Micro and Nano Systems at LAAS-CNRS: Which Technologies for Today and Tomorrow ?

Anne-Marie Gué, 9 Novembre 2007

Why developing new and innovative technologies ?

Micro and nanotechnologies are a key point for:

- Health and safety: early diagnosis, drug discovery, artificial

Biology and health:
monitoring and detection of bio and chemical species
from micro-volumes to single species (molecule, cell, …)

…as, …) and climatic changes

Power management:
Autonomous and energy saving systems,
energy harvesting, energy storage

Communication:
Tele communications, Communicating systems

Technological needs and challenges

The Chinese puzzle !

Complex systems:
- multi functionalities
- multi disciplinary
- heterogeneous (materials

Nano in Micro:
- Size reduction
- new and revolutionary principles

Various and numerous fields of application:
- large variety of working
- size specification
- cost requirements
- diversification of support or substrate
- …

new structural and functional materials

3D and heterogeneous integration

nanopatterning: structural and chemical patterning

(very) low cost devices: low cost materials and simplified processes

large area systems, flexible systems

Outline

- From s.c. to multimaterials
- From planar technology to 3D and heterogeneous structures
- From physics to multidisciplinarity

From Planar technology to 3D and heterogeneous structures

Doubleside process

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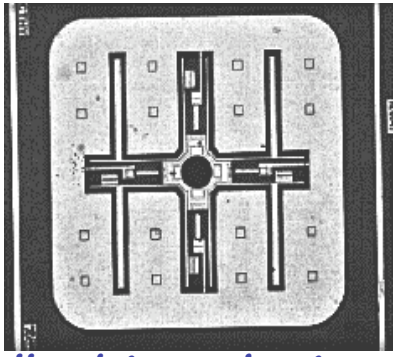
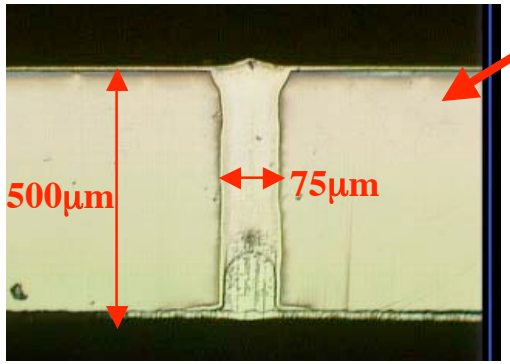
Double-side processes

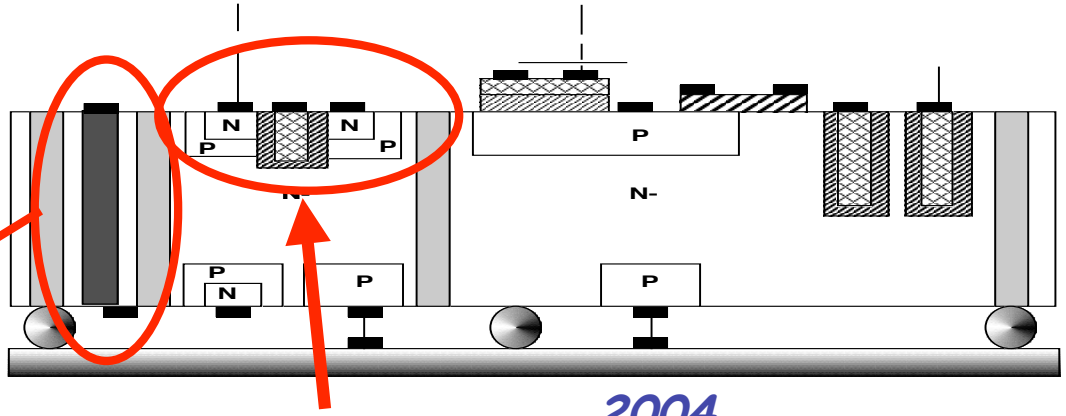
At the beginning …



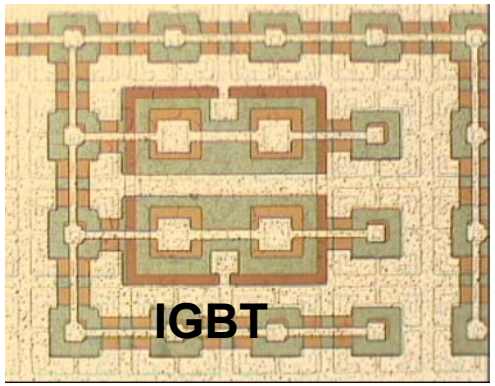
Optically driven thyristor 1980

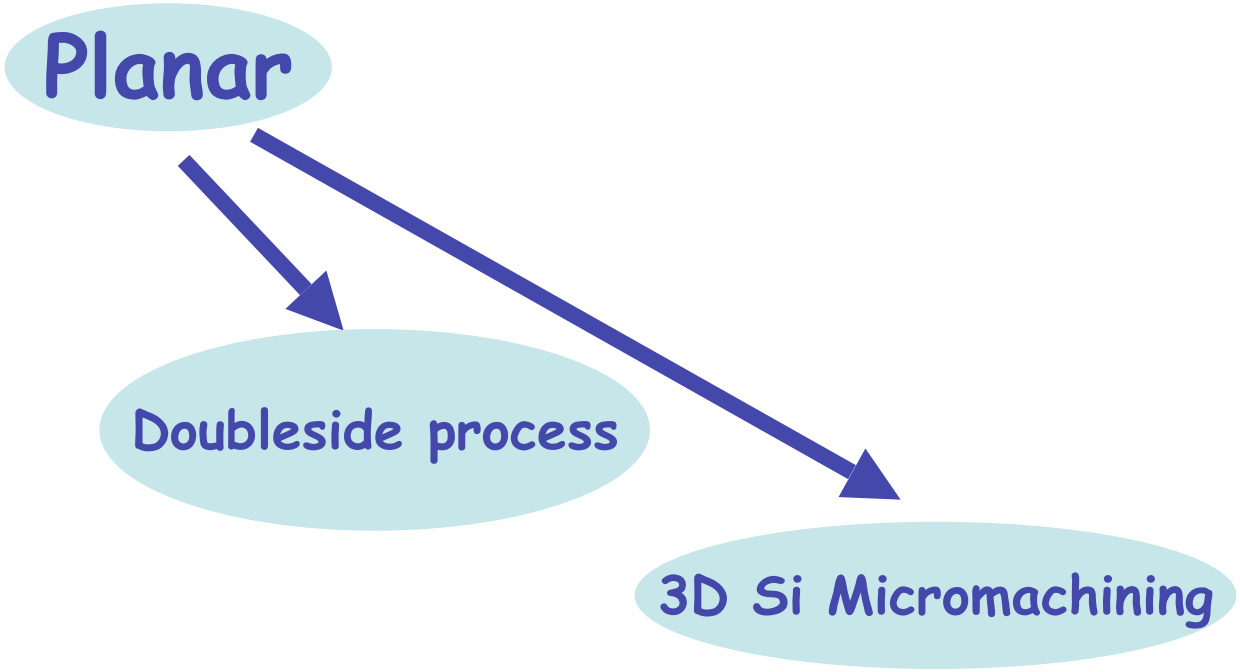
Thru-wafer vias :
- thru-wafer DRIE
- Al thermomigration
- Specific vertical LPCVD furnace





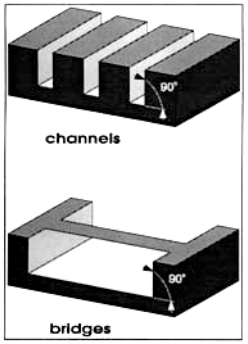
2004

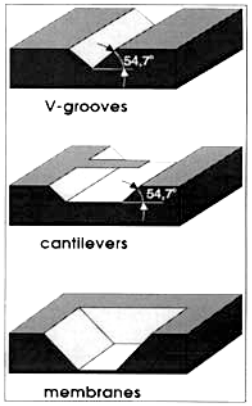


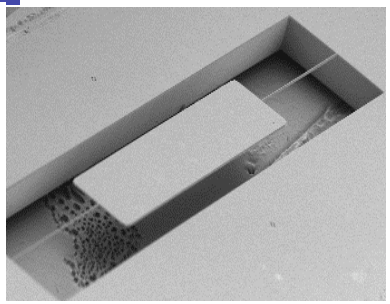

Planar
Doubleside process
3D Si Micromachining

Si Bulk and surface micromachining

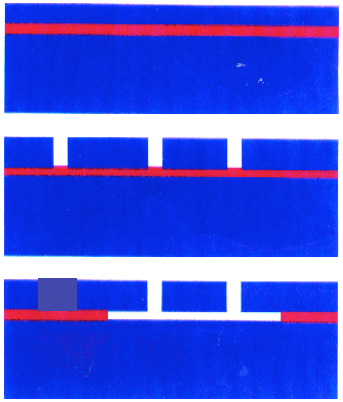
Si wet etching KOH





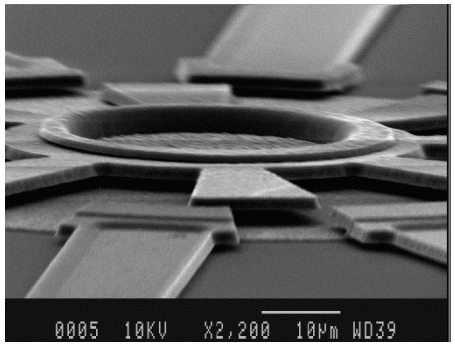


Si surface micromachining

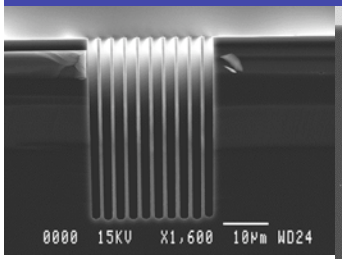


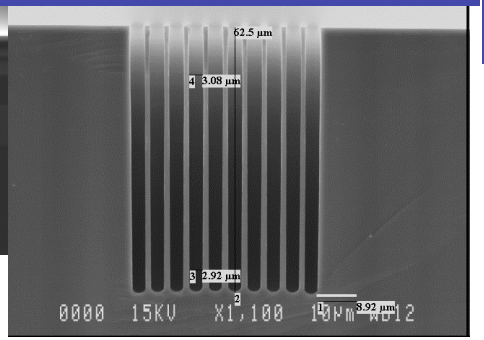
Si SiO_2

Sacrificial layers:
SOG, SOD, oxidized polySi

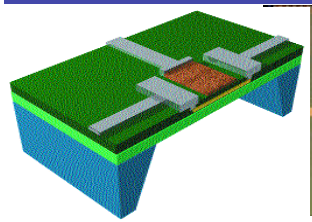


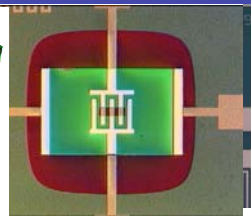
Si DRIE for non linear capacitance

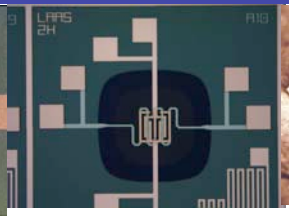


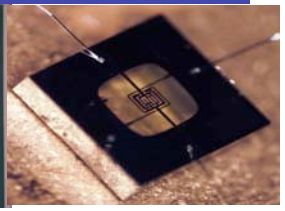


Thin delectric suspended membranes (hot plates)









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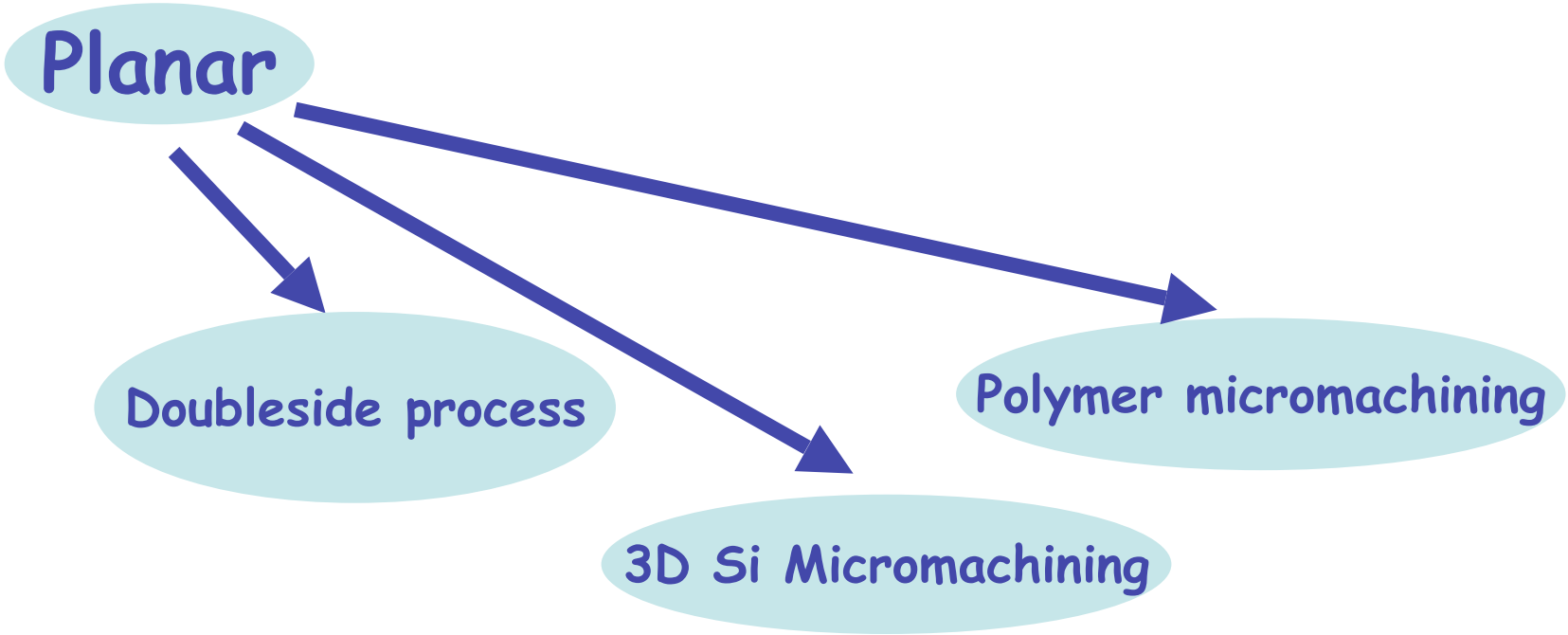
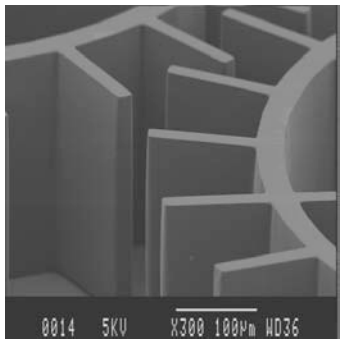
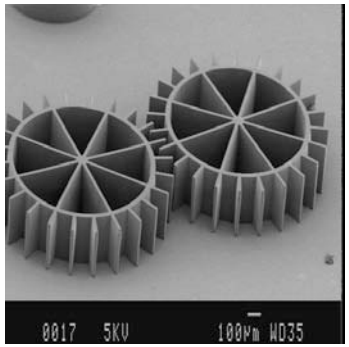

Planar
Doubleside process
Polymer micromachining
3D Si Micromachining

Polymer micromachining: direct lithography

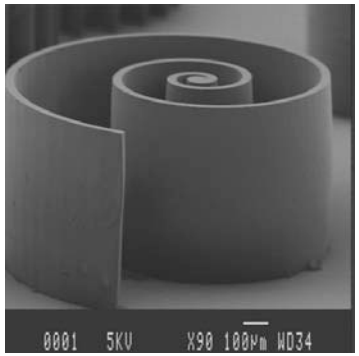
Negative Photoresist (SU 8)



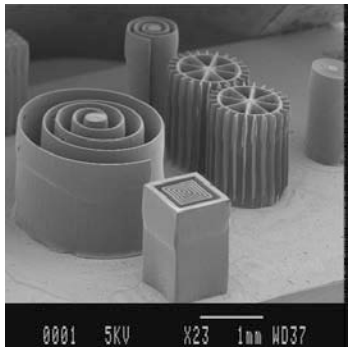
E=200µm



E=300µm

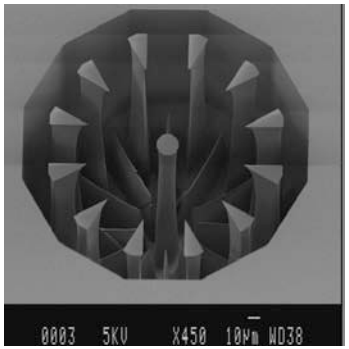


E=500µm

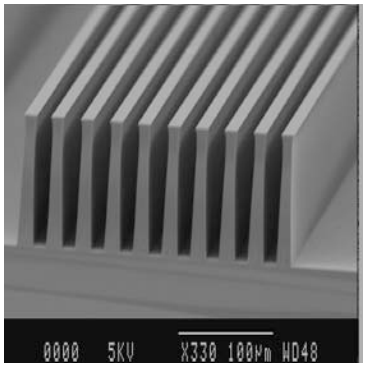


E=1,2mm

Positive Photoresist (AZ 9260)



e=100µm

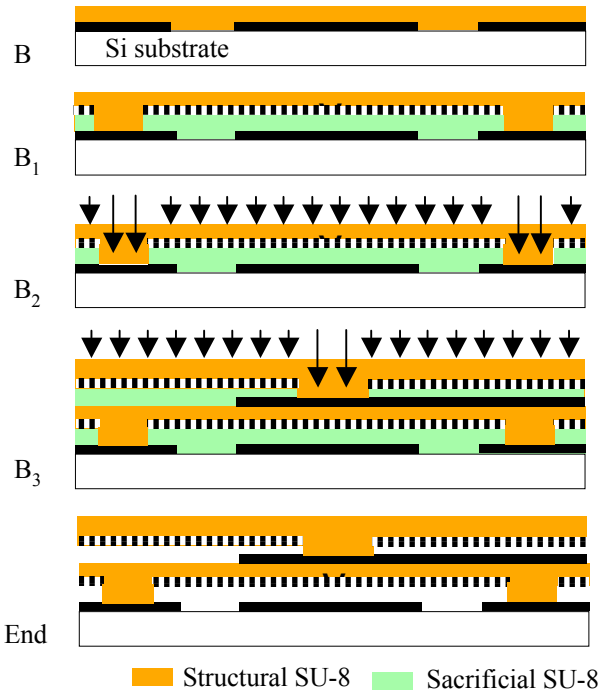


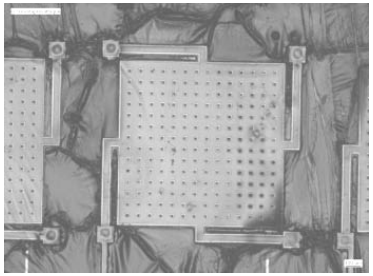
e=100µm

Polymer micromachining: sacrificial layer technology

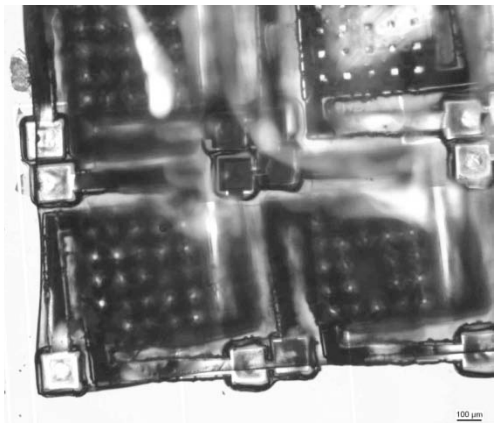
Adaptative optics

[SU8/SU8]



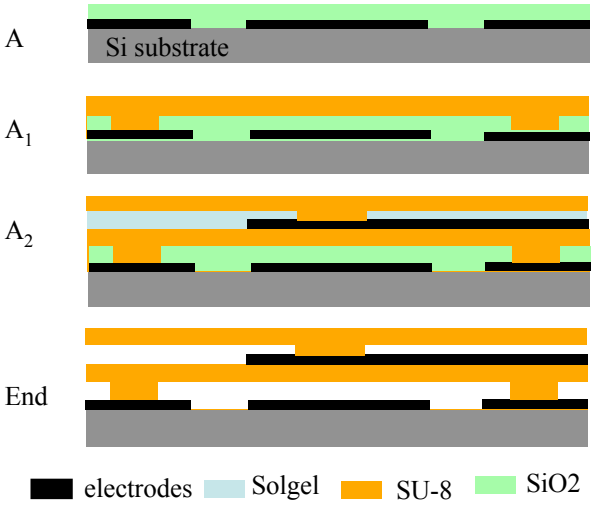


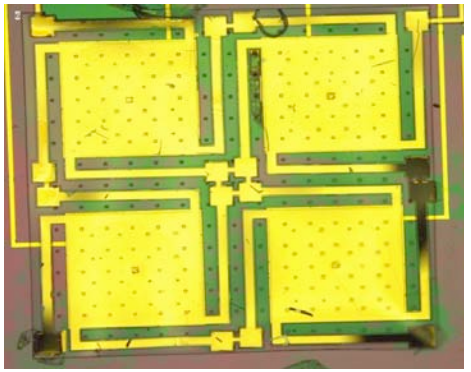
First level (B_2)



Two levels (end)

[SiO_2/SU8] + [Solgel/SU8]





Pitch: 500µm to 1mm

Key features

- mirror: roughness < λ/10
- vertical actuation: up to 10 µm
- pitch: 500 µm to 1 mm

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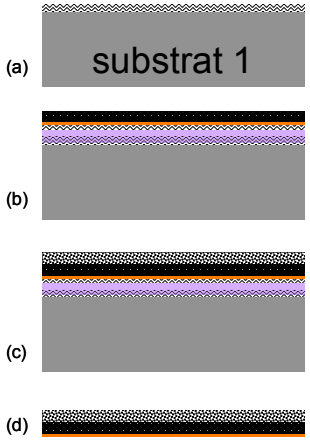
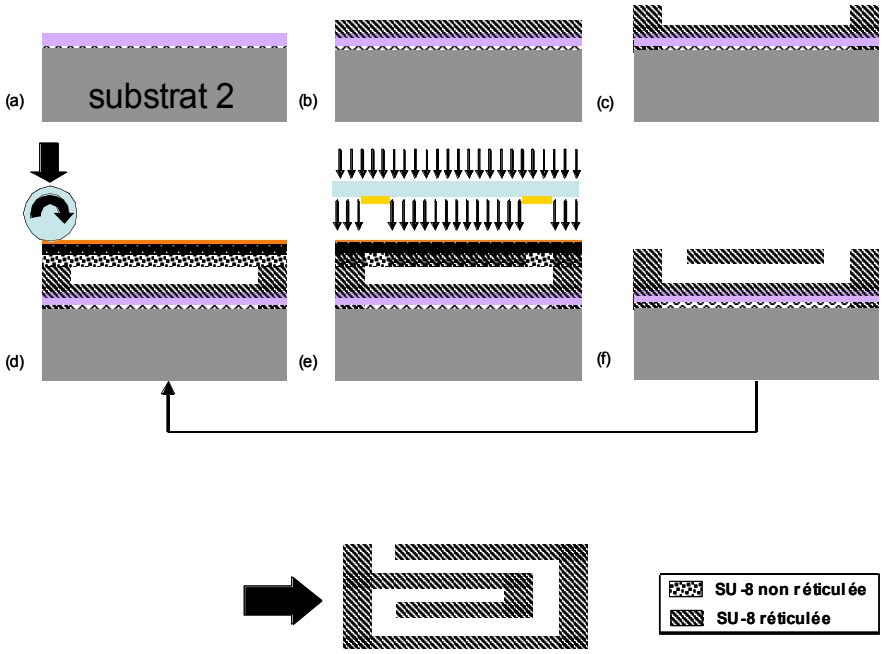
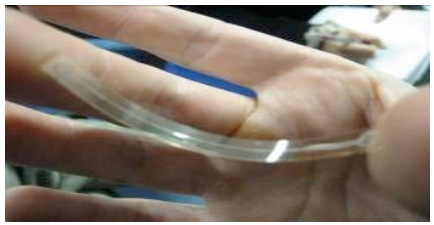
Polymer micromachining: SU 8 dry films lamination

{ Realization of a non crosslinked SU8 flexible film

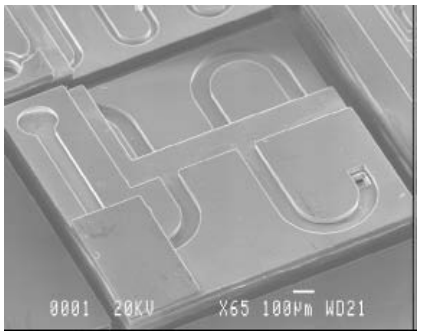


} Stacking and patterning of SU8 films

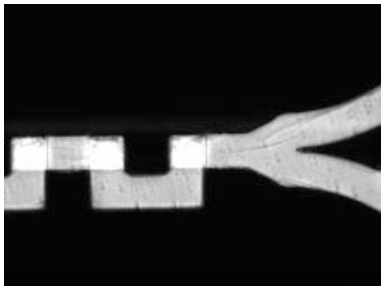




➡ *flexible SU-8 chip*



➡ *multilevel network*



➡ *3D micromixer*

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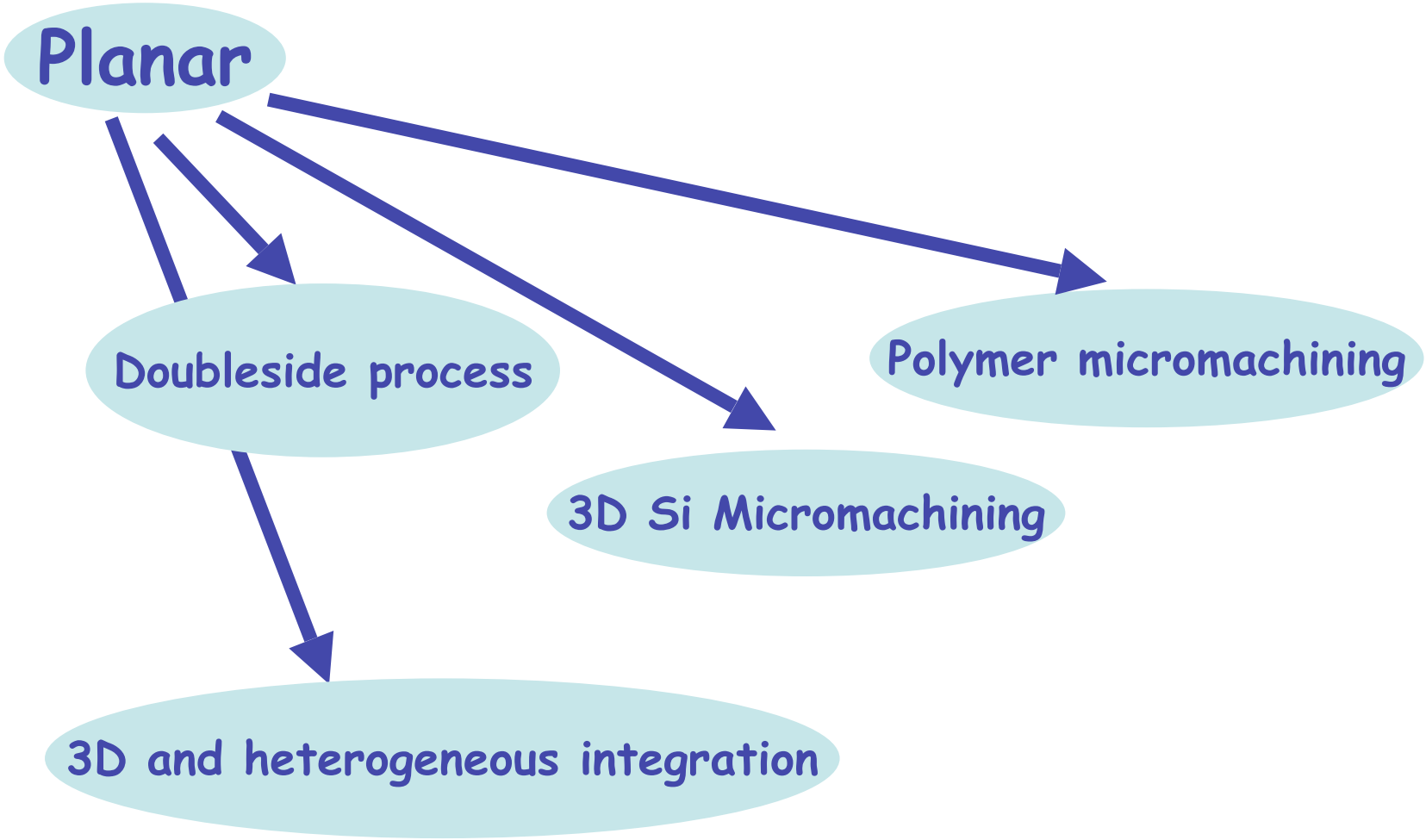
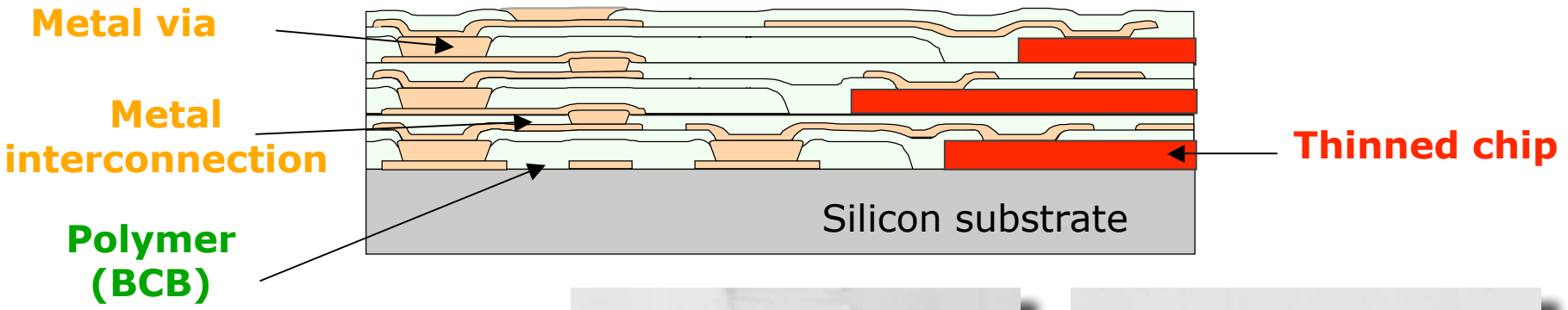
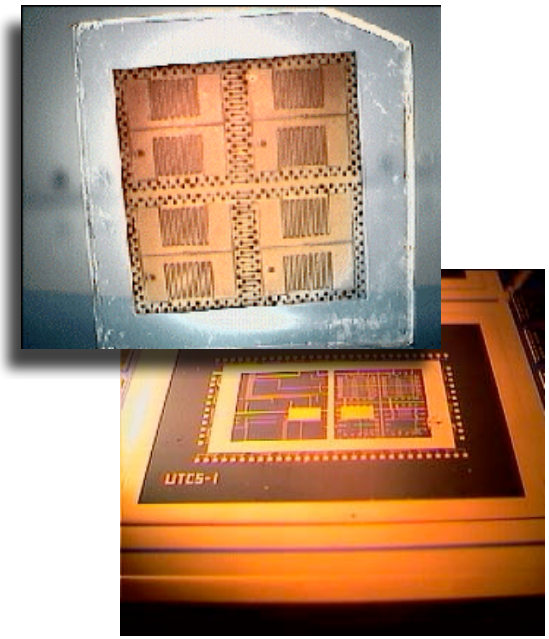
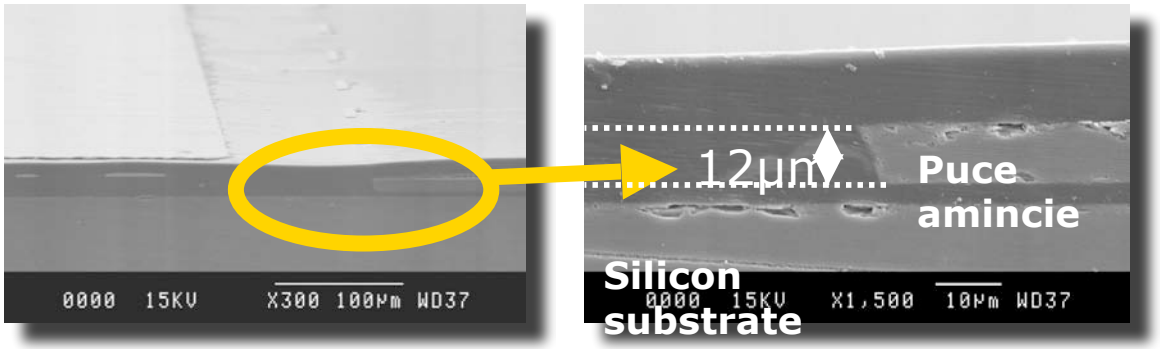

Planar
Doubleside process
Polymer micromachining
3D Si Micromachining
3D and heterogeneous integration

Ultra-Thin Chip Stacking

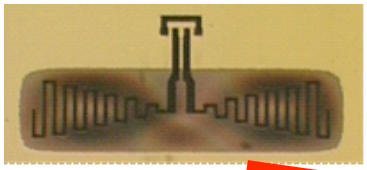


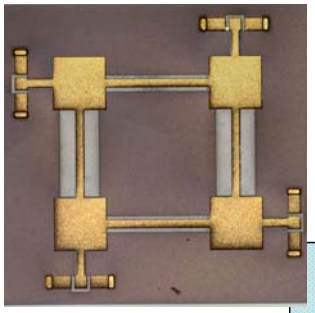




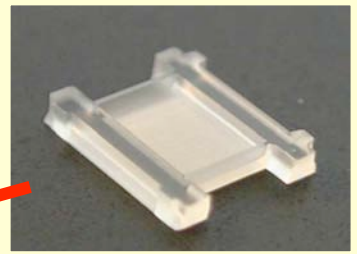
	PCB	MCM-V	3D Ultra-compact
Active volume/ total volume ratio	25x10^{-6}%	0.003 %	30 %
Mass (gr.)	52	7	0.5
Size (mm)	63x63x5	19.5x19x11	20x20x0.5
Volume (cm^3)	20	4.7	0.2

RF Heterogeneous integration

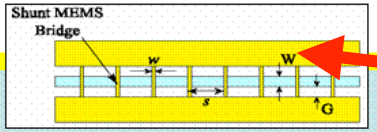




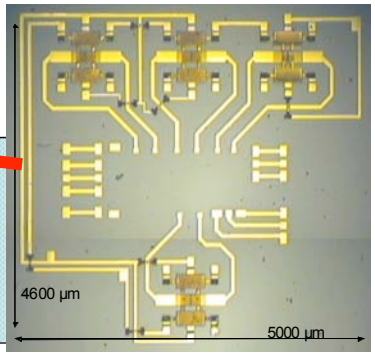
Antenna coupling topology



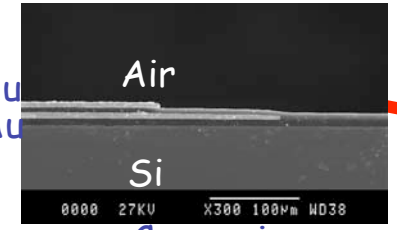
package



MEMS phase shifter



Silicon substrate



BCB Au Au BCB

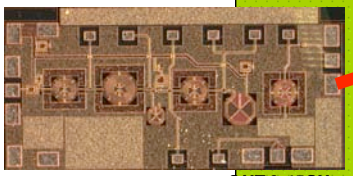
Cross view

10-20 µm

bcb

Active SiGe

100-200 µm



Silicon L.R. = mechanical and thermal chuck

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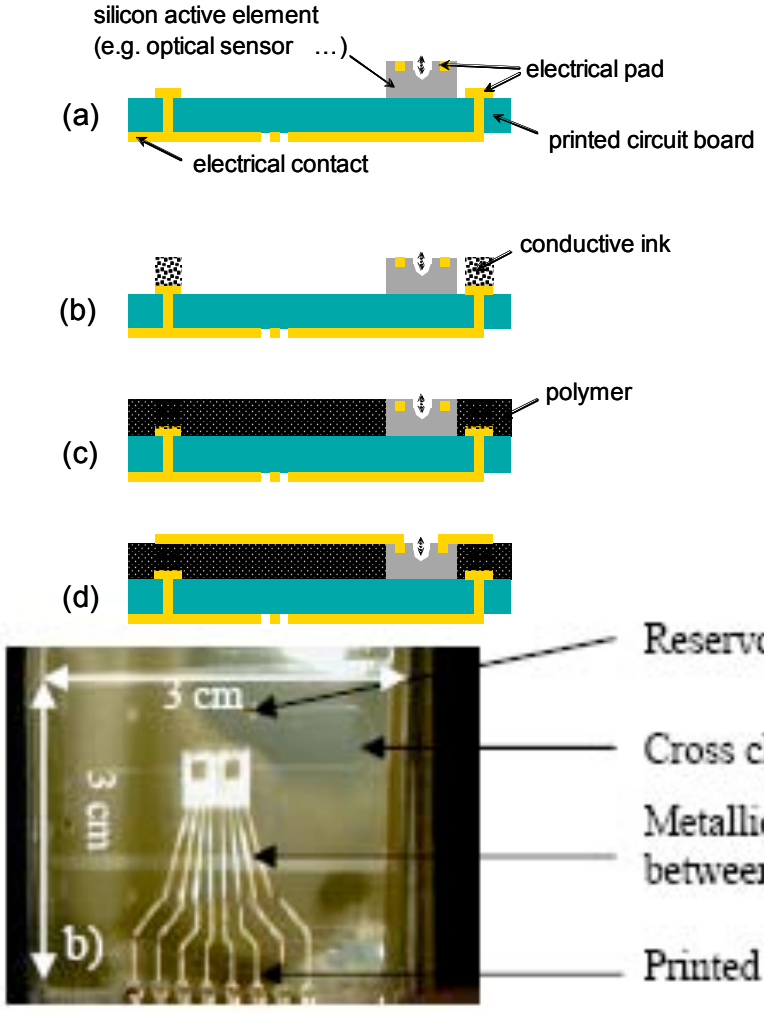
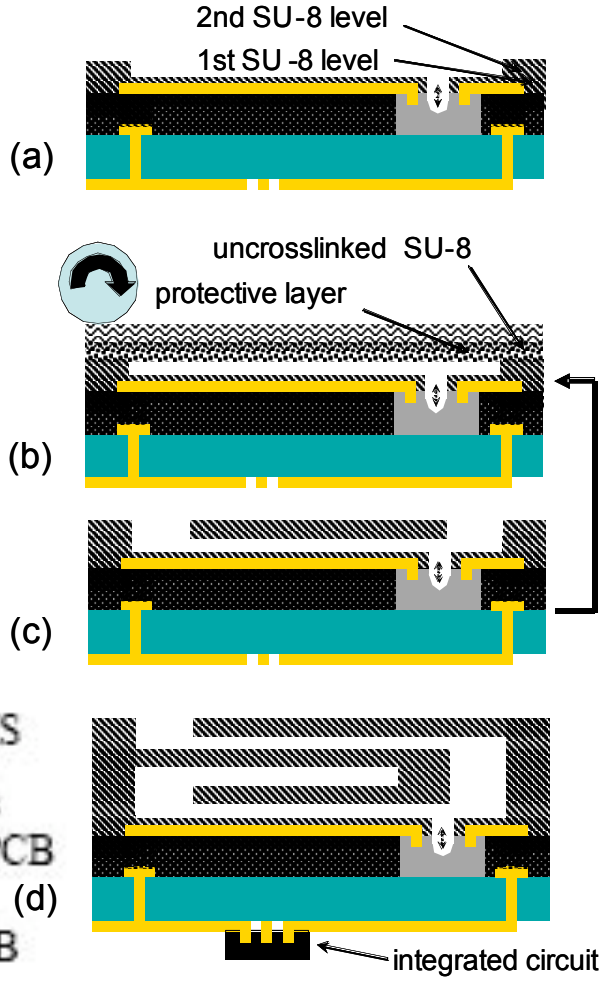
3D and heterogeneous integration





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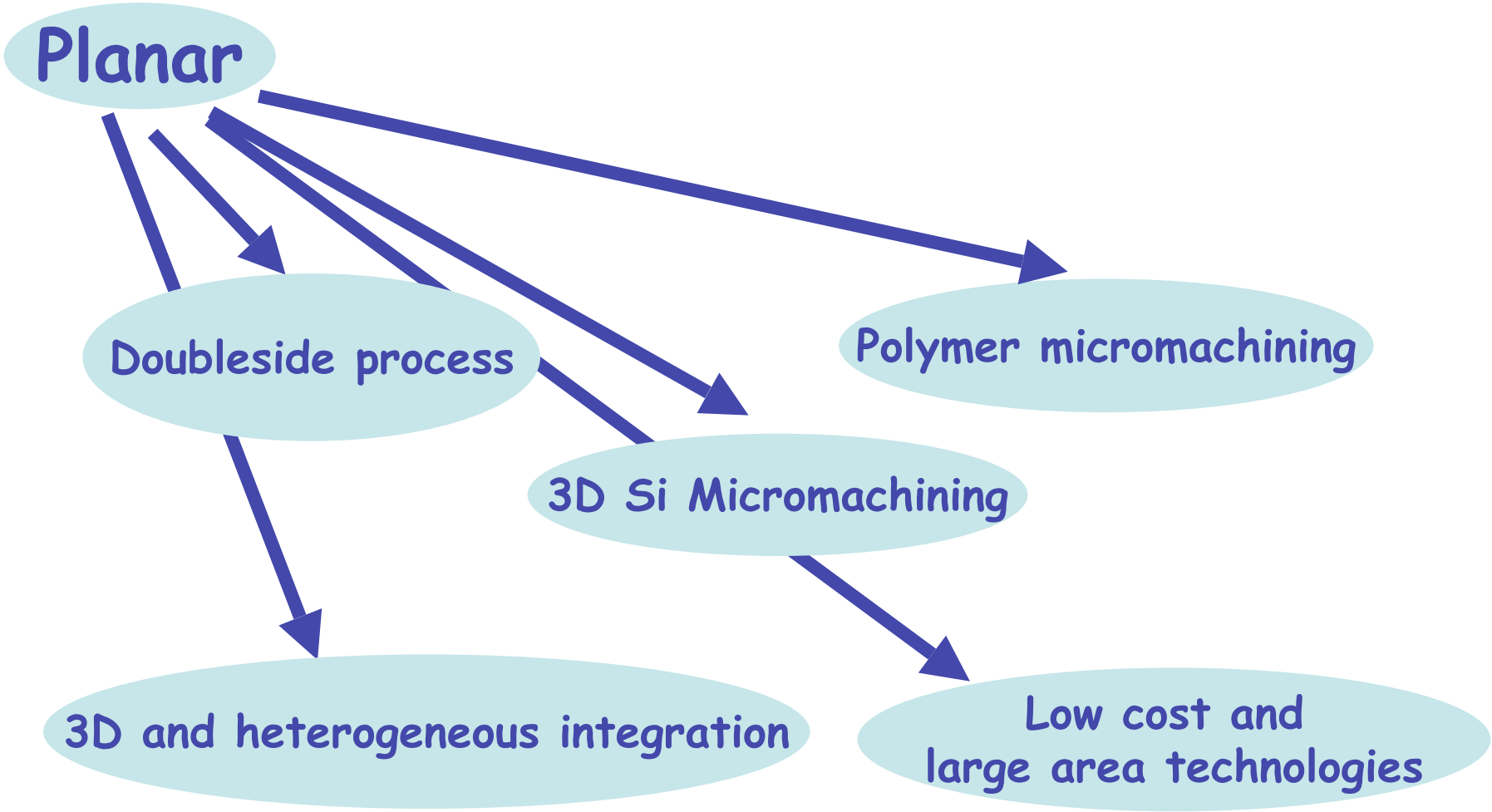
Planar
Doubleside process
Polymer micromachining
3D Si Micromachining
3D and heterogeneous integration
Low cost and
large area technologies

Ink jet technology

(under development)

Micro optics

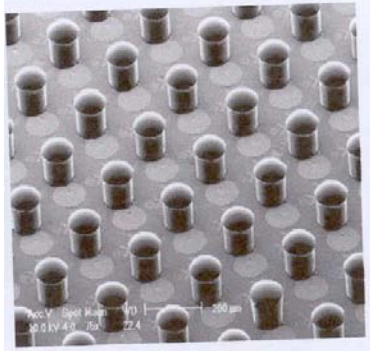

Figure 17. Wafer level fabrication of pedestals and microlenses on VCSEL wafer.

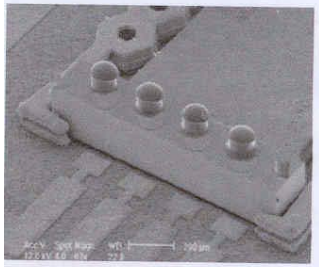

Figure 25. A lensed VCSEL die is positioned by a MEMS clamper.

3D polymer microlenses

ink:

H_2O 30 to 50% : monitoring of viscosity and surface tension
Photoinitiator : triarylsulfonium hexafluorophosphate ;
Hydrolyse (3- glycidyloxypropyl trimethoxysilane) : sol gel

Wave guides

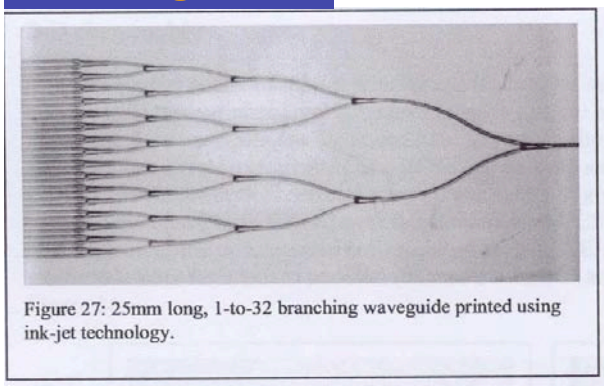

Figure 27: 25mm long, 1-to-32 branching waveguide printed using ink-jet technology.

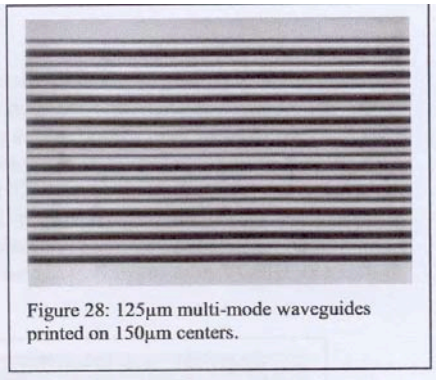

Figure 28: 125µm multi-mode waveguides printed on 150µm centers.

Results :

dimensions : Ø 50 µm to 2 mm ;
High : 6 µm to 150µm
Focal length : 100 µm to 2 mm
Surface roughness: 40 nm
indice : monitored through sol gel composition

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Ink jet technology

Bumping

(under development)

Solder printing: Ø 80µm, high 100µm

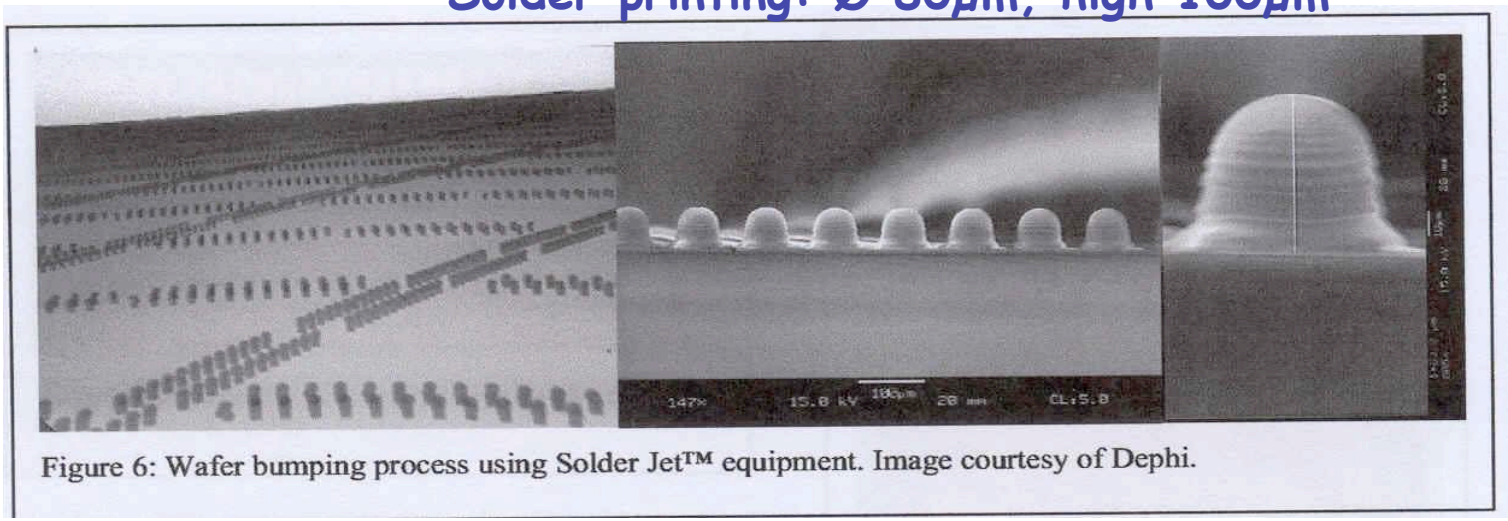
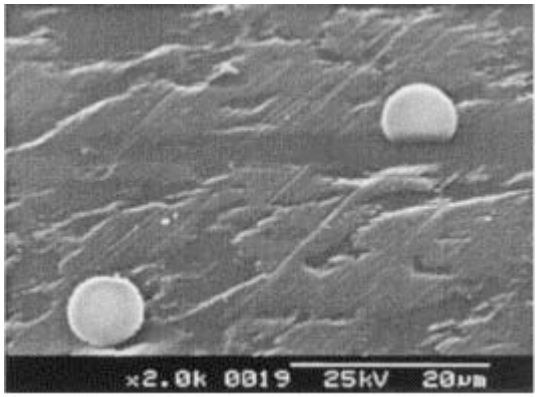


Figure 6: Wafer bumping process using Solder Jet™ equipment. Image courtesy of Dephi.



5µm Ø bumps

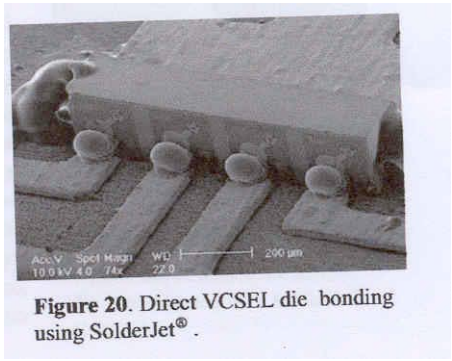
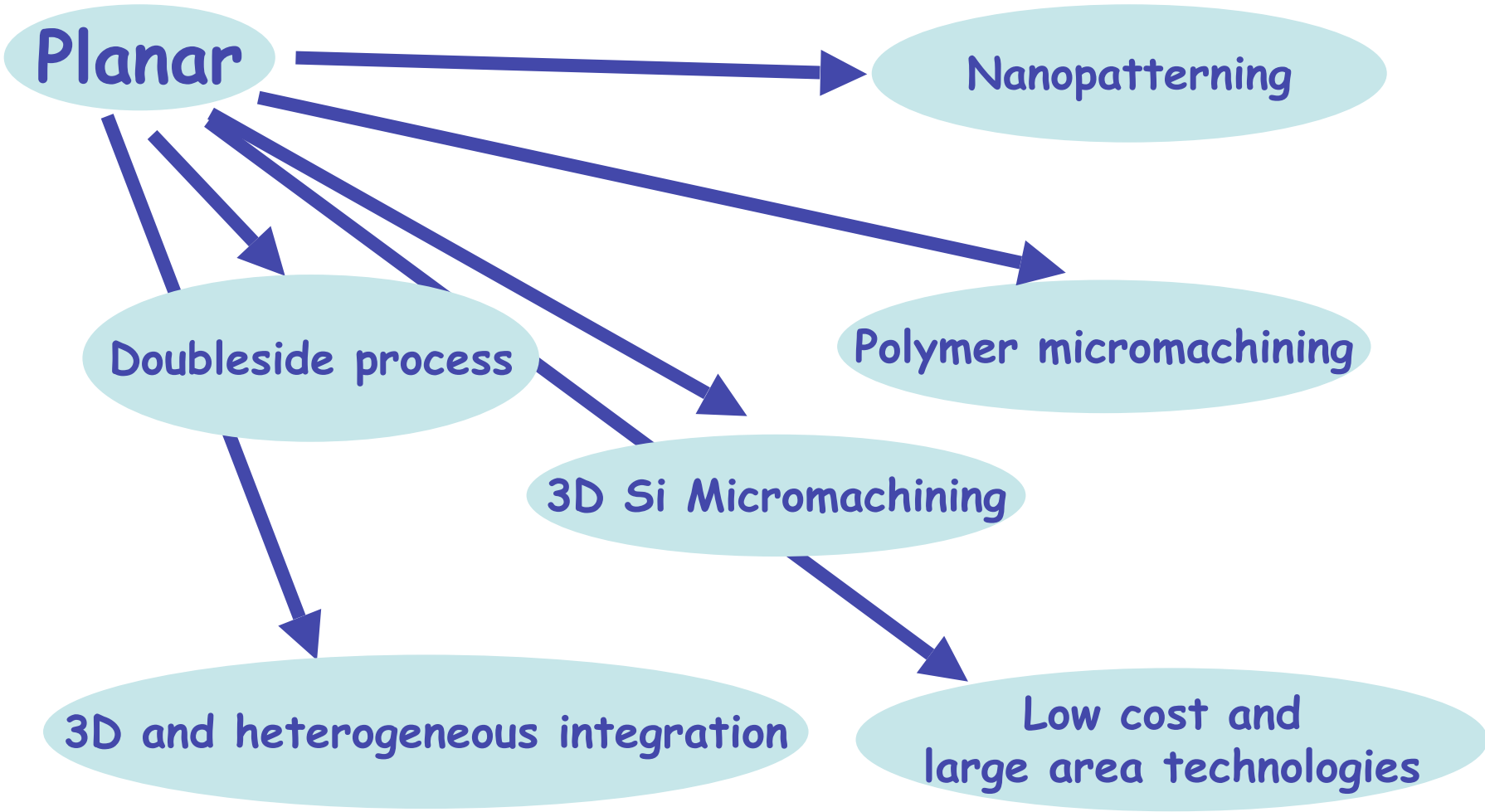


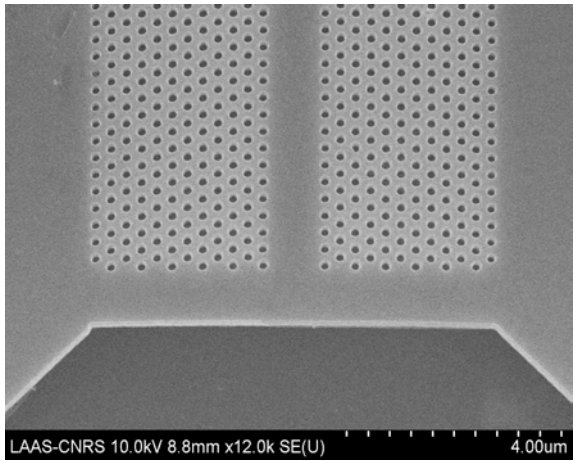
Figure 20. Direct VCSEL die bonding using SolderJet® .

Wedge bumping Ø 100µm

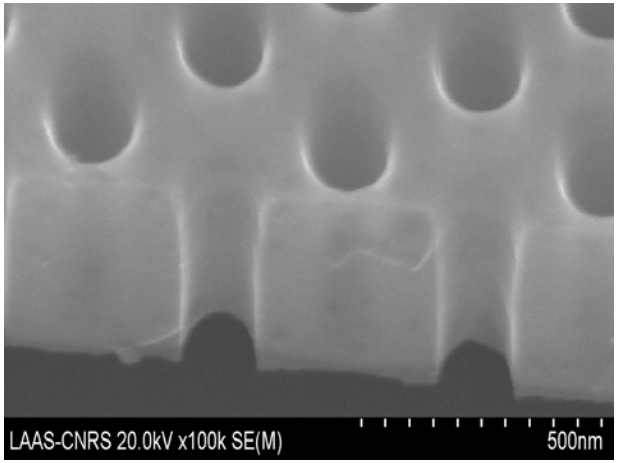

Planar
Nanopatterning
Doubleside process
Polymer micromachining
3D Si Micromachining
3D and heterogeneous integration
Low cost and
large area technologies

ICP Nanomachining

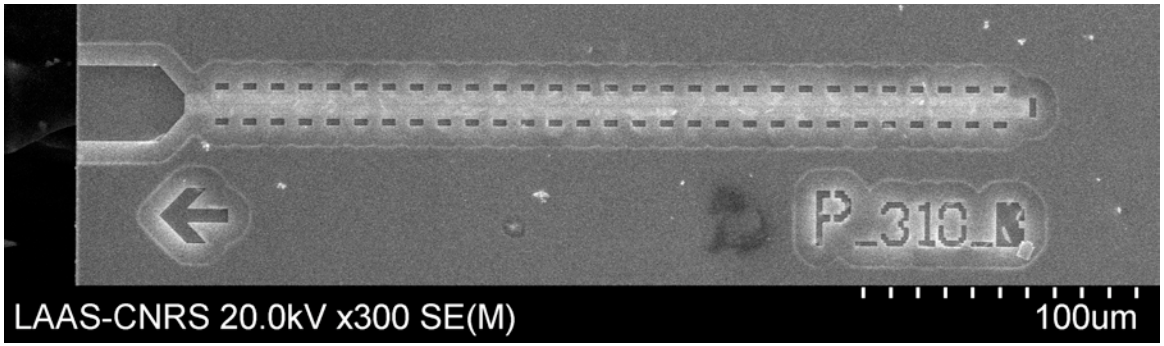
Photonic crystal lasers



15° tilted image of the etched mirror



Detail image of a cleaved edge through the PhC holes



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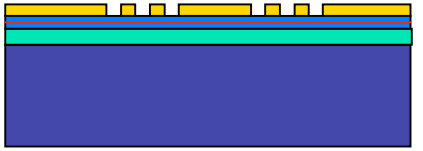
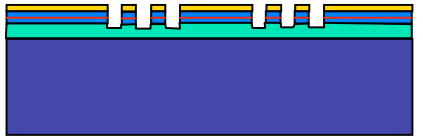
Growth (MBE (In)GaAs/AlGaAs)



Resist spin coating
Electronic lithography



PhC etching (ICP Cl_2/N_2)

Membrane release (chemical etching)

Thinning, cleavage

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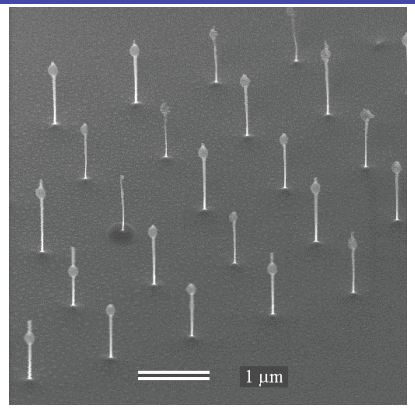
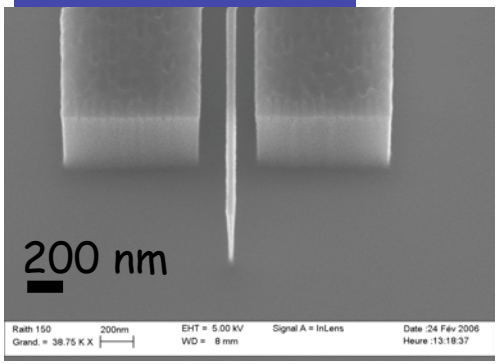
ICP Nanomachining

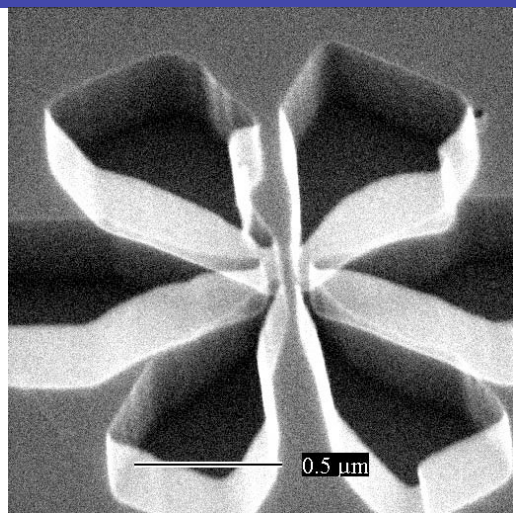
GaAs ICP nanomachining



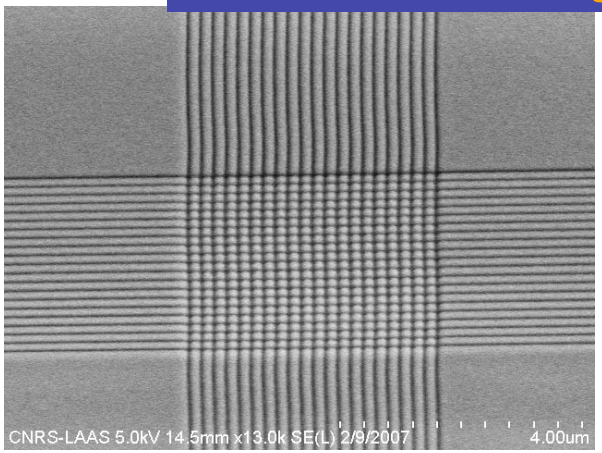
Si nanomachining

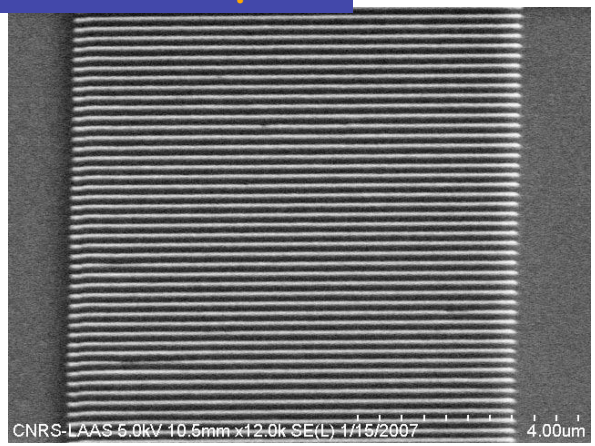


Si nanomachining for stamping



Glass micromachining for nanoimprint





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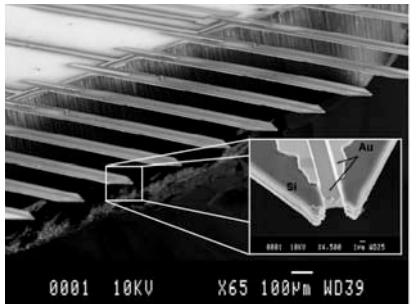
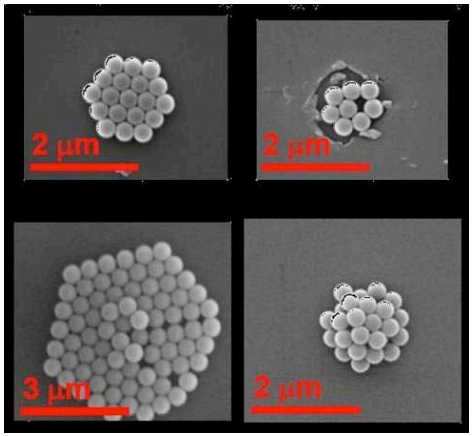
Soft-Lithography and Self-Assembly

Combine top-down and Bottom-up approaches

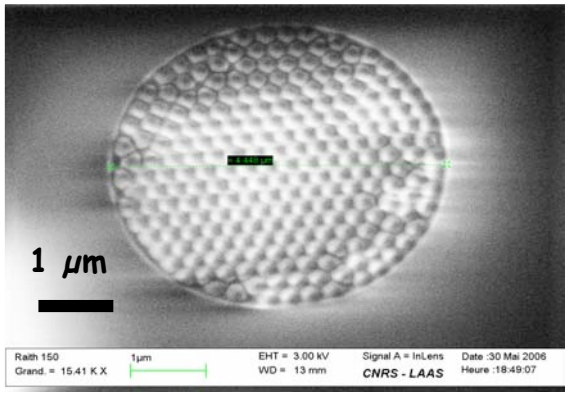
MEMS based spotter for direct self assembly

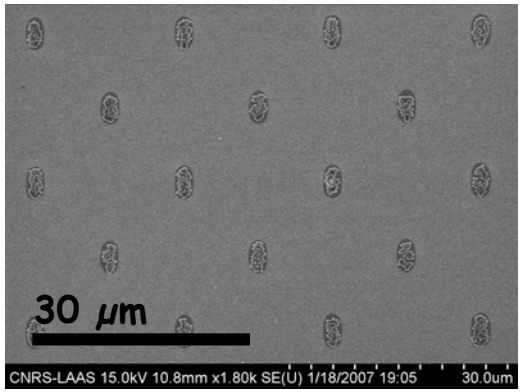




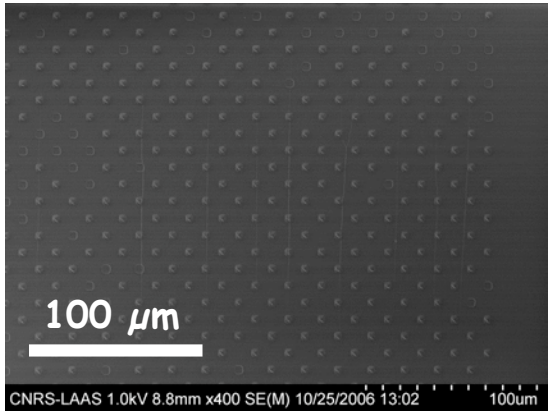
Nanobead cristal formation

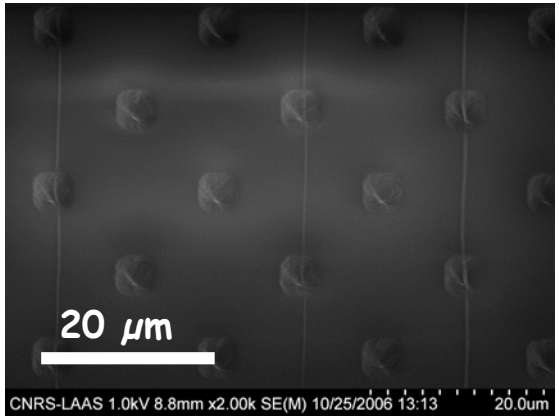
Directed assembly of ordered nanoparticles on patterns





Directed assembly of DNA





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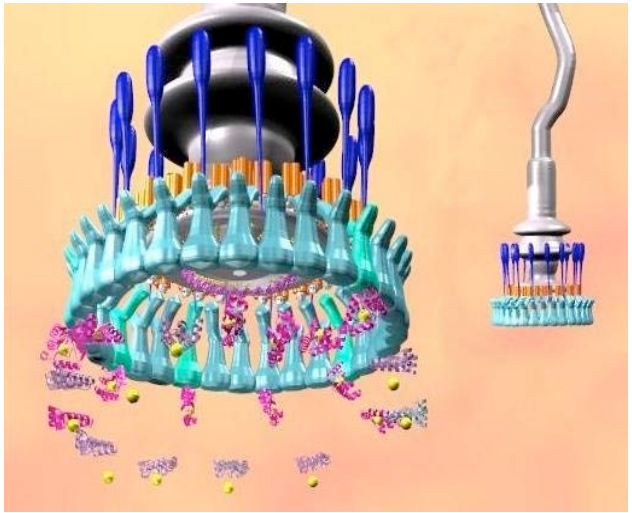
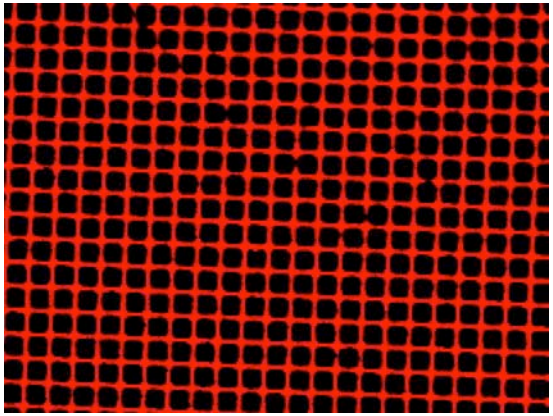
Assembling Nanobiomachines

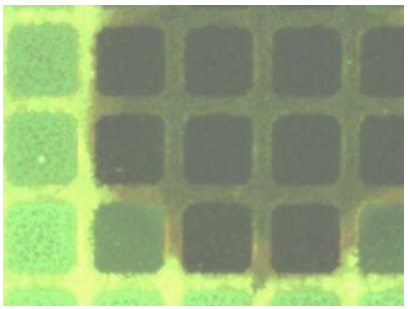
Assemble the flagellar rotary nano-motor of bacteria on a solid surface

A new model for the flagellar nanomotor

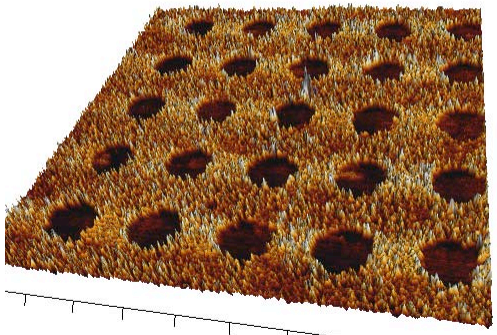


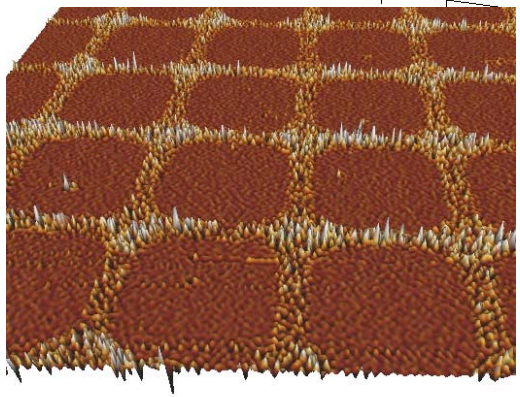
Soft-Lithography and self-assembly techniques for creating nanodomains of supported lipidic membranes





Liquid AFM imaging of the assembly process





Anne-Marie Gué, 9 Novembre 2007

From s.c. to multimaterials

s.c. + metal and alloys

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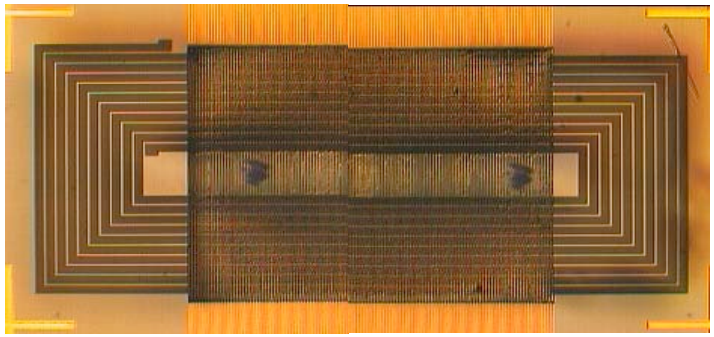
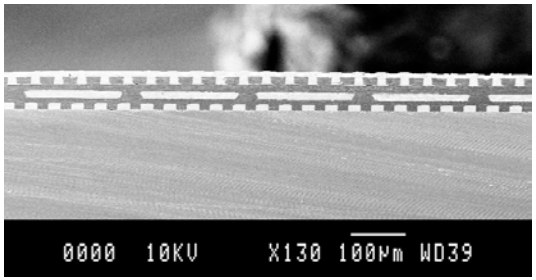
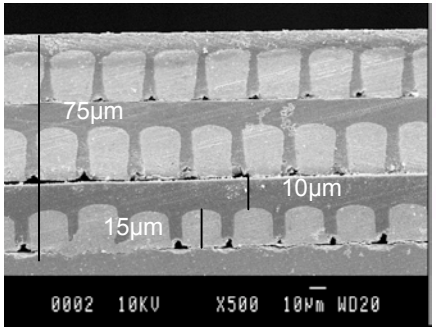
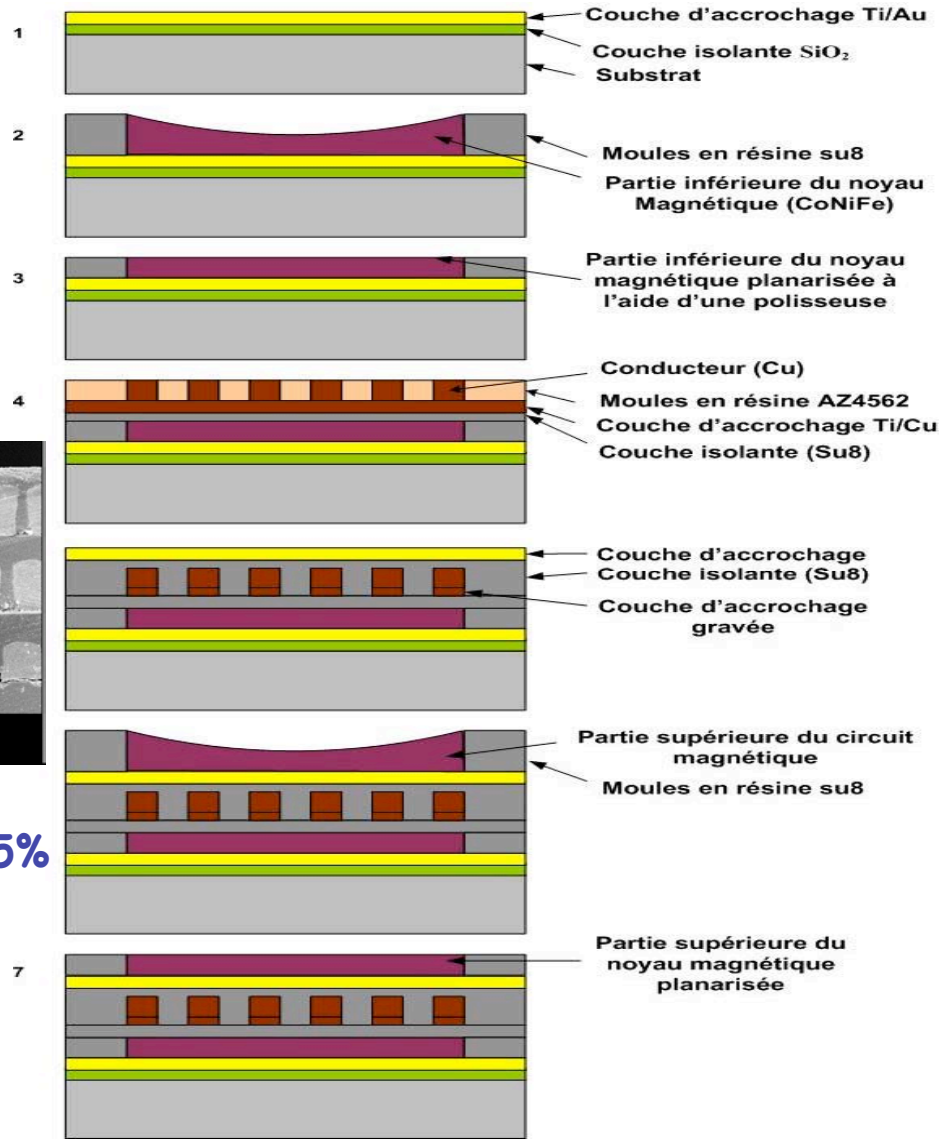
Electrodeposition

Magnetic coupling









Coil: Cu
Roughness : 20A
e=20µm to several hundred
Magnetic circuit: $Fe_{25}Co_{60}Ni_{15}$

Homogeneity : 5%
Stress : 5 MPa

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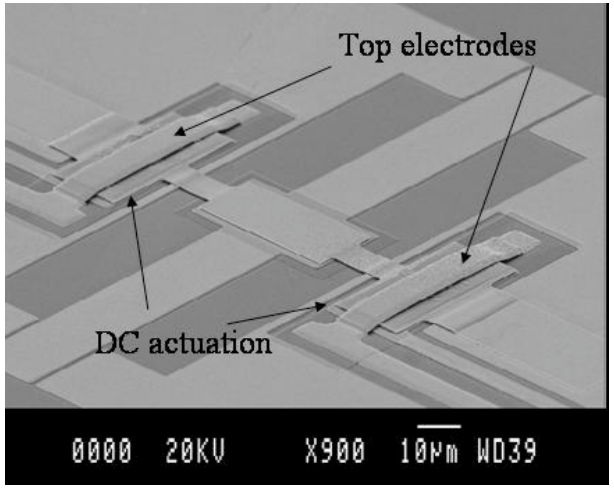
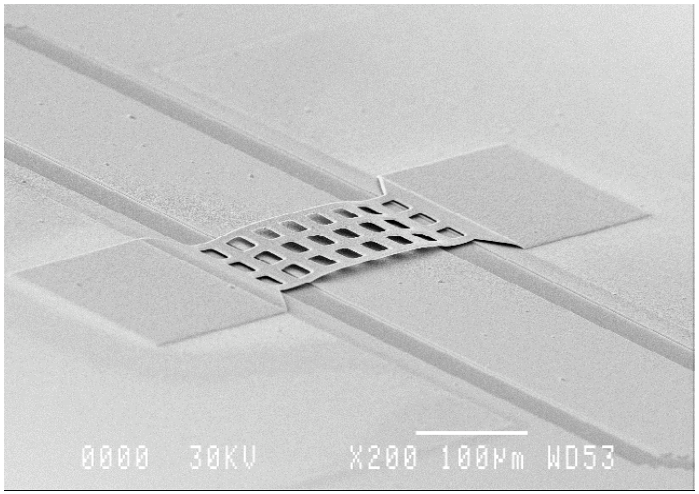
Electrodeposition

RF MEMS

- Wafer level gold deposition
- e= 10µm
- Homogeneity : 5%
- Roughness : 20A
- Stress : 10 MPa





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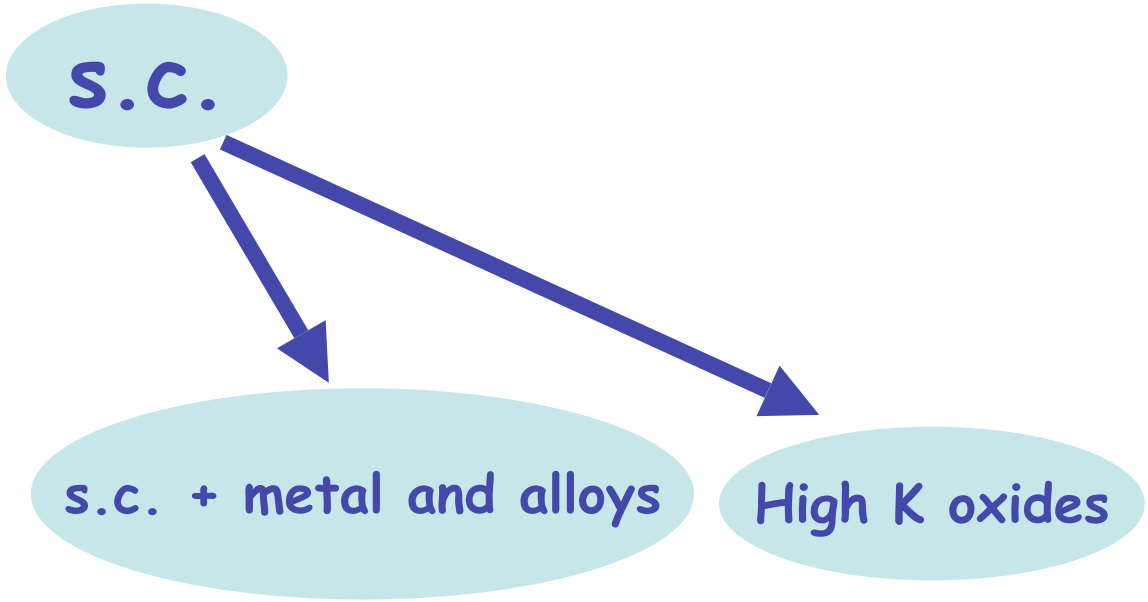
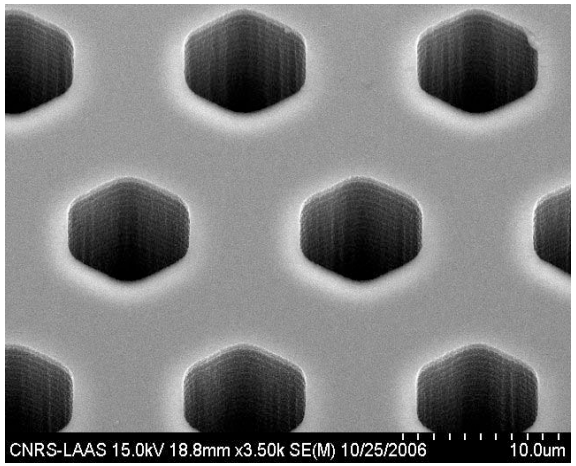
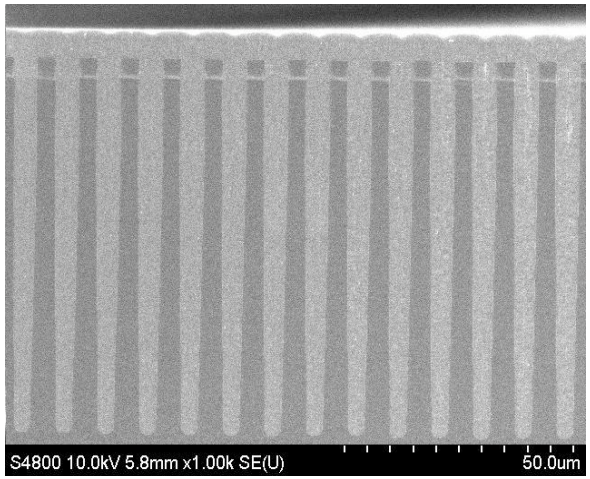

S.C.
s.c. + metal and alloys
High K oxides

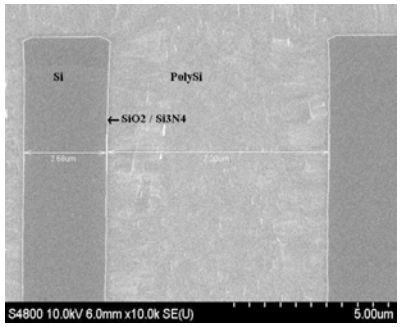
3D capacitors

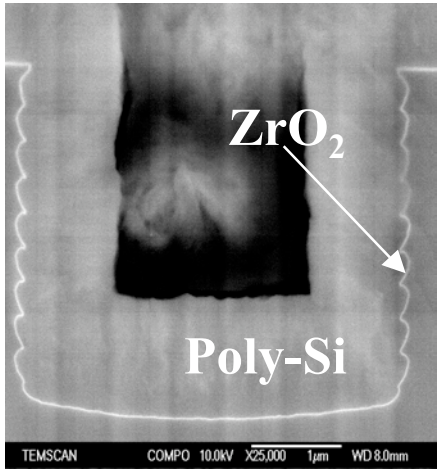
Goal: 500 nF/mm²



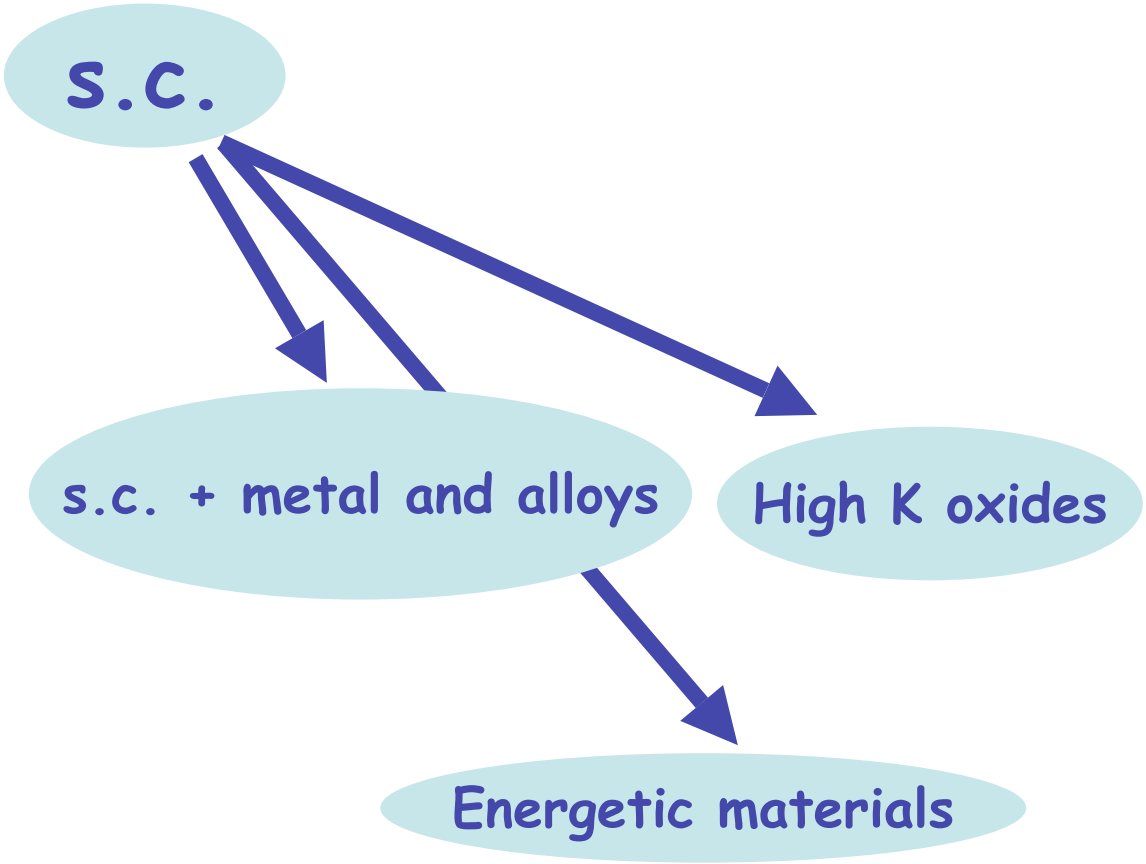
- Deep silicon etching (high ratio)
- Electrochemical etching
- High K deposition in trenches





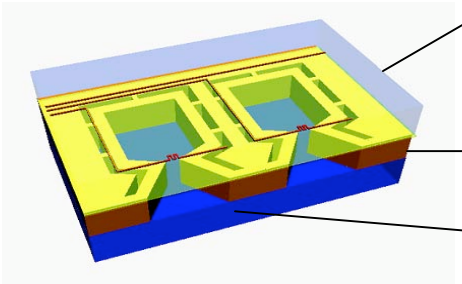


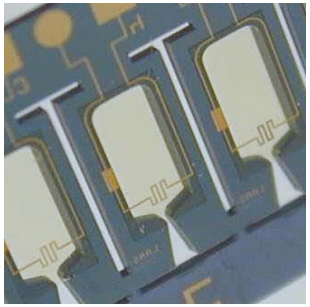
Partnership:
LAAS, INL, LEMHE, LCC


S.C.
s.c. + metal and alloys
High K oxides
Energetic materials

Energetic (Nano) materials for micro sources

Pyrotechnical µthrusters

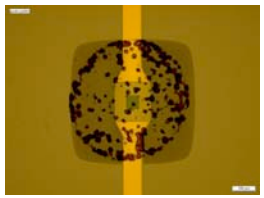




Pressure micro sources (*Collaboration with LCC*)

Energetic materials « gas generation » :

$$[Mn(NO_3)_4]_3[Co(NH_3)_6]_2 \rightarrow Co_2O_3 + 3\,MnO_2 + 18\,H_2O + 12\,N_2 + \tfrac{9}{2}\,O_2$$



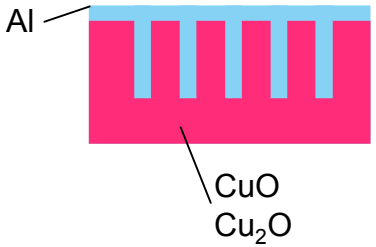
Ink jet deposition: drop Ø ~100µm
Thickness : 1.4µm
Deposited mass : 195ng

Temperature: 223°C
Energy release ΔH = 333J/g
gaz : N2, O2, H2O

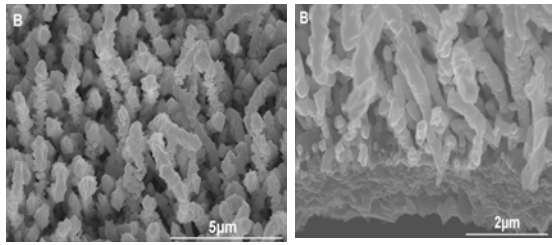
Heat micro sources (*Collaboration with CIRIMAT*)

Ex: composite Al/CuO nanostructured by Al evaporation Al on a network CuO nanowires (Ø : 10-50nm)

$$2Al + 3CuO \rightarrow Al_2O_3 + 3Cu + 4067\ \mathrm{J/g}$$



Structure and material design



SEM photo : CuO/Al nanowires of 10nm as diam.

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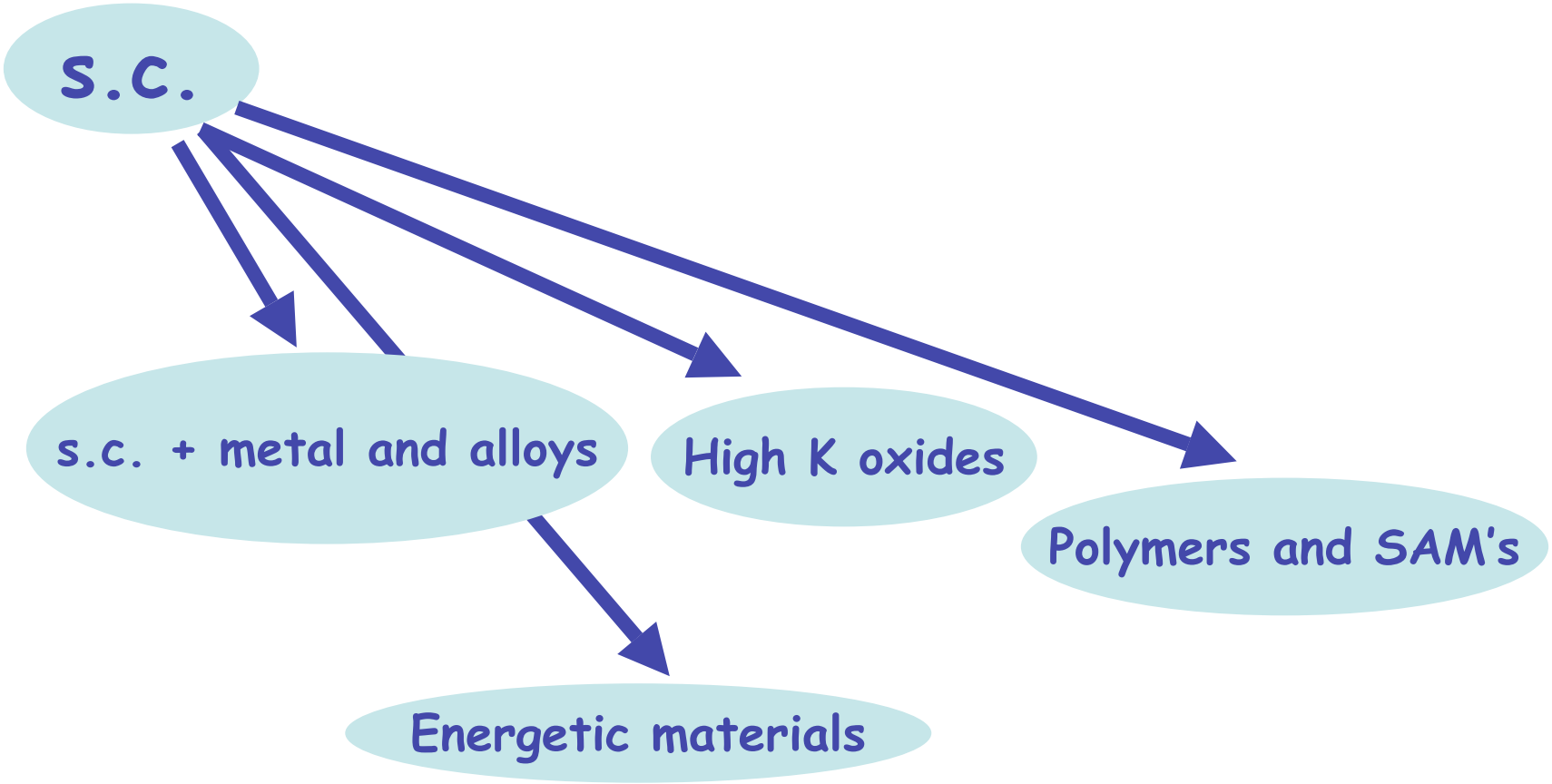
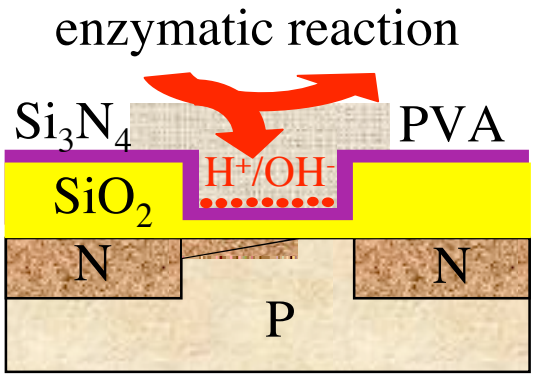

S.C.
s.c. + metal and alloys
High K oxides
Polymers and SAM's
Energetic materials

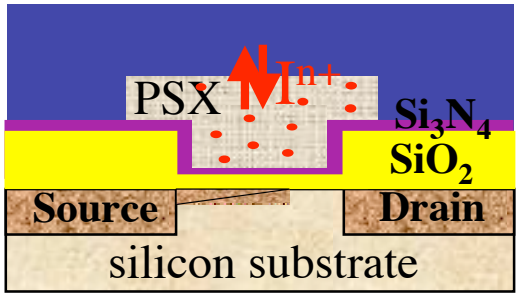
(Bio) Chemical Sensitive layers

Chemically-sensitive, photosensitive polymers using spin coating and photolithography standard techniques



Integration of poly vinyl alcohol (PVA) based enzymatic layers on the pH-ISFET sensitive gate: realisation of EnFETs:

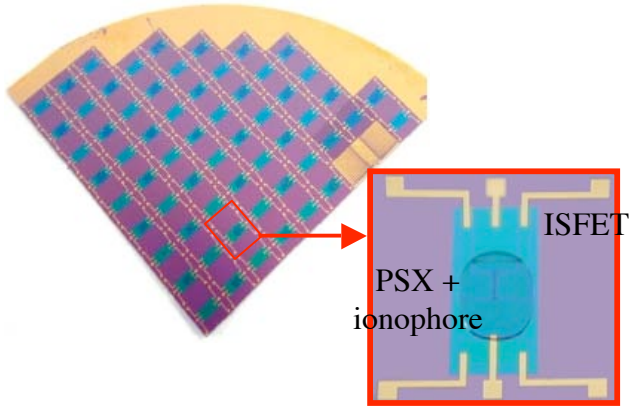
- Urease: CO(NH2)2 (urea) + H2O ----> 2NH3 + H2CO3
- Creatinine deiminase:
  créatinine + H2O ----> N-methyl-hydantoïne + NH3
- Others hydrolases…



Integration of ionophores using polysiloxane-based polymers: realisation of ion-sensitive layers

Application to standard ionophores

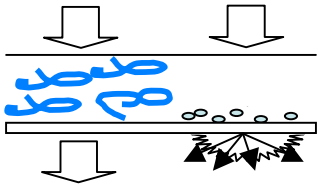
- Nonactin for the NH4+ ion detection
- Tetradodecyl ammonium nitrate (TDDAN) for the NO3- ion detection
- Valinomycin for the K+ ion detection
- Monensin for the Na+ ion detection
- …



Active polymers for micro optics

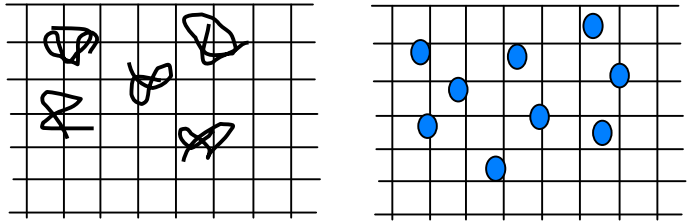
Light diffusion

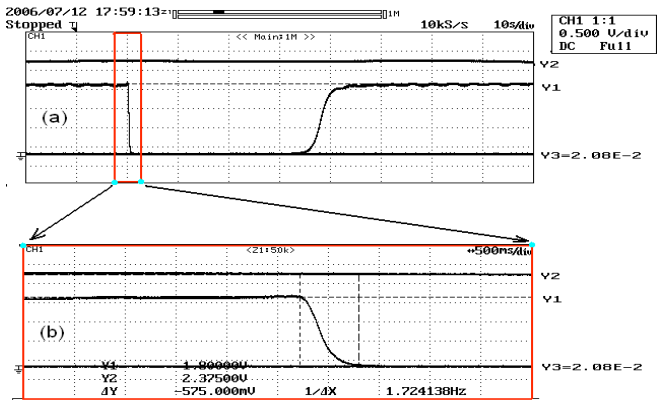
➲ PNIPAM in H_2O



0.3 s / 3s; [670-1070] nm
attenuation ≈ 38 dB,
for all polarizations

➲ PNIPAM encapsulated in Hydro gel

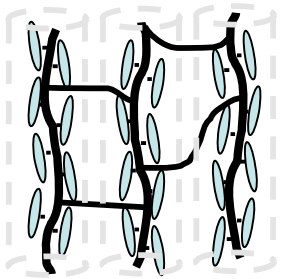




Phase modulation through thickness variation

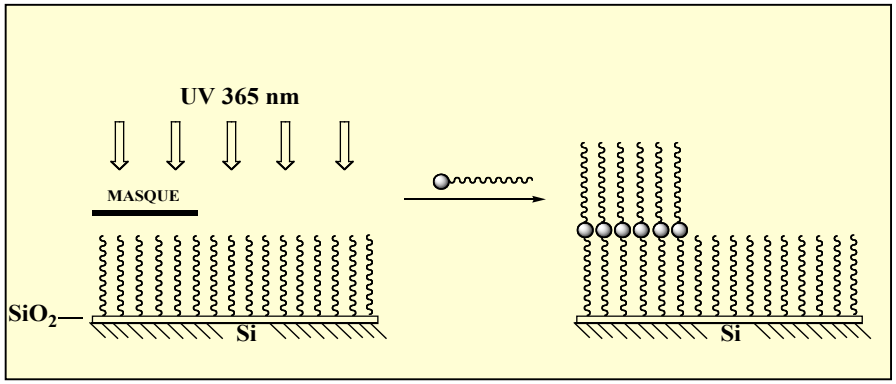
➲ Gel and liquid cristal : electro active

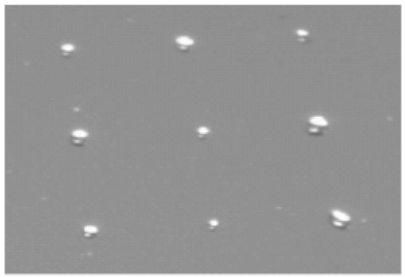
Coll. P. Keller (Inst. Curie)
L. Mager, S. Mery (GMO-IPCM, Strasbourg)



SAM's

Patterning hydrophilic and hydrophobic areas using standard photolithography (365 nm)

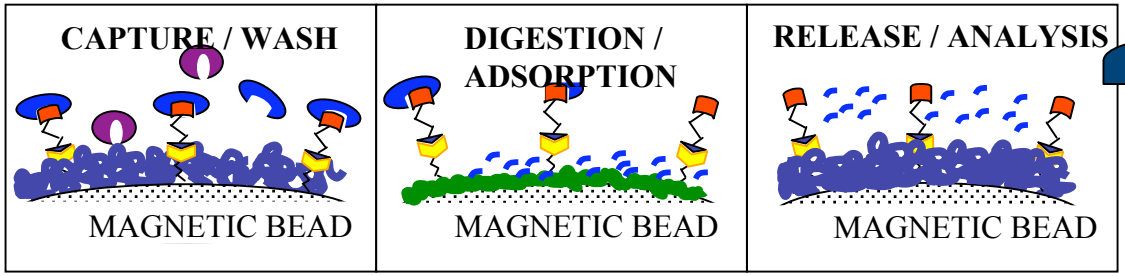




Hydrophilic spots
10 to 100 µm

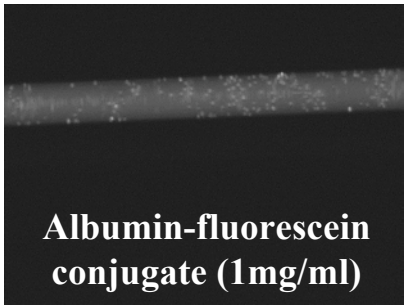
Contact Angle
θ = 112 °
Δθ = 77°

Stimuli responsive surface



T < T* T > T* T < T*

ΔT 32 °C



Chemical genomics

Anne-Marie Gué, 9 Novembre 2007

Concluding remarks

- We are ready to take up the challenge …
- … but it is a huge task and almost a new job
- We need partners !!! :

material synthesis and elaboration, chemistry, surface chemistry, biochemistry, physics of fluids and interface, …

- Many thanks to all of my colleagues
- Thank you for your attention

Anne-Marie Gué, 9 Novembre 2007