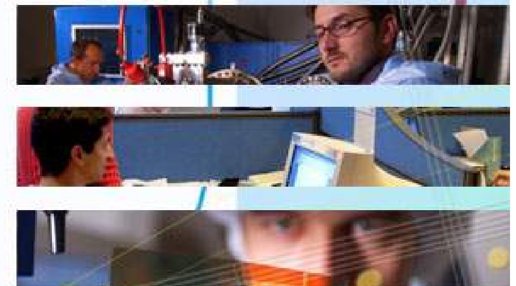
micro and nanoelectronics
microsystem
ambiant intelligence
image chain
biology and health

2007

CEA-LETI as a European model of cooperation in nanoelectronics

M. Brillouët



leti

MINATEC

cea

leti

MINATEC

2007

Outline

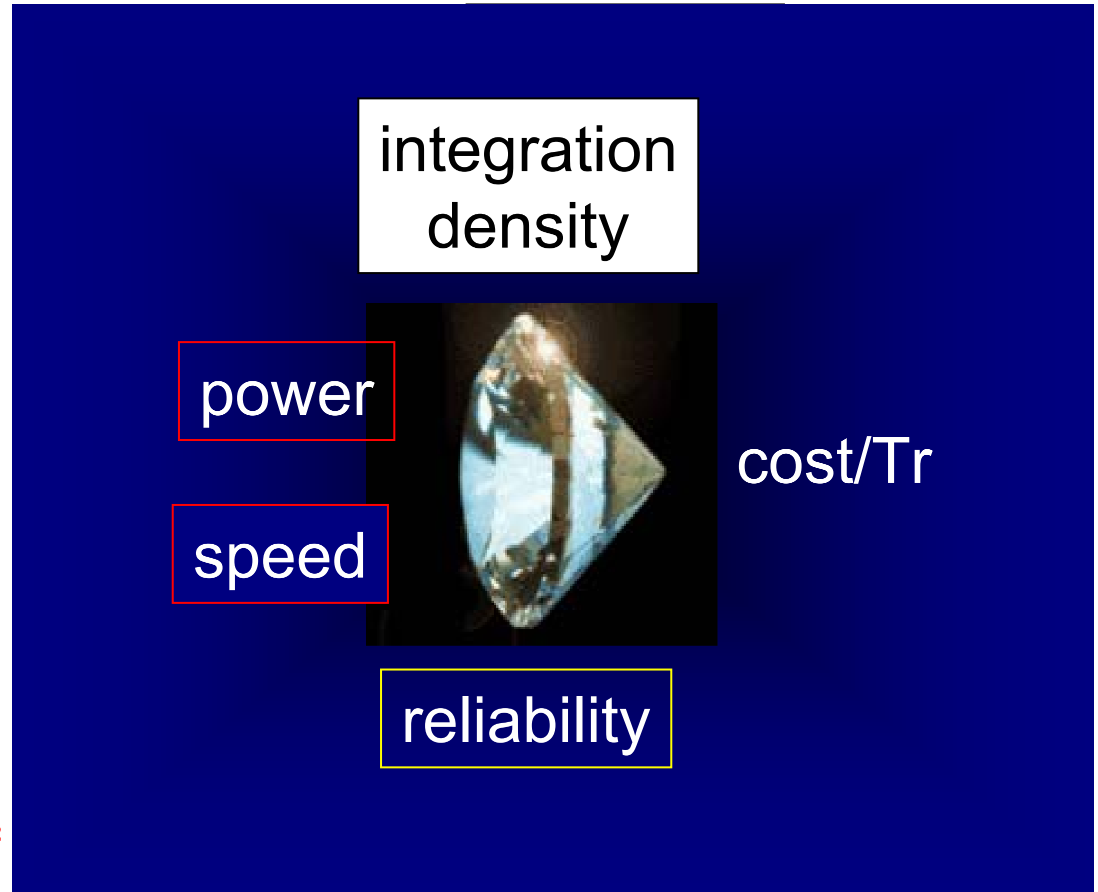
➔ A changing R&D landscape in nanoelectronics

- The European models, incl. CEA-LETI
- Characterization in nanoelectronics
- Conclusion

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

The happy scaling

R. Dennard © IEEE



dimensions t_{ox}, L, W	**$1/\alpha$**
doping	**α**
voltage	**$1/\alpha$**
integration density	**α^2**
delay	**$1/\alpha$**
power dissipation/Tr	**$1/\alpha^2$**

Smaller = better: for how long?

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

No hard physical limits, but…

Quantum size ‘limit’

τ (s)

10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}

Memory

complexity

Logic

P = 100 W/cm²

high speed

Quantum τ ‘limit’

1 10 100 1,000

Cell size (nm)

after Zhyrnov

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l’autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

R&D spending: a gathering storm

VLSI RESEARCH INC

Where the Chip Making Industry Clicks to Find its Weather

Chip Making R&D Versus Revenues

(Worldwide in $M)

1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00

1957 1960 1963 1966 1969 1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002 2005 2008 2011 2014 2017 2020

Total RD&E (Chip + Eq)
Semiconductor Revenues

decreasing revenue growth

increasing R&D cost

RESTRICTED DATA: for access and use only within your company, as per your company's agreement with VLSI Research Inc.
Copyright © 2005 VLSI Research Inc

from D.Hutcheson - 2005 Int.Conf. on Charact. and Metrology for ULSI Technol.

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

The January 2007 PR ‘tsunami’

NXP founded by Philips

EETIMES

NXP to exit Crolles2 Alliance
(01/16/2007 2:55 AM EST)
SAN JOSE, Calif. — NXP Semiconductors on Tuesday (Jan. 16) said that it shall not extend its current cooperation in the Crolles2 Alliance beyond the initial term expiring at the end of 2007. NXP (Eindhoven, the Netherlands), formerly Philips Semiconductors, has decided to pursue a different path for its future development of process technology. It will work with long-time foundry partner Taiwan Semiconductor Manufacturing Co. Ltd. (TSMC). […]
"We've chosen to strengthen our cooperation with TSMC, in the area of advanced CMOS development,'' stated Frans van Houten, NXP president and CEO, in a statement. "This move will enable NXP to concentrate more on creating innovative, differentiating process options, such as embedded non-volatile technology in 45nm for our state of the art system-on-chip products, while building on the process platform from TSMC."
The strengthened global R&D cooperation will be built upon the existing NXP Research organization at the IMEC facilities in Leuven, Belgium, and TSMC corporate R&D in Hsinchu, Taiwan. TSMC (Hsinchu) is also a core member of IMEC.

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

The January 2007 PR ‘tsunami’

NXP founded by Philips

Launched by Motorola
freescale semiconductor

EETIMES

Freescale joins IBM's 'fab club‘

(01/23/2007 12:01 AM EST)

SAN JOSE, Calif. — In a major change of direction, Freescale Semiconductor Inc. on Tuesday (Jan. 23) announced plans that it will join IBM Corp.'s "fab club" for joint semiconductor research and development. The move appears to be perhaps another nail in the coffin for the troubled Crolles2 Alliance, which is on shaky ground right now. It also raises questions about Freescale's deals with its current silicon foundry partners, such as Taiwan Semiconductor Manufacturing Co. Ltd. (TSMC) and United Microelectronics Corp. (UMC).

Under its new R&D strategy, Freescale (Austin, Texas) will become a partner in IBM's technology alliance starting at the 45-nm node. Freescale will also participate in the R&D alliance at the 32- and 22-nm nodes and beyond.

The agreement includes the development of CMOS and silicon-on-insulator (SOI) technologies. […]

The IBM alliance provides "levels of investment significantly higher than what we could have accomplished at Crolles2." […]

Sadana did not elaborate on Freescale's manufacturing strategy, which is characterized as a so-called "fab-lite" model.

He insisted that Freescale will continue to work with TSMC and UMC despite joining the IBM "fab club."

At present, Freescale outsources about 20-to-25 percent of its chip production to the foundries, namely TSMC and UMC. The rest is produced in-house within its various fabs.

But at the 45-nm node and beyond, however, it is widely believed that Freescale will have most of its chips made at the foundries within the IBM "fab club."

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

The January 2007 PR ‘tsunami’

EETIMES

Texas Instruments exits process development race

(01/24/2007 5:27 AM EST)

LONDON — Texas Instruments Inc., one of the largest and most successful integrated device manufacturers, has decided to drop the costly business of digital logic process development and rely on foundry partners for its processes.

According to reports TI (Dallas, Texas) development has decided to stop internal development at the 45-nanometer node and use foundry supplied processes at 32-nm, 22-nm and thereafter.[…]

TI (Dallas, Texas) made the announcement that it would exit digital CMOS process development […and] the company would close its Kilby wafer fab in Dallas. […]

"One way we'll do this is by changing the way we develop advanced digital process technology. Instead of separately creating our own core technology, we will work collaboratively with our foundry partners to specify and drive the next generations of digital process technology[…]" said Rich Templeton […].

TI has long used foundries, such as Taiwan Semiconductor Manufacturing Co. Ltd., United Microelectronics Corp. and Semiconductor Manufacturing International Corp.[…].

It seems unlikely that TI would ever construct a leading-edge wafer fab again and is set to let its own manufacturing of advanced digital CMOS wither on the vine.

leti

MINATEC

2007

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

The January 2007 PR 'tsunami'

EETIMES

ST decides to import CMOS, change Crolles function

(01/25/2007 9:15 AM EST)

LONDON — Carlo Bozotti, chief executive officer of STMicroelectronics NV, told analysts Wednesday (Jan. 24) that ST would align with "industry leaders" to obtain a 32-nm CMOS process for use in its wafer fabs and as a platform for specialized extensions.

Bozotti did not say who would provide ST with its 32-nm CMOS platform but said: "It is obvious we have alternatives."

[…]

Speaking during a conference call for analysts Bozotti said that the Crolles2 Alliance would complete the development of 45-nm CMOS process technology during 2007 but there would then be a "discontinuation" in the role of the Crolles development center and pilot fab.

Bozotti said that because of the increased cost of developing 32-nm CMOS manufacturing process technology it had been decided to import advanced CMOS and that ST would then use the Crolles research facility to develop derivative proprietary technologies that would be important to its wireless business unit. Bozotti listed image sensor, radio frequency and analog extensions to basic CMOS as the technologies that would be developed at Crolles. […]

"It is a clear change in strategy...but Crolles will remain the key center for advance technology development while on the CMOS bulk we will align with industry leaders and make sure this technology is available in our facilities," Bozotti said.

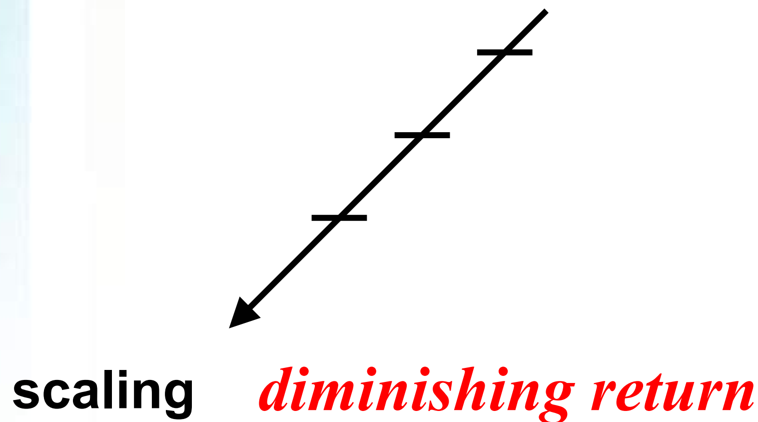
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Moving away from pure scaling…

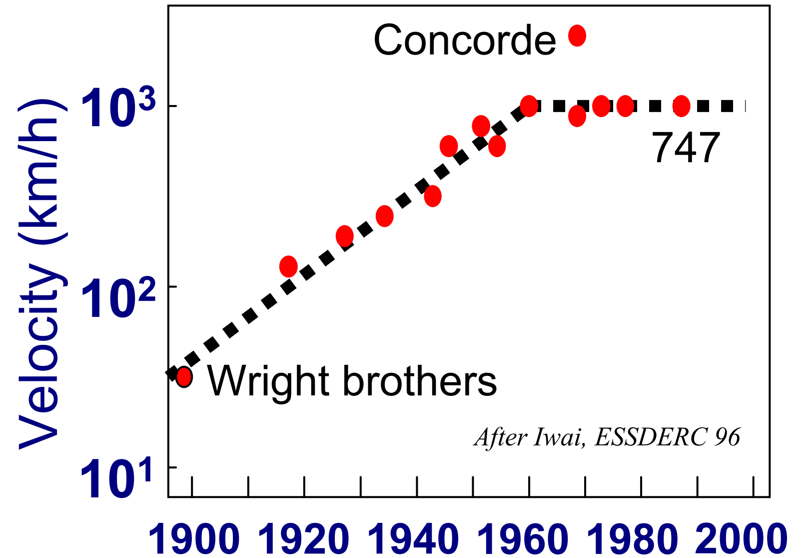
Si CMOS-based logic

+ new materials
+ new device architectures

Driver = cost + performance /**gate**

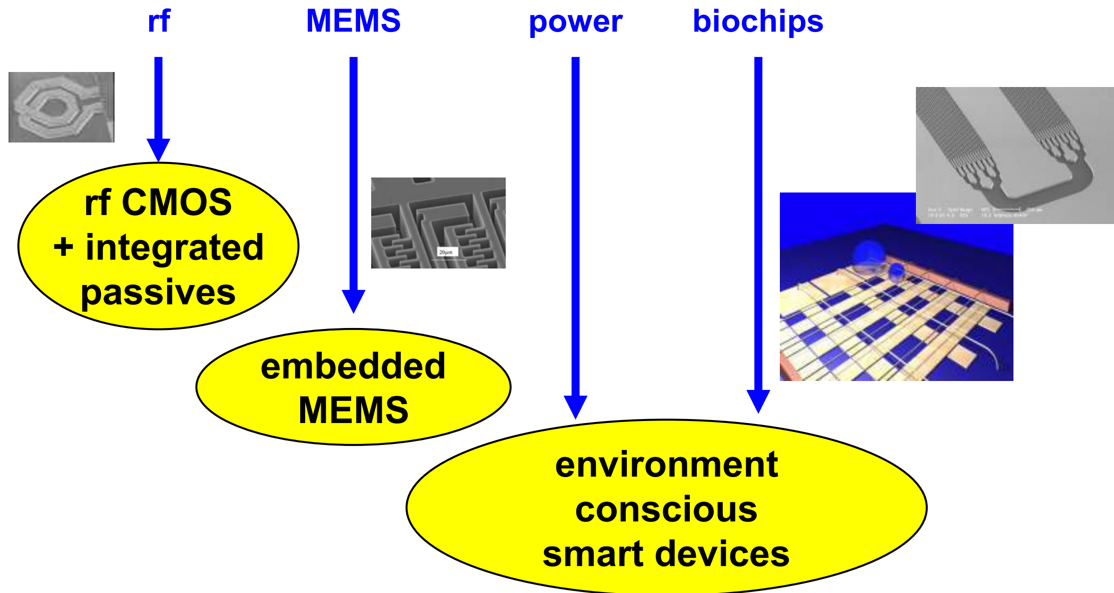


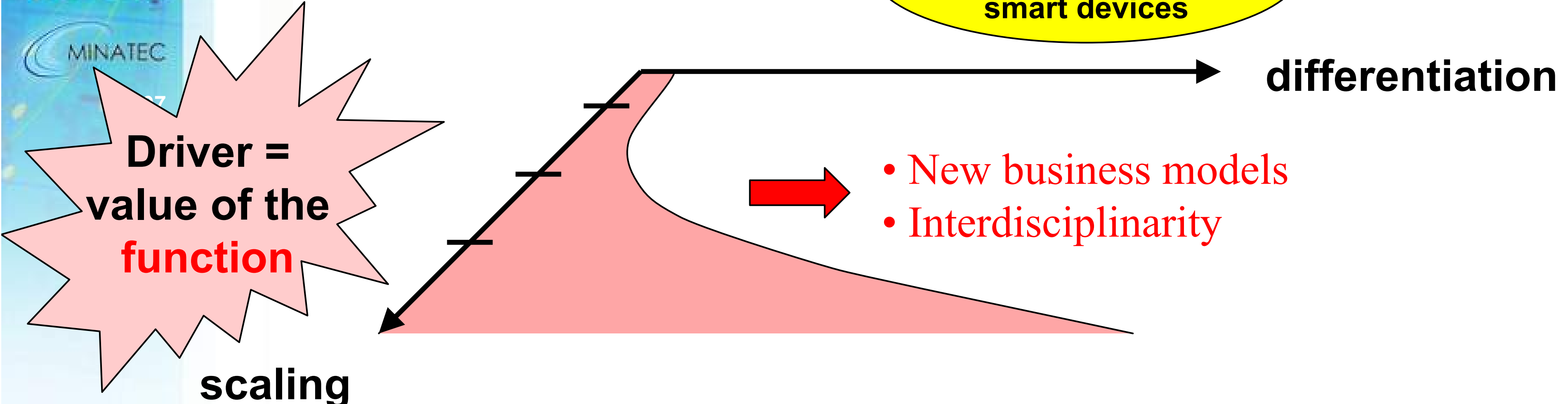
scaling ***diminishing return***



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

…through differentiating technologies…





- New business models
- Interdisciplinarity

"the emergence of many new ideas and technologies, several of which are suitable for only certain function(s) and do not have broad application, may be signaling a coming dispersion of microelectronics technologies to address an increasingly diverse set of market-driven applications" [ITRS03, ERD]

…towards mastering the system complexity

system integration

usage
service
software
technology

multiple standards
multiple players
multiple technologies

differentiation

scaling

Driver = value of the application

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

The IC technology landscape

process in-house

memories

processors

PLDs

ASICs

MEMS

power

...

niche markets

product diversity

process outsourced

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Where are the European companies?

process in-house

product diversity

process outsourced

SAMSUNG
qimonda
intel
IBM
Infineon technologies
ST
Chartered semiconductor manufacturing
NXP founded by Philips
tsmc
UMC

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

Outline

- A changing R&D landscape in nanoelectronics

➔ The European models, incl. CEA-LETI

- Characterization in nanoelectronics

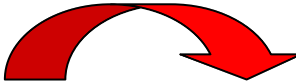
- Conclusion

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

An European way of thinking: application driven enabling technologies

Health

Mobility / Transport

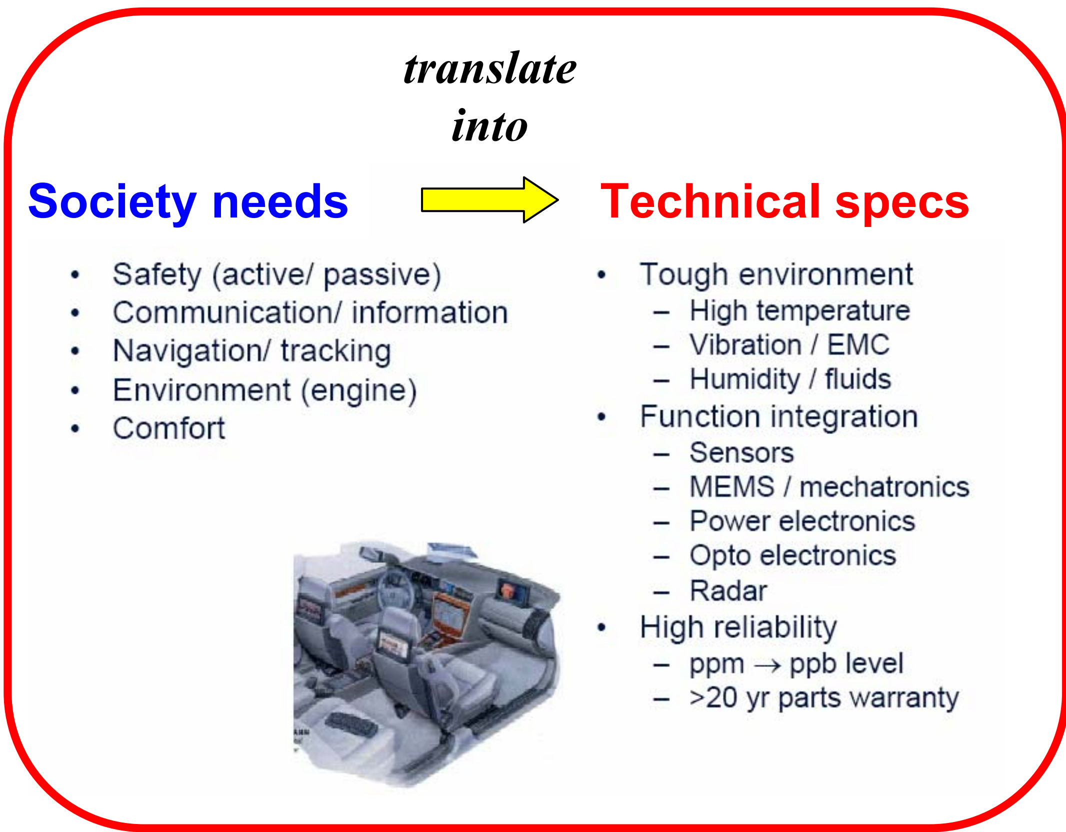


Security / Safety

Communication

Education / Entertainment

Energy / Environment



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

A full coverage of the nanoelectronics themes

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

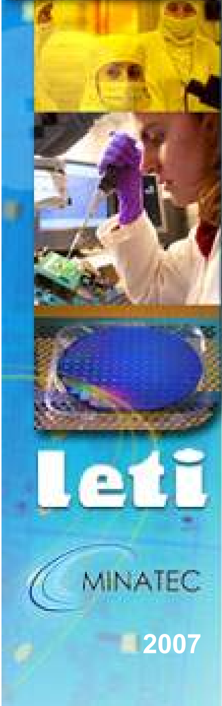
leti

MINATEC

2007

300mm R&D ecosystems

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA



imec : an open international model

Lithography (incl. DRAM eval.)
- Hyper NA Immersion
- EUVL

Front End (incl. DRAM eval.)
- PLANAR
- EMERALD
- GATE STACK

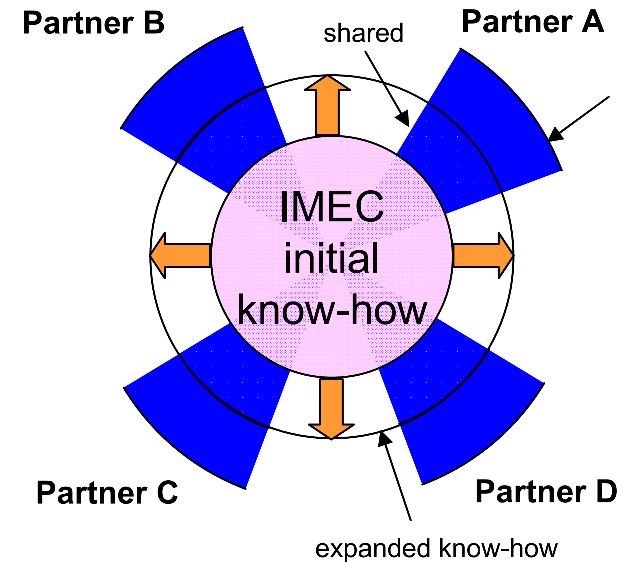
Back End (incl. DRAM eval.)
- Cu/Low k
- 3D-SiC

Flash Memory
- Floating Gate
- Charge trapping
- Flash Scaling

Explore
Exploratory Materials and Device Research for CMOS based Technologies
- Ge/III-V, expl. high-k
- Post-CMOS nano

Supporting Expertise Centers
- Cleaning & Contamination (UCP program)
- Materials Characterization & Metrology
- Reliability & Modeling

Core Program



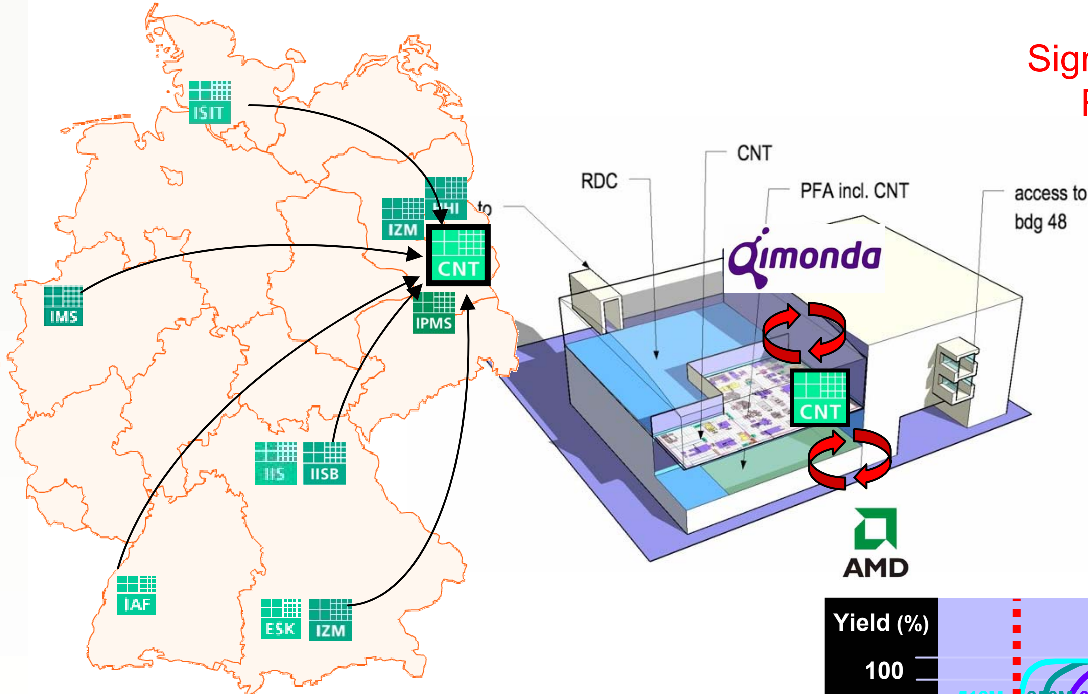
All results of the work belong to IMEC and its partners without any accounting to each other

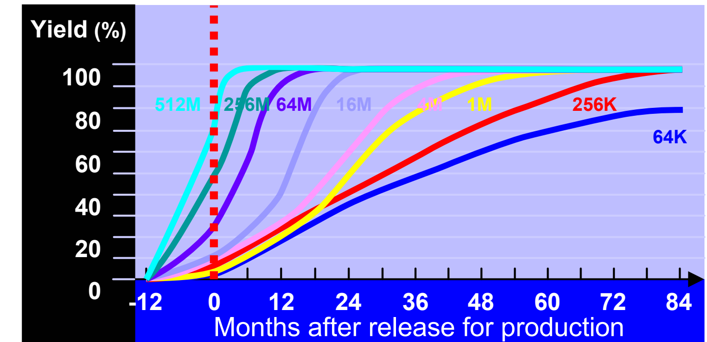
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

: the CNT model

Research docking… …in manufacturing

Significant volume of wafers
Realistic environment
Cost efficiency

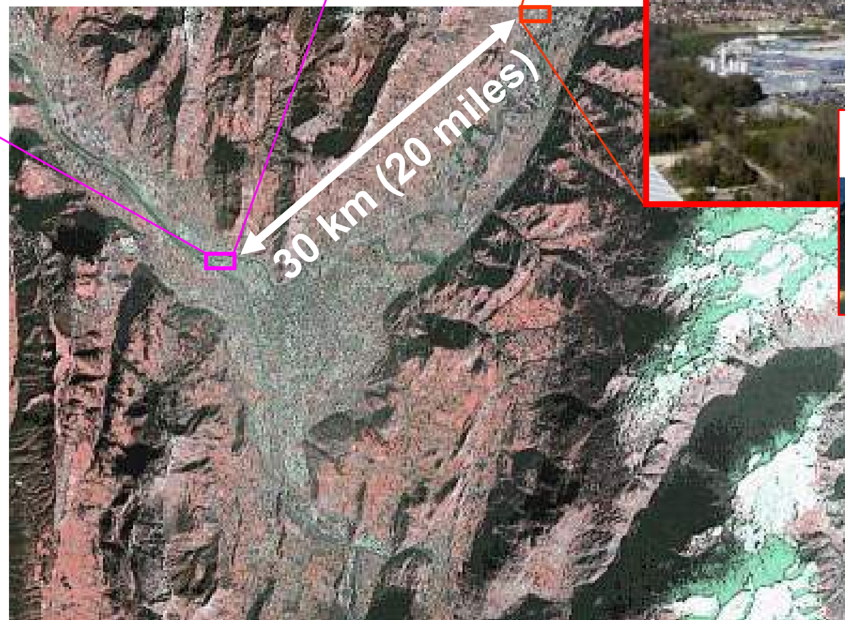




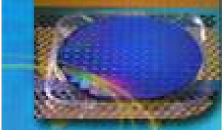
Source: VLSI Research

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

: close collaboration with industry and academia



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA



leti

MINATEC

2007

A complete set of research platforms

From advanced concepts to pilot lines

Short loops with industrial sites

Cooperative with academia and industry

More Than Moore
200mm

200mm
More Moore
& Beyond CMOS

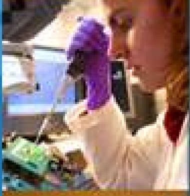
300mm
More Moore

leti

Nanoscale
Characterization

Nanosciences

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

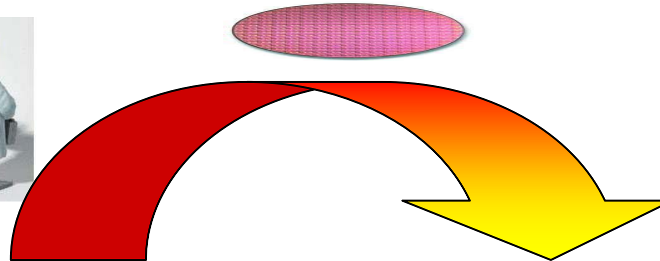


leti

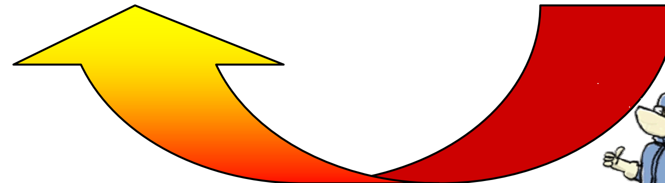
MINATEC

2007

A close collaboration with industry



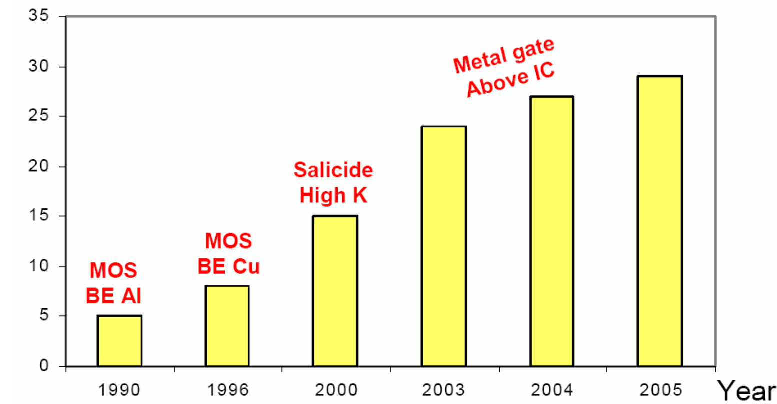
- people X-assignment
- wafer exchange
- value-added investments



© IMEC

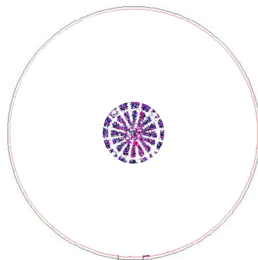
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Need for a sensitive contamination control

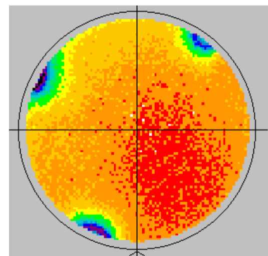


metals

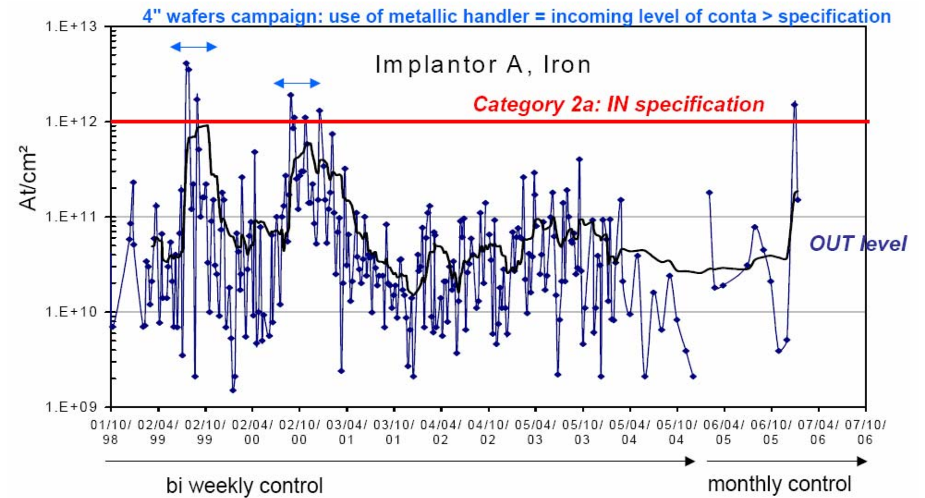
50+ tools
monthly control



Chuck footprint



Cu from a contaminated quartz boat

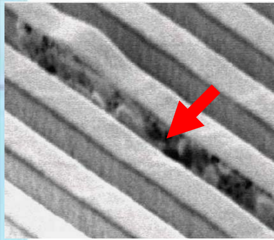


from A. Danel – CEA/LETI

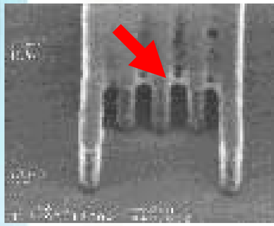
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Need for a sensitive contamination control

from M. Veillerot – CEA/LETI



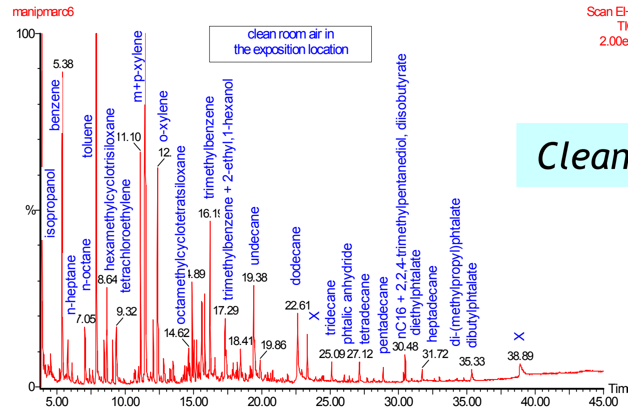
Al corrosion



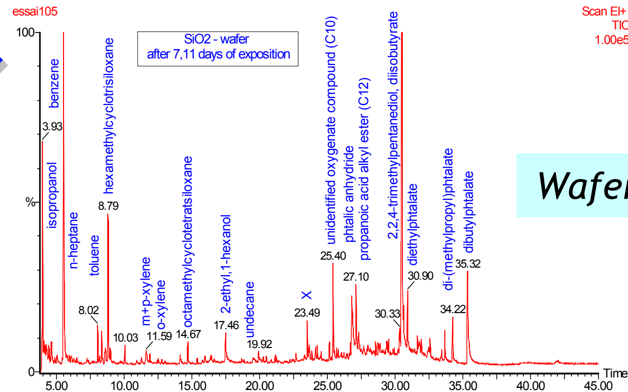
T-top

organic contamination

TD-GC/MS

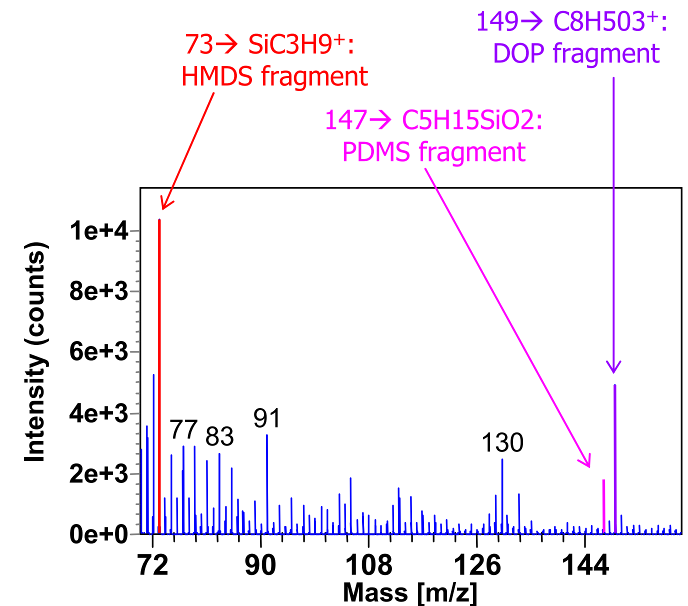


Clean room



Wafer

ToF-SIMS



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

: an campus reinforcing the link with academia

2007

Education

1500 students

- Attract young people
- New competences

Research

1 200 p. on applied research
500 p. on fundamental research

- Pluridisciplinarity
- Speed up innovation

Valorization for Industry

1000 partners

- Hosted teams
- Access to facilities
- Start-ups

Pole:
Concentration of tools and competencies

MINATEC:
Focus:
Micro and nano-technologies

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Hosting research teams in a Pilot Line

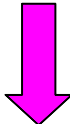
leti

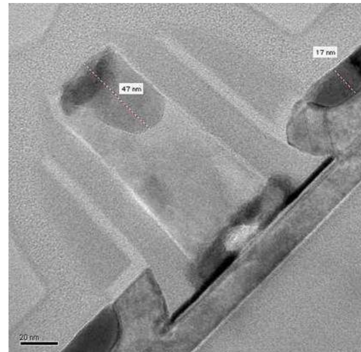
MINATEC

2007

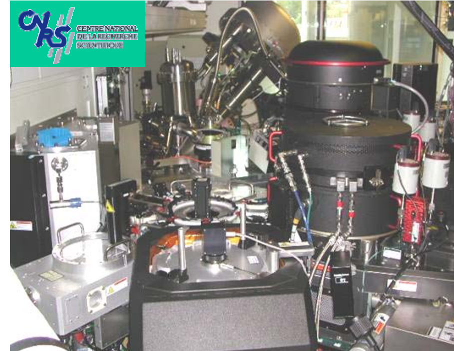
Hosted research team

Applied on real problems



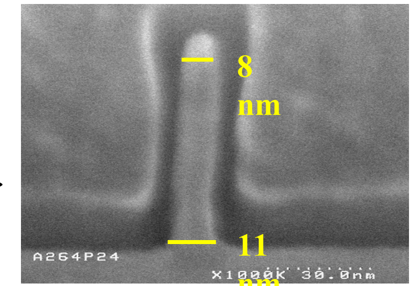


FD-SOI + high k/metal gate

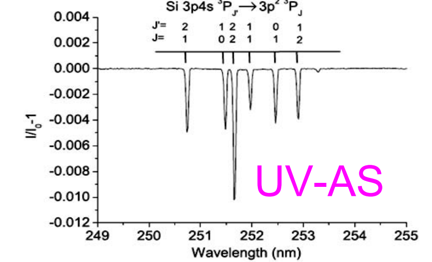


Industrial equipment

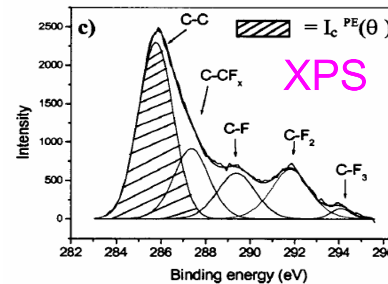
Ultimate patterning



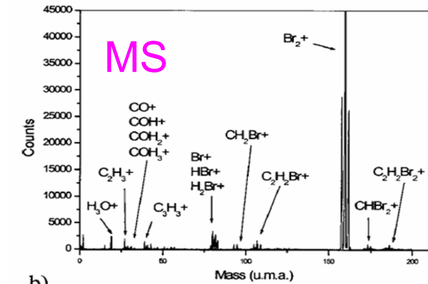
Understanding etch mechanisms



M.Kogelschatz et al.
J.Phys. D37 (14) 1954 (2004)



E.Pargon et al.
J.Vac.Sci.Technolog. B22 (4) 1858 (2004)



b)

E.Pargon et al.
J.Vac.Sci.Technolog. B23 (1) 103 (2005)

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

Outline

- A changing R&D landscape
  in nanoelectronics

- The European models, incl. CEA-LETI

➔ **Characterization in nanoelectronics**

- Conclusion

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Trends in nanocharacterization

composition
charge
stress
spin
optical
molecular conformation
multivariate

1D (layer) → 2D (X-section) → 3D (single object)

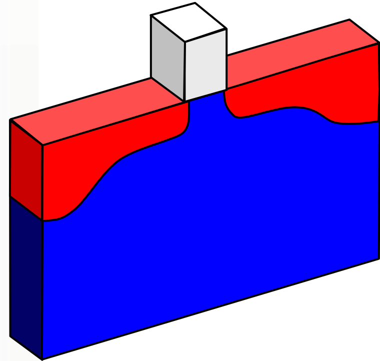
+statistical data

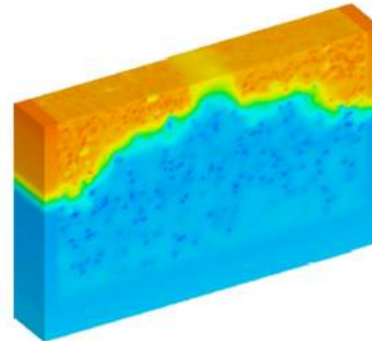
µm
nm
atoms
multiscale

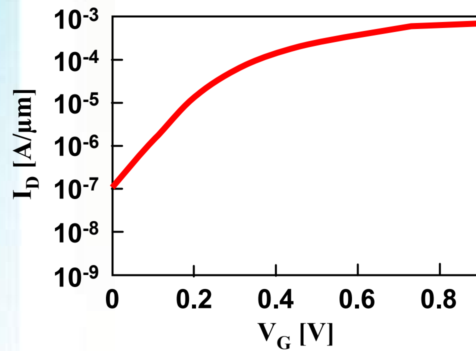
time

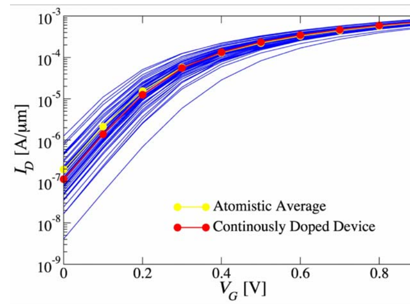
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

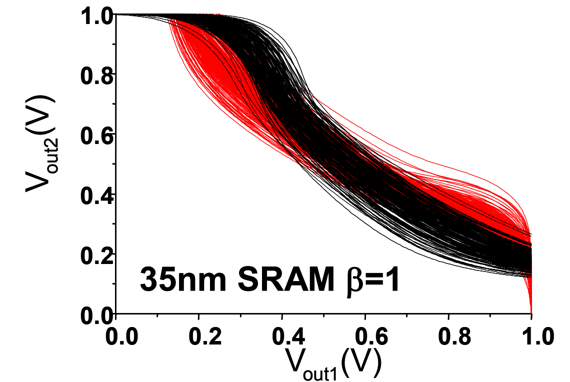
3D dopant fluctuation: a major problem











from Asenov ESSCIRC '04

ideal MOST ⇨ actual MOST ⇨ unstable SRAM

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

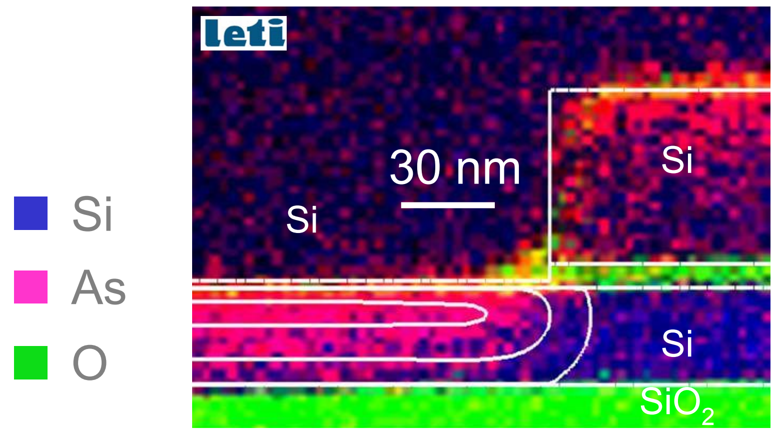
leti

MINATEC

2007

3D dopant profile: how to measure it?

■ Si
■ As
■ O

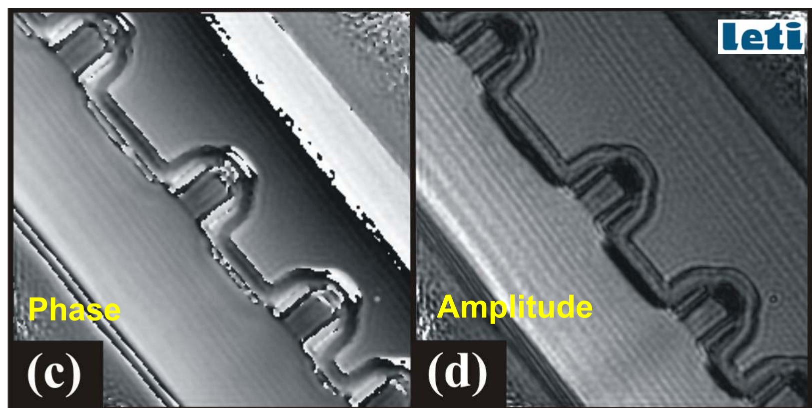


Courtesy: JP. Barnes – CEA/LETI

TEM + EDX

< 1nm

> 10^{19} cm^{-3}



Courtesy: D. Cooper – CEA/LETI

holographic TEM

< 1nm

$10^{16} – 10^{20}$ cm^{-3}

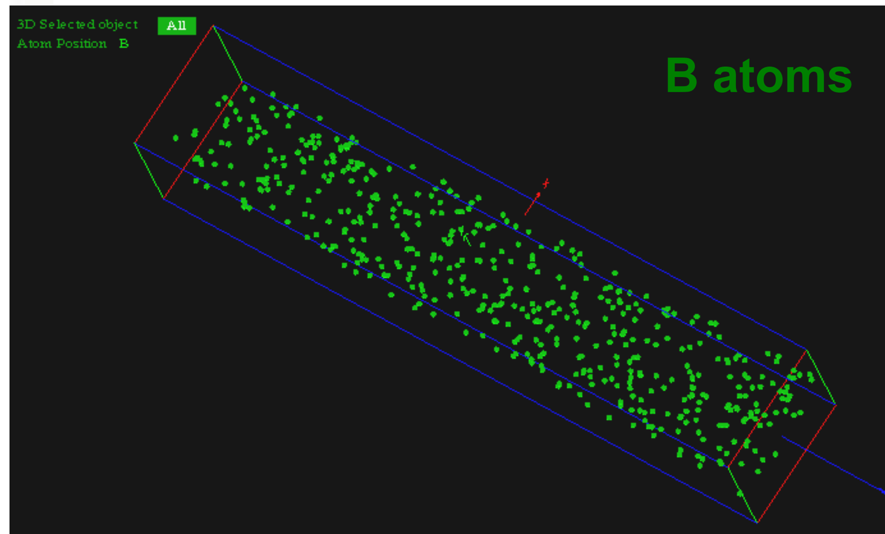
still mostly 2D

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

3D dopant profile: how to measure it?

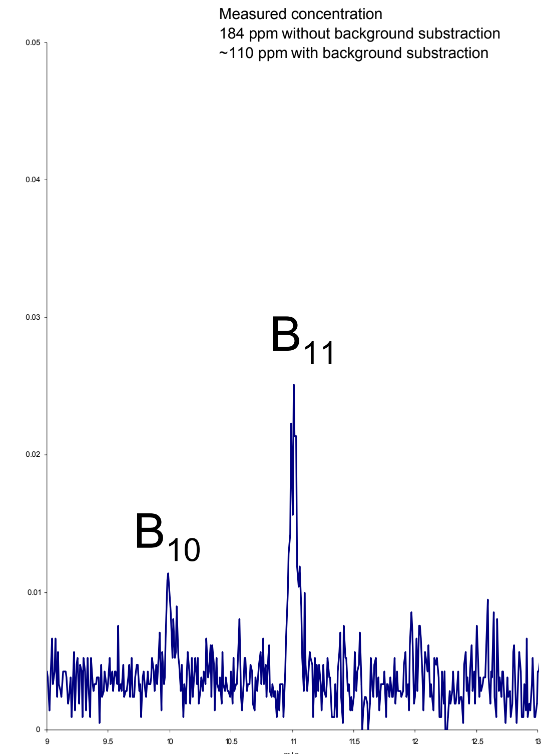
TEM tomography?

fs laser assisted tomographic atom probe



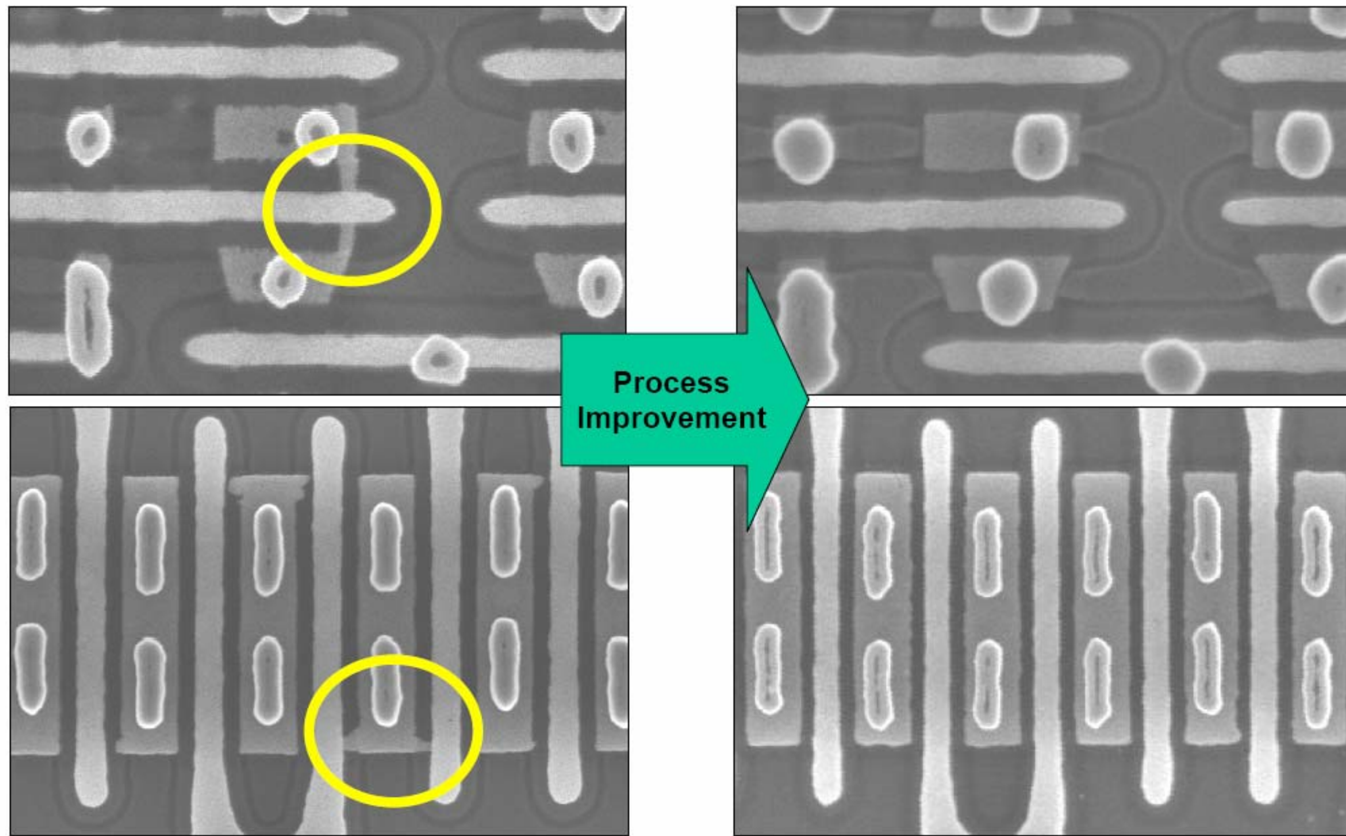
10 Matoms Si, 1000 atoms B

Courtesy: B. Deconihout et al. – Rouen Univ. & CNRS



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Salicide: stress-assisted diffusion



Ni moves into the silicon; affected by strain

Technology for Innovators™ TEXAS INSTRUMENTS

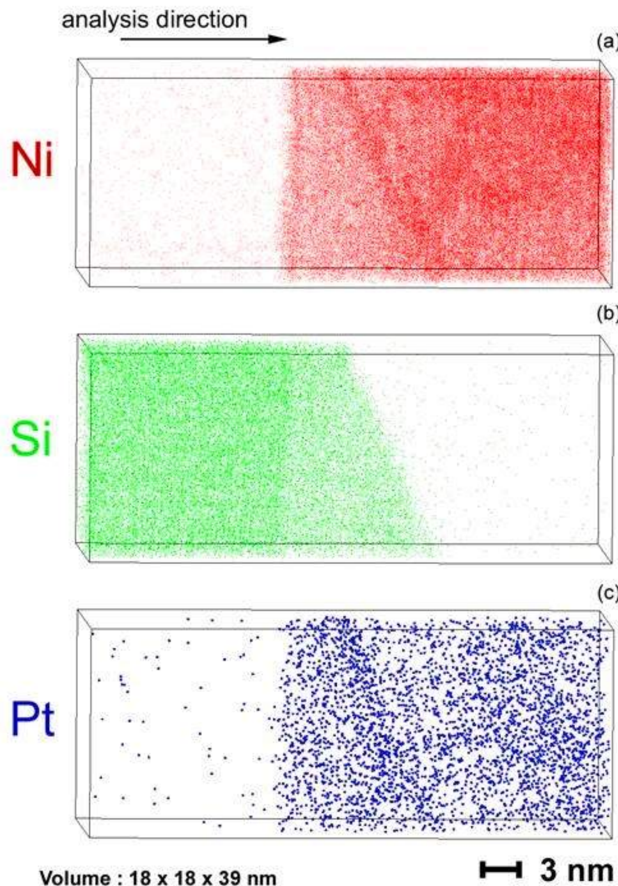
from H. Stork, - 2005 Int.Conf. on Charact. and Metrology for ULSI Technol.

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

NiPtSi 3D characterization

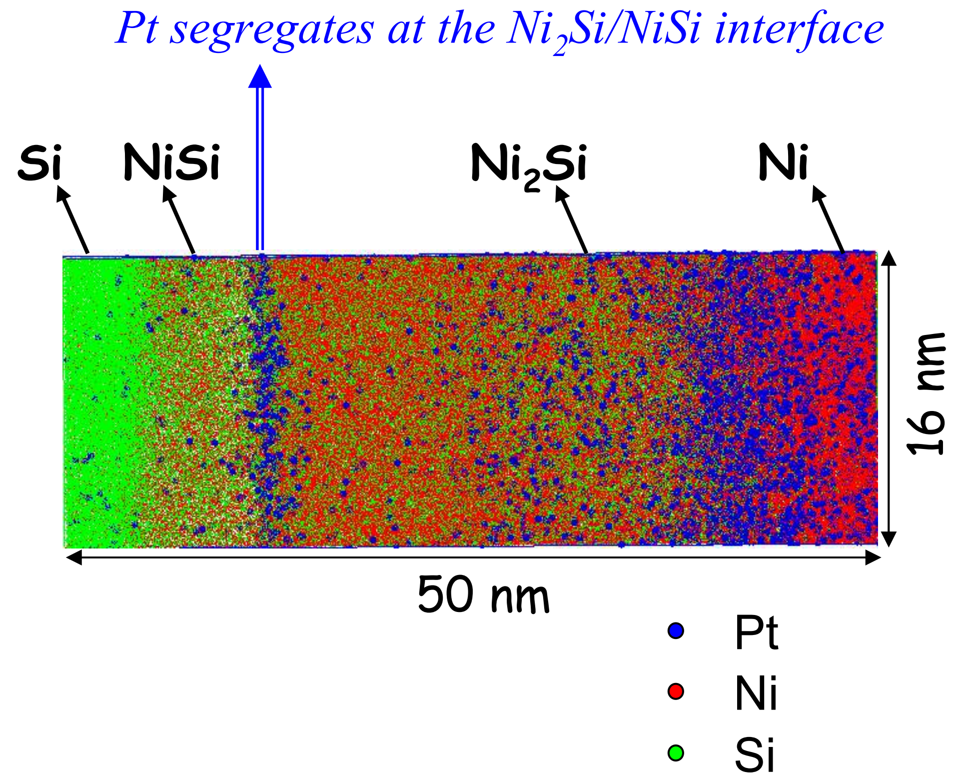
as deposited

after 290°C 1h



from K.Hoummada et al., APL 89 181905 (2006)

Pt segregates at the Ni_2Si/NiSi interface



after O. Cojoccaru, E. Cadel

L2MP

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITÉ DE ROUEN

cea

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Interconnection challenges

inlaid barrier

capping barrier

seed layer

via fill

porous dielectrics

Cu

ULK_1

Cu

ULK_2

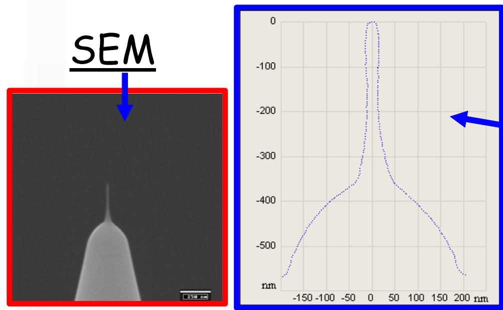
ULK_1

Cu

ULK_1

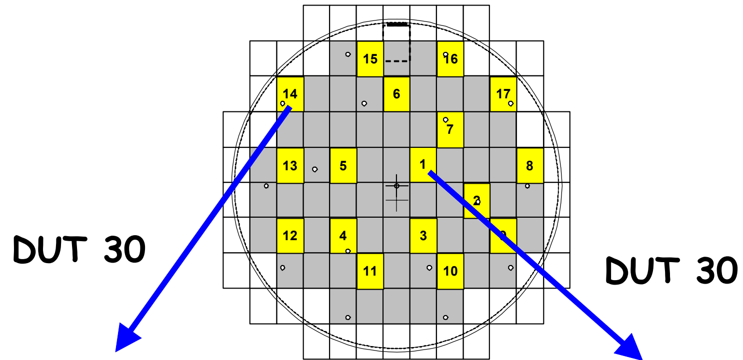
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

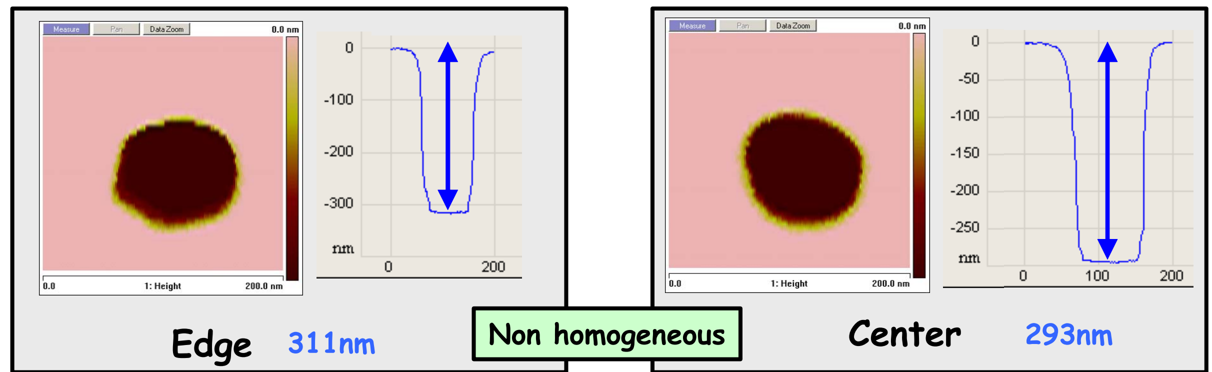
3D AFM via characterization



Cylindrical tip

Wafer mapping
Statistical data





Courtesy: J. Foucher – CEA/LETI

cea

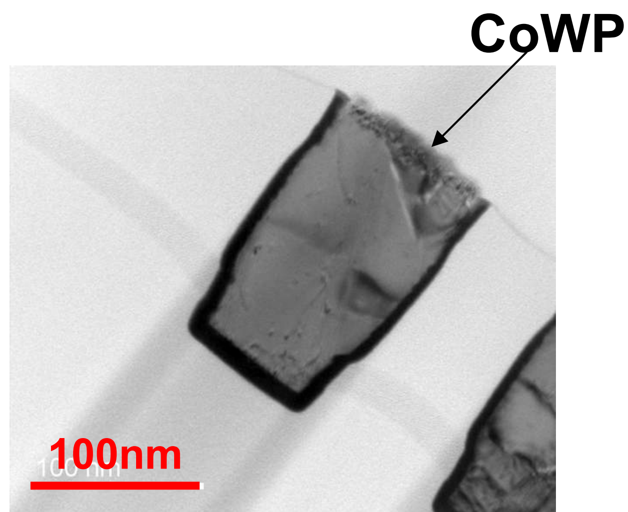
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

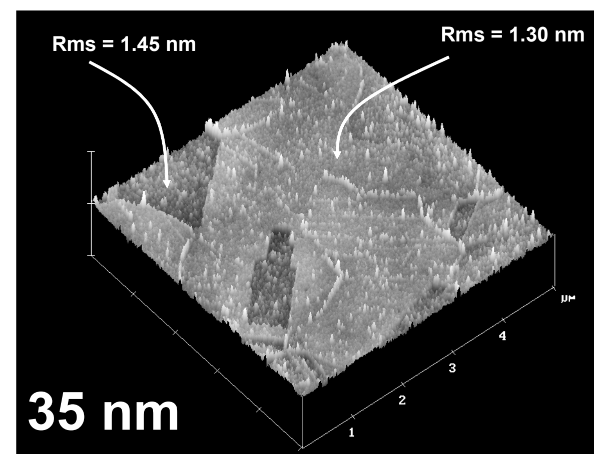
Via barrier + seed TEM tomography

from H.Stegmann et al. ME 65 171 – 183 (2003)
& Science, Technology and Education of Microscopy: an Overview p.187
& from E. Zschech Future Fab Issue 14

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

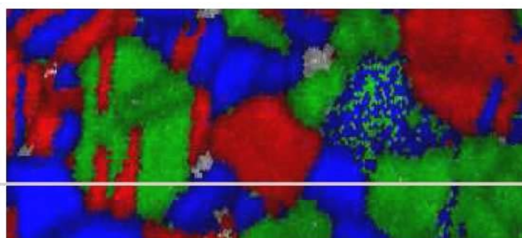
Electroless self-aligned barrier



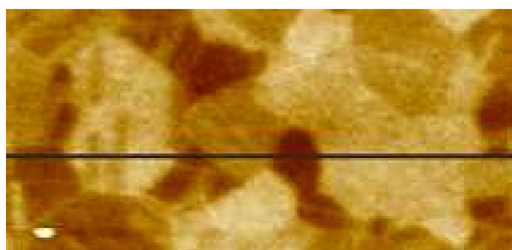


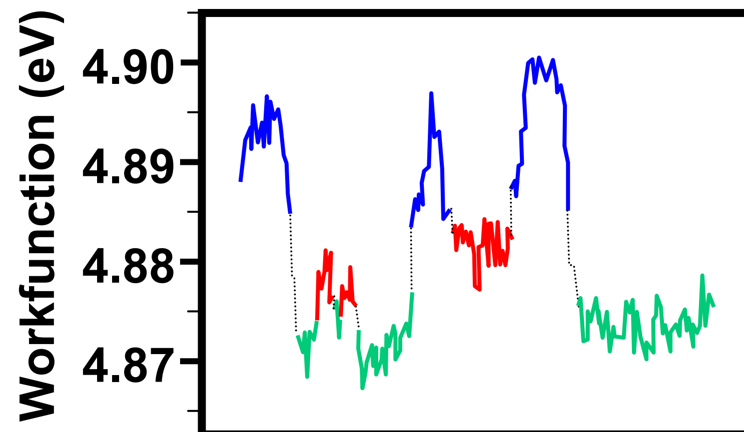
EBSD

<111>
<100>
<110>



KFM





from N.Gaillard et al. APL 89 154101 (2006)

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

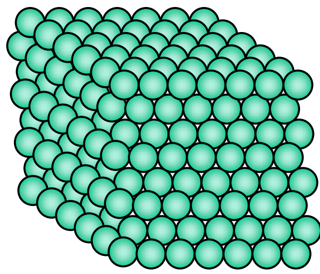
leti

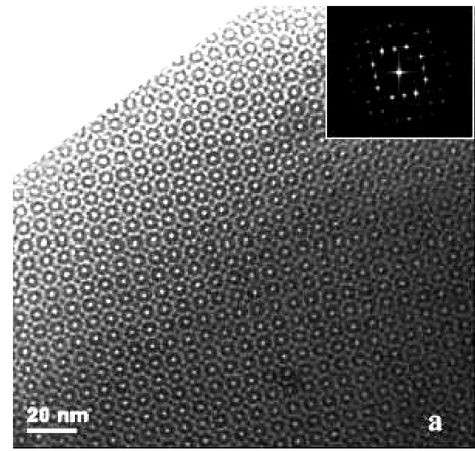
MINATEC

2007

Which kind of ULK porosity?

periodic **self-organized pores**





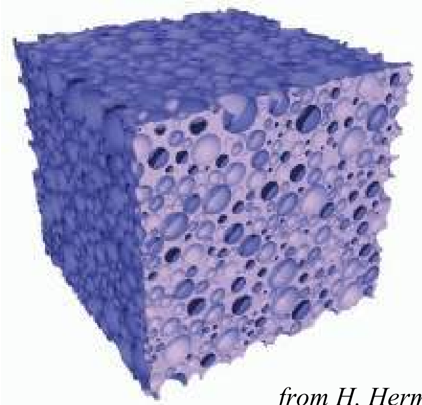
from Z.Zhang et al. Microporous & Mesoprous Materials 90 23-31 (2006)

random **optimum closed pore system**

70% porosity

$f(R) \propto (R/R_0)^{-3.3}$

physics of sandpile

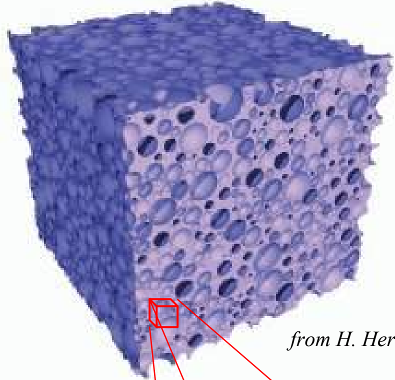


from H. Hermann (2004)

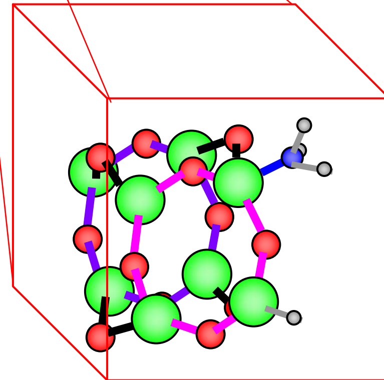
What is optimum wrt. k value, process & mechanical properties?

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

ULK: understanding the porous structure

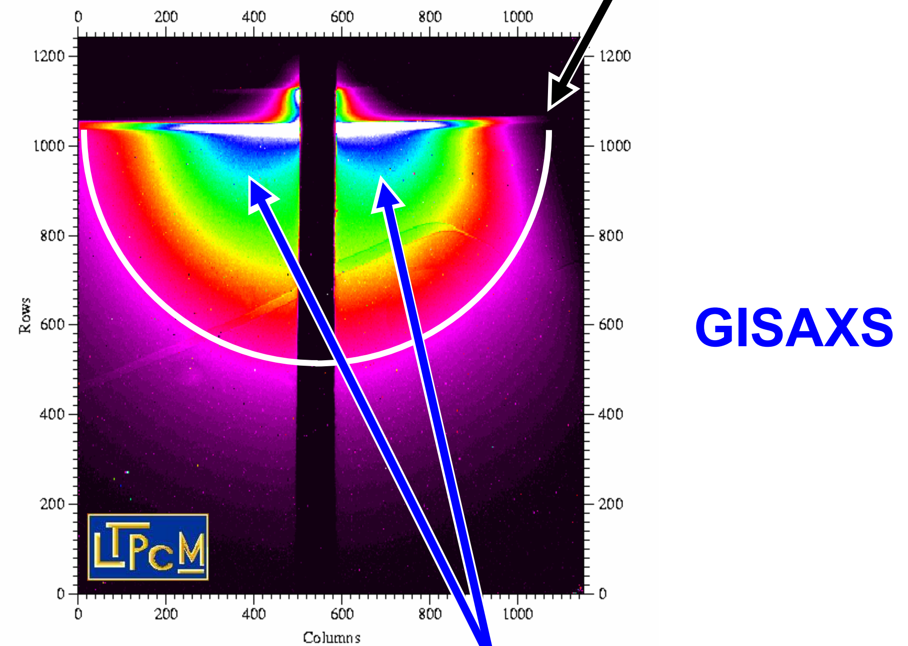


from H. Hermann (2004)



- Si
- O
- C
- H

- **Diffusion bump**
  - ⇨ **pore shape**
  - ⇨ **pore size**



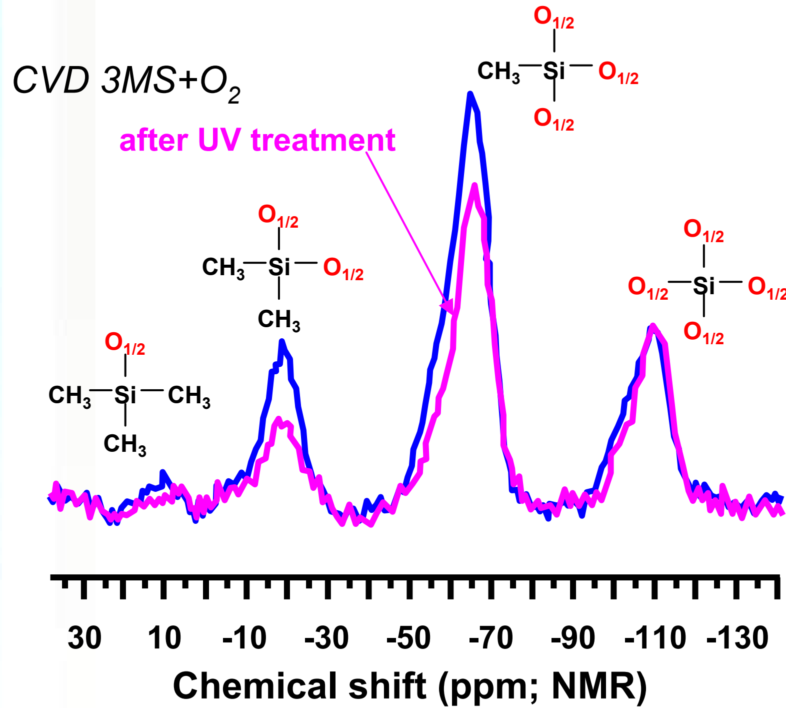
GISAXS

- **Correlation peak**
  - ⇨ **distance between pores**
  - ⇨ **pore organization**

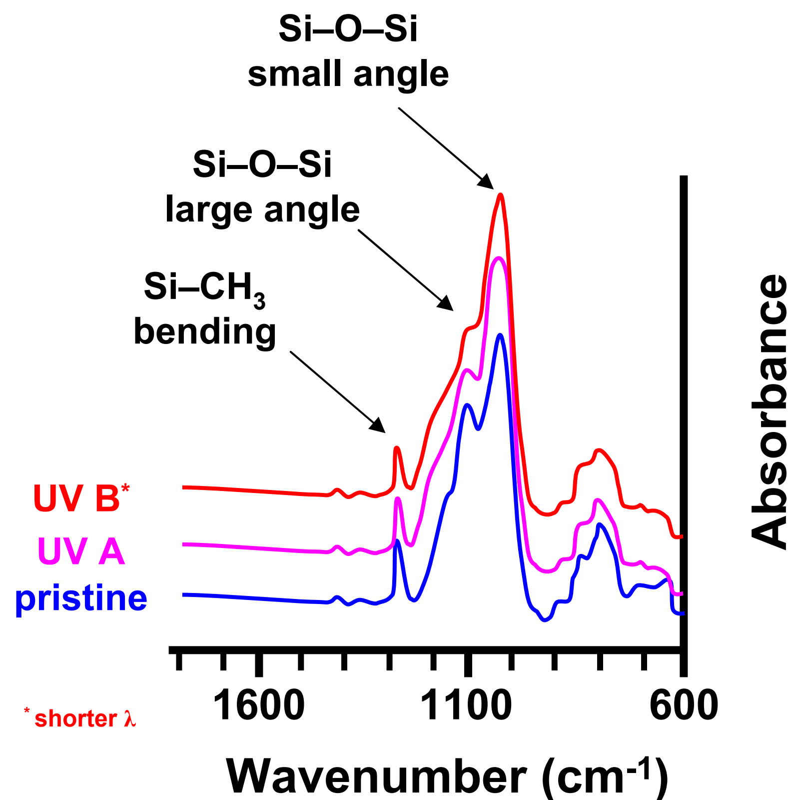
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

ULK: understanding the porous structure

axcelis

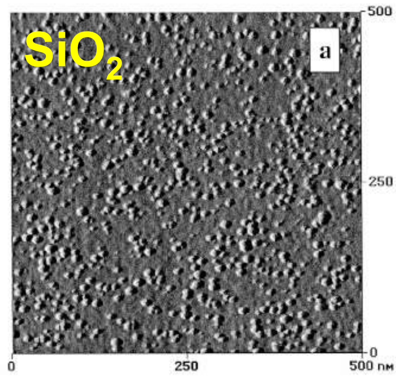


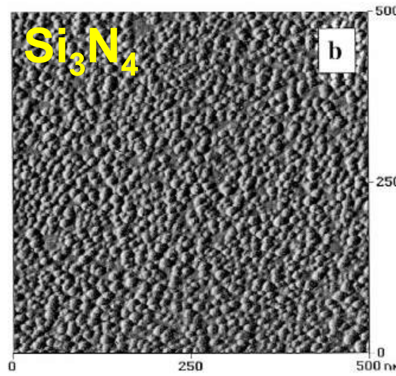
after F. Iacopi et al., J. Appl. Phys. 99 053511 (2006)



© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

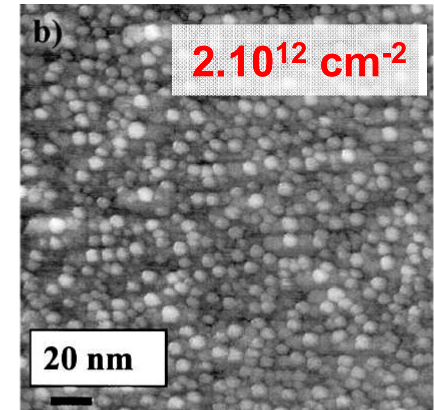
Using nanocrystals for NVM



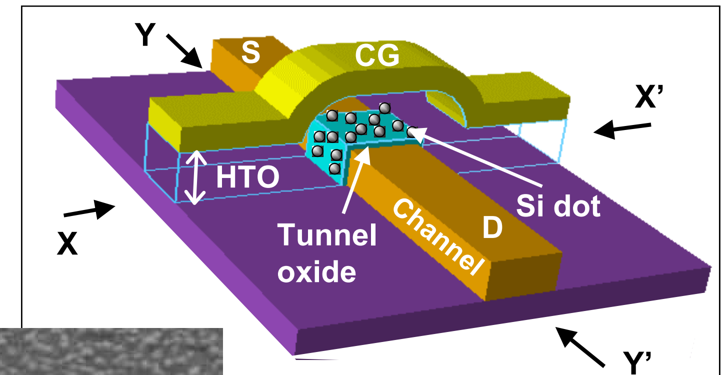


from T.Baron Appl. Surf. Sci. 164 29-34 (2000)

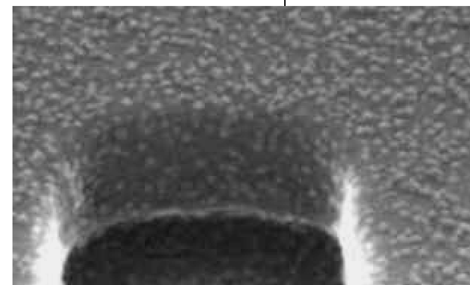
…targeting high dot density



from T.Baron Appl. Phys. Lett.. 79 1175 (2001)



… & applied on complex 3D structures



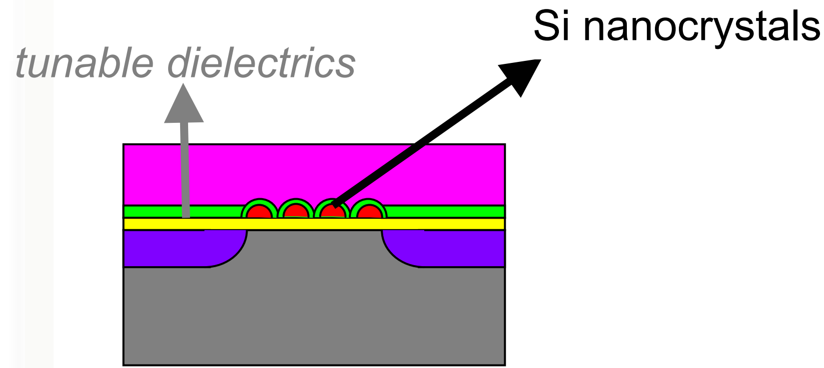
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

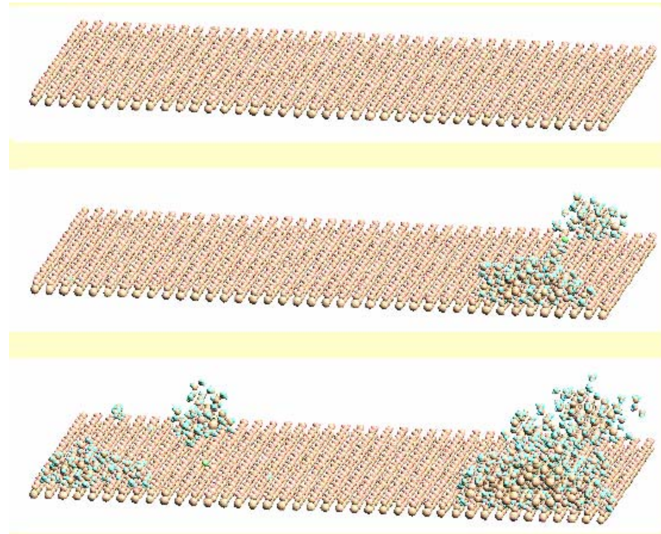
leti

MINATEC

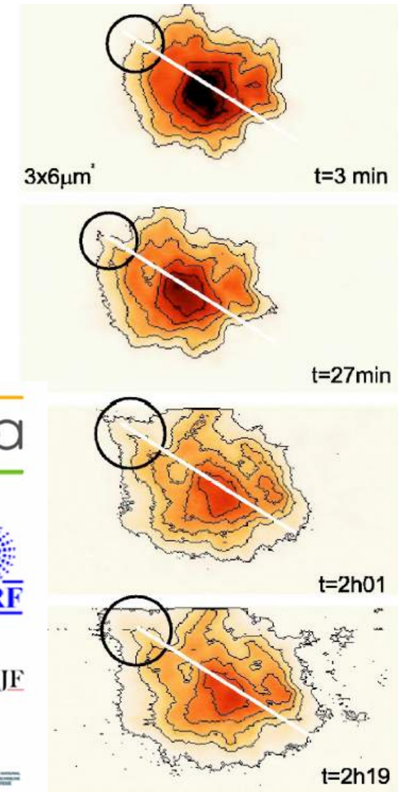
2007

nc-NVM simulation & characterization





atomistic simulation

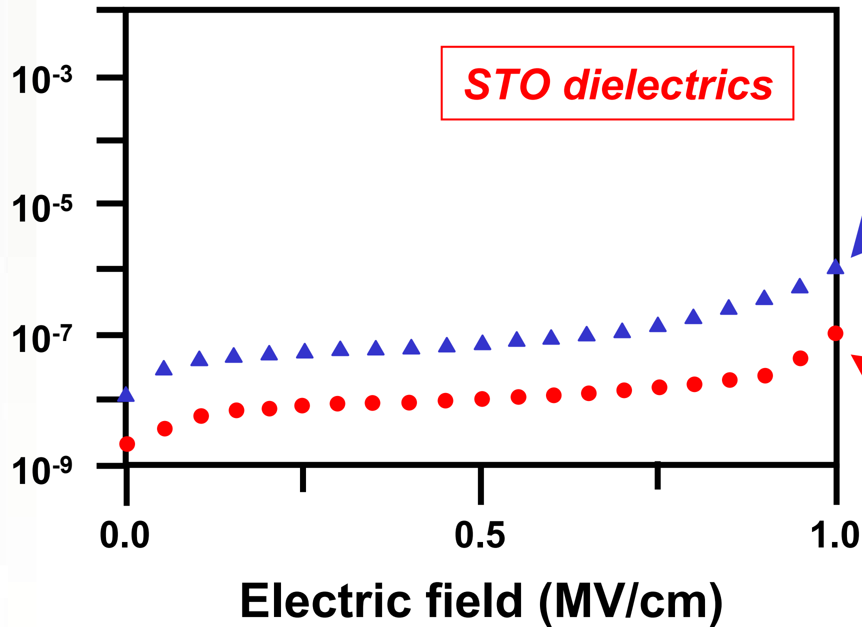


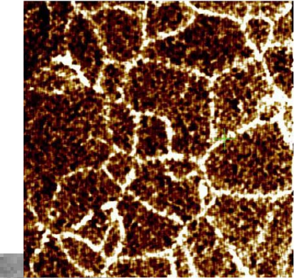
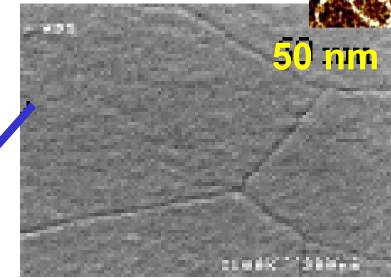
charge spreading by EFM

from R.Dianoux et al. Phys.Rev. B71 125303 (2005)

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

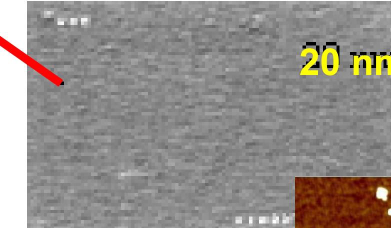
MIM capacitor: material optimization

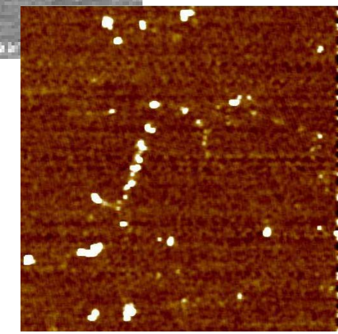


SEM pictures

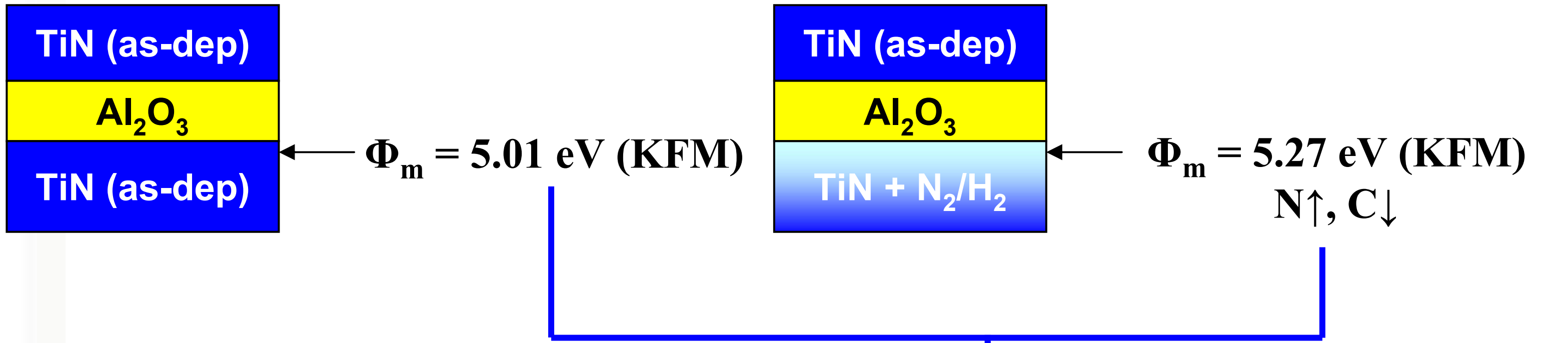
TUNA

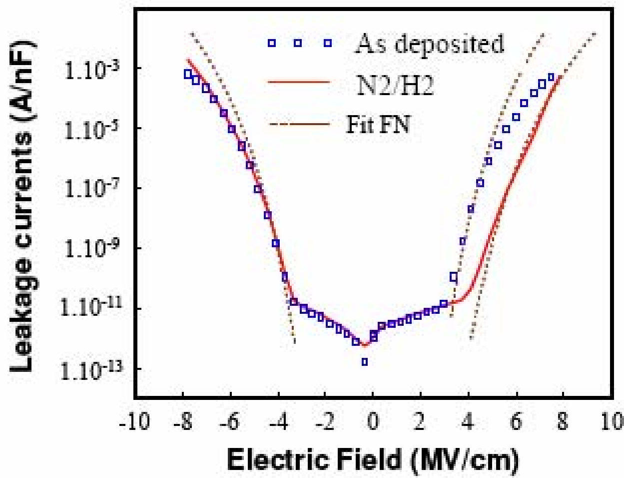




© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

MIM capacitor: effect of the electrode material





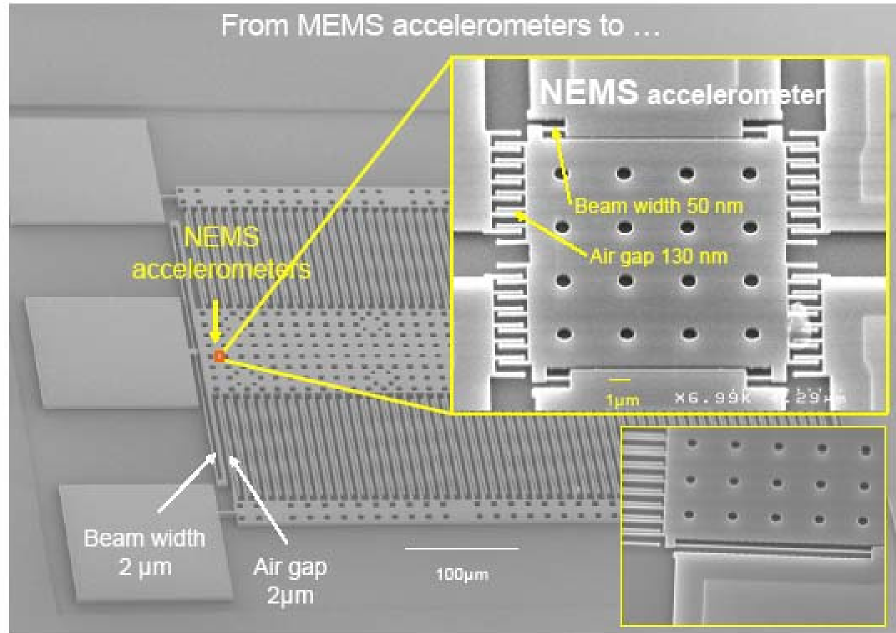
Courtesy of Aurélie Bajolet (STM)

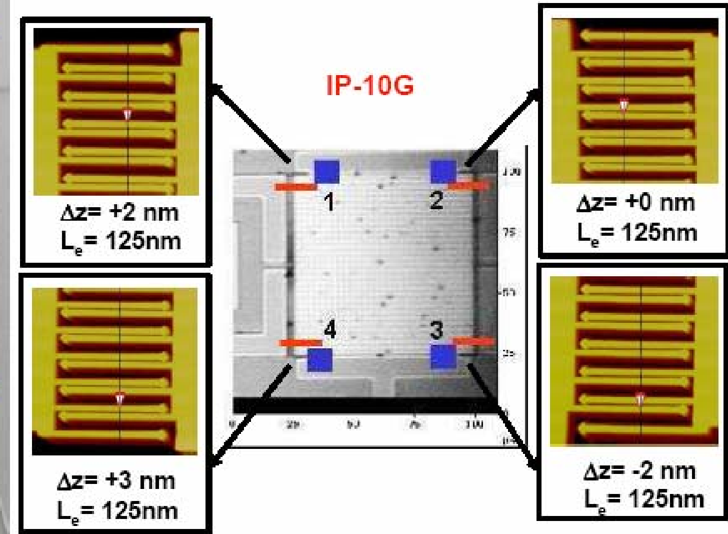
$\Delta\Phi_m$ = 0.26 eV (KFM)
consistent with
the electrical measurements
[$\Delta\Phi_m \approx$ 0.3 eV]

from N. Gaillard et al., MAM 2006

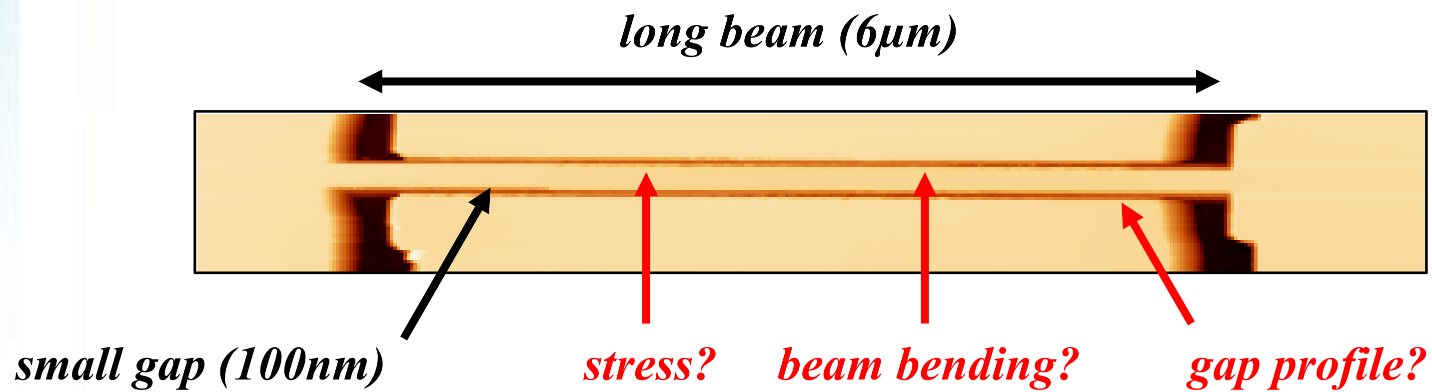
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

NEMS characterization





AFM characterization of NEMS



cea

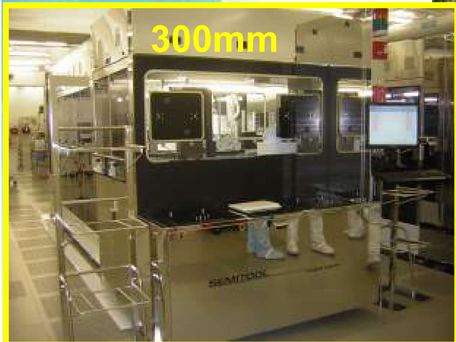
© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

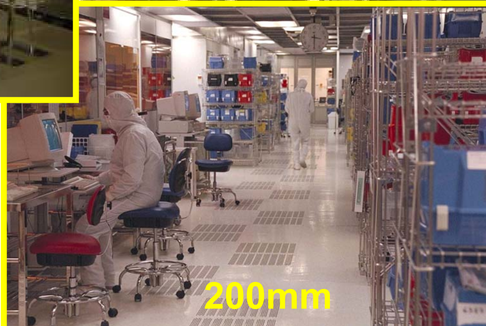
Need of pooling resources together

NanoCharacterization Center

MINATEC
POLE D'INNOVATION

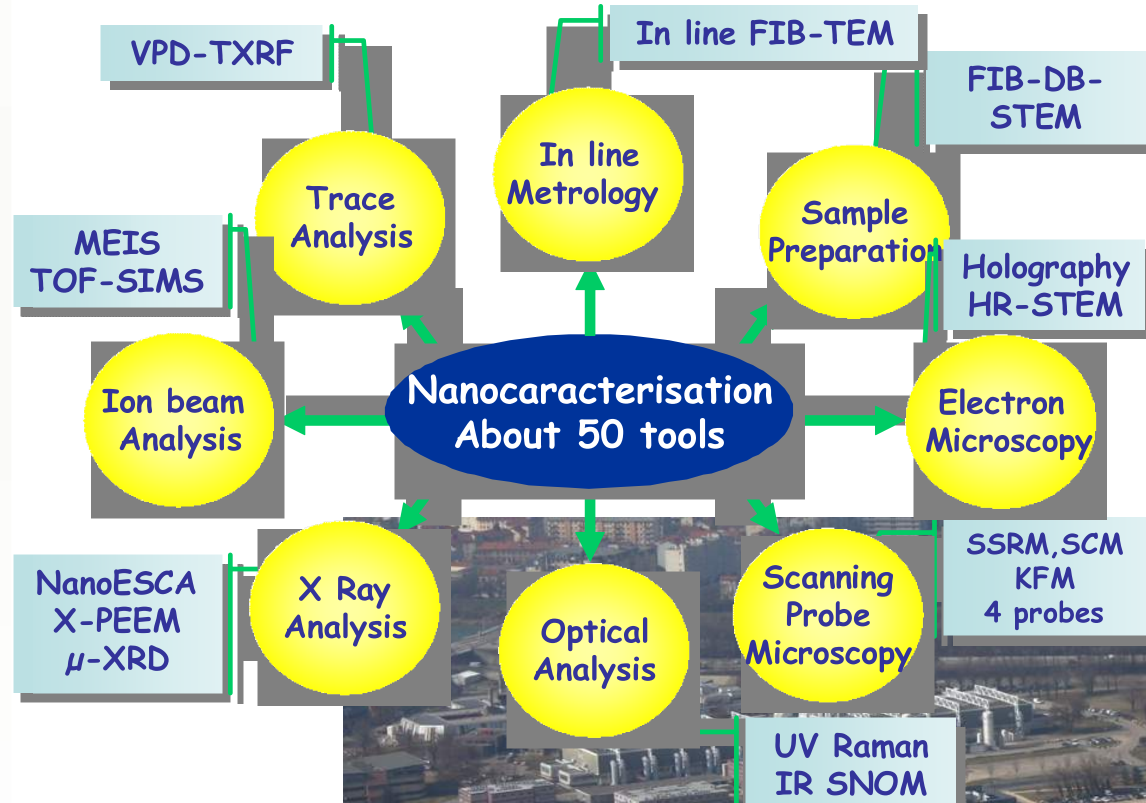
leti

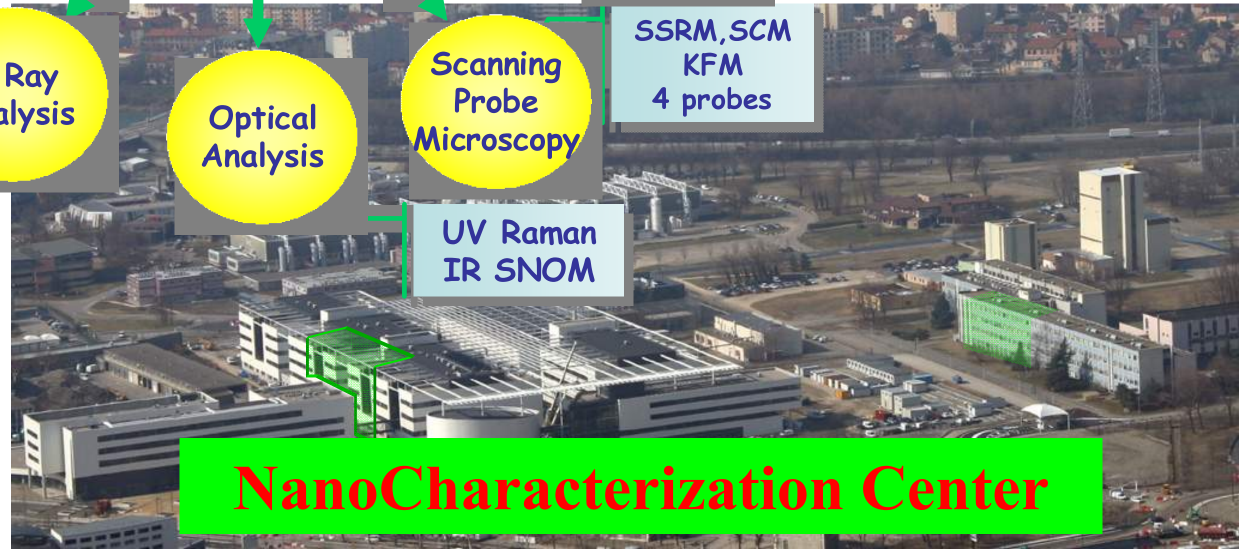




© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Need of pooling resources together





© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

Outline

- A changing R&D landscape in nanoelectronics
- The European models, incl. CEA-LETI
- Trends in characterization

➔ Conclusion

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

leti

MINATEC

2007

Conclusion

- The microelectronic industry is on the verge of a major qualitative change
- More specialization and consolidation will happen in the next future
- New ways of R&D appear in a “coopetitive” environment
- Nanocharacterization for microelectronics will need to pool more resources in close proximity
- CEA-LETI developed a cooperation model robust to the present evolution

© CEA 2007. Tous droits réservés.
Toute reproduction totale ou partielle sur quelque support que ce soit ou utilisation du contenu de ce document est interdite sans l'autorisation écrite préalable du CEA
All rights reserved. Any reproduction in whole or in part on any medium or use of the information contained herein is prohibited without the prior written consent of CEA

Thank you for your attention

micro and nanoelectronics
microsystem
ambiant intelligence
biology and health
image chain

Innovation for industry

Loyalty
Entrepreneurship
Team work
Innovation

leti

MINATEC
POLE D'INNOVATION

cea