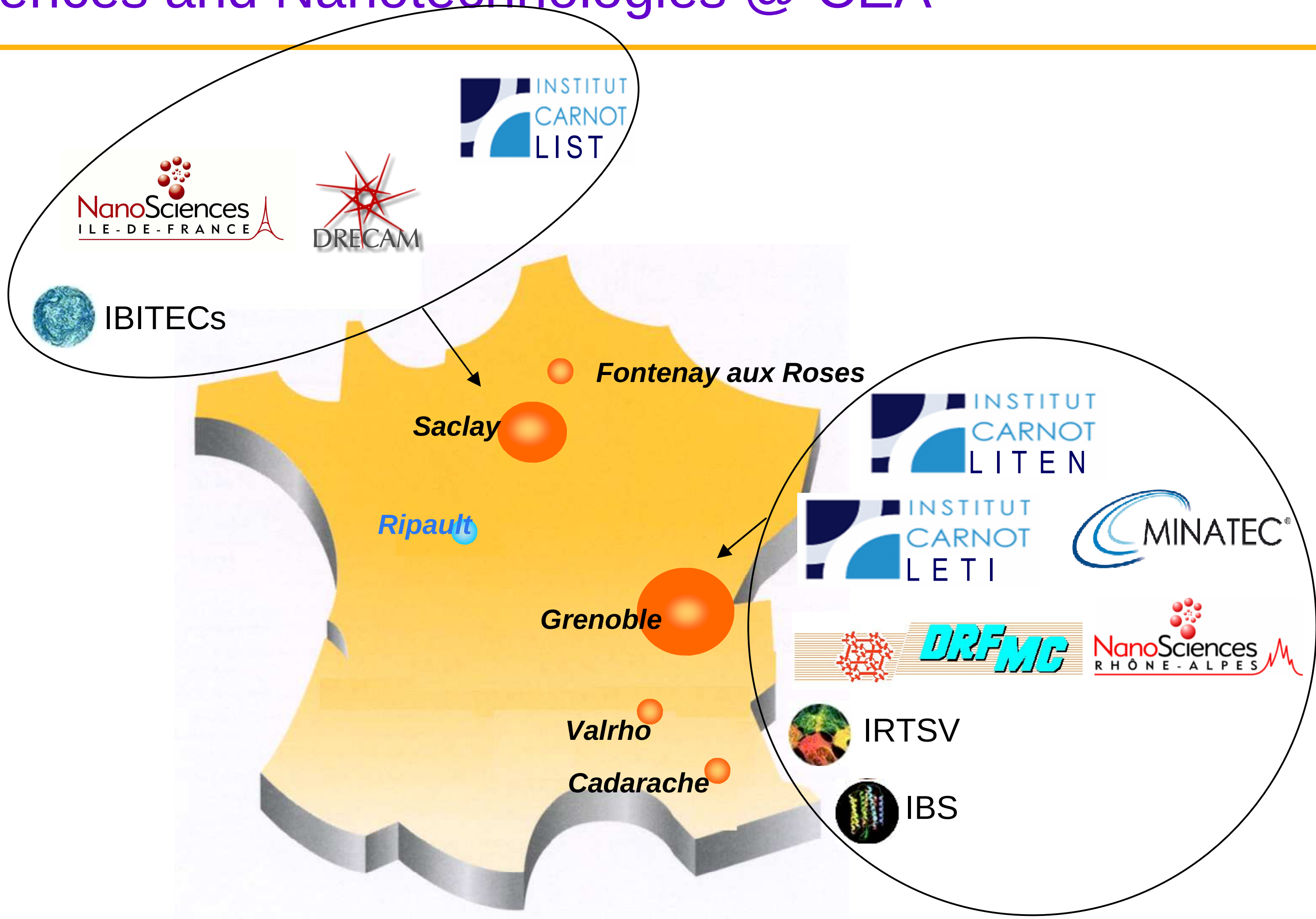
Health technologies

- A transverse capability involving the operational divisions of CEA operated **as a continuum from Science to Technology**

- 1900 people:
  800 in Nanoscience and 1250 in Nanotechnology

- Strong collaborations with CNRS and Universities
- Worldwide partnerships: Europe, US, China, Korea, Canada

Nanosciences and Nanotechnologies @ CEA



1900 people in Nano @ CEA ~250M€ budget 2006

The CEA Minatec Nano-Characterisation Centre

A leading edge nanocharacterisation centre in Europe :

100 researchers and students
40 characterisation tools
1 500 m² laboratories
15 M€ investment

8 Competence Centres :

- Scanning Probe Microscopy
- Electron microscopy
- X ray diffraction
- Ion beam analysis
- Mechanical tests
- Surface analysis
- Optical techniques
- Sample preparation

Material Science Research (CEA-DSM)

Technological Research (CEA-DRT)

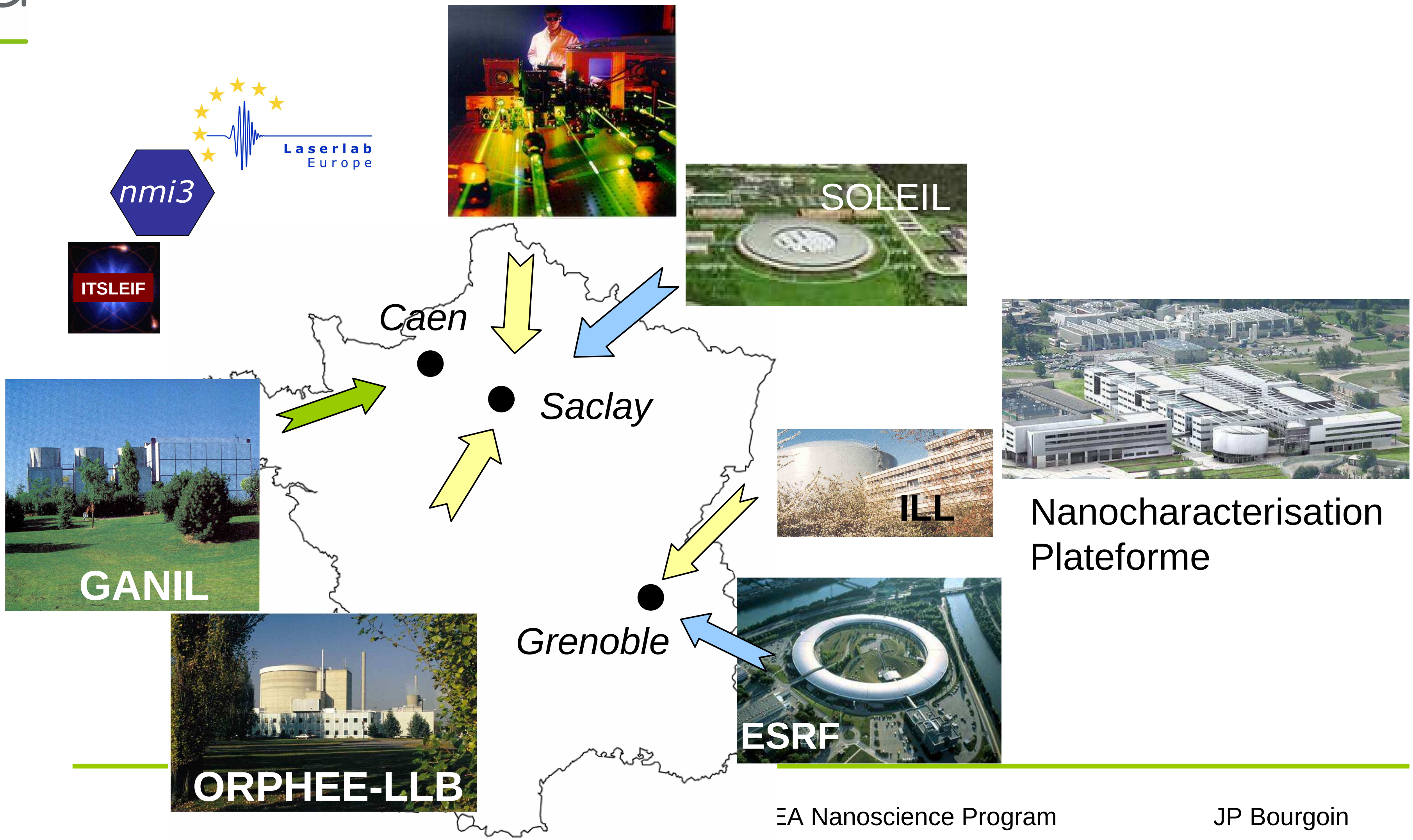
Service Supply for Industry

Partnership:

SERMA TECHNOLOGIES

Other facilities and infrastructures

– Networked Clean rooms in Saclay and Grenoble
– Large scale infrastructures for lasers, ions, neutrons, synchrotrons



Nanoscience: CEA's strategy

A synergy between discovery research and program oriented research: to answer nanotechnologies questions and enrich them with upstream science at the cutting edge.

- The transverse program : involves all CEA divisions, contributing to a continuum from Science to Technology
- Minatec (Grenoble) : an ecosystem integrating fundamental and applied research.

$\Rightarrow$

• Make teams from fundamental research and applied research work together: cooperative projects, joint teams

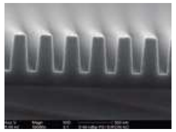
• Systematically seek potential applications

•Technological capabilities covering the continuum (example of nanodevices):

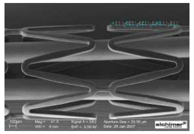
- Fast lithography for exploratory nanodevices within the flexible clean room at CEA Saclay/Grenoble centers
- 100 mm lithography facility 'PTA' with CNRS at Grenoble
- 200 and 300 mm Integration Technology Platform at LETI

From fundamental research to industrial applications

- 135 patents in nanoscience (DSM)
- 1200 patents in nanotechnology (LETI)
- Beside the alimentation of the innovation pipeline through the CEA technological research division, 11 Startups directly born from nanoscience in DSM

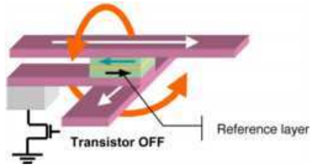


alchimer
coating solutions

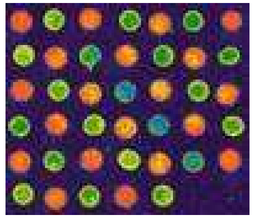


alchiMedics
coating solutions

PEGAS-TECH

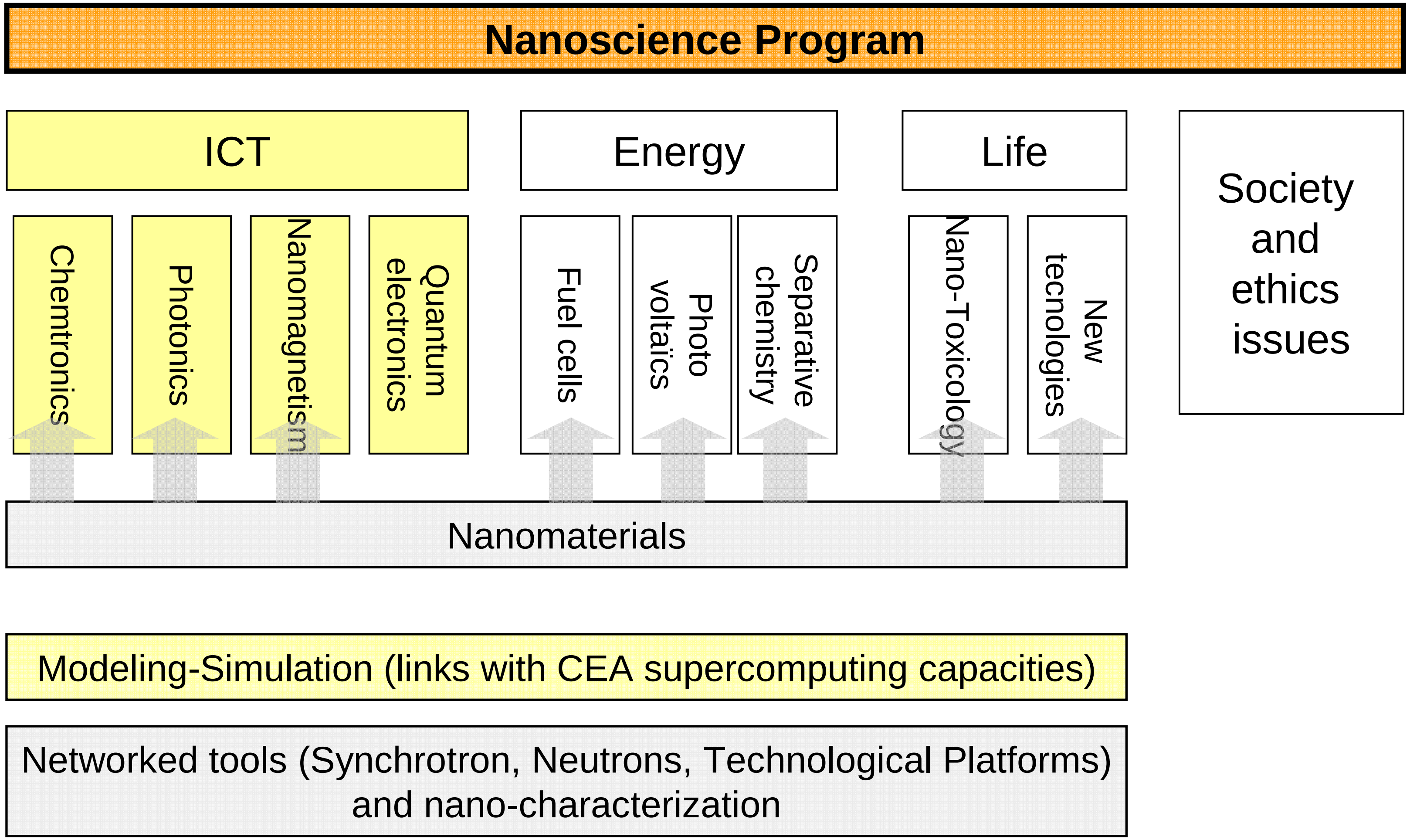


CROCUS Technology
Blossoming Future

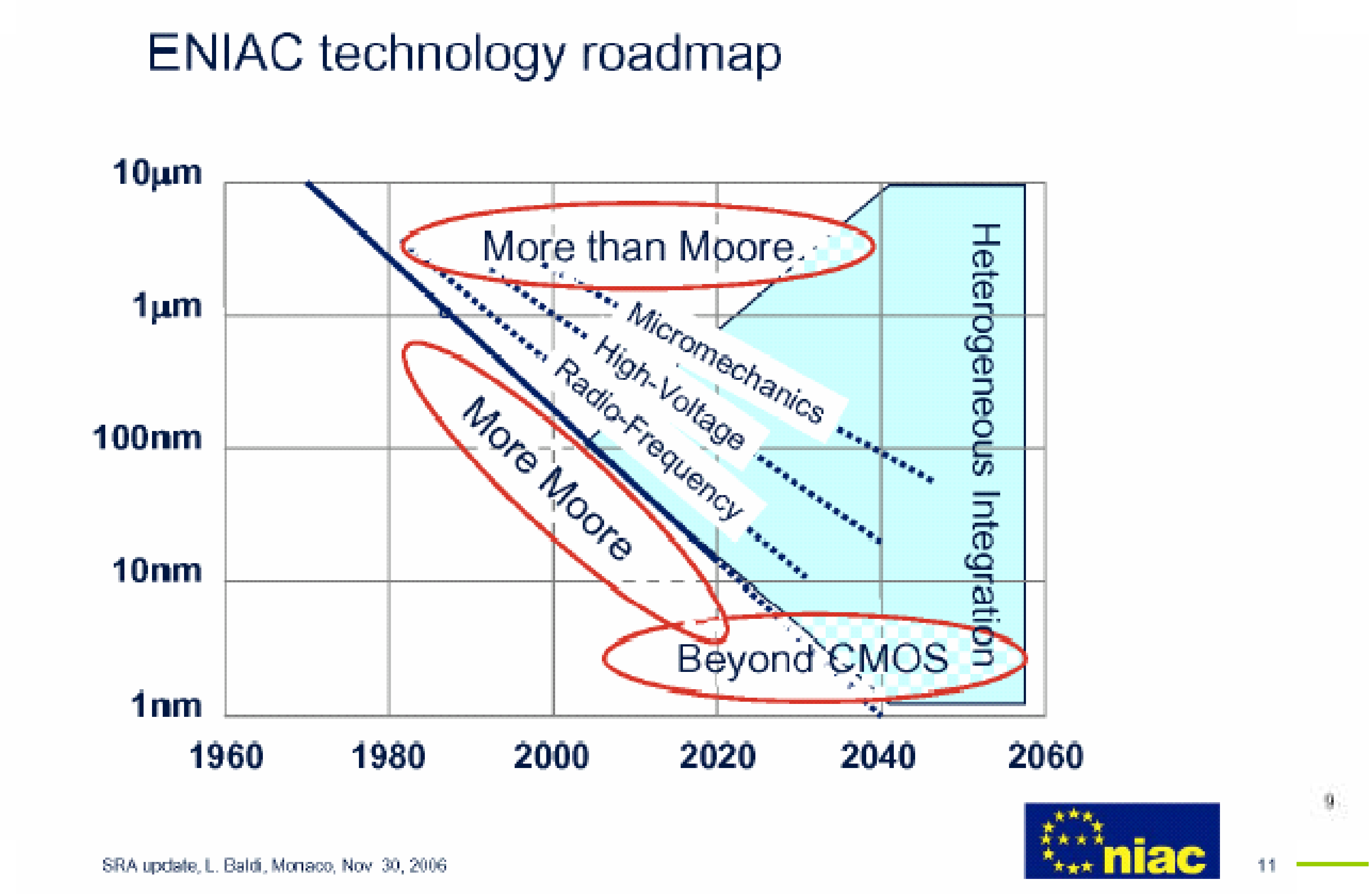


Cellabio search

Nanoscience @ CEA : organization



Around CMOS



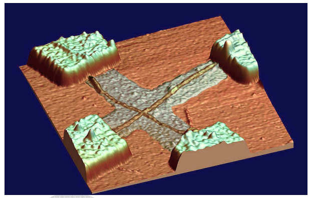
ENIAC technology roadmap
10µm
1µm
100nm
10nm
1nm
1960
1980
2000
2020
2040
2060
More than Moore
Micromechanics
High-Voltage
Radio-Frequency
More Moore
Beyond CMOS
Heterogeneous Integration
SRA update, L. Baldi, Monaco, Nov 30, 2006
niac
11

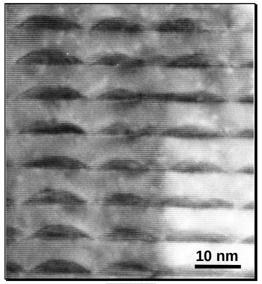
Nanoscience @ CEA: topics relevant for *CMOS and beyond*

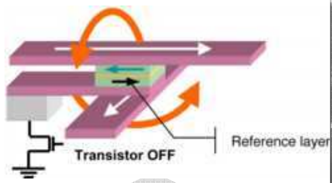
Nanoscience Program

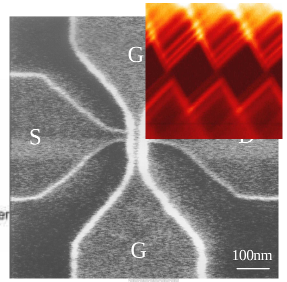
ICT

Chemtronics | Photonics | Nanomagnetism | Quantum electronics

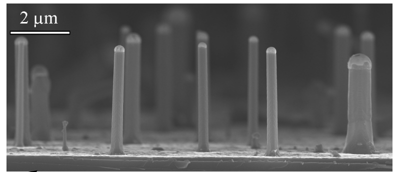




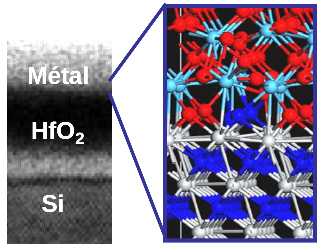




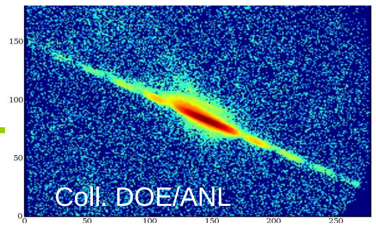
Nanomaterials



Modeling-Simulation (links with CEA supercomputing capacities)

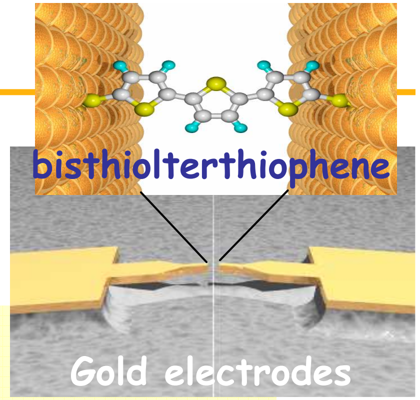


Characterization and Networked tools (X-rays, Neutrons, Technol. Platforms)

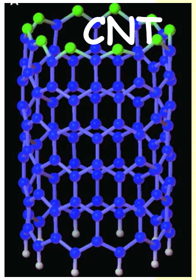


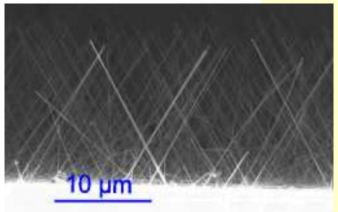
Chemtronics program

Chemtronics Program



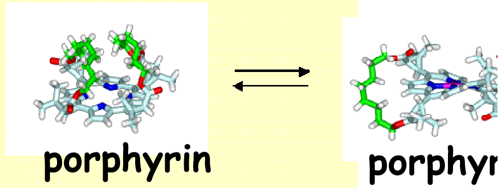
180 researchers in Grenoble and Saclay in 2007
expanding to 250 by 2010

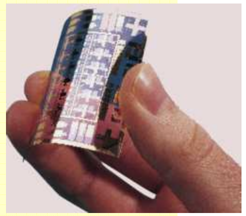




Chemistry for nanoelectronics

- **Molecular electronics**
  - Molecularr memories (bi-stable molecules)
  - Carbon nanotubes
  - Semi-conducting nanowires and QD
- **Flexible electronics** (polymers and composites)
- *Self-assembly*
- *nanosimulation and new architectures*
- *heterogeneous integration onto Silicon*



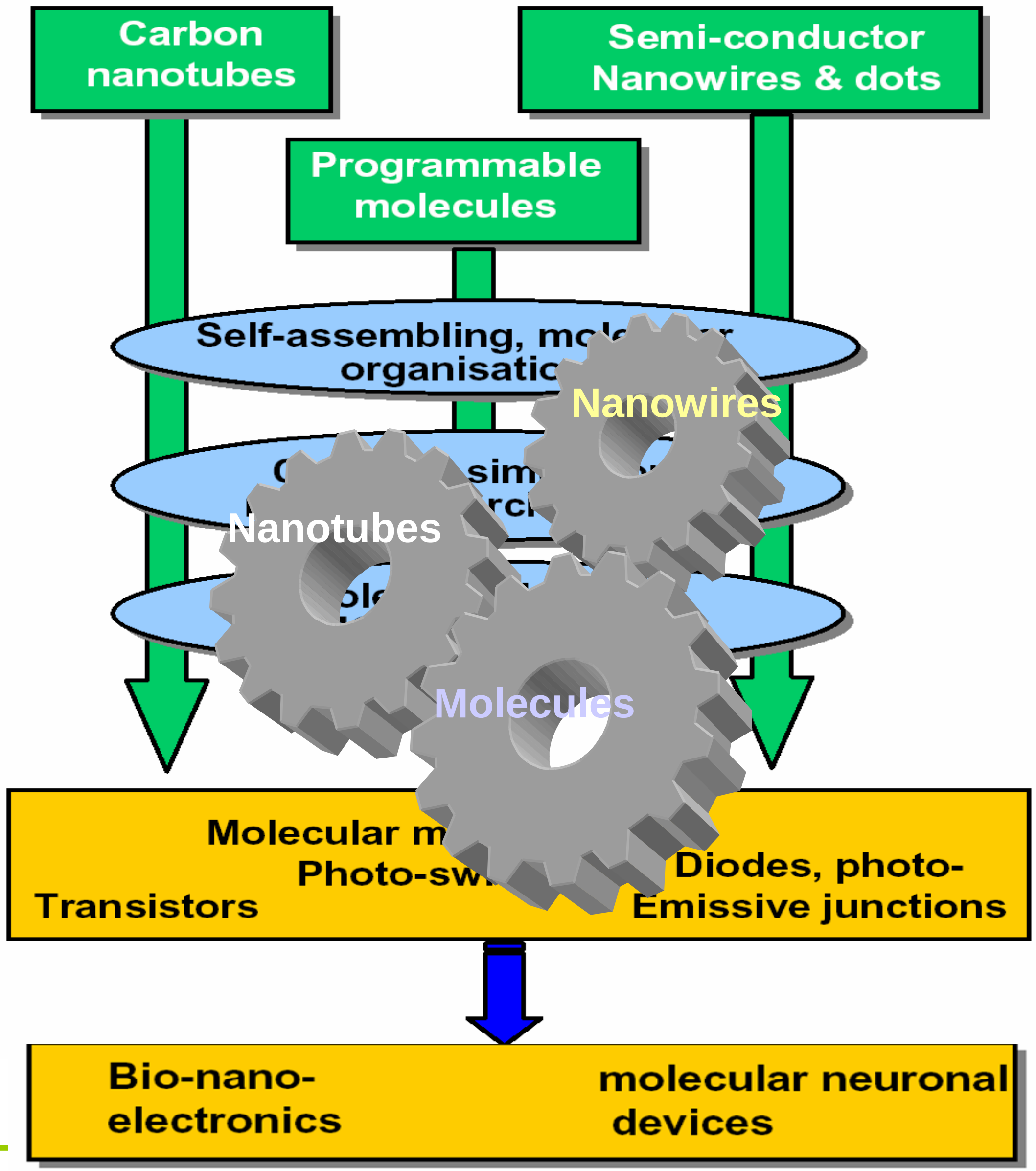


Robert.baptist@cea.fr et Serge.palacin@cea.fr

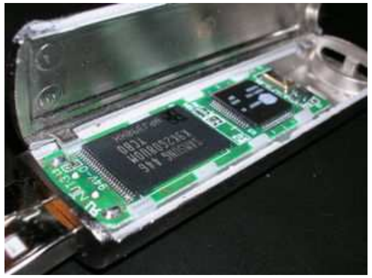
Chemtronics program Organization

Fundamental

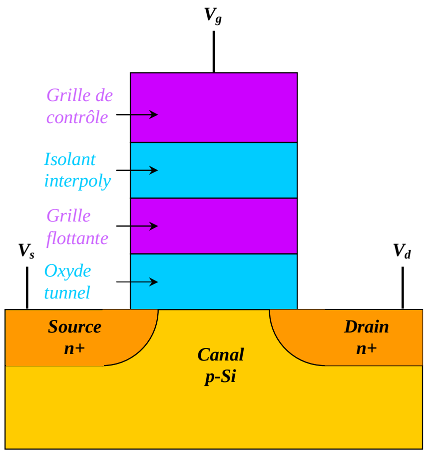
Applied



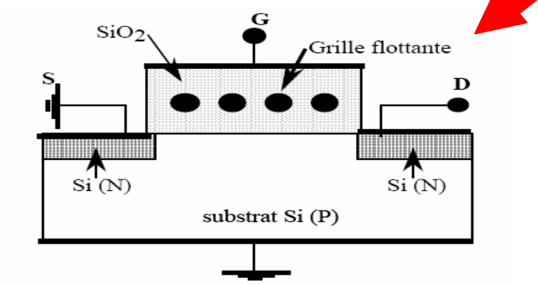
Flash memory miniaturisation



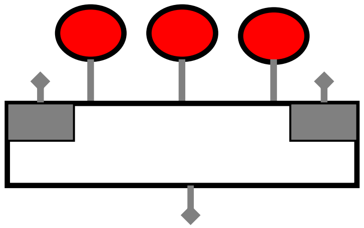
Current characterisitcs:
Prog Voltage: 15/20 V
Prog Time : 10µs/1ms
Retention time: 10 years
Cycling $>10^5$



Problems:
- Prog V too high
- tunnel oxide: too thin



Floating gate



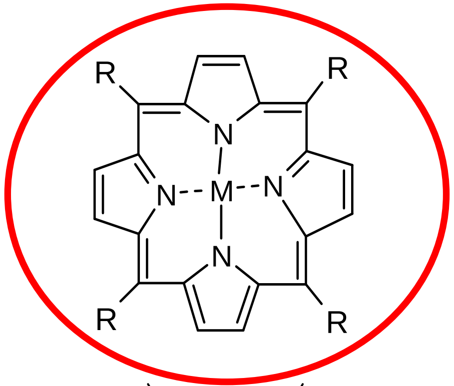
Molecules as discrete storage sites ?

Molecular memories: Interdisciplinarity

1- Choice of molecules

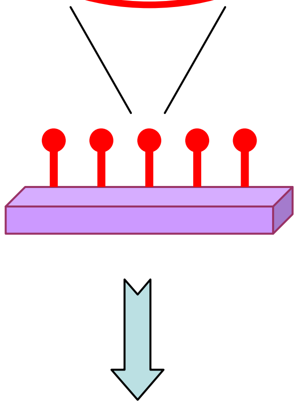
- Electroactive (redox)
- stable T℃ <400℃

Molecular Chemistry

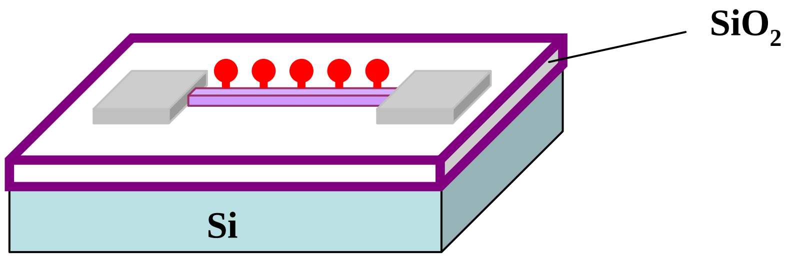


2- Choice of grafting
- Si-C covalent bond between molecule and surface
- Direct or indirect anchoring

Surface chemistry

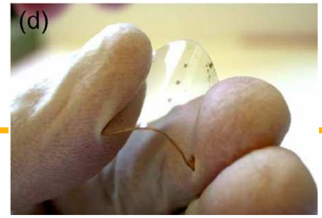


3- Choosing integration
- Nanowire memory



Microelectronics

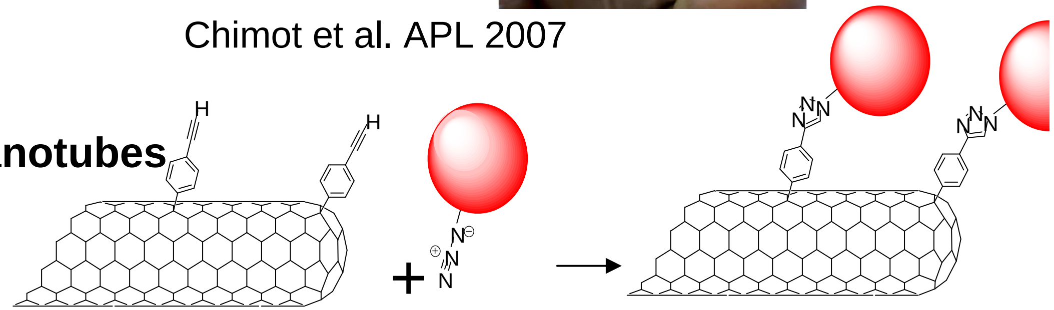
Chemtronics Highlights 2007



- **GHz frequency flexible carbon nanotubes transistors**

Chimot et al. APL 2007

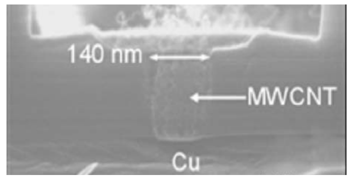
- **Click-chemistry onto carbon nanotubes**



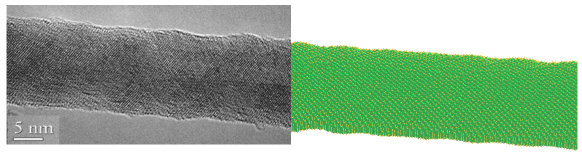
Campidelli et al. JACS 2007 in press

- **20Ω nanotubes interconnects**

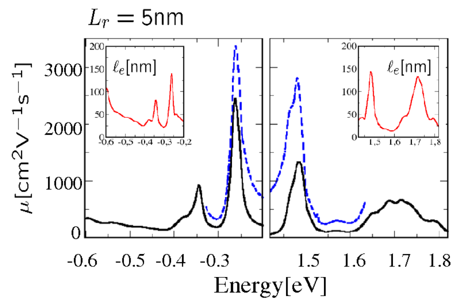
Coiffic et al.
Nanoletters 2008



- **Simulation of the influence of the rugosity onto the transport properties of Si NWs**

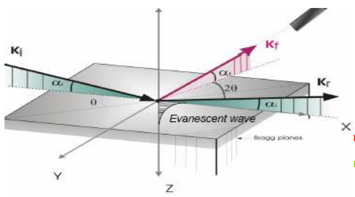


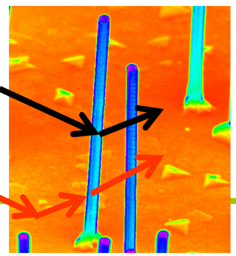
- **X-Rays characterization of InAs NWs**

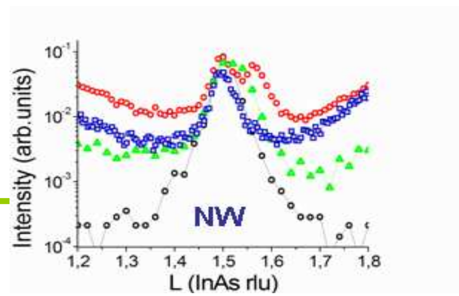


Y.M. Niquet PRL 2007

J. Eymery et al. Nanoletters 2007

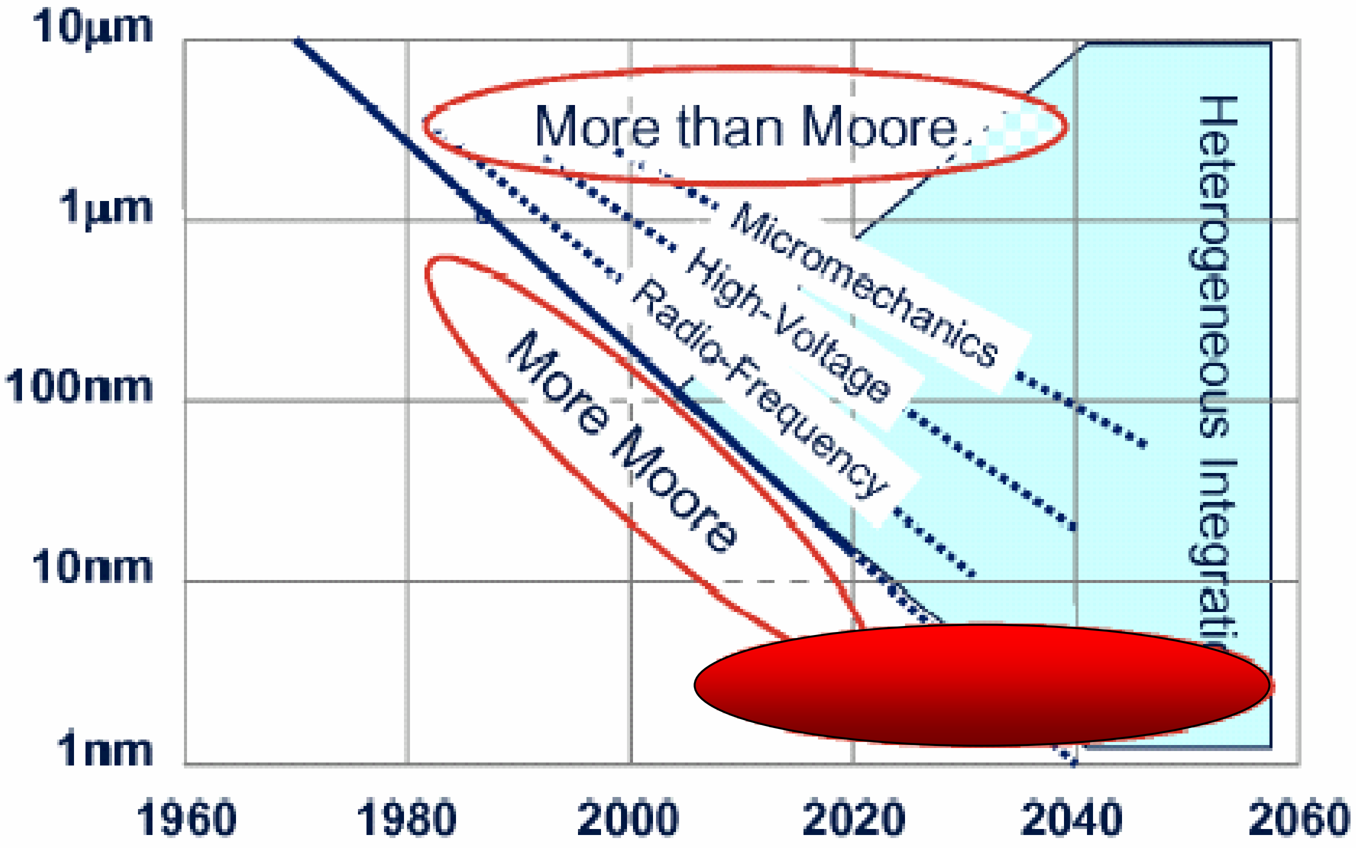






Nano-electronics

ENIAC technology roadmap



SRA update, L. Baldi, Monaco, Nov 30, 2006

Major issues addressed by Nanoelectronics CEA teams

5 research groups: 60 researchers

- What are the quantum limits set by reduced size of nano-conductors?
- Are quantum effect a drawback for nanoelectronics?
- Can we find and exploit new quantum functionality ?
- What are the limits due to energy limitation

→ explore quantum laws of conduction at nano- or molecular level

→ implement quantum information functionality in nano-circuits

→ understand quantum de-coherence mechanisms

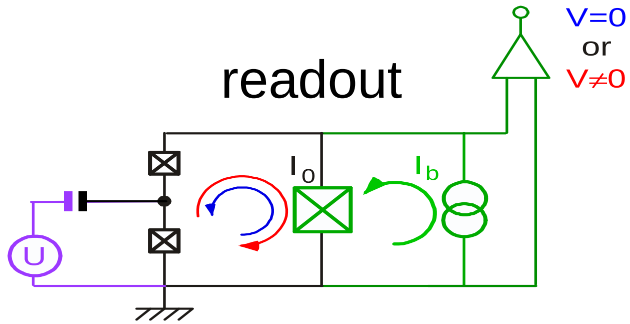
→ develop nanolithographic / nanostructuration techniques

→ master the positioning of molecules, Carbone Nanotubes or nanowires in circuits

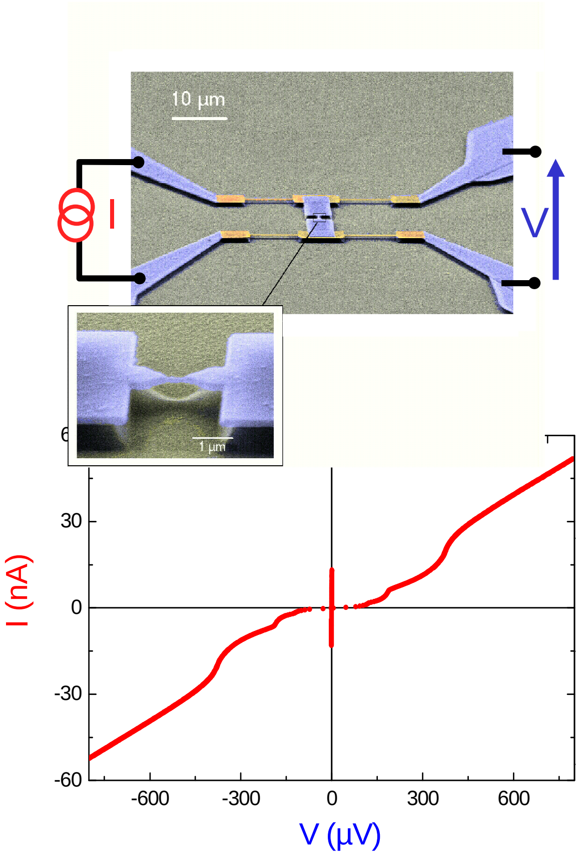
→ invent new tools to reveal new quantum effects or properties

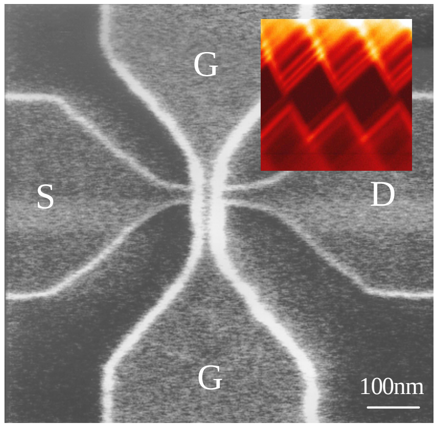
Mesoscopic Physics and Quantum Electronics

- Single atoms and molecule transport, physics and use of Josephson junctions, quantum coherent circuits, superconducting Qbits, physics of single dopants in nano-transistors, full counting statistics measurements,….

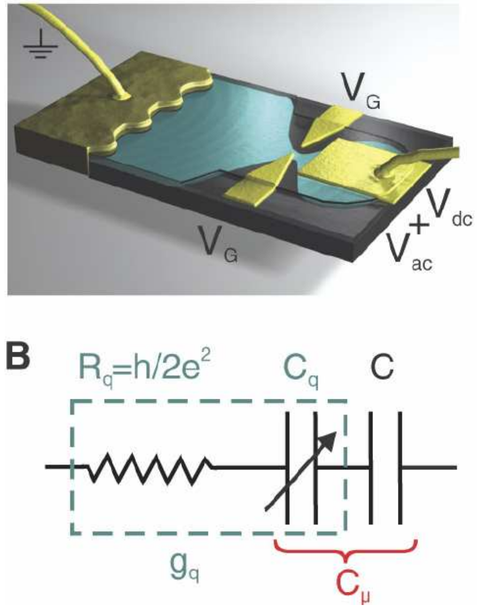


Vion et al Science 2002





Sanquer et al APL 2006



Glattli et al Science 2006

Urbina et al PRL

Nanophotonics

Nanophotonics' issues

ca 50 researchers mainly in Grenoble

QD and microcavities based on compound SC:

CdTe, CdSe, GaN/AiN, InAs/GaAs

epitaxial self-assembly , top down nanofabrication, optical spectroscopy

One single photon emission

Nanostructures, microcavities and photonics crystals based on Si/SiO_2

photophysics and photochemistry of molecular assemblies

new nearfield imaging techniques and applications to storage

Nanomagnetism

Nanomagnetism

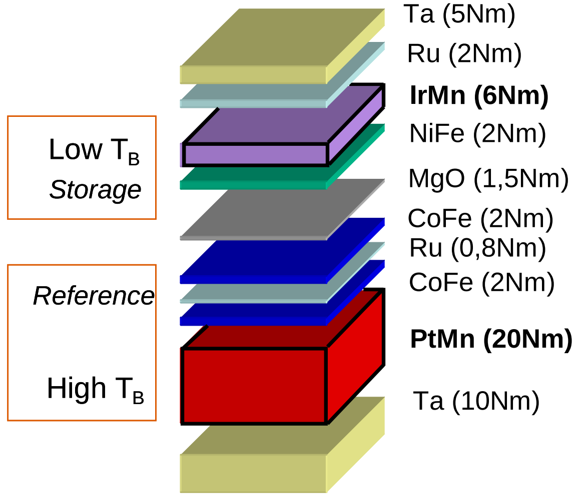
- following the pioneer work on GMR
- develop spintronics (memory, logic, sensors) based on understanding basic phenomena (spin transfer) and mastering layered magnetic materials

CROCUS Technology
Blossoming Future

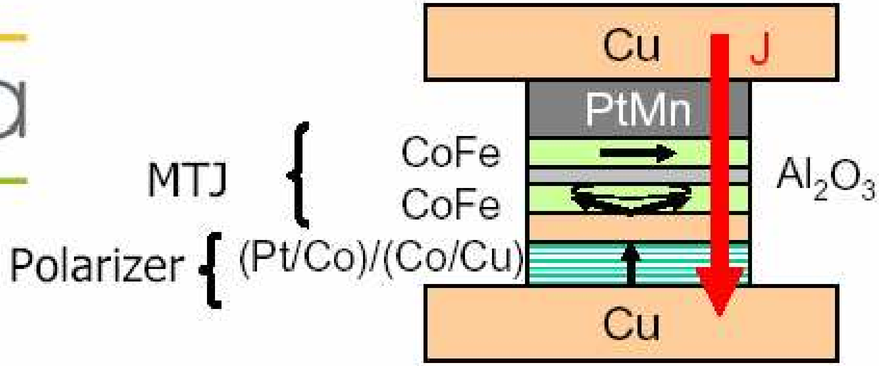
Magnetic memories (TAM RAM, MRAM….)

B. Dieny : 30 patents filed since 1996 (11 for 2007)

Crocus created in 2006 : 30 people in Grenoble and California 13,5M€ funds

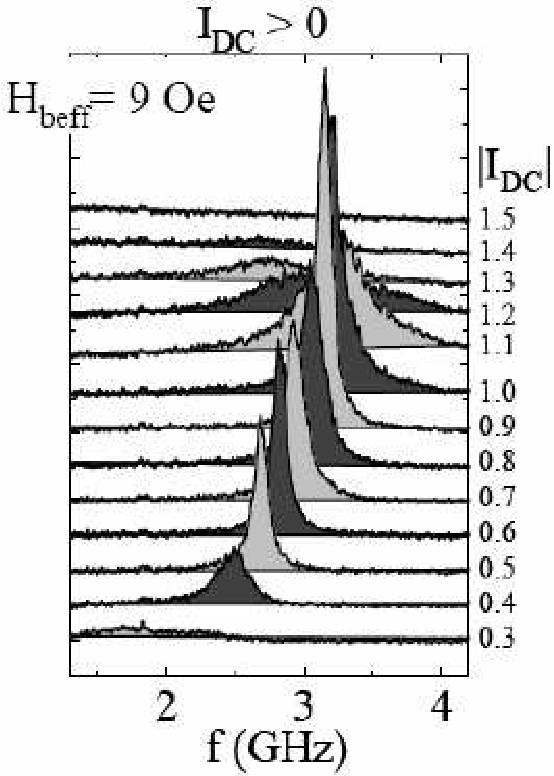


frequency tunable RF oscillators



Patents SPINTEC + Appl.Phys.Lett.86, 022505 (2005)

Precession (2GHz-40GHz)
Tunnel magnetoresistance } $\Rightarrow$ **RF Voltage**



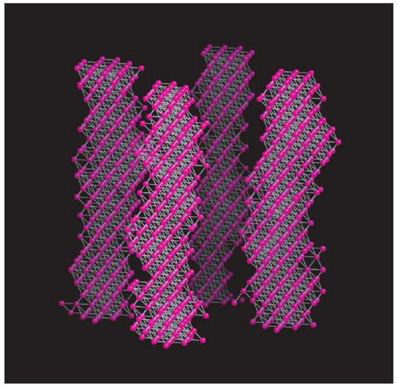
Nat.Mat 2007

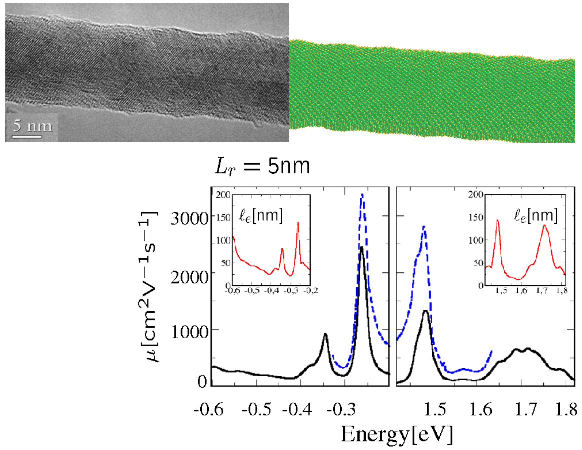
Frequency tunable RF oscillators, frequency controlled by current density

Nanosimulation

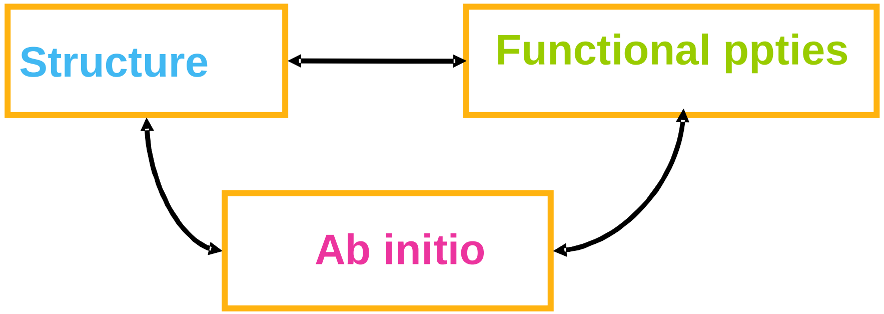
Nanosimulation : golden age ahead

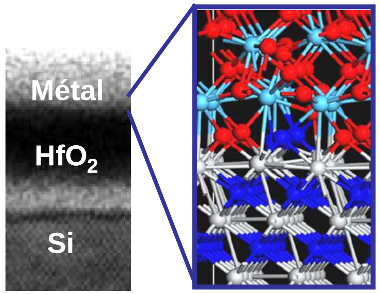
Target: a virtual lab for the design of devices, circuits, materials and systems





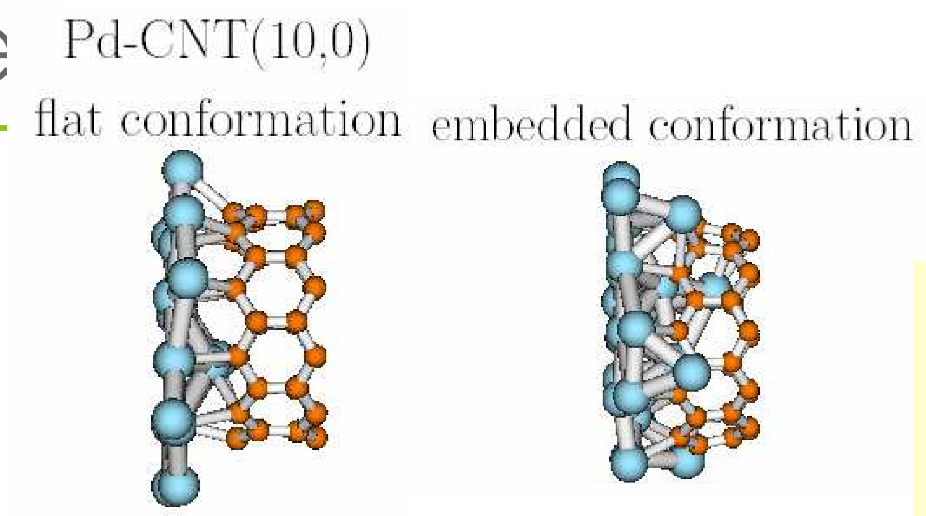
Benefiting from interactions with the CCRT

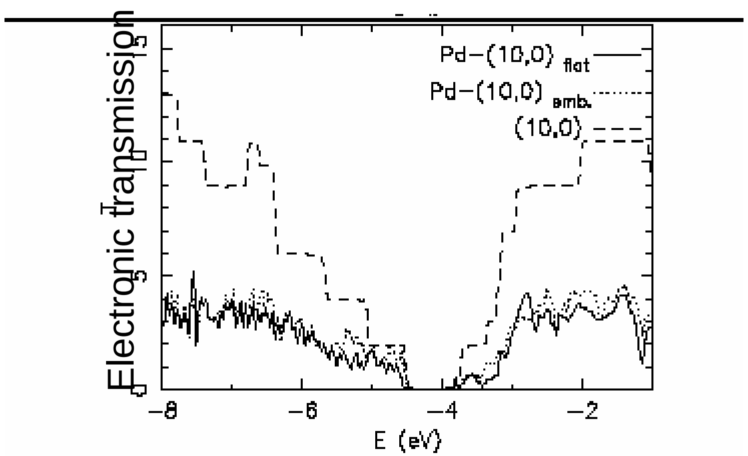




Thierry.deutsch@cea.fr

Including more physics: multiscale approach





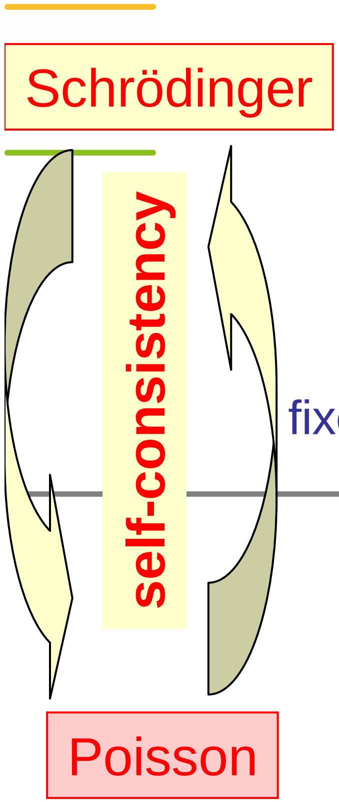
(10,0) flat *vs* embedded conf.

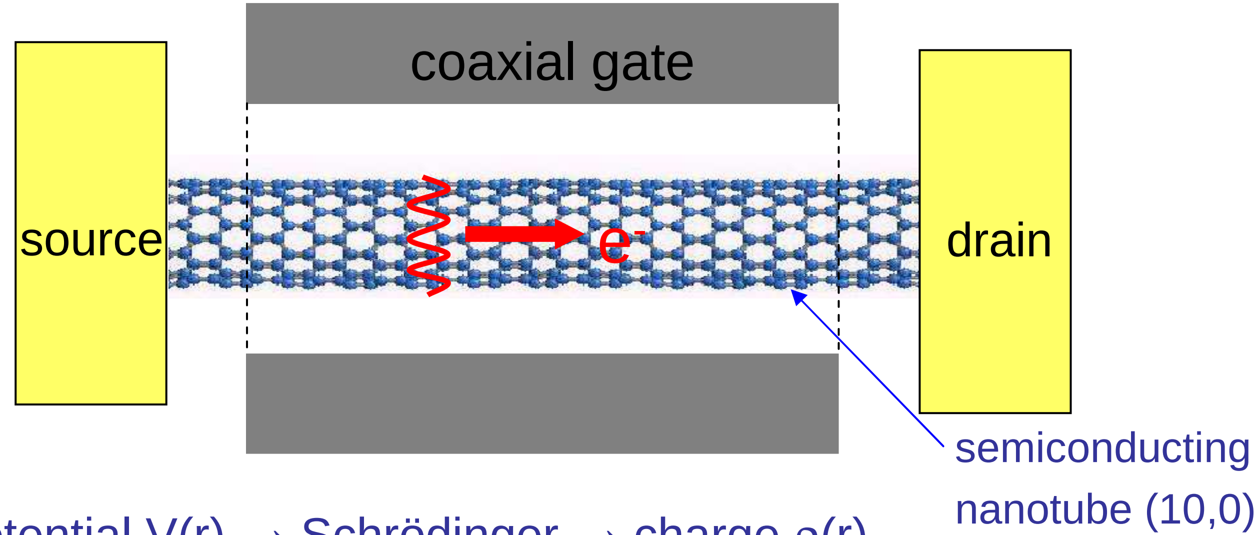
From atomistic to device modelling:

- *ab initio*
- quantum transport
- Monte Carlo device simulation
- Compact modelling of devices
- Circuit simulation

S. Roche, F. Triozon, (CEA)
C. Adessi and X. Blase (CNRS)
and many co-workers...

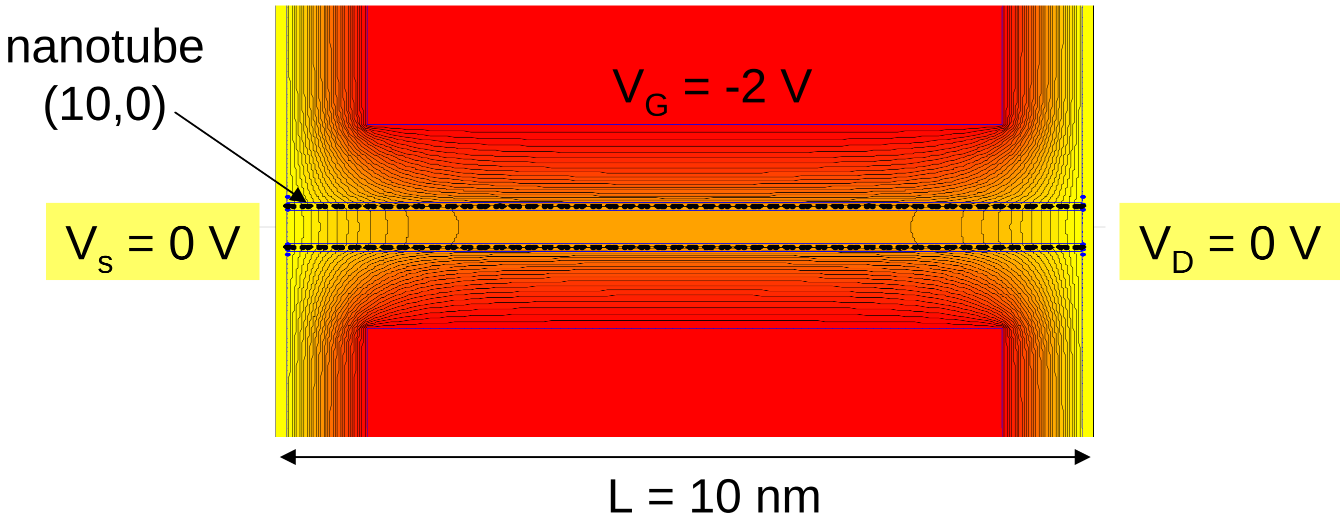
Simulation of CNT -FETs





fixed potential V(r) → Schrödinger → charge ρ(r)

(S. Roche, F. Triozon)



charge ρ(r) → Poisson → new potential V(r)

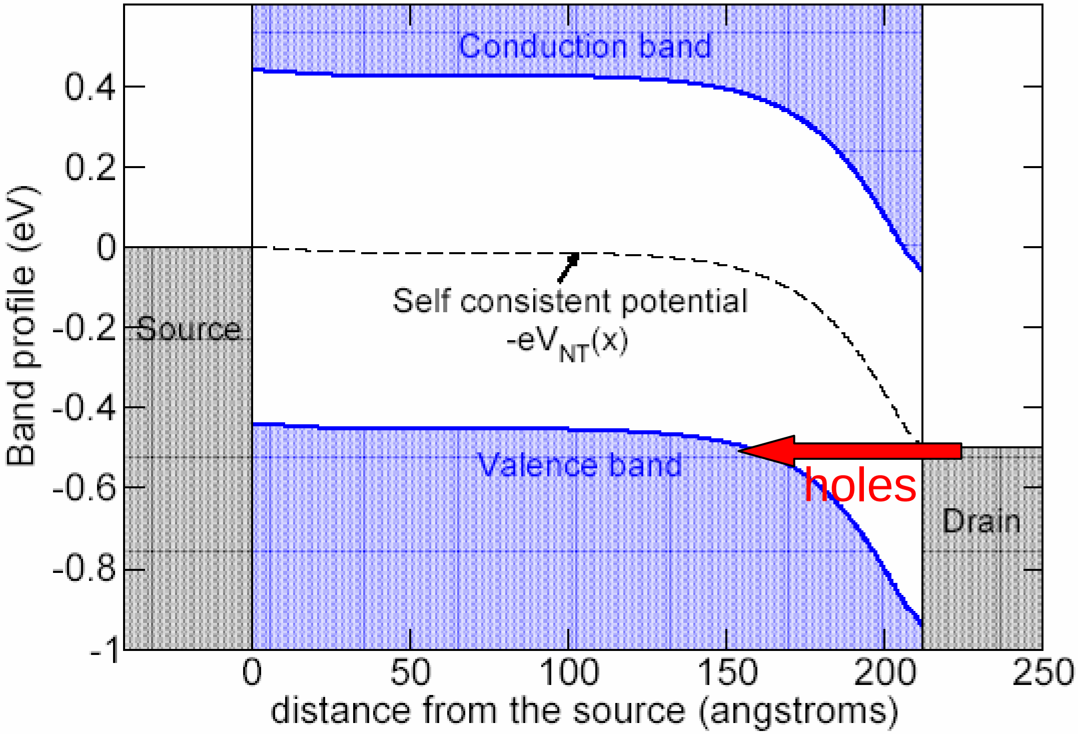
(Y.-M. Niquet)

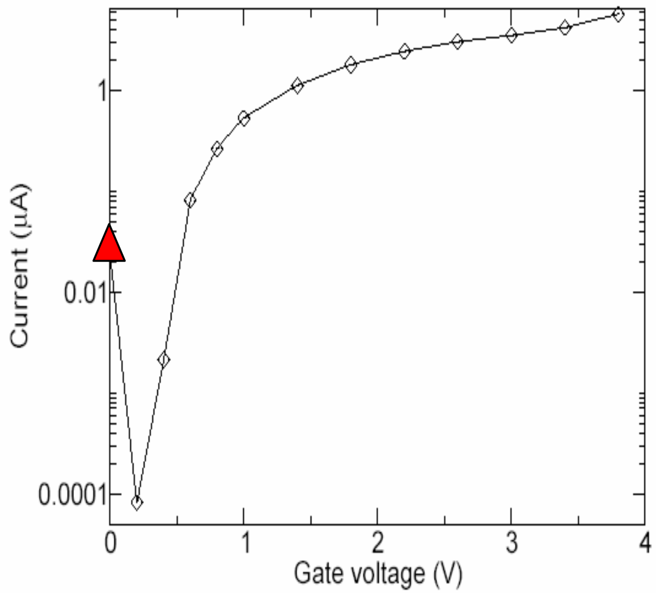
Method: Non-equilibrium Green's functions (NEGF)

Exemple: aplication to the ambipolar transistor

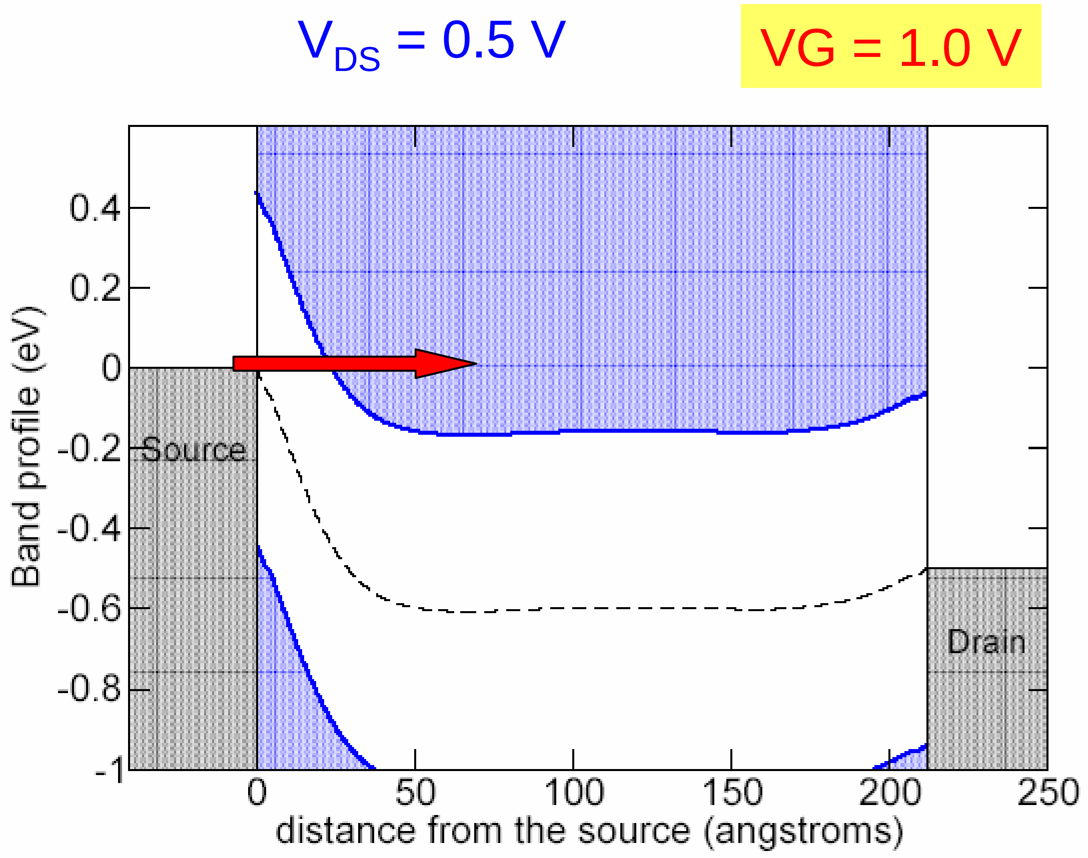
V_{DS} = 0.5 V

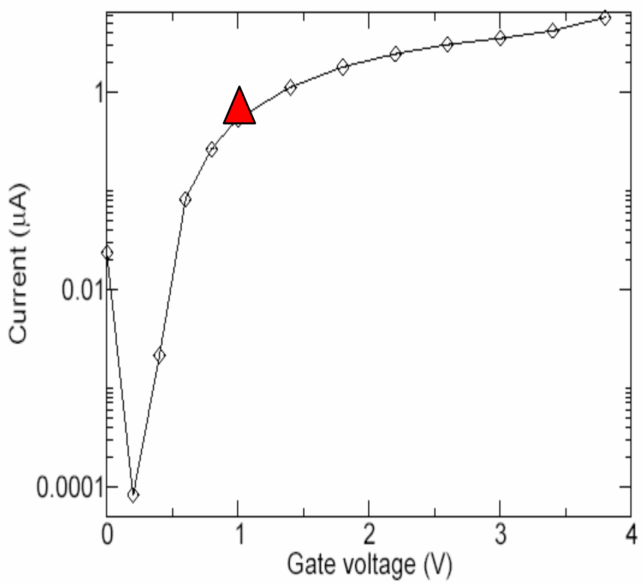
VG = 0 V



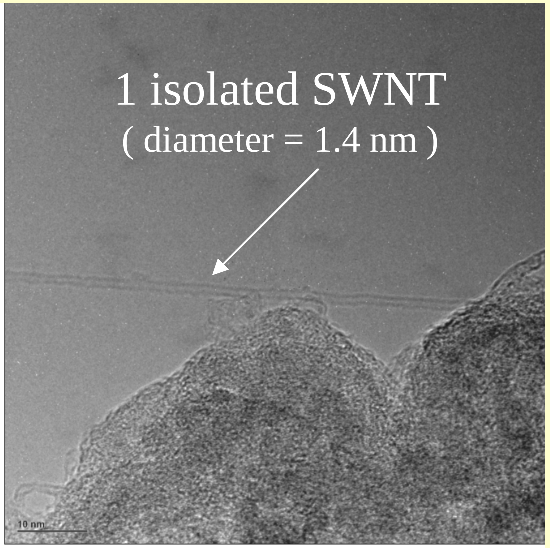


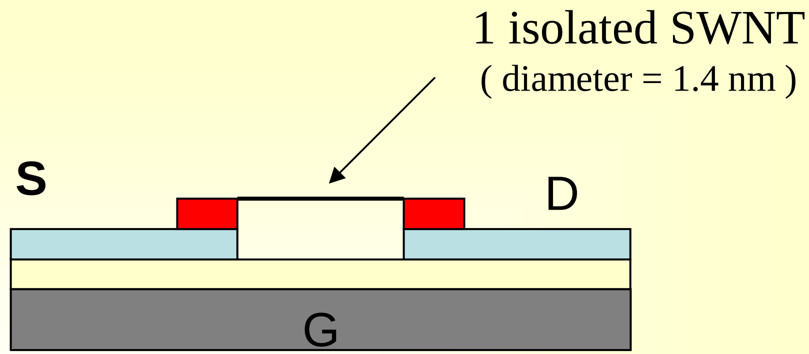
Exemple: ambipolar transistor



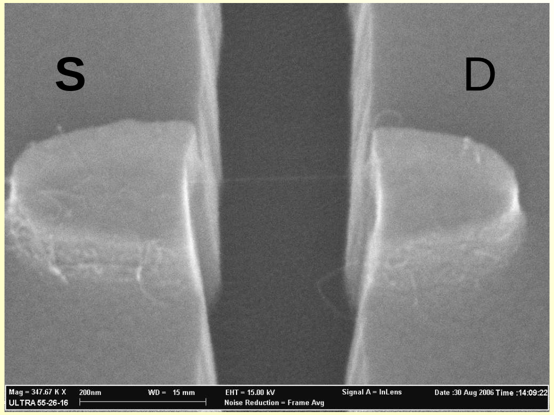


Comparison with experience: Carbon nanotubes devices





Basewafers from Leti



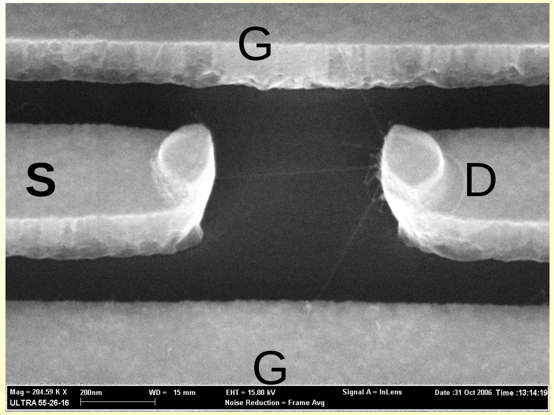
CNT FET
Back-gate

(gap 300 nm)

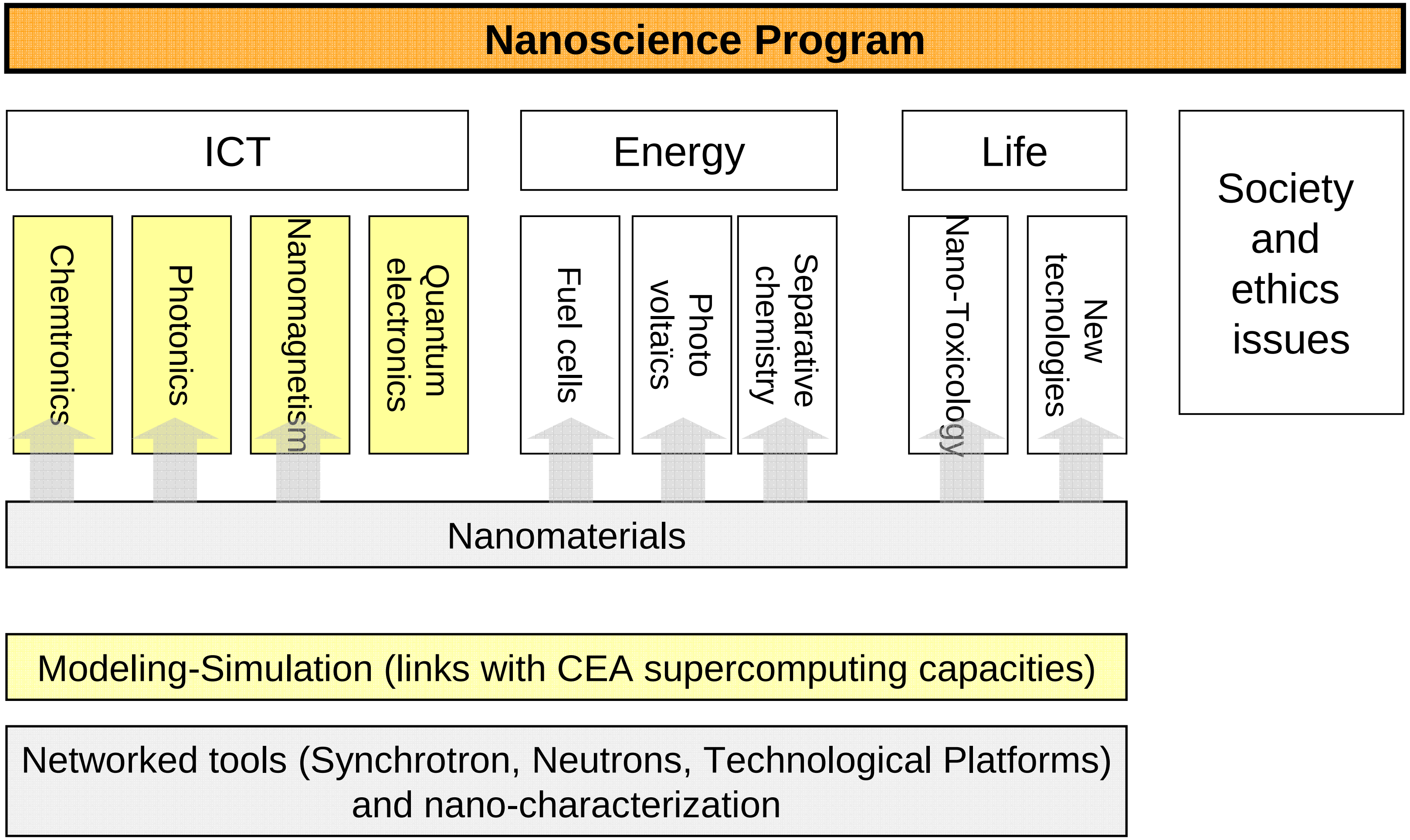
CNT FET

Side gates

(gap 450 nm)



Nanoscience @ CEA : organization



Porphyrin – bottom-up – CNT – P3HT – Molecular memory – self-assembling – FerroFET – ballistic – Nanowire – DNA – Multis ... ials — suprar ... ance – diazor ... ling – STM/ ... iwall – silicon – nanotube – interconnect – graphene – integration – bifunctional – Synthesis – Mesoporous - CMOS – More Moore – Neurone – architecture – Rubrene – SNOM – Plastic -

Thank you for your attention