Approcci combinatoriali alla scoperta di nuovi materiali

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FONDAZIONE
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Outline

Scienza combinatoriale

Tavola di Mendeleev e possibili combinazioni

Approcci sperimentali

Nuovi materiali e nuove interfacce

FONDAZIONE
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MANY AT A TIME Program head Andreas Marzinik (front to back) and lab specialists Raphael Gattlen and Urs Rindisbacher of Novartis Pharma AG, Basel, Switzerland, pipette coupling reagent into 96-well reaction blocks.

COMBINATORIAL CHEMISTRY

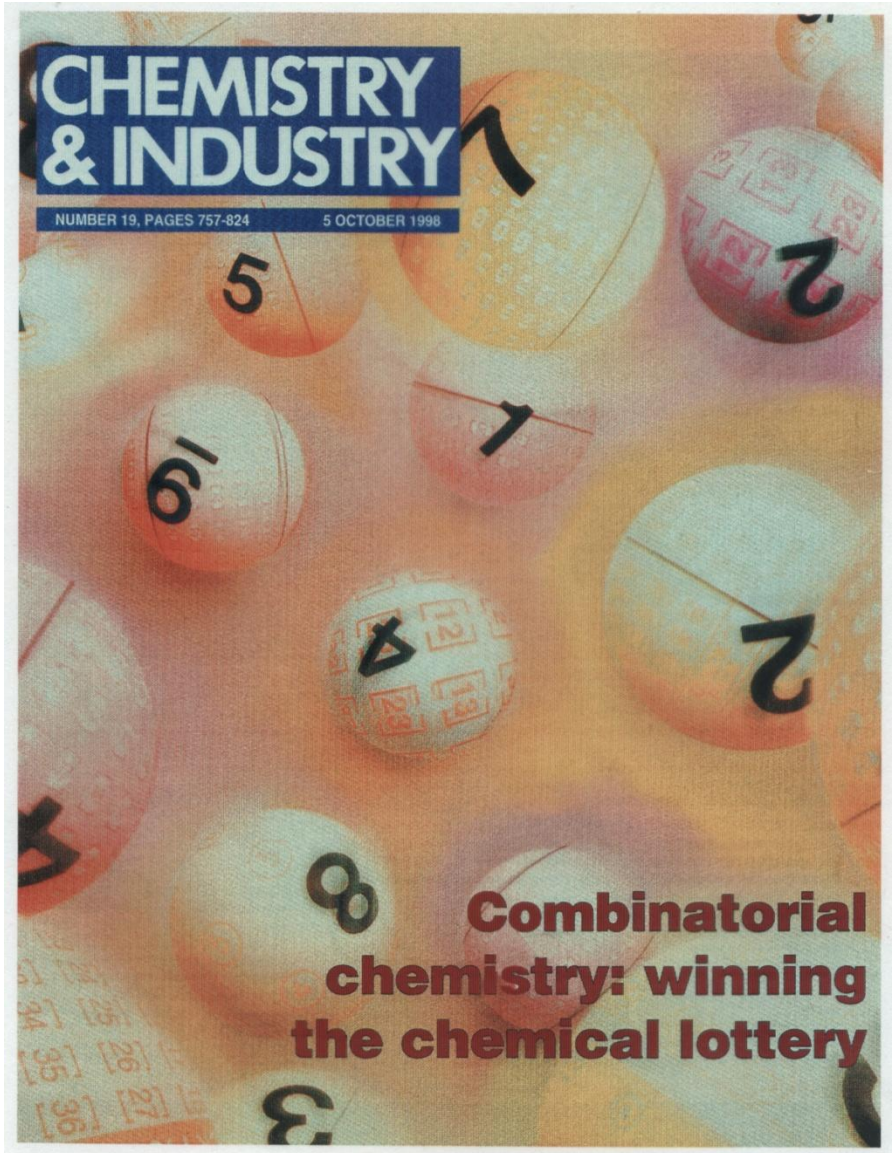
Chemical & Engineering News, August 2001

A Combinatorial Approach to Materials Discovery

X.-D. Xiang,* Xiaodong Sun, Gabriel Briceño, Yulin Lou, Kai-An Wang, Hauyee Chang, William G. Wallace-Freedman, Sung-Wei Chen, Peter G. Schultz*

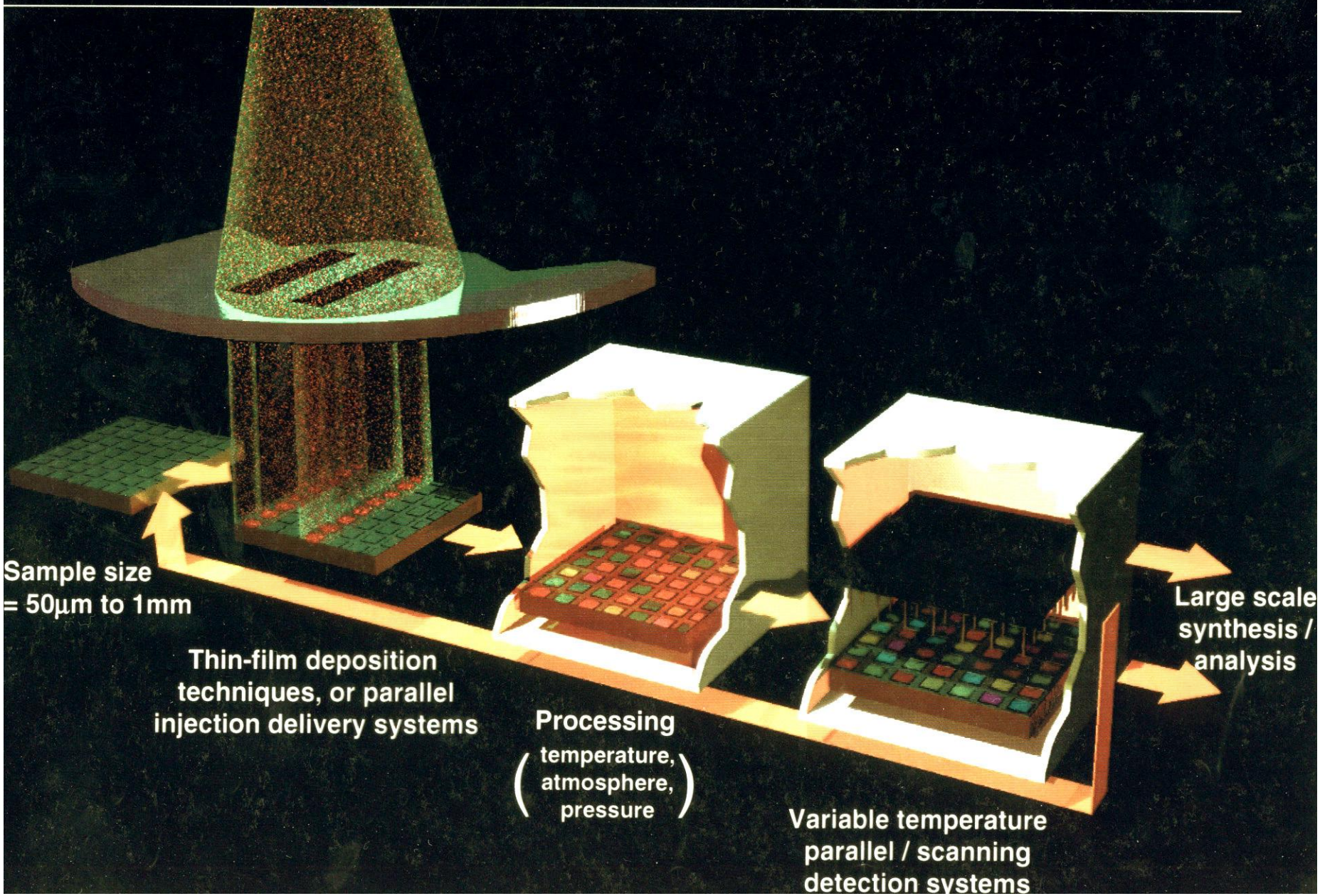
A method that combines thin film deposition and physical masking techniques has been used for the parallel synthesis of spatially addressable libraries of solid-state materials. Arrays containing different combinations, stoichiometries, and deposition sequences of $BaCO_3$, Bi_2O_3, CaO, CuO, PbO, $SrCO_3$, and Y_2O_3 were generated with a series of binary masks. The arrays were sintered and BiSrCaCuO and YBaCuO superconducting films were identified. Samples as small as 200 micrometers by 200 micrometers in size were generated, corresponding to library densities of 10,000 sites per square inch. The ability to generate and screen combinatorial libraries of solid-state compounds, when coupled with theory and empirical observations, may significantly increase the rate at which novel electronic, magnetic, and optical materials are discovered and theoretical predictions tested.

Science 268, 1738 (95)


CHEMISTRY & INDUSTRY
NUMBER 19, PAGES 757-824
5 OCTOBER 1998
Combinatorial chemistry: winning the chemical lottery

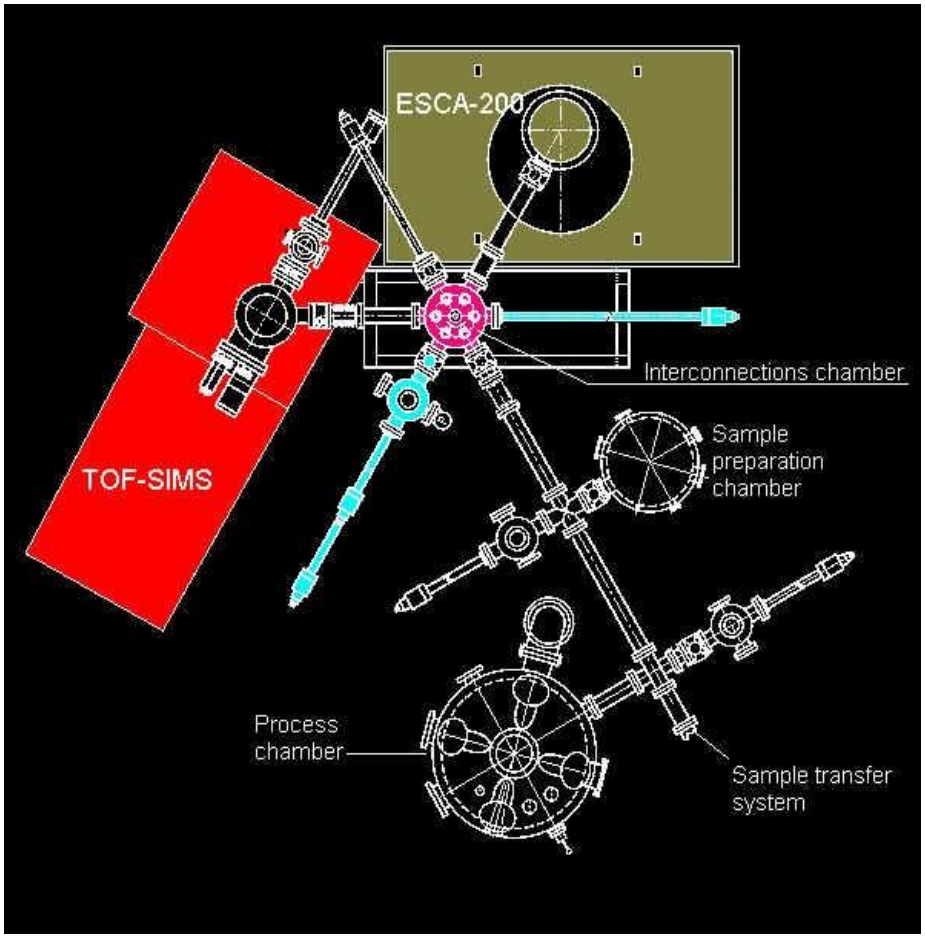

MRS BULLETIN
Serving the International Materials Research Community
A Publication of the Materials Research Society
April 2002, Volume 27, No. 4
Combinatorial Materials Science
Ge
Mn
Co
0.0
0.2
0.4
0.6
0.8
1.0

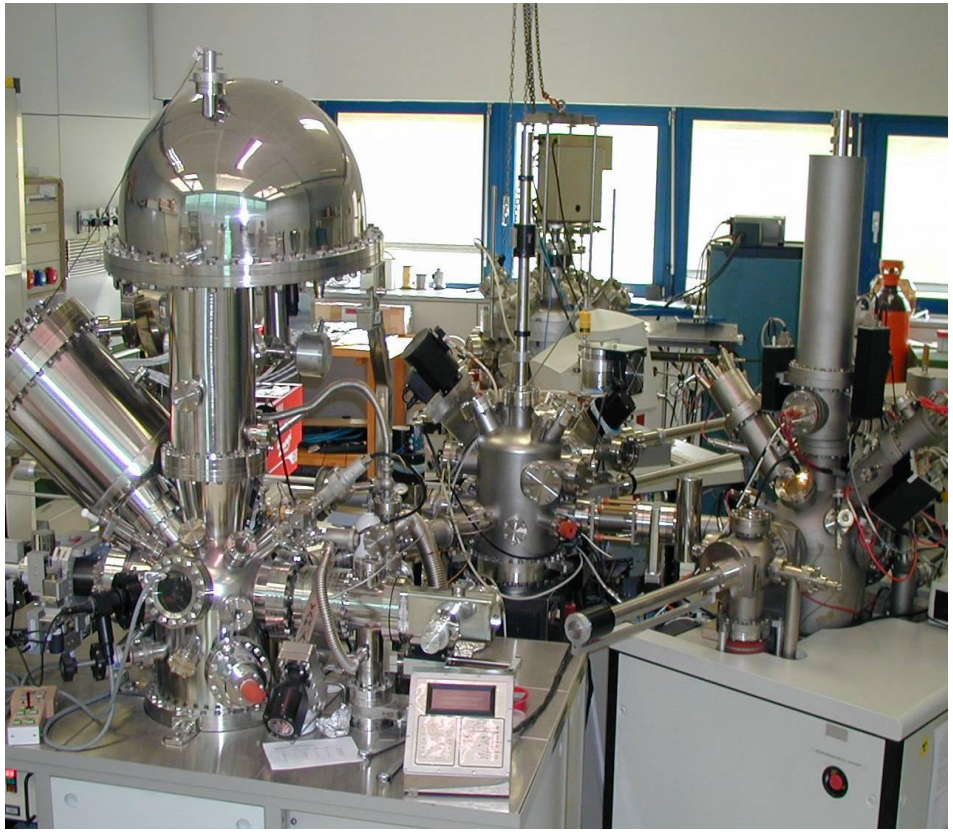
COMBINATORIAL APPROACH TO MATERIALS



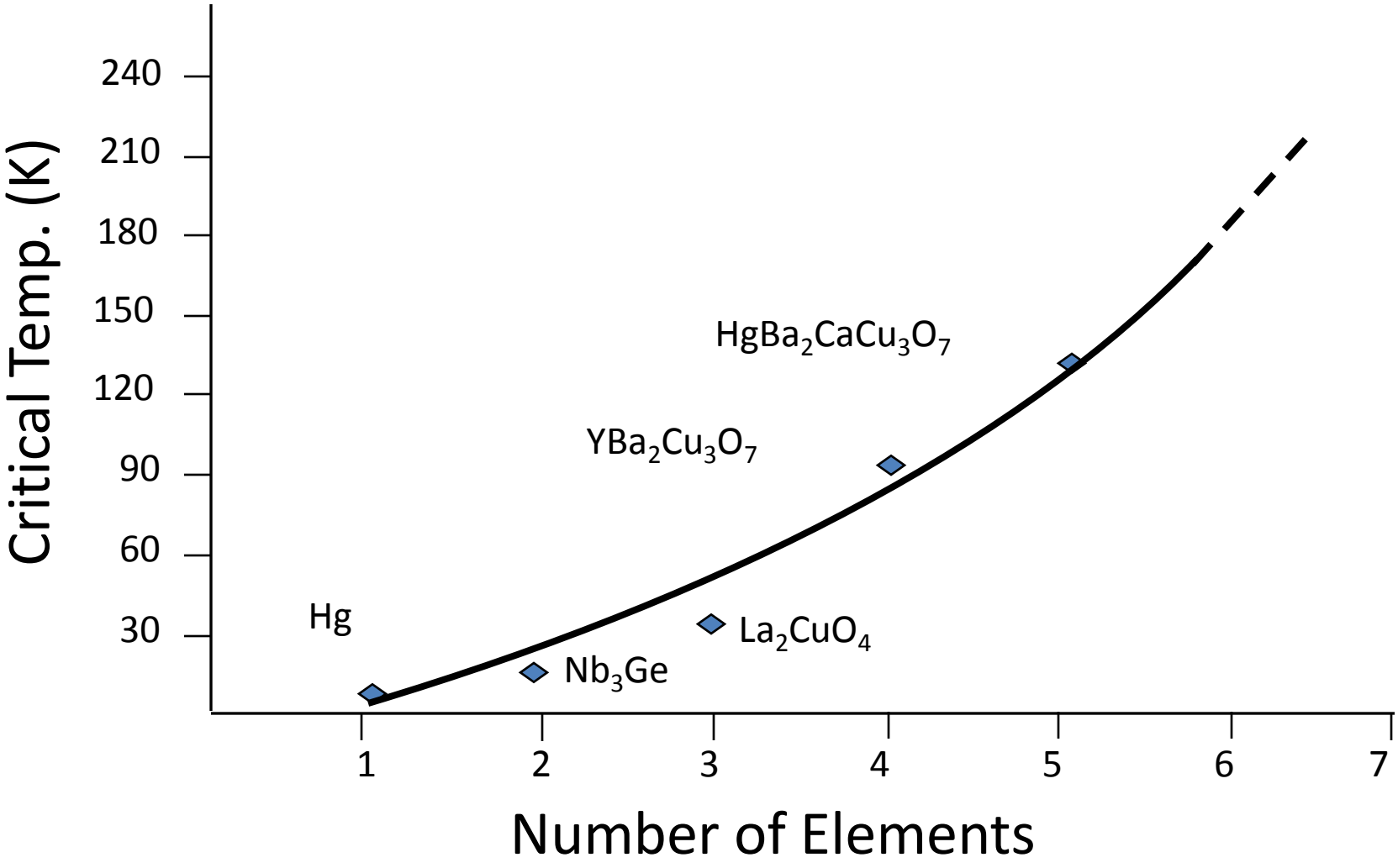
Sintesi di materiali tramite approccio combinatoriale in FCS adattando e utilizzando l'apparato già esistente

CLUSTER LAB

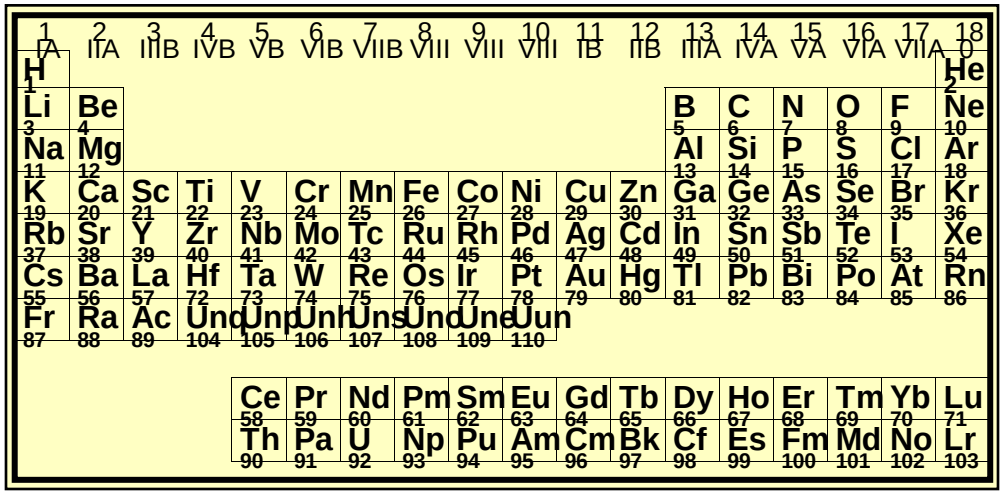




Correlation between materials complexity and physical properties



How many different compounds are there?



Take 60
"useful" elements.

There are about
30,000 known inorganic
compounds.

Binary compounds have the form AB. (e. g., MgF, SiC, ZnO,.....)
60 x 60 x different combinations: **most are known**.

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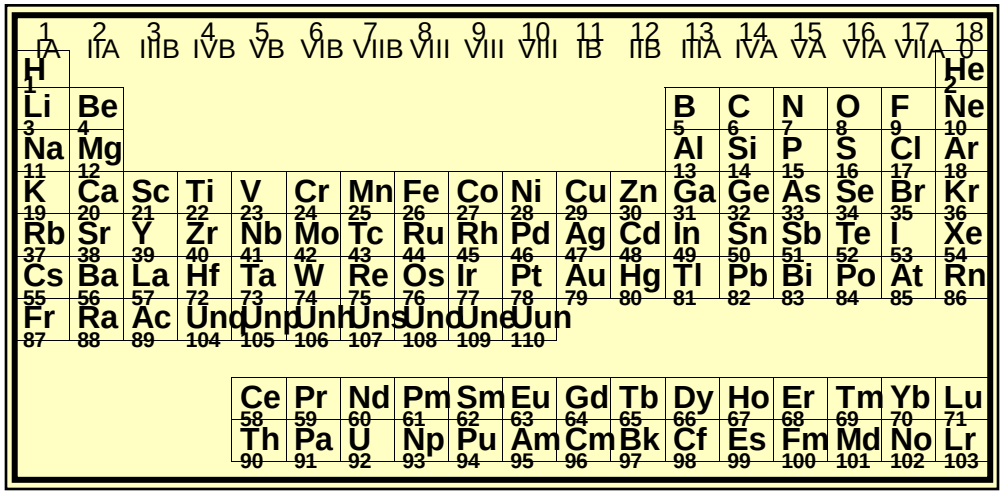

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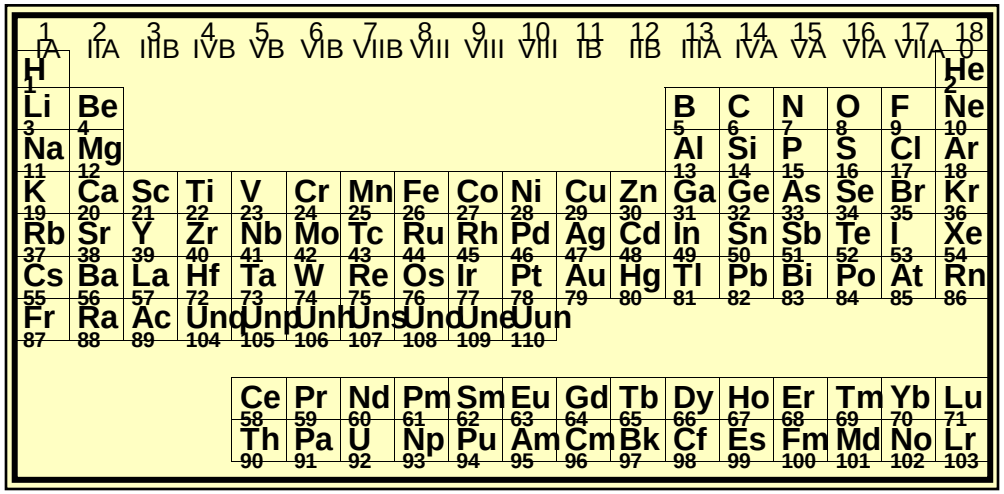

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Quaternary compounds have the form ABCD. (YBaCuO, AlNiCOFe,...)
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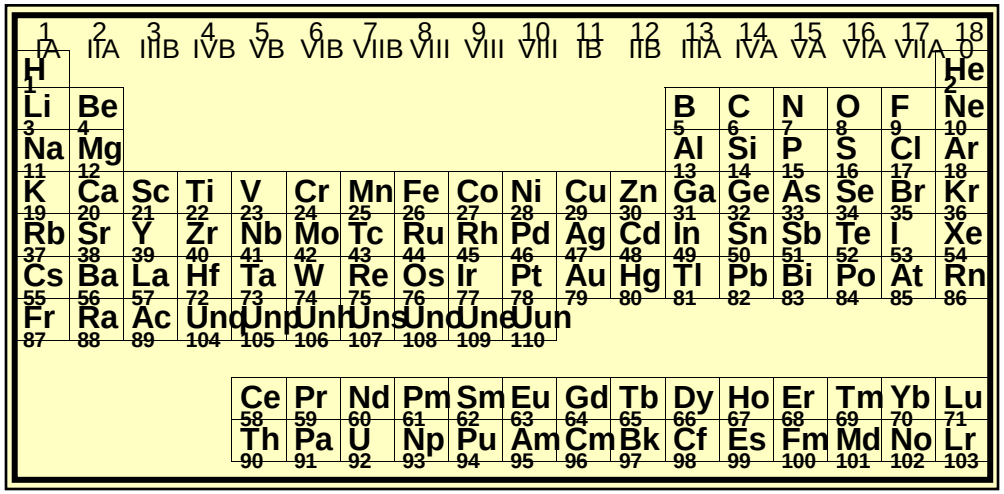

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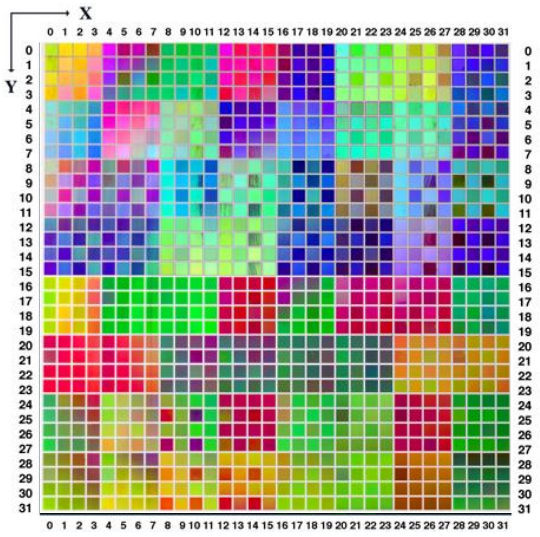
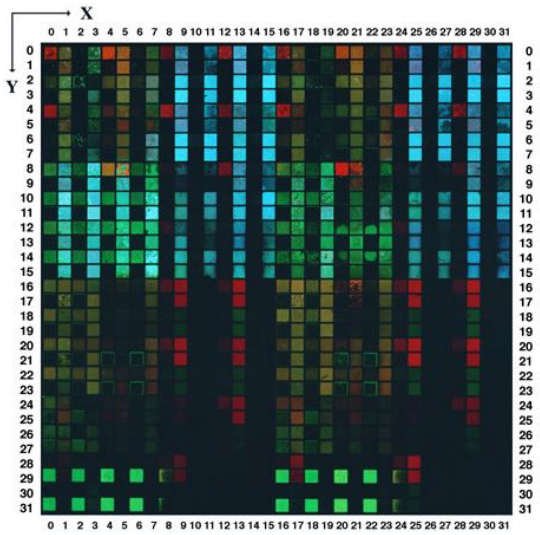
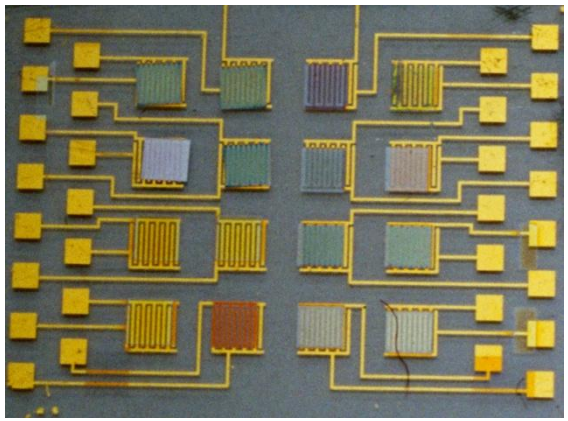
Combinatorial libraries of inorganic materials

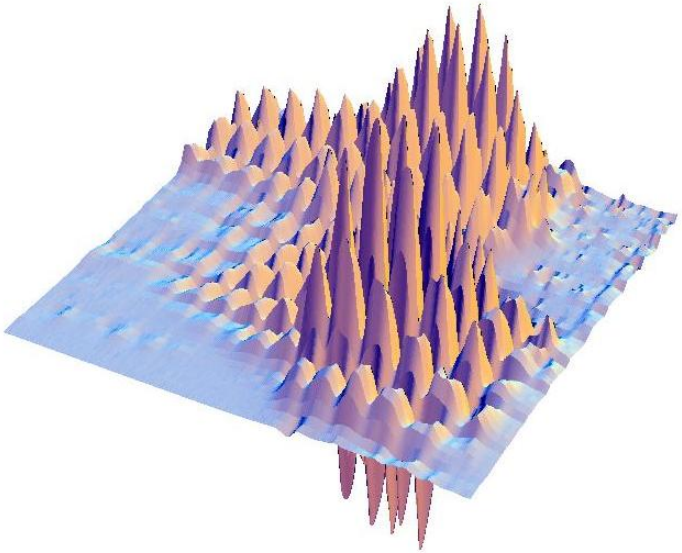




Luminescent materials libraries, Science **279**, 1712 (1998)



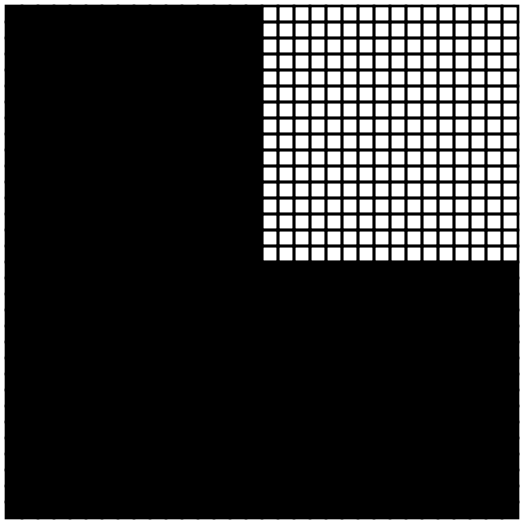
Semiconductor gas sensor library, “electronic nose”, Appl. Phys. Lett. **83**, 1255 (2003)



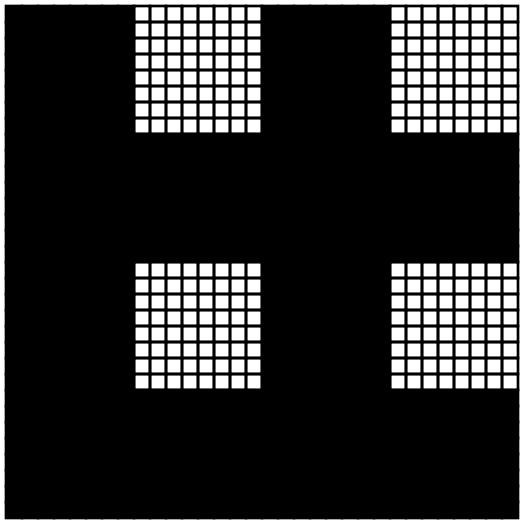
Magnetic shape memory alloy library, Nature Materials **2**, 180 (2003)

Quaternary Masks

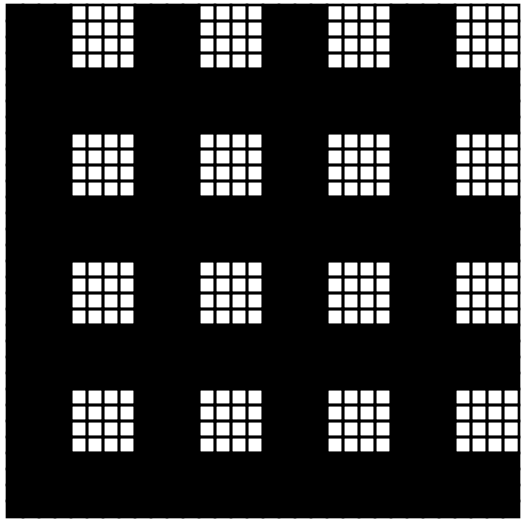
A



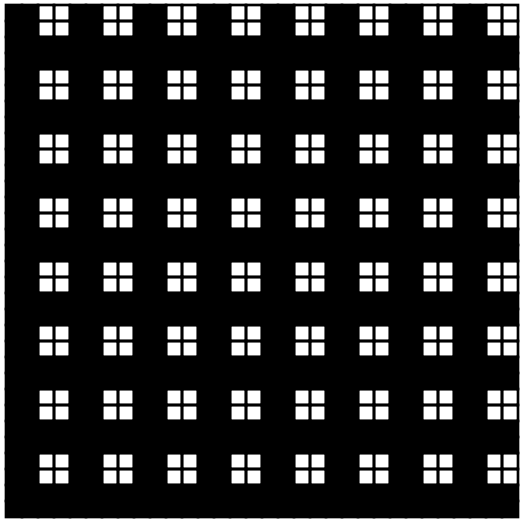
B



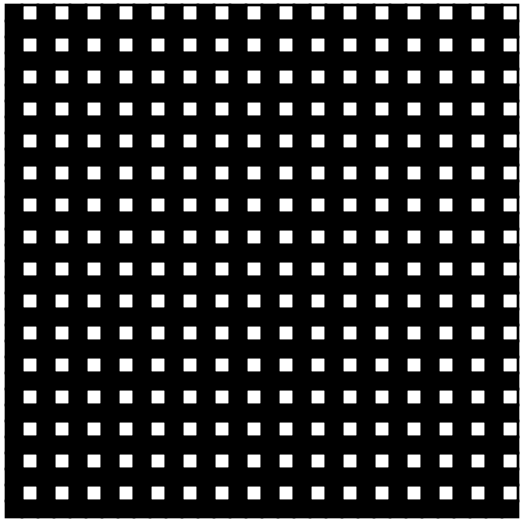
C



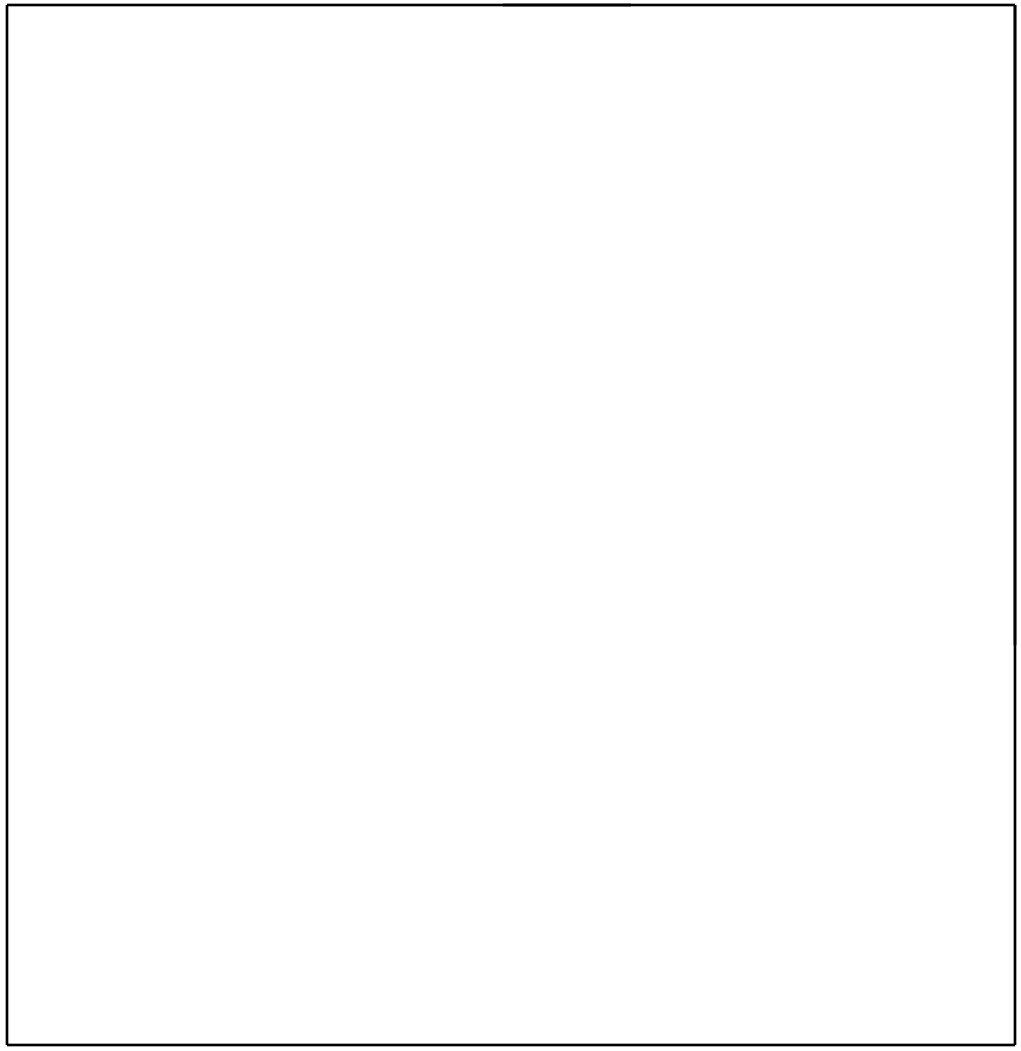
D



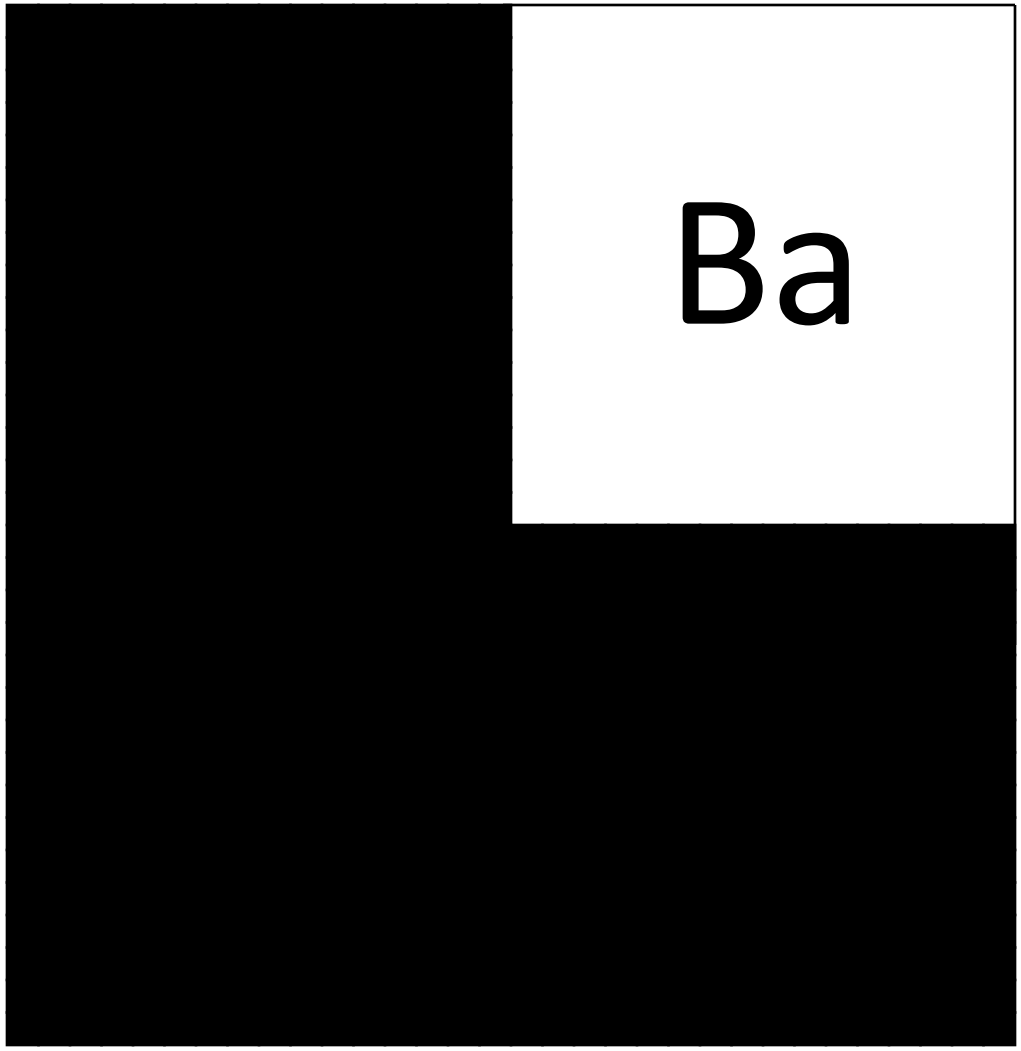
E



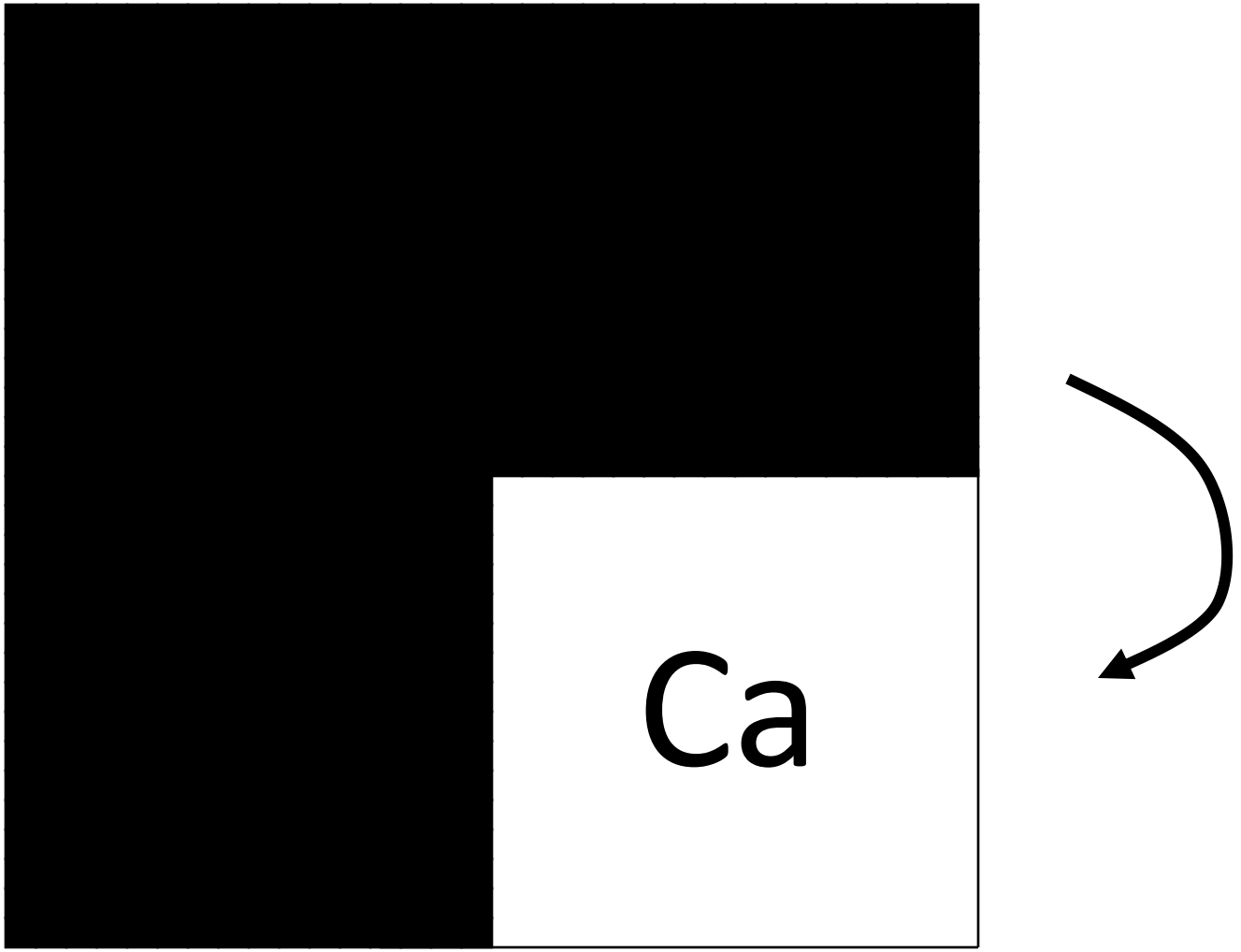
Quaternary Masking



Quaternary Masking: 1st mask, 1st position

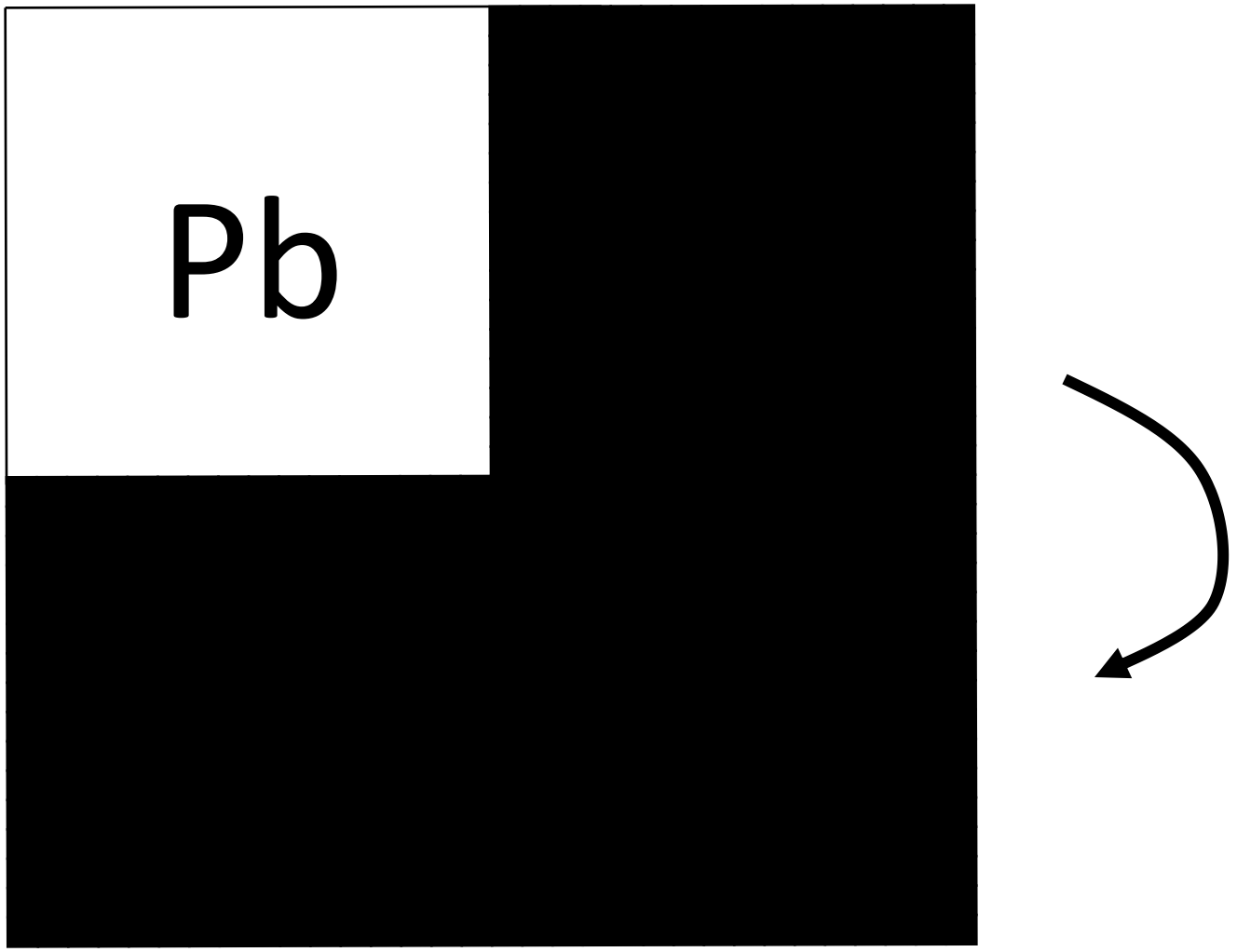


Quaternary Masking: 1st mask, 2nd position

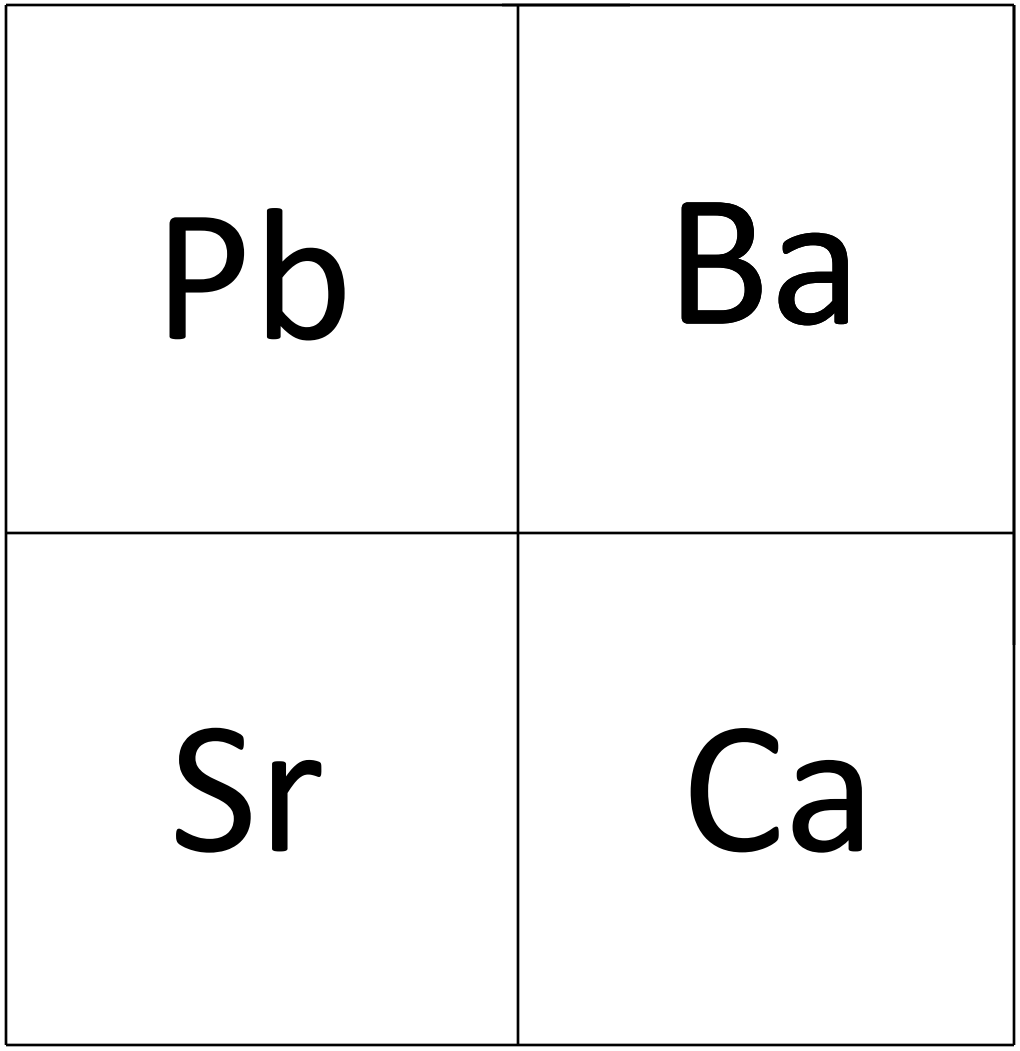


Quaternary Masking: 1st mask, 3rd position

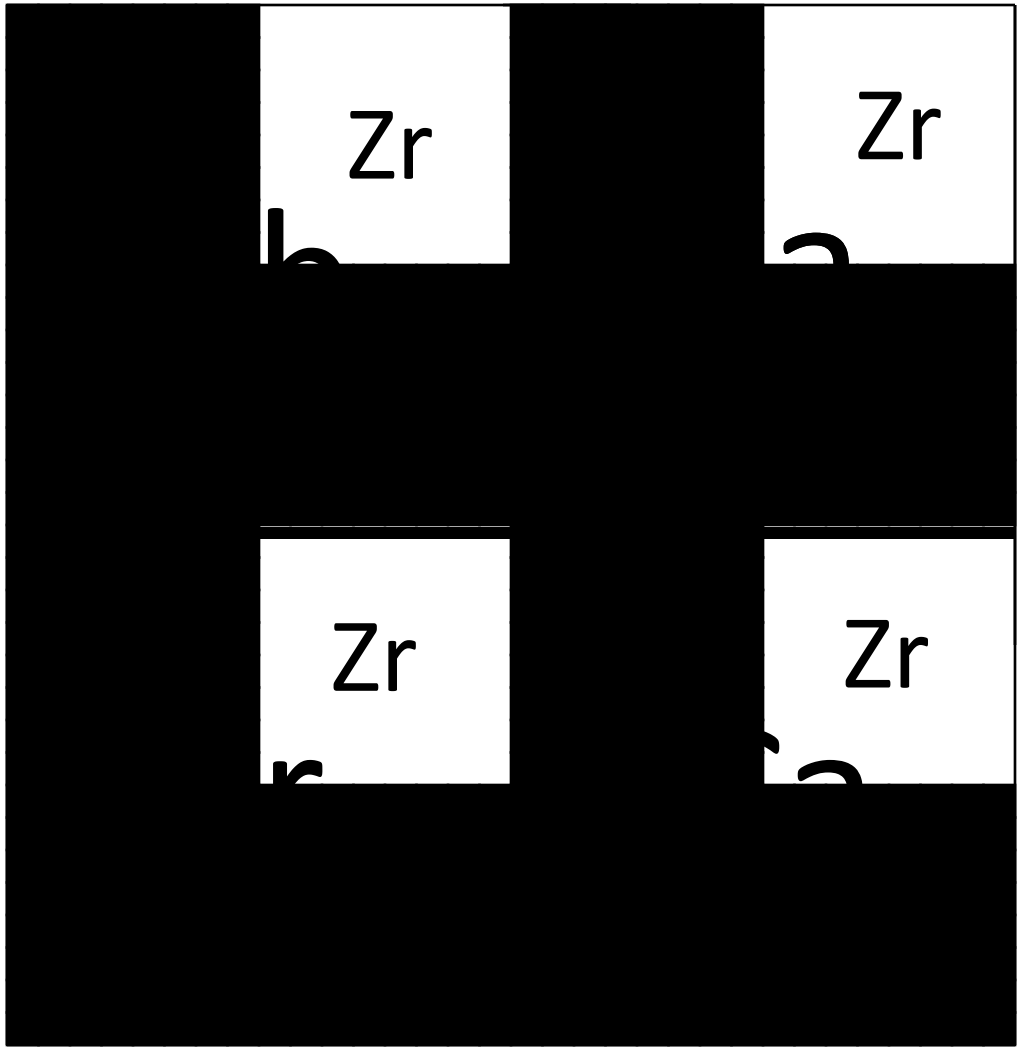
Quaternary Masking: 1st mask, 4th position



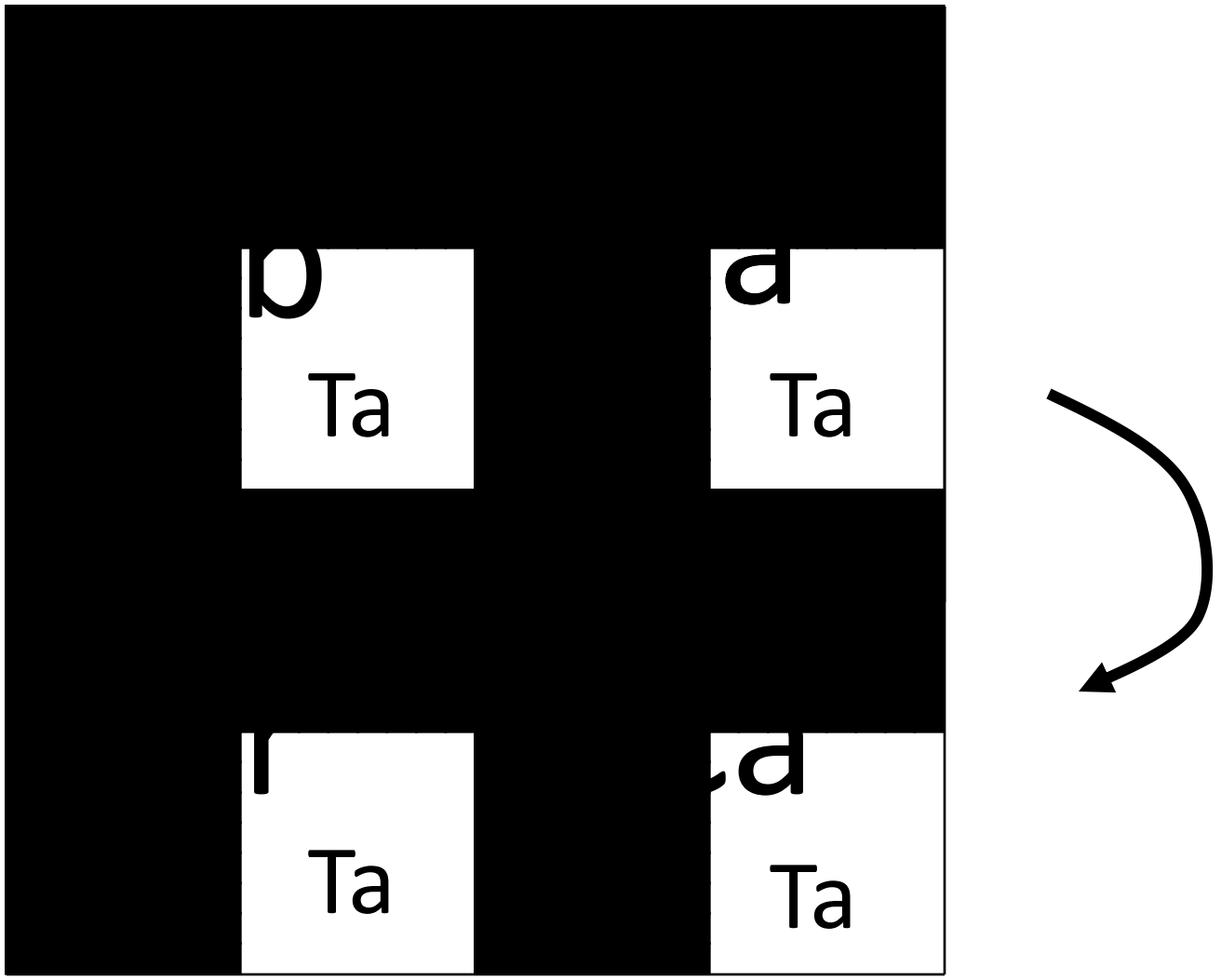
Quaternary Masking: after 1st mask



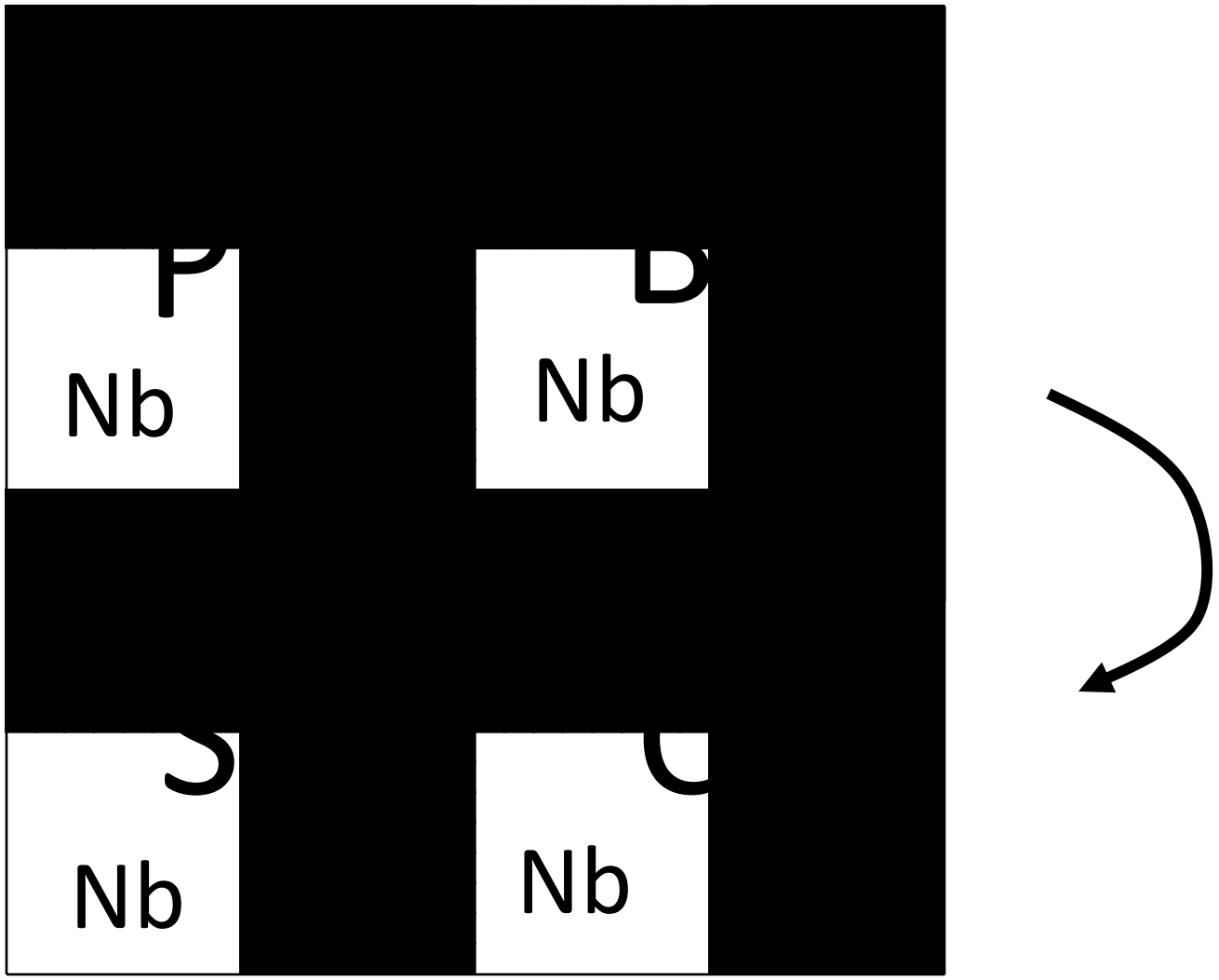
Quaternary Masking: 2nd mask, 1st position



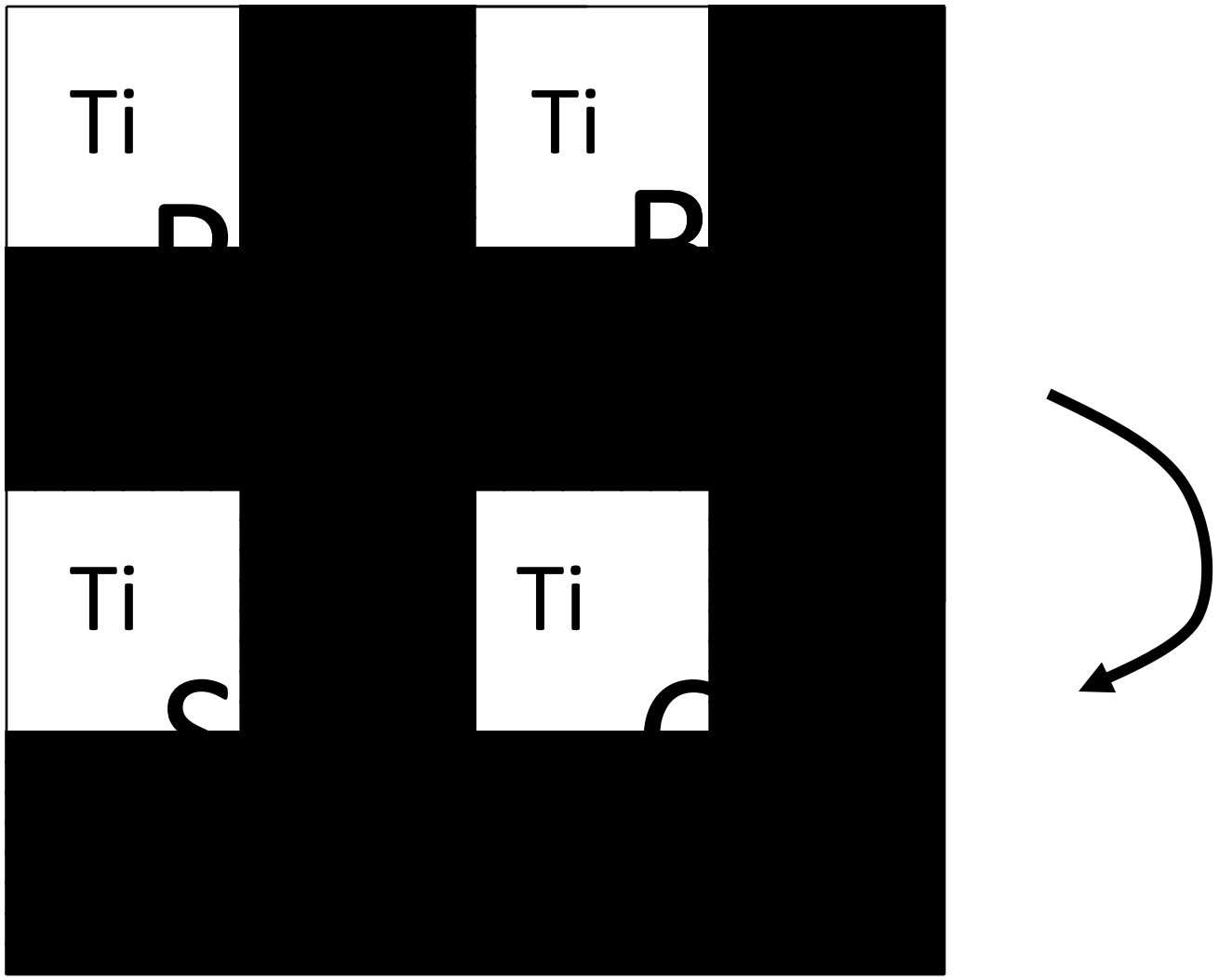
Quaternary Masking: 2nd mask, 2nd position



Quaternary Masking: 2nd mask, 3rd position



Quaternary Masking: 2nd mask, 4th position



$PbTiO_3$	$PbZrO_3$	$BaTiO_3$	$BaZrO_3$
$PbNb_2O_6$	$PbTa_2O_6$	$BaNb_2O_6$	$BaTa_2O_6$
$SrTiO_3$	$SrZrO_3$	$CaTiO_3$	$CaZrO_3$
$SrNb_2O_6$	$SrTa_2O_6$	$CaNb_2O_6$	$CaTa_2O_6$

depositions: 4 x n

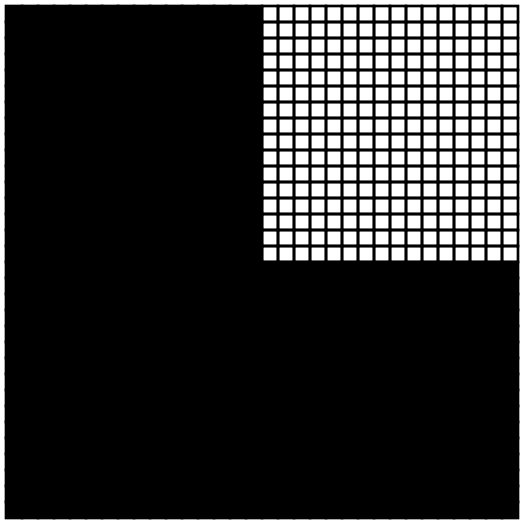
combinations: 4^n

5 masks:

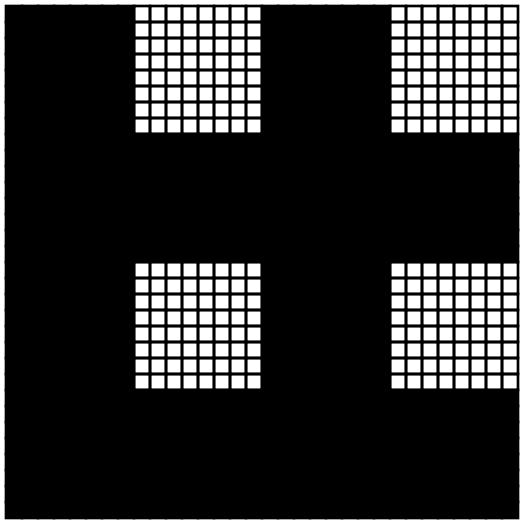
4 x 5 = 20 depo's

4^5 = 1024 samples

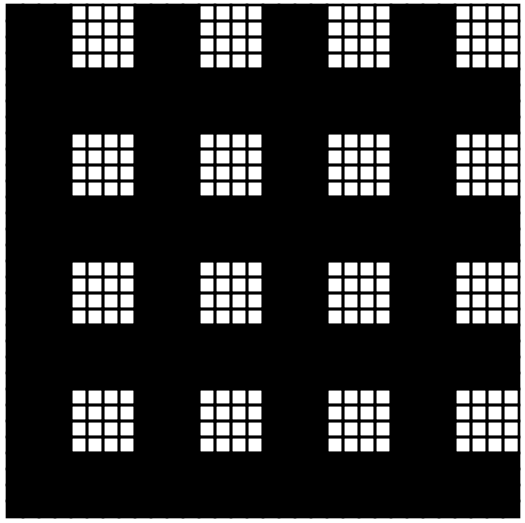
A



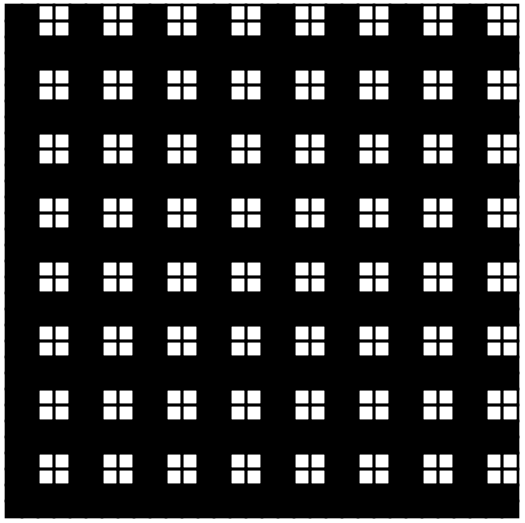
B



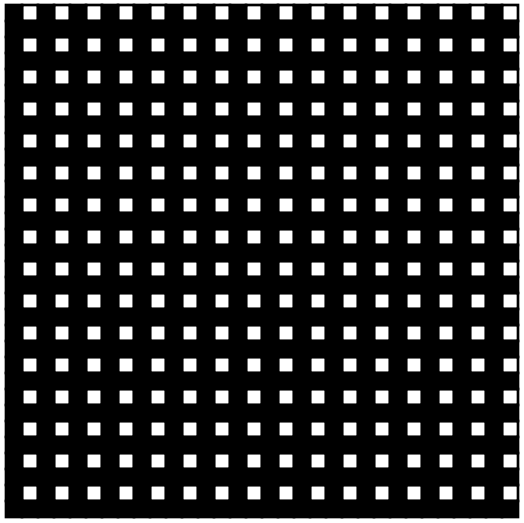
C

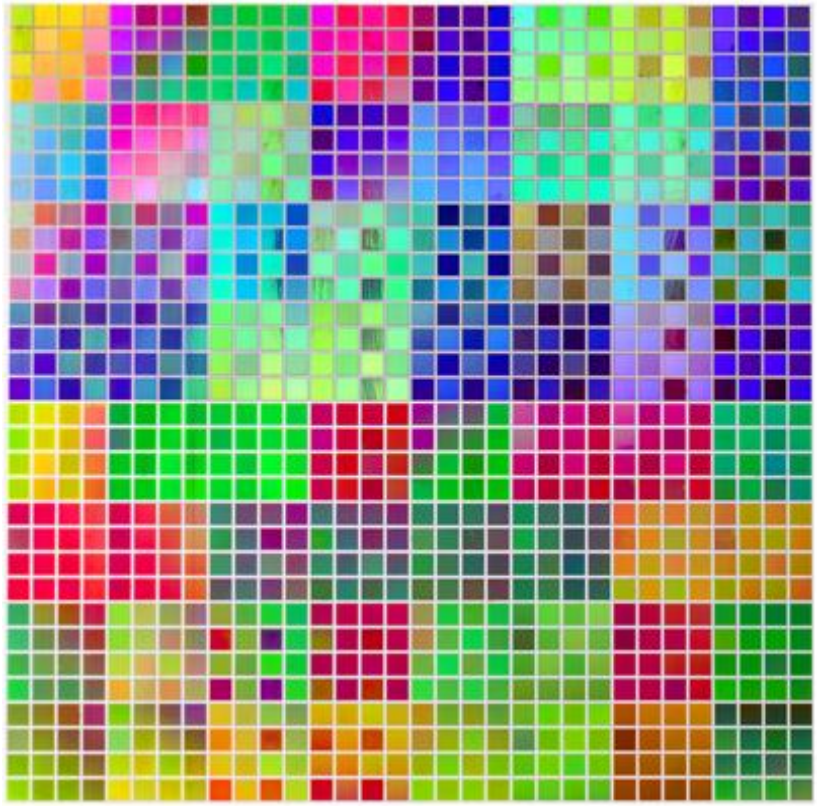


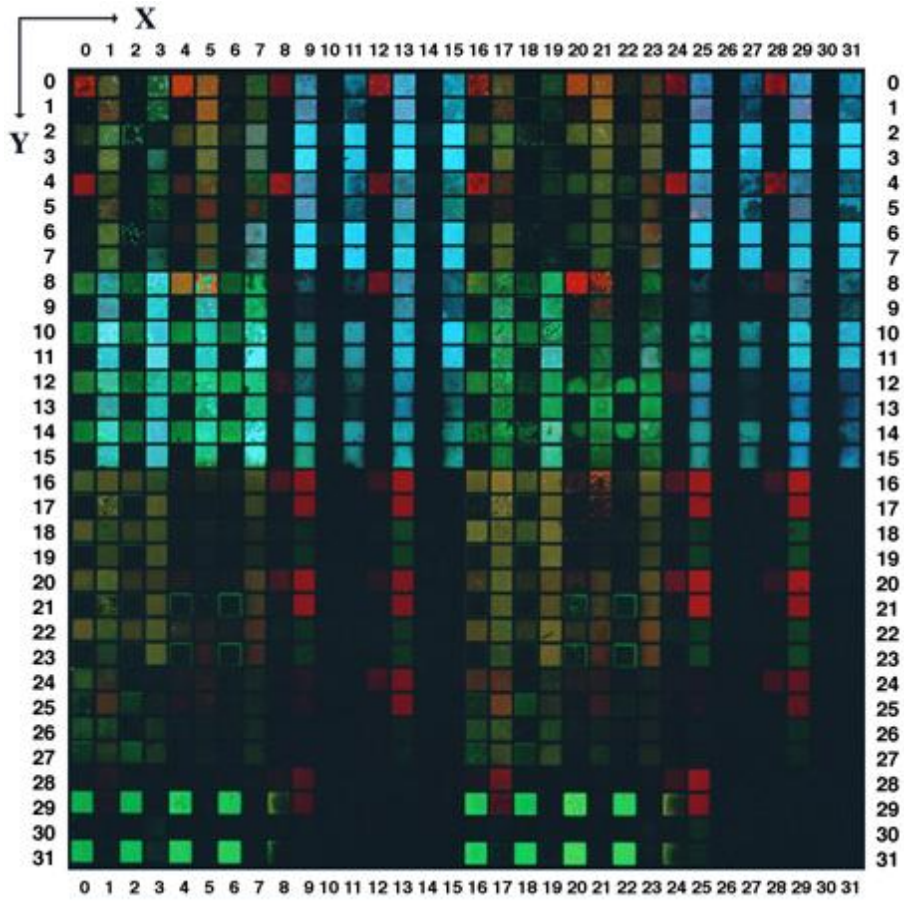
D



E







(Right) Luminescent image of the same library after thermally processed under UV excitation.

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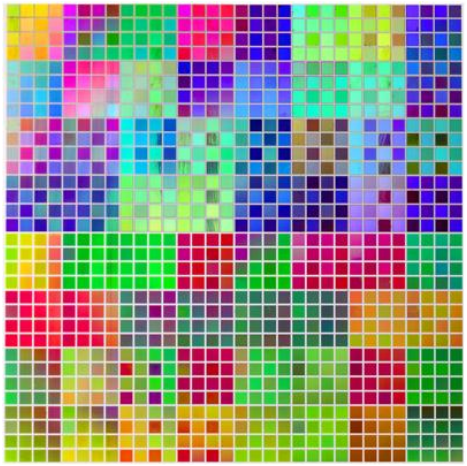
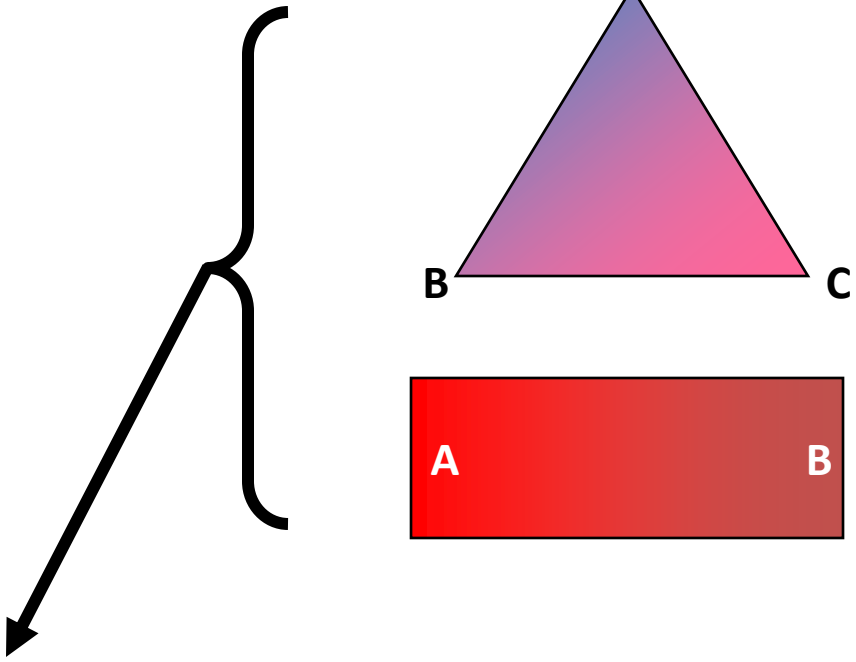
Various combinatorial experimental designs

discrete libraries vs composition spreads

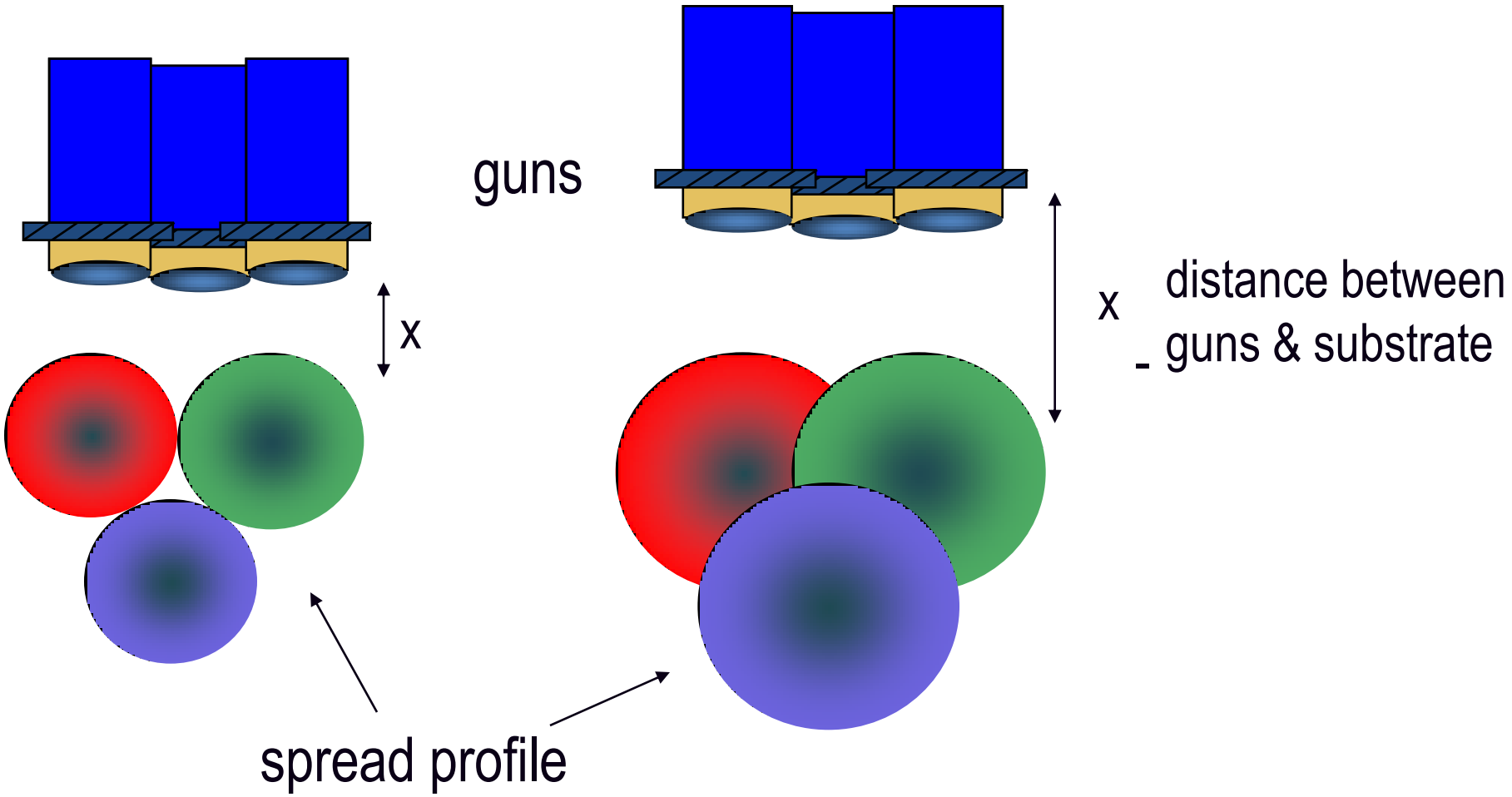




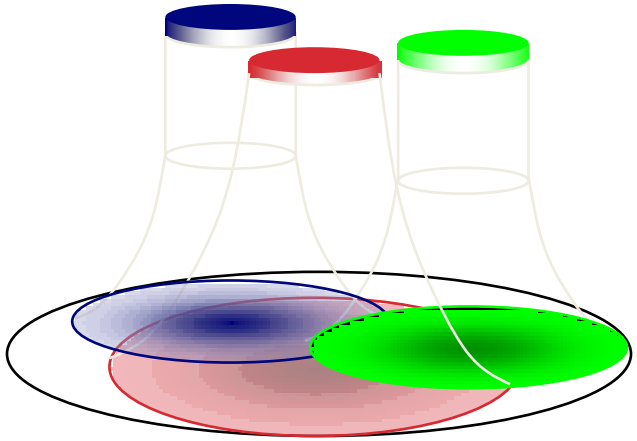
- **Composition spreads allow continuous mapping of physical properties and phase boundaries**
- **Run to run variation in ordinary experiments is removed**

Combinatorial UHV Co-sputtering (P_{base} ~1x10^{-9} Torr)

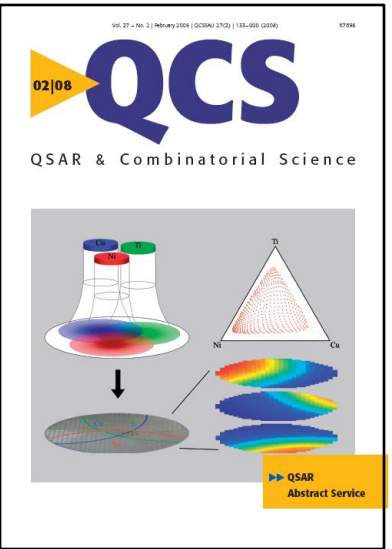
CCS-Continuos Composition Spread Approach



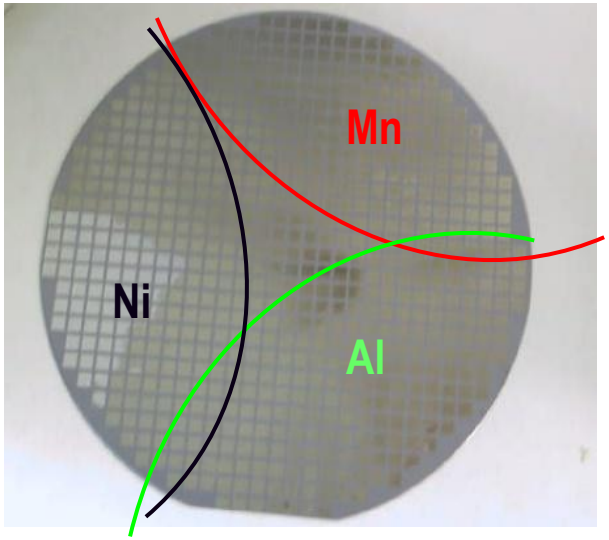
Composition Spreads of Ternary Metallic Alloy Systems

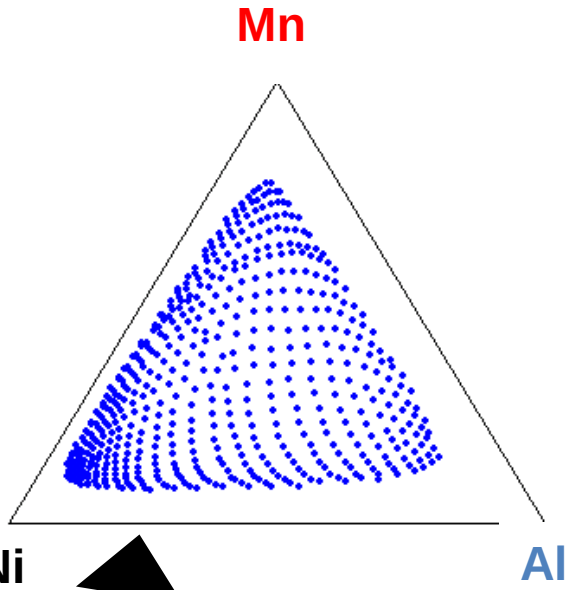


Co-sputtering scheme



3” spread wafer

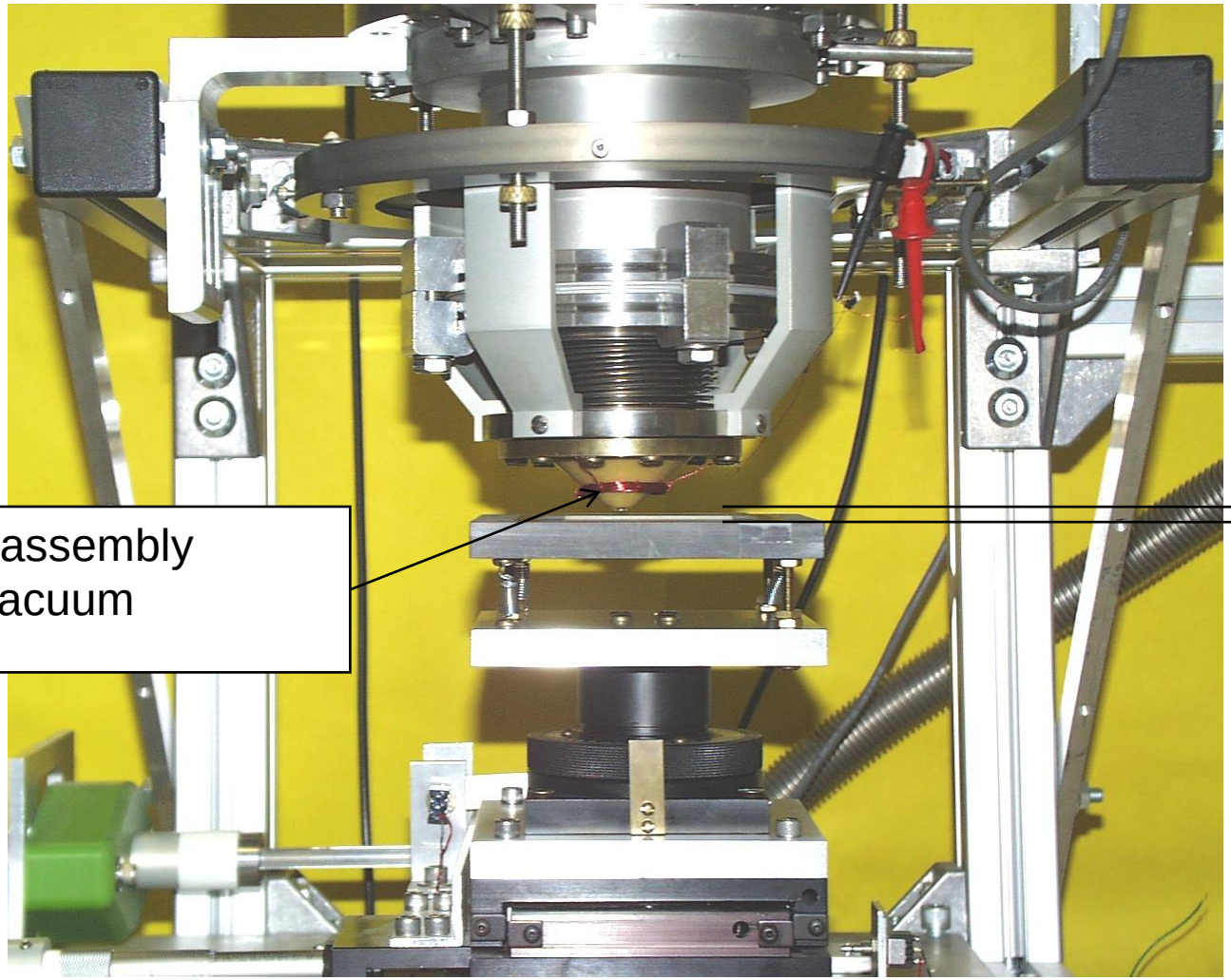




Phase diagram

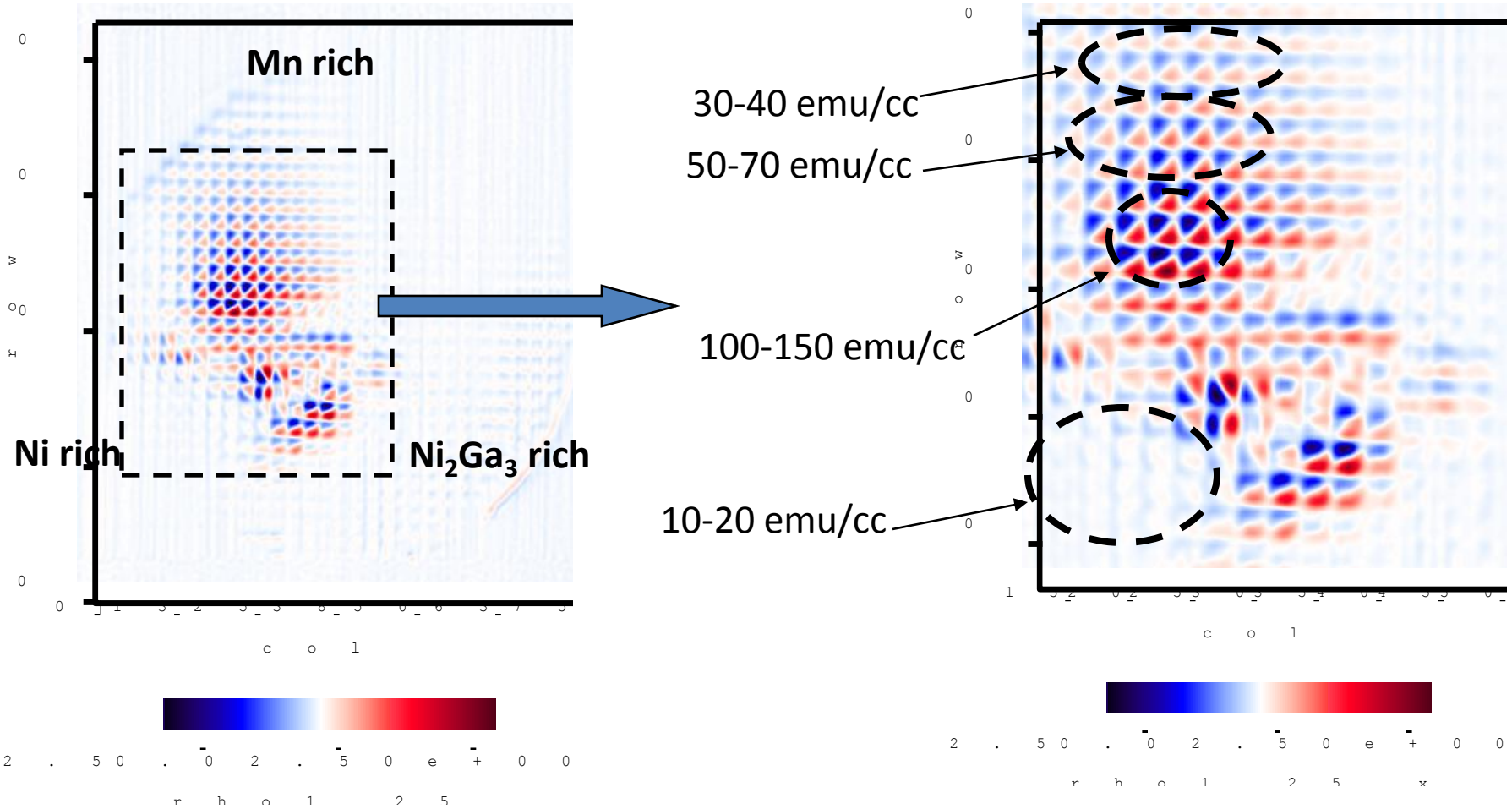
Composition is mapped using an electron probe (WDS)

Scanning SQUID microscope based on $YBa_2Cu_3O_7$ thin film (F. Wellstood, UMD)

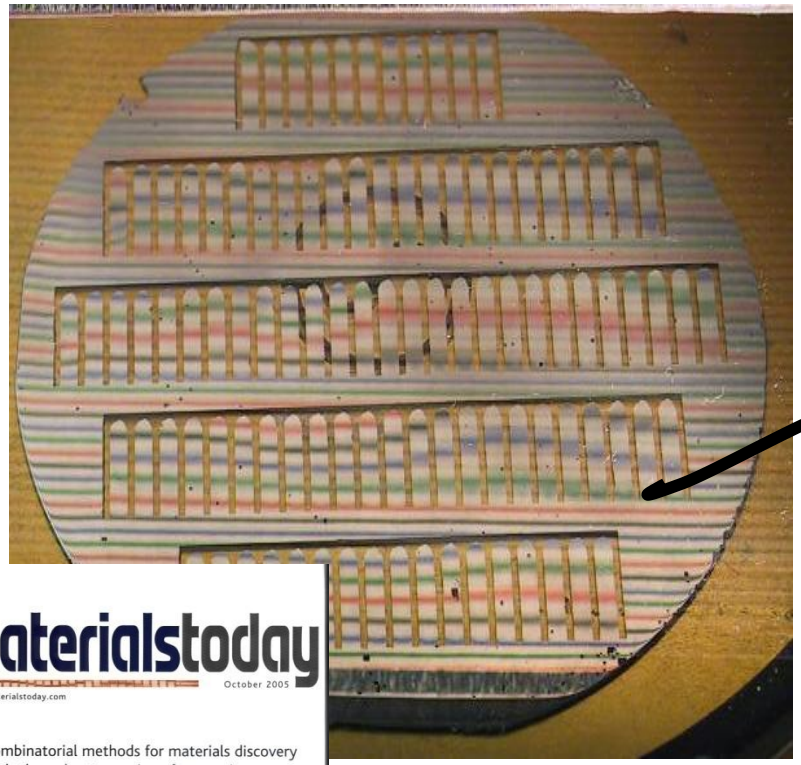


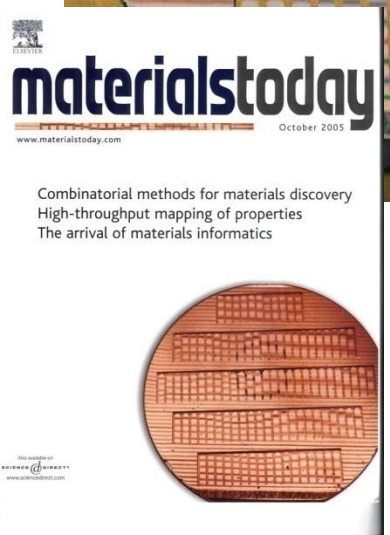
Room temperature samples are measured

Scanning SQUID image of a Ni-Mn-Ga spread wafer (room temperature)

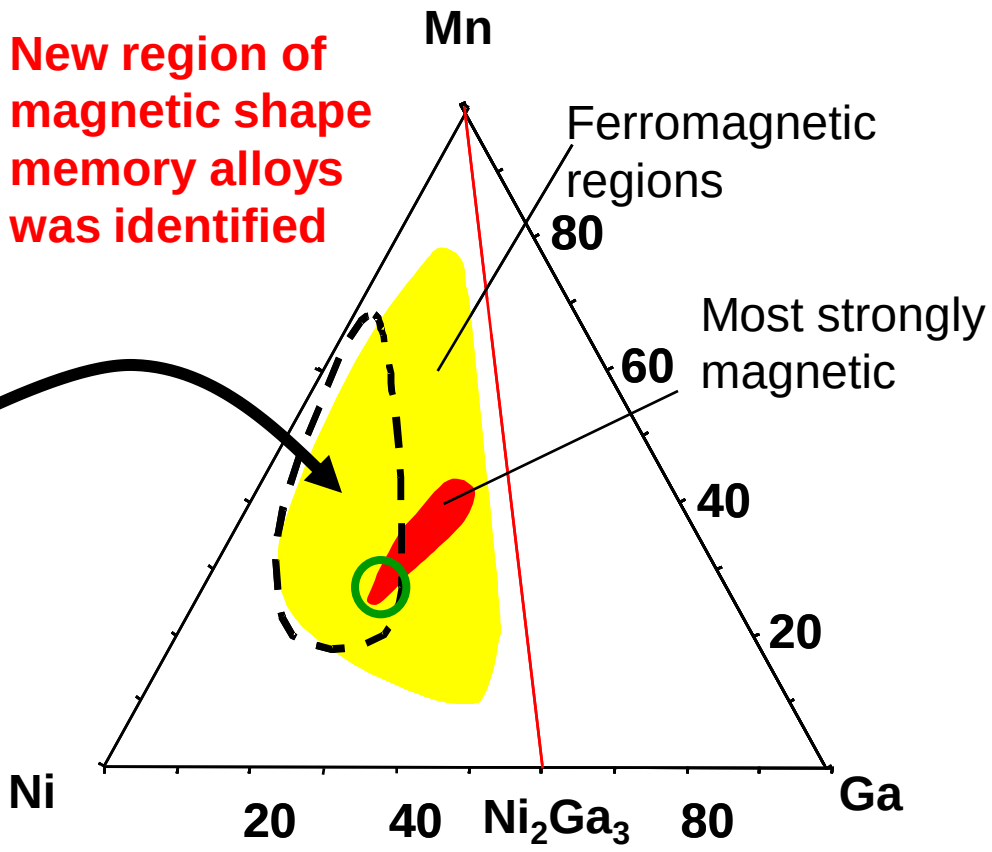


Combinatorial search of ferromagnetic shape memory alloys



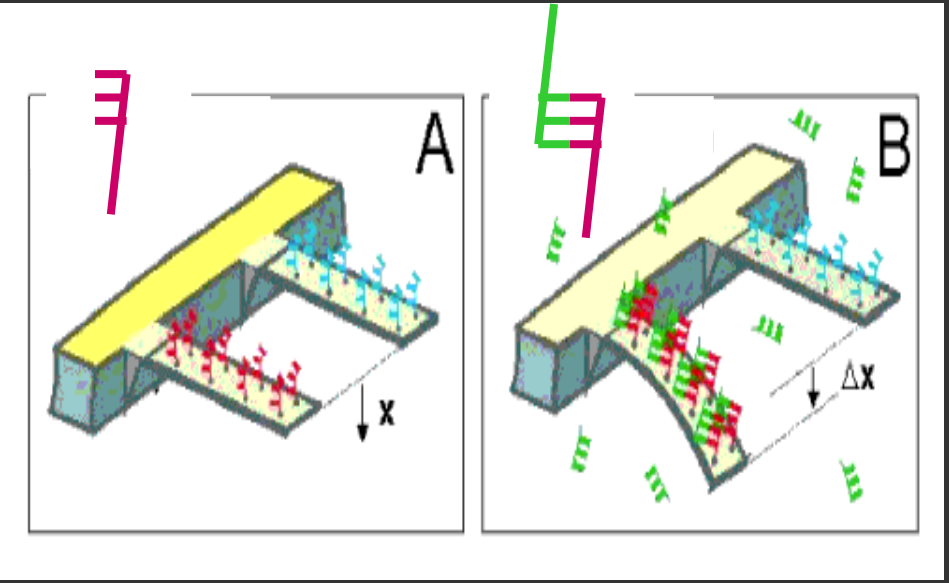


Composition gradient fabricated on micromachined cantilever arrays

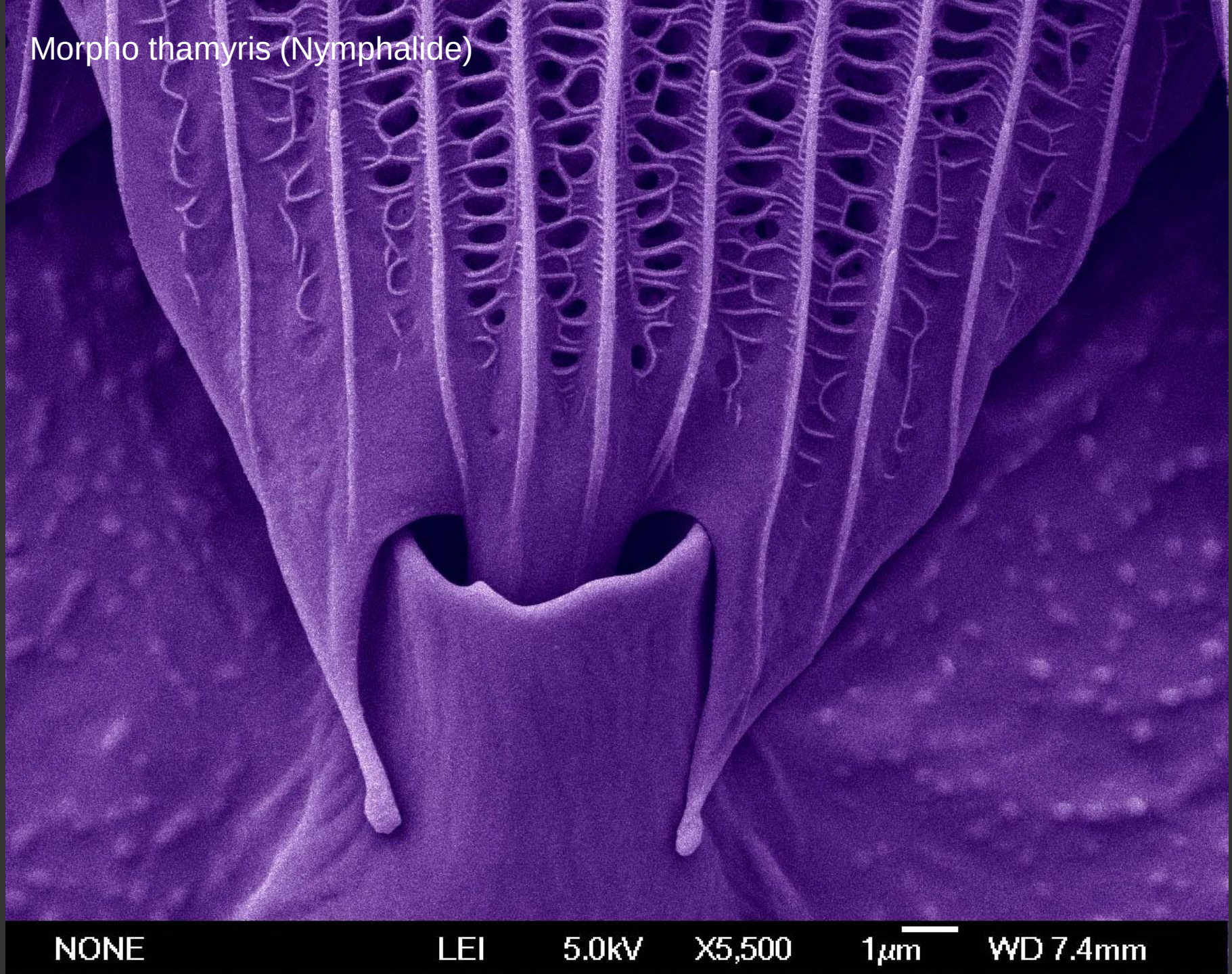


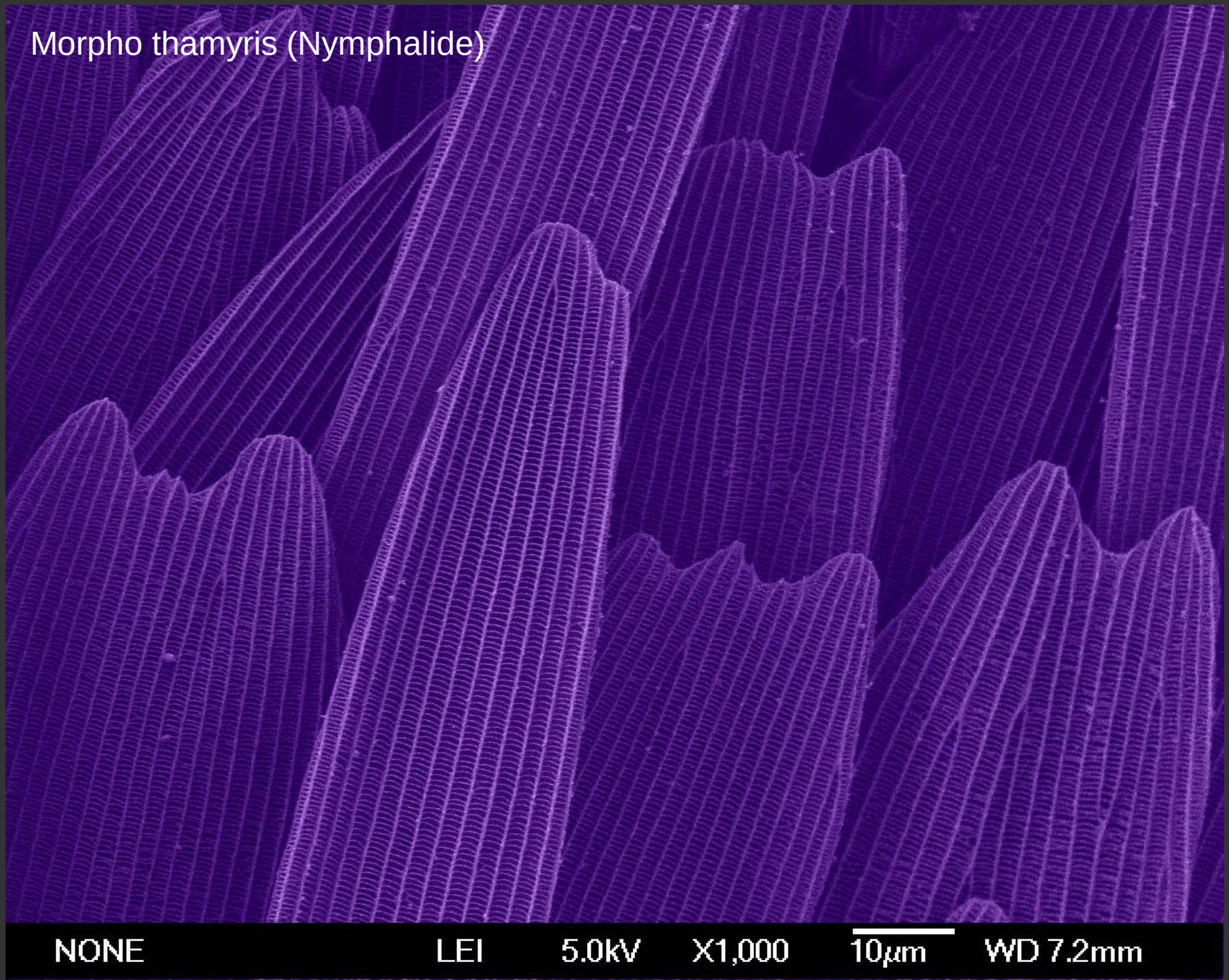
Nature Materials 2, 180 (2003)

“Sistema di monitoraggio rapido del gruppo sanguigno e per la rivelazione di reazioni immunoematologiche”



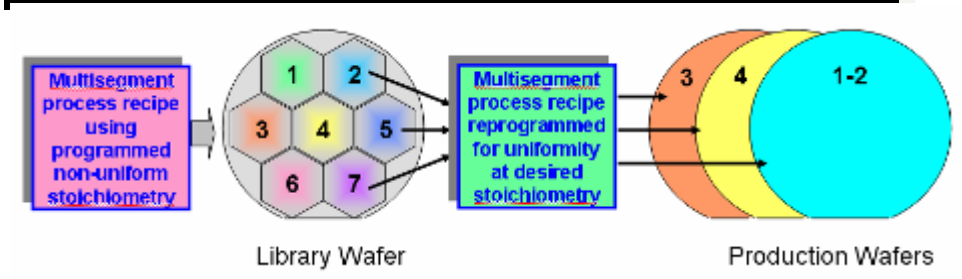
macro → micro → nano

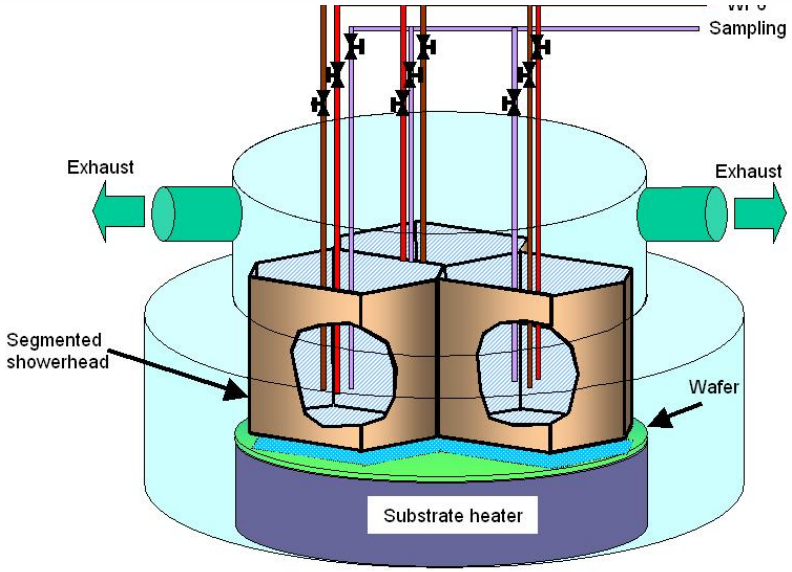

Morpho thamyris (Nymphalide)
NONE
LEI
5.0kV
X5,500
1μm
WD 7.4mm

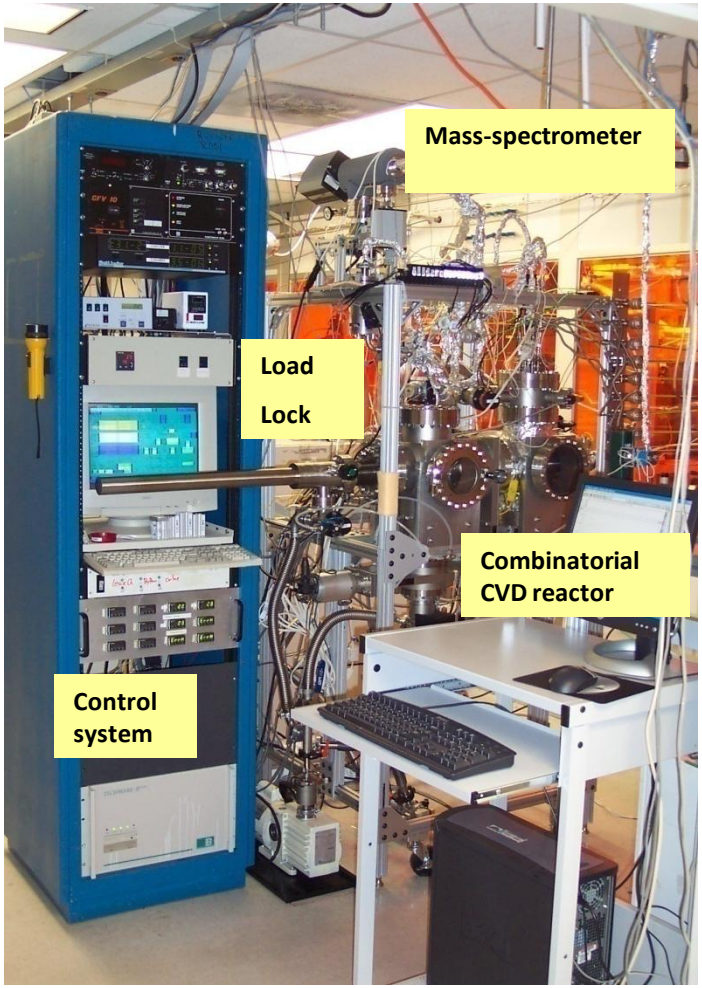

Morpho thamyris (Nymphalide)
NONE
LEI
5.0kV
X1,000
10µm
WD 7.2mm

Spatially Programmable Equipment Design for Combinatorial CVD

New paradigm for intelligent design and control of semiconductor process equipment

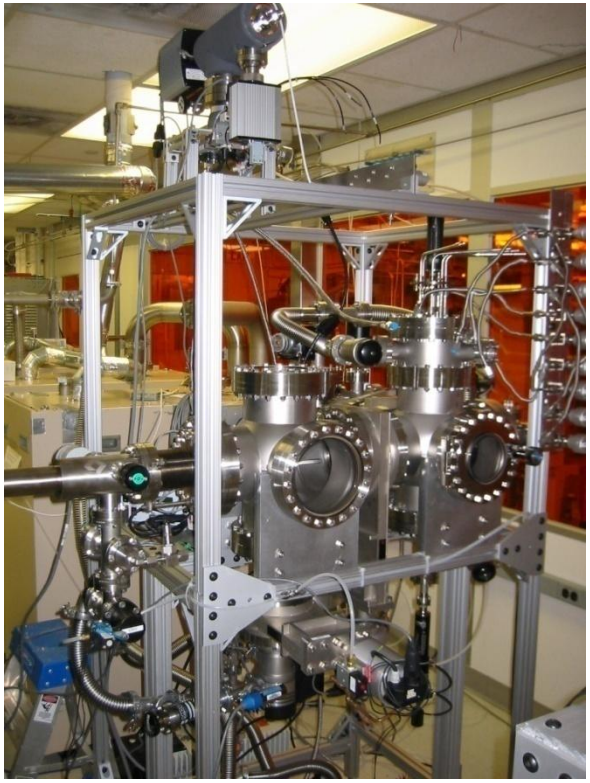


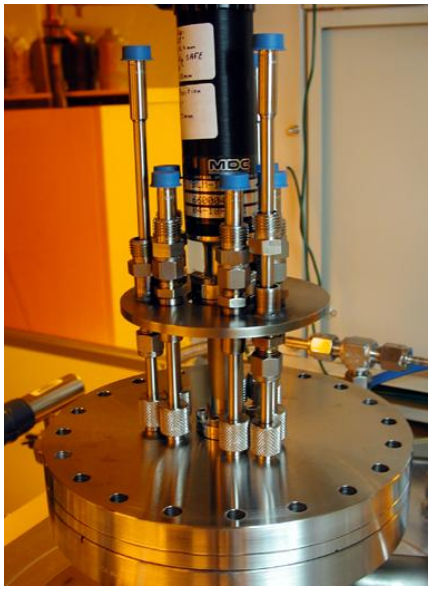


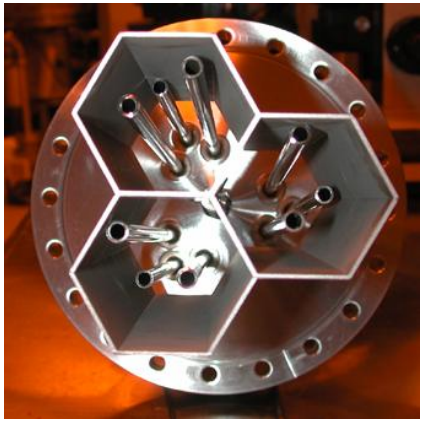


G. W. Rubloff, R. Adomaitis, et. al.

Combinatorial CVD Reactor

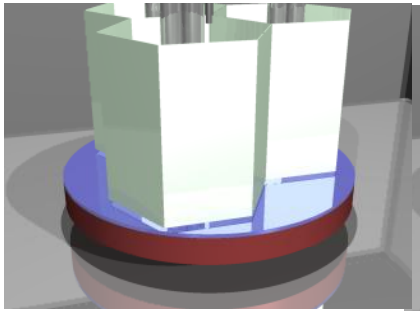


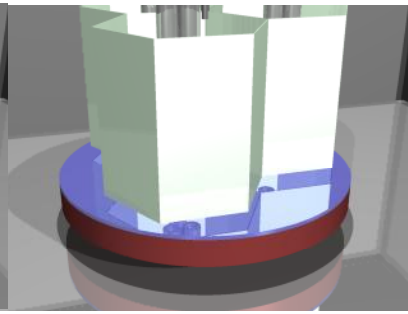


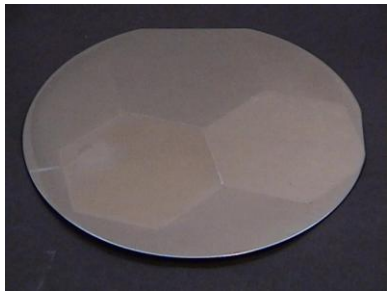


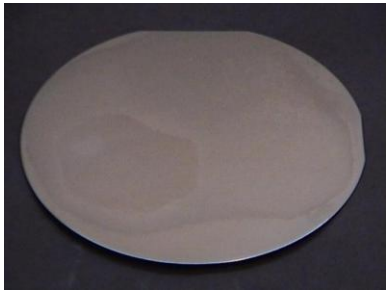
Segment-wafer spacing

1mm **3mm**

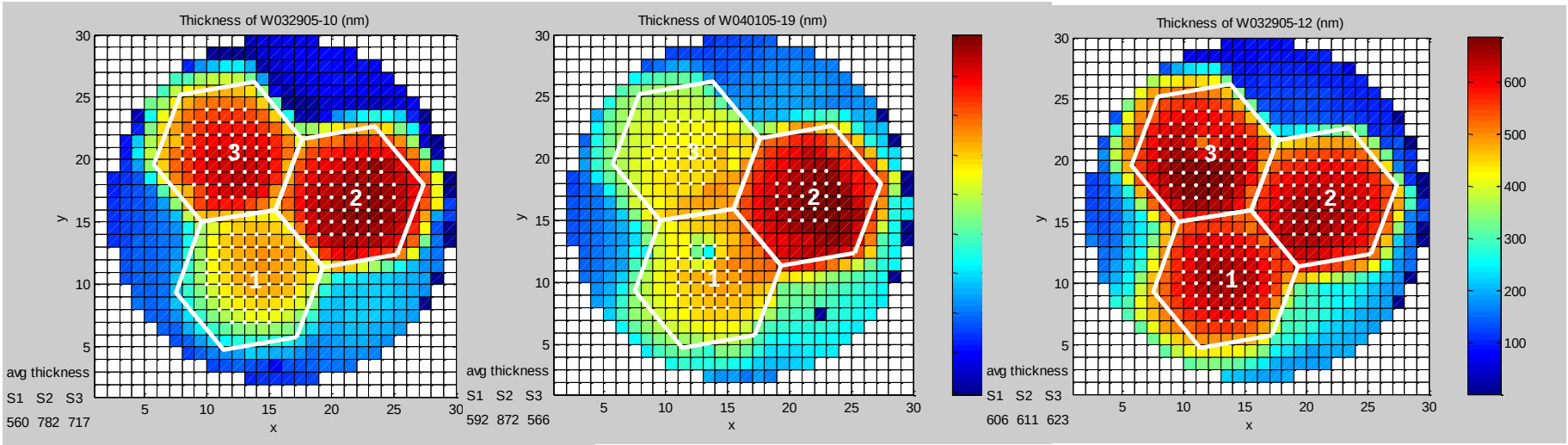








Combi-CVD Programmability



W032905_10	S1	S2	S3
WF6	6	9	12
H2	24	36	48
Ar	30	15	0

W040105_19	S1	S2	S3
WF6	9	12	6
H2	36	48	24
Ar	15	0	30

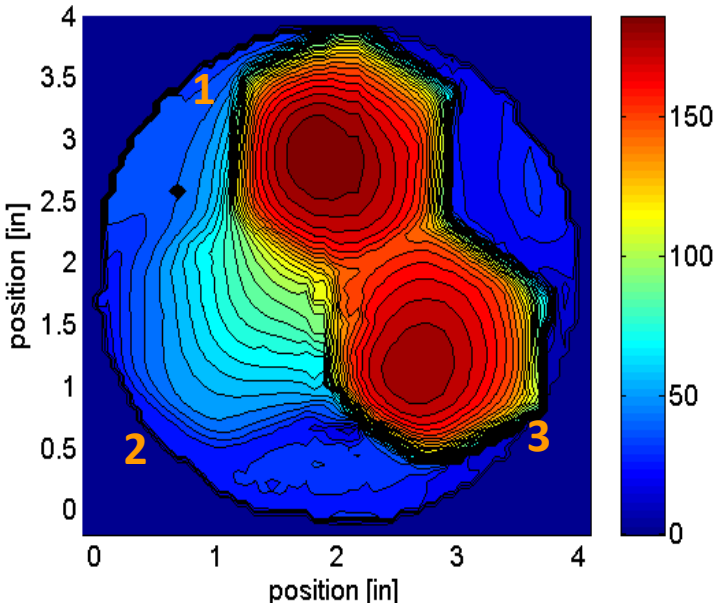
W032905_12	S1	S2	S3
WF6	12	6	9
H2	48	24	36
Ar	0	30	15

- Spatially programmable CVD enables combinatorial studies
- Post-process mapping of thickness/rate
- Composition mapping (IRST microcombi project)

Combinatorial W CVD from WF_6/H_2

Reactant flow distributions

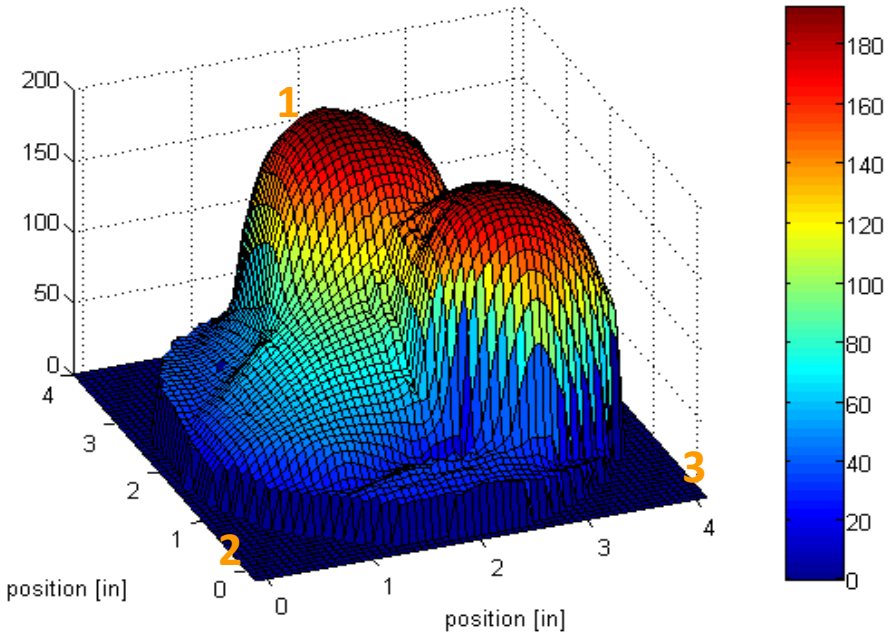
	Seg 1.	Seg 2.	Seg 3.	
Ar	0	60	30	[sccm]
WF6	12	0	6	[sccm]
H2	48	0	24	[sccm]
Total	60	60	60	[sccm]



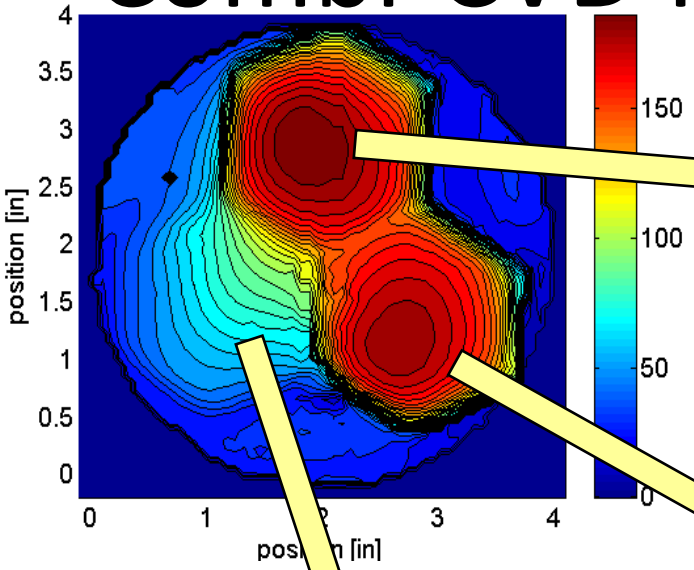
Film thickness distributions

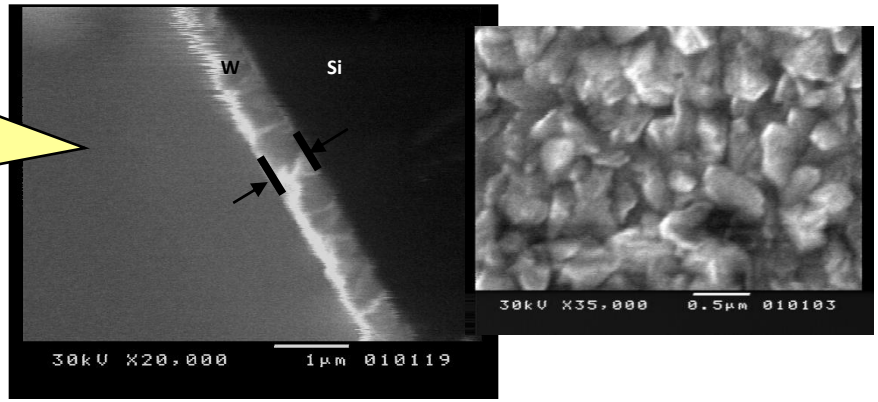
Growth rate $\propto [P_{H2}]^{1/2}$

Heater T : 400 °C
Chamber P : 1 torr
Gap : 1mm
Process time : 10 min



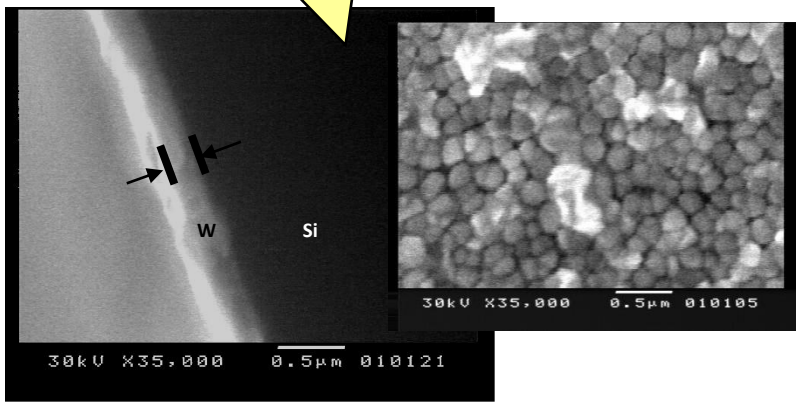
Combi-CVD Materials Synthesis

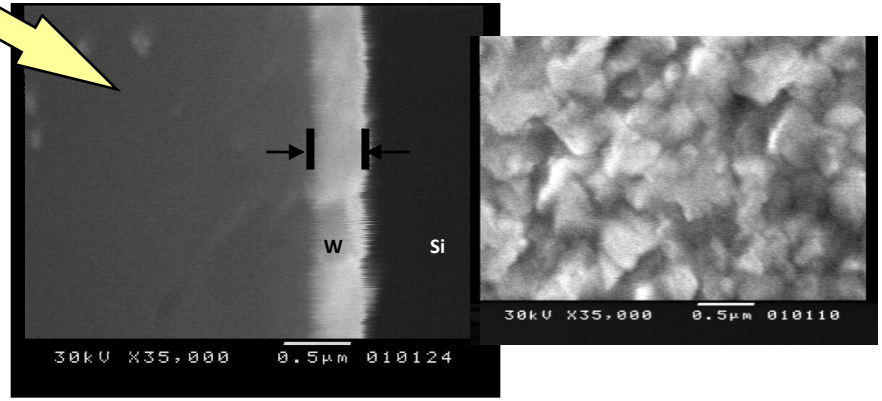




X-SEM

SEM





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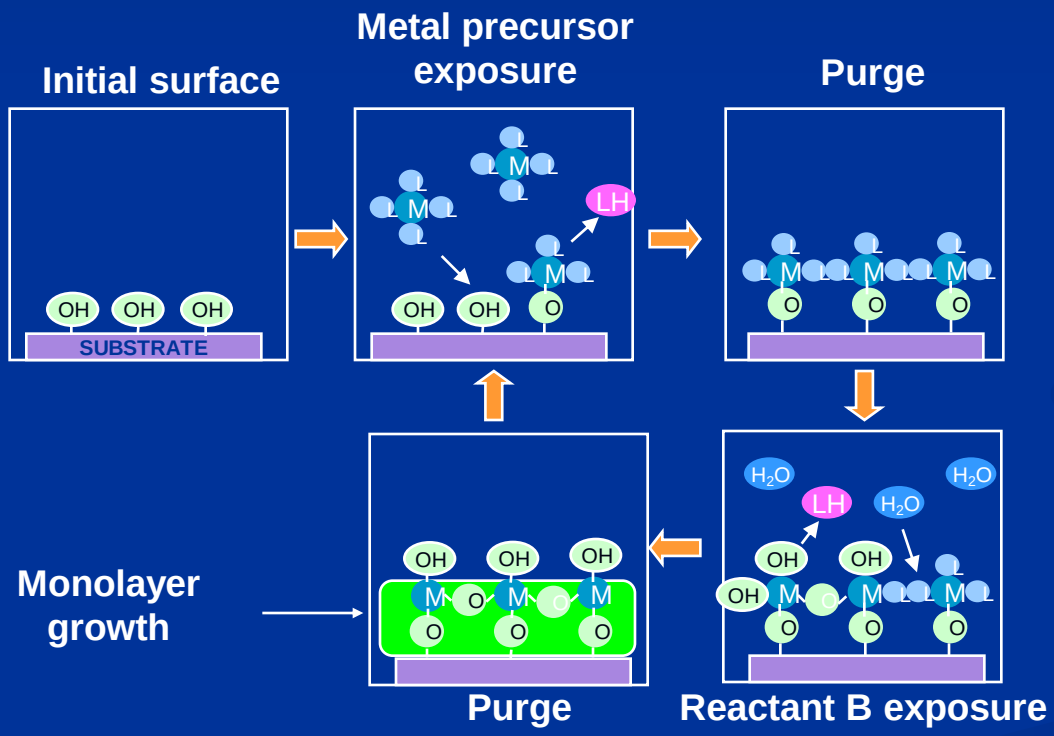
Atomic Layer Deposition

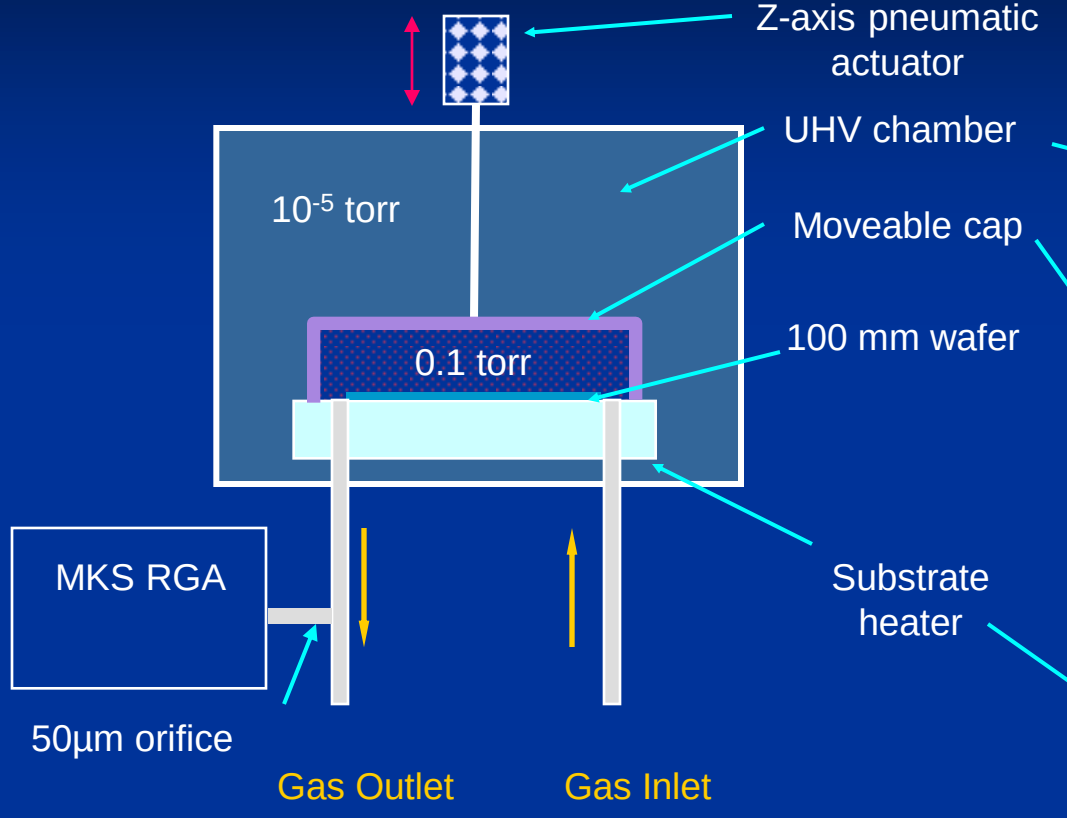
a simple picture
an ideal process

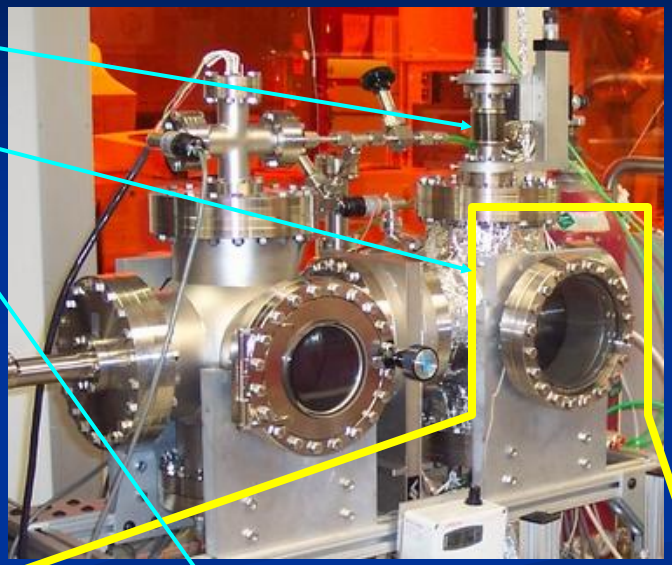


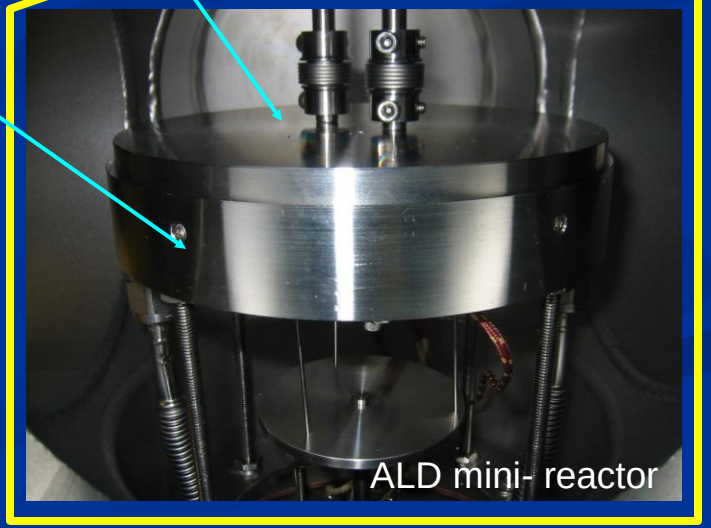
BUT…

- ***Nucleation & surface condition dependence***
- ***Temperature-dependent growth***
- ***Dose dependencies***
- ***Incomplete layer adsorption & reaction***
- ***Multilayer adsorption & reaction***

ALD reactor design



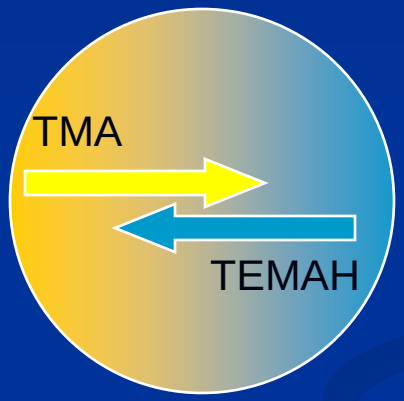




100 mm substrate heater with inlet / outlet slits

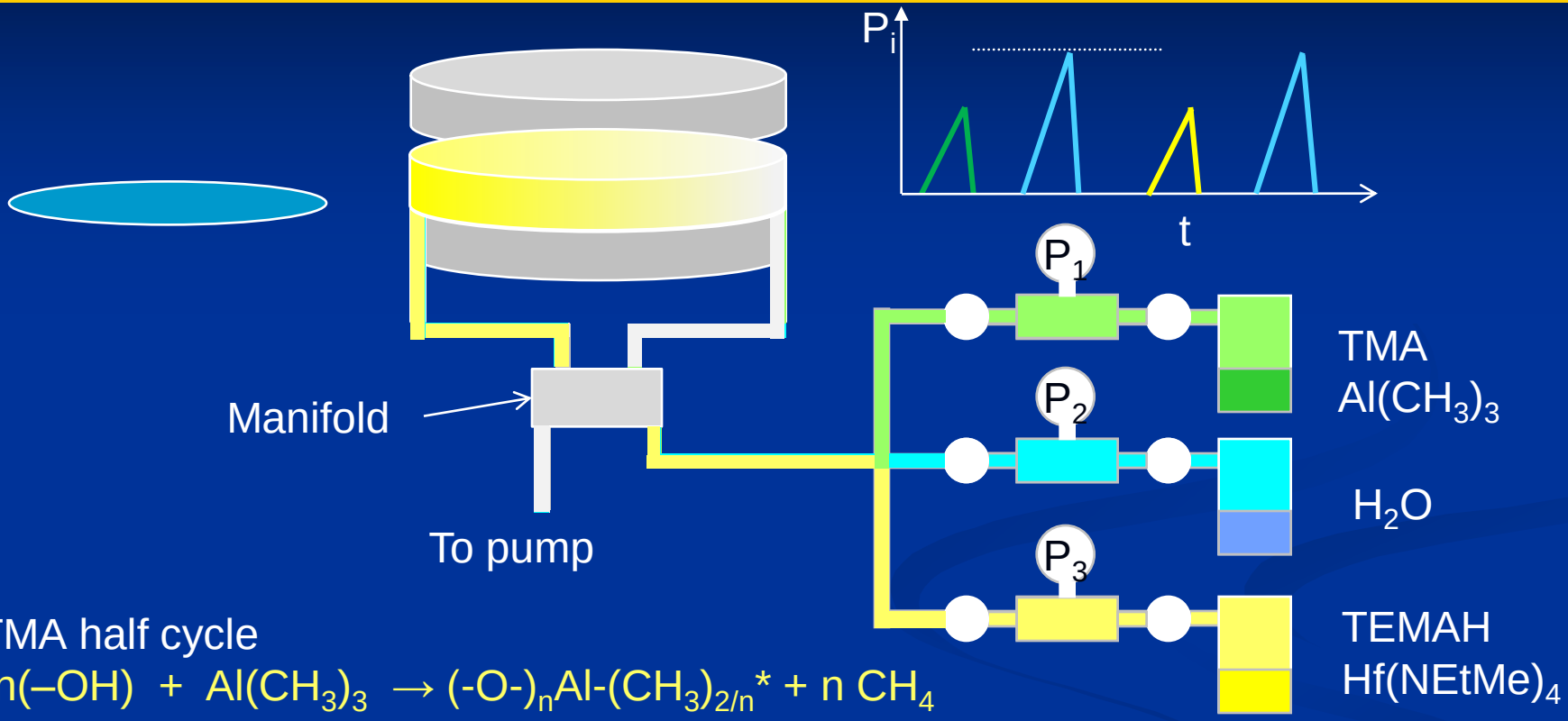
Our approach to combi ALD

Final objective:
Compositional gradient for ternary systems requires thickness gradient across wafer



Tuning of materials properties via compositional gradient

Process flow sequence for combi Hf-Al-O films



TMA half cycle

$n(–OH) + Al(CH_3)_3 \rightarrow (-O-)_nAl-(CH_3)_{2/n}^* + n\ CH_4$

H2O half cycle

$-O-Al-(CH_3)_n^* + n\ H_2O \rightarrow (-O-)Al-(OH)_n^* + n\ CH_4$

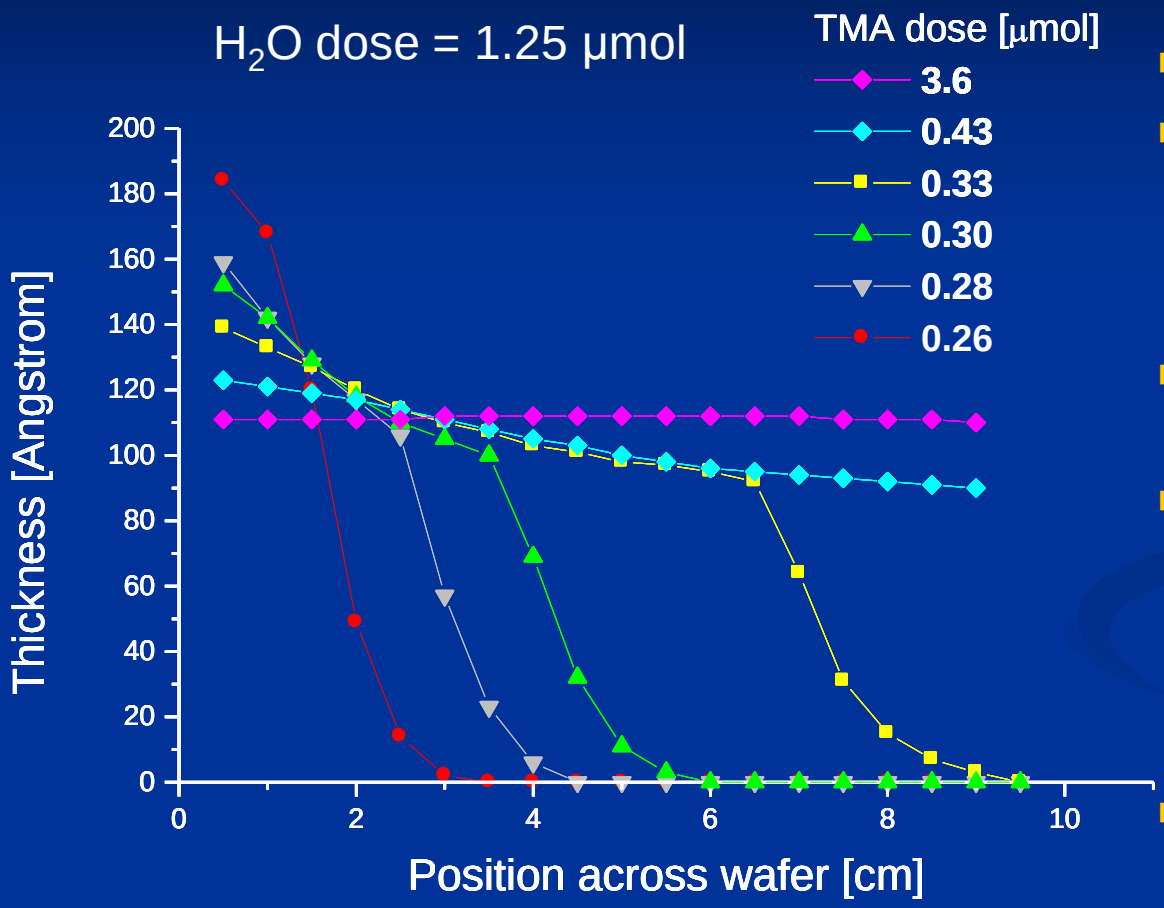
TEMAH half cycle

$–OH + Hf-(NE_tM_e)_4 \rightarrow (-O-)_2Hf-(NE_tM_e)_2^* + 2NE_tM_e$

H2O half cycle

$(-O-)_2Hf-(NE_tM_e)_2^* + 2\ H_2O \rightarrow (-O-)_2Hf-(OH)_n^* + 2NE_tM_e$

Effect of TMA dose on thickness profiles

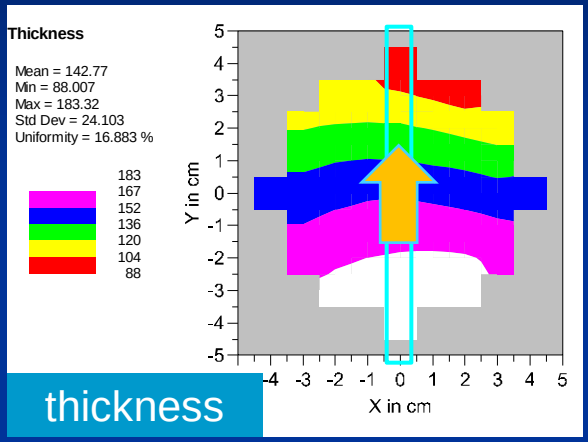


- Fixed saturating water dose
- Decrease in TMA dose (3.6 to 0.43) results in increasing but continuous thickness non-uniformities (<30%)
- Below critical dose, discontinuous profile
- Higher growth rate at inlet
  - May result from localized OH* oversaturation as H2O/TMA increases and multilayer deposition
- Higher growth at inlet aggravates TMA depletion near outlet

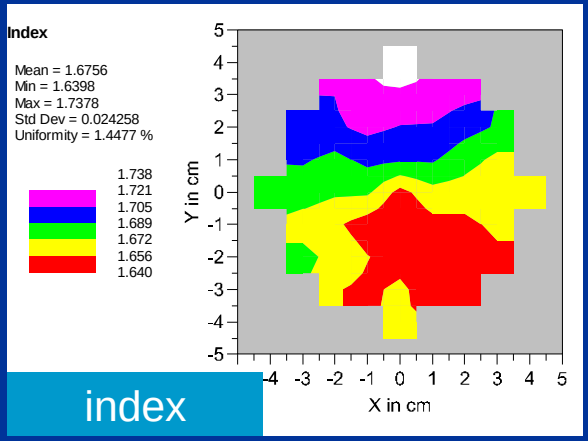
ALD cross-flow arrangements makes it easy to see when reaction is unbalanced as it amplifies consequent non uniformities

Ex-situ wafer characterization under water-starved conditions (0.8 µmol)

Spect. ellipsometry

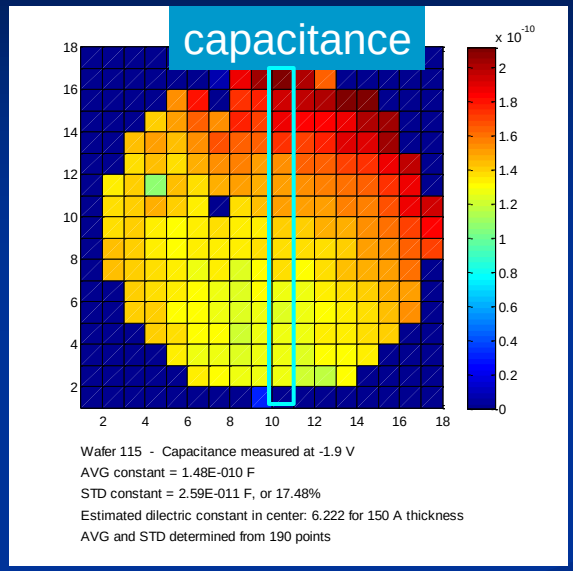


thickness

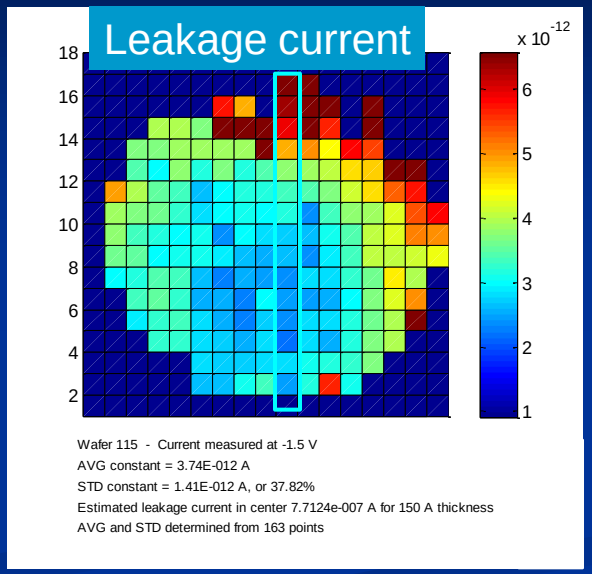


index

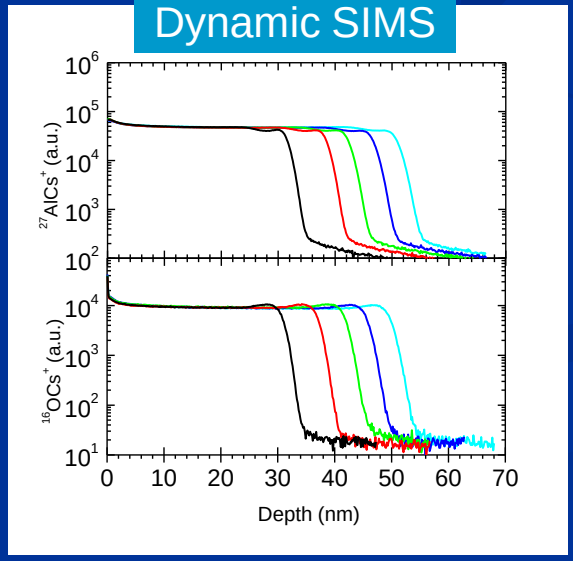
capacitance



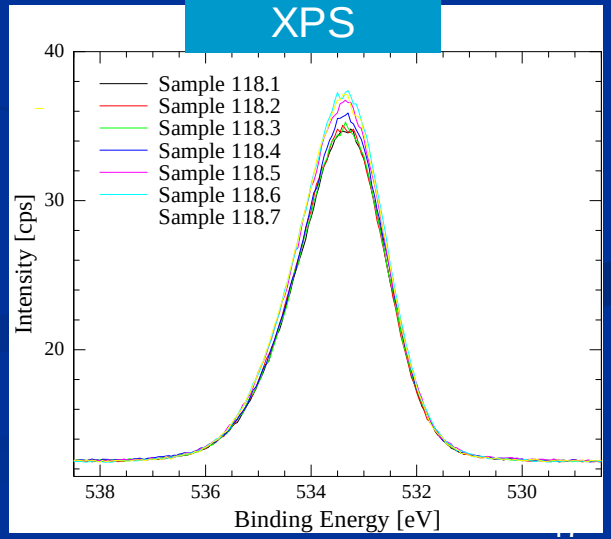
Leakage current



Dynamic SIMS

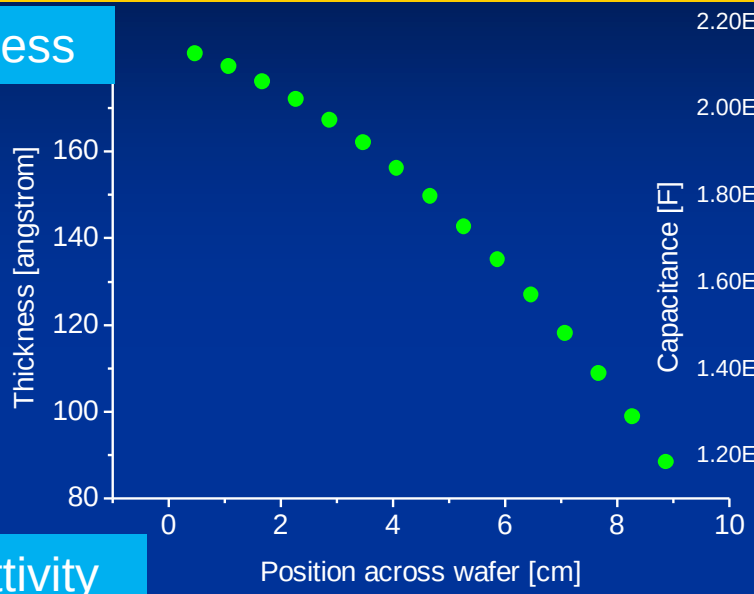


XPS

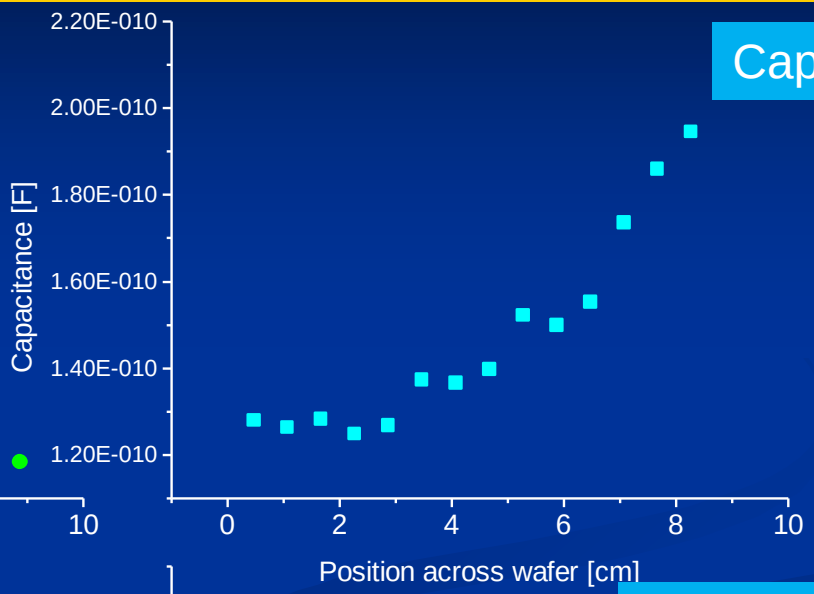


Film properties across wafer under water-starved conditions (0.8 µmol)

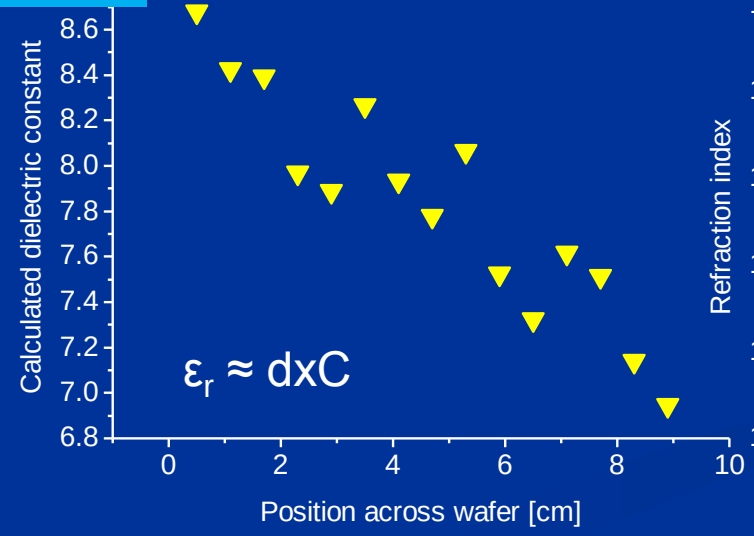
Thickness



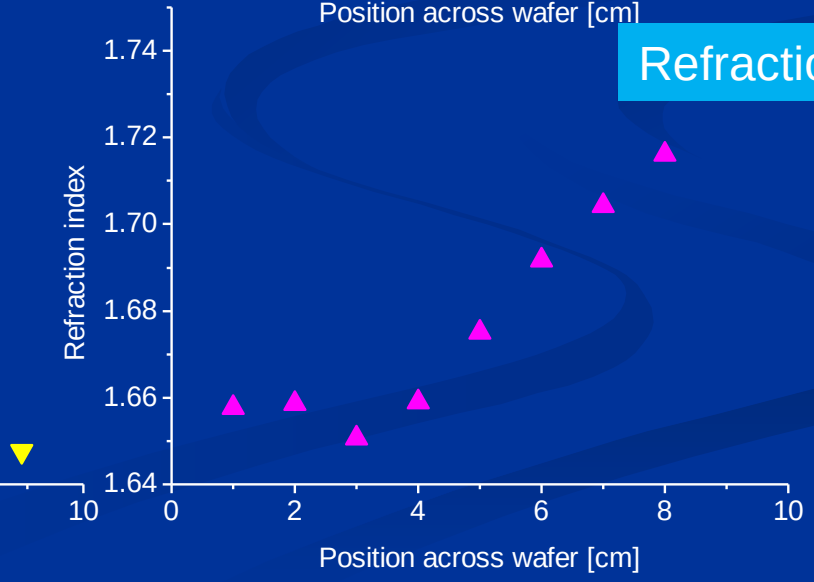
Capacitance



Permittivity

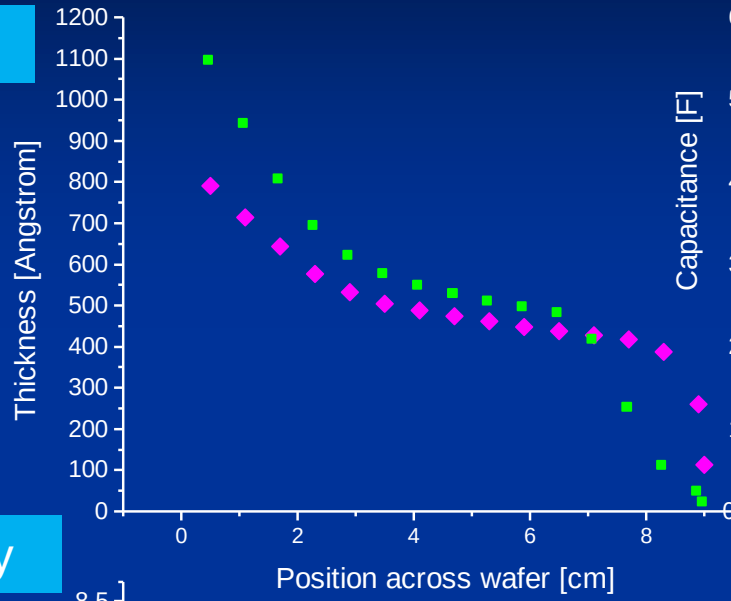


Refraction index

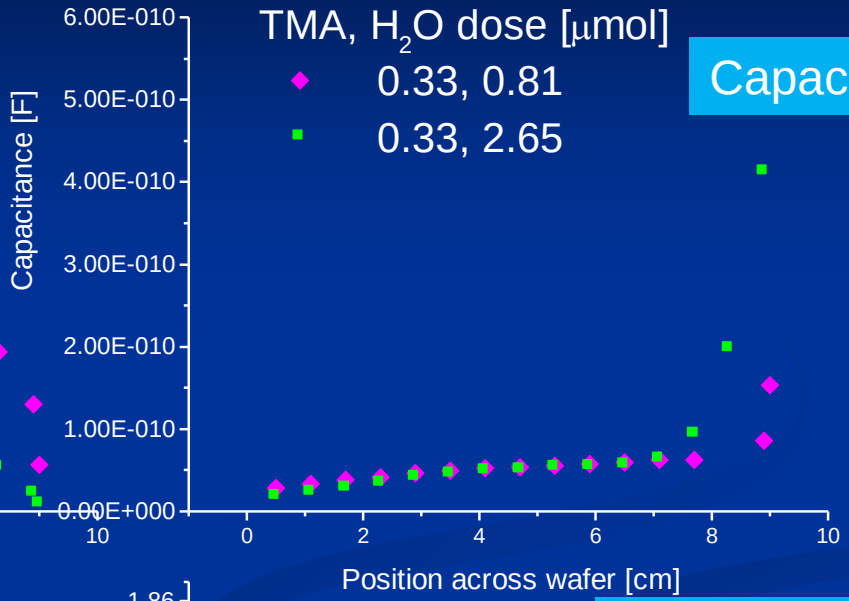


Film properties across wafer for TMA-underdosed films

Thickness

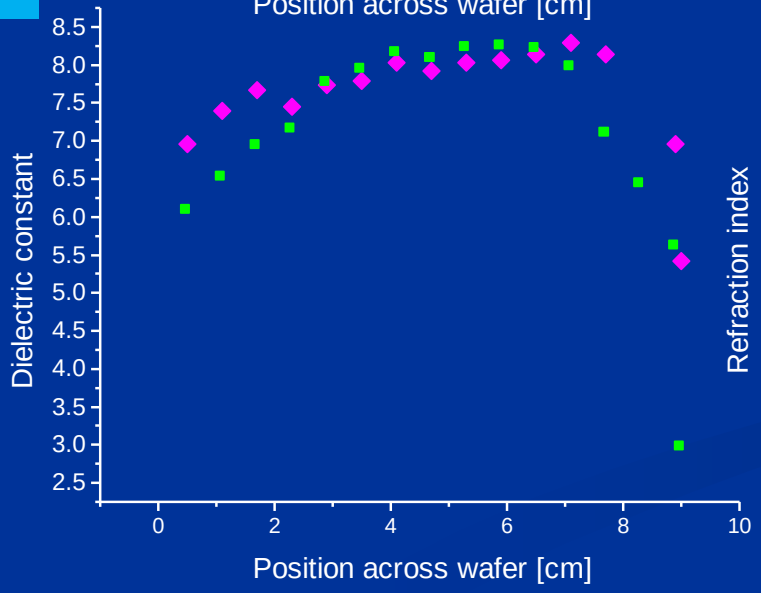


Capacitance

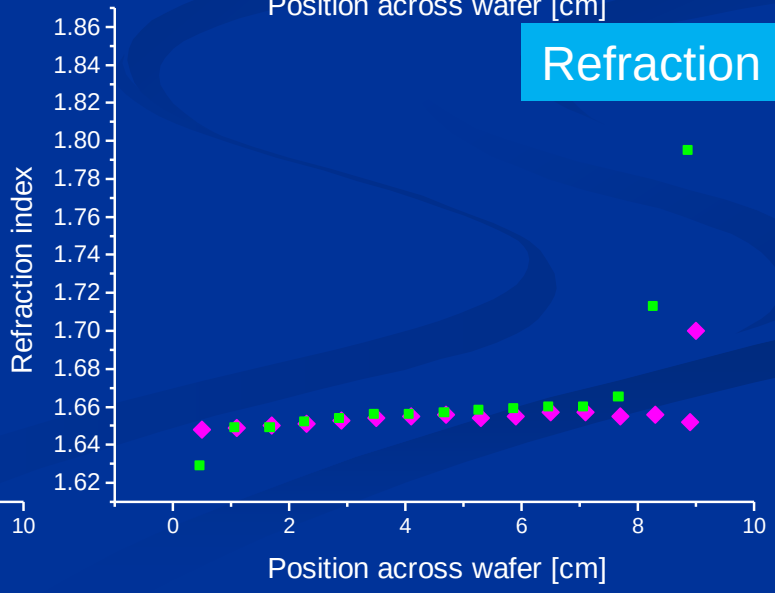


TMA, H_2O dose [μmol]
- 0.33, 0.81
- 0.33, 2.65

Permittivity

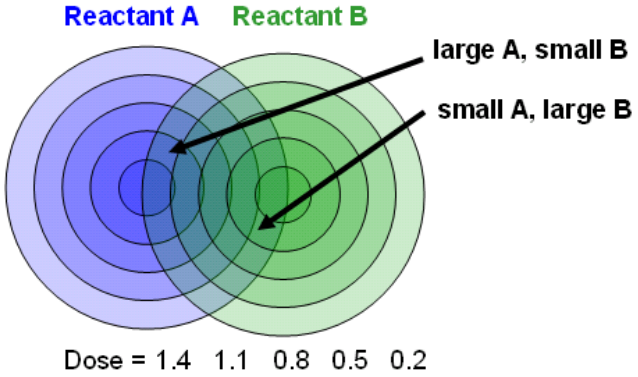


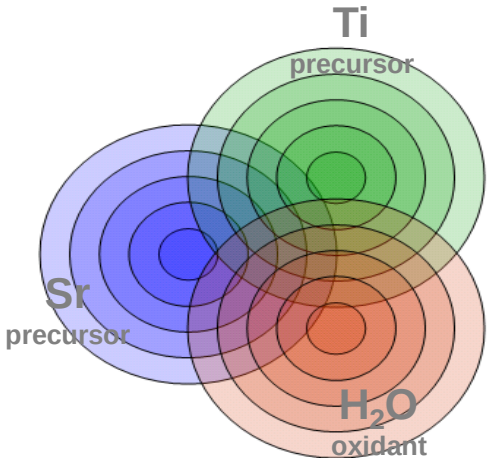
Refraction index



Combinatorial ALD

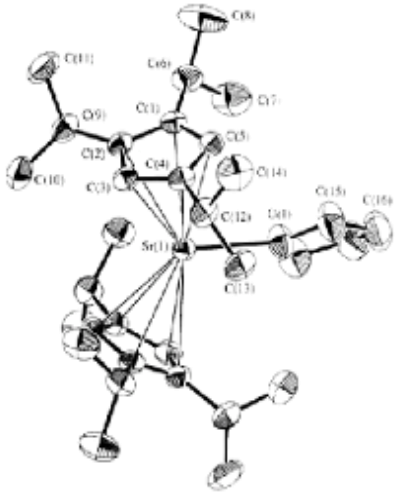
Numerous process recipe permutations in real-world ALD



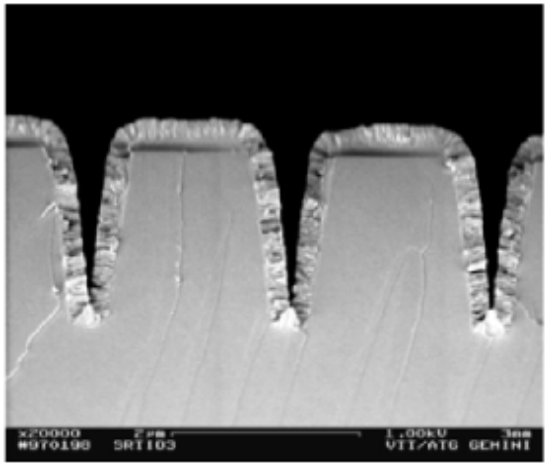


$$Sr(C_5{}^iPr_3H_2)_2 + H_2O + Ti(O^iPr)_4 + H_2O \rightarrow SrTiO_3$$

crystalline already at 250 °C



$Sr(C_5{}^iPr_3H_2)_2(THF)$



(Vehkamäki et al., Electrochem. Solid State Lett. 2 (1999) 505.)

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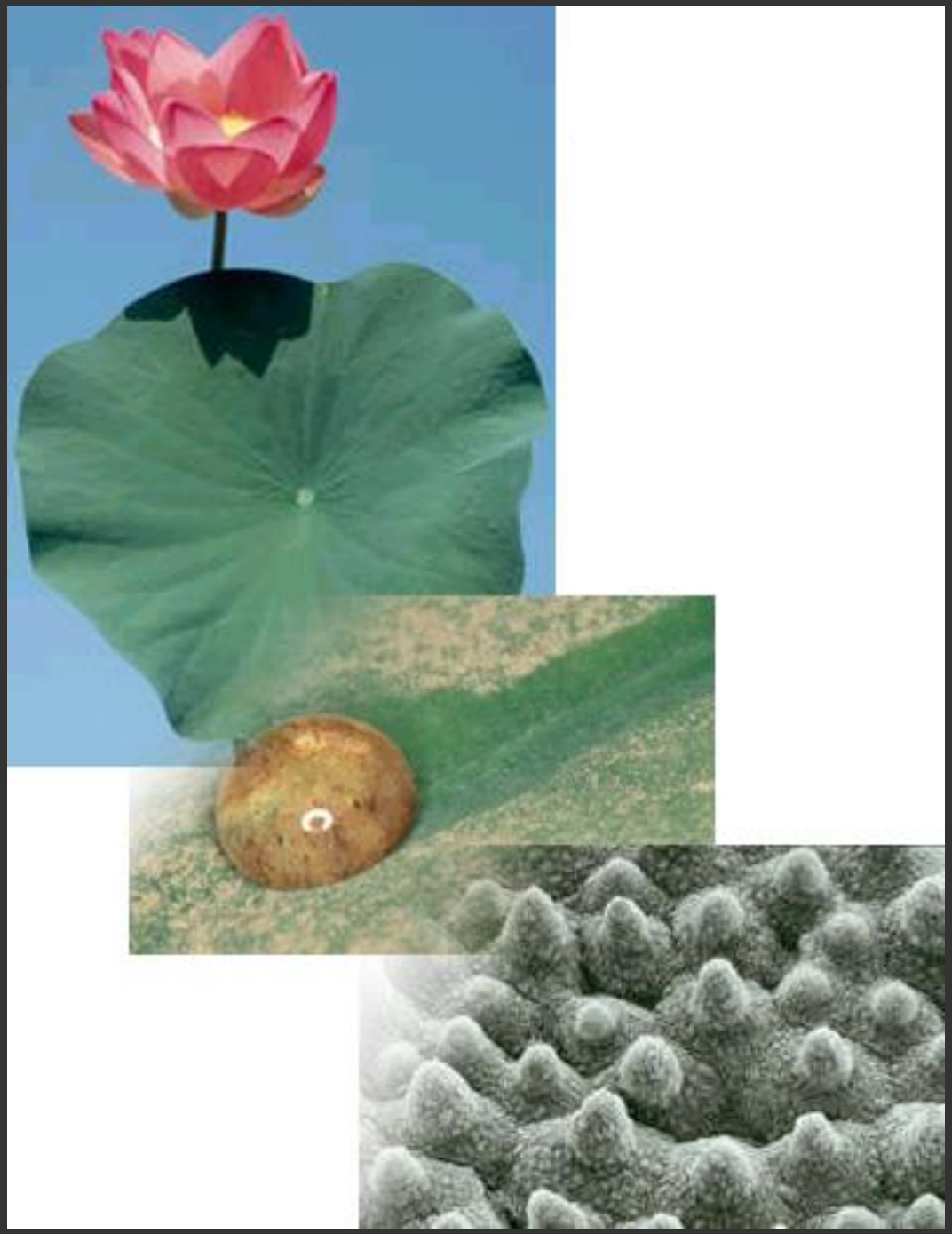
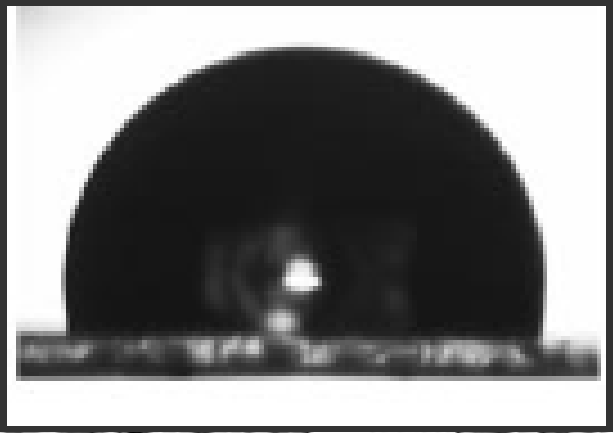
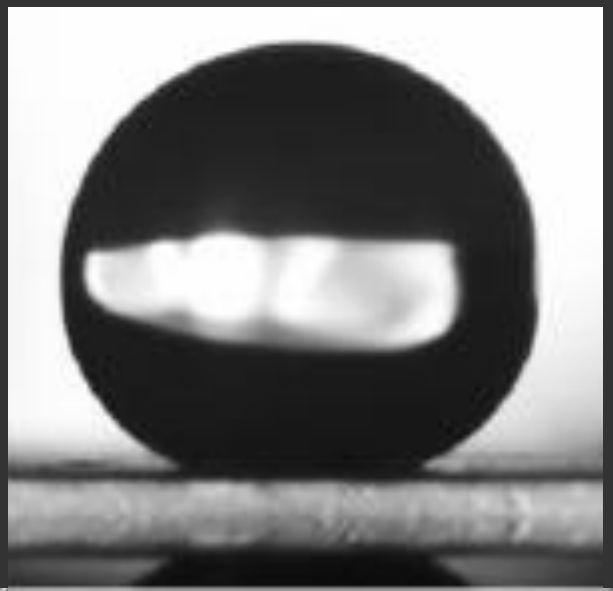
Phleum pratense
Codolina

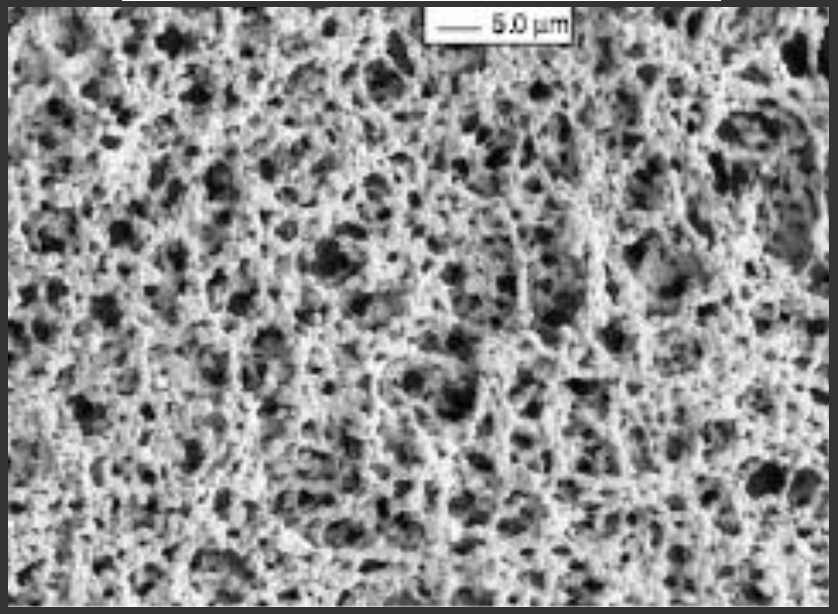
NONE LEI 2.0kV X2,300 10µm WD 24.3mm

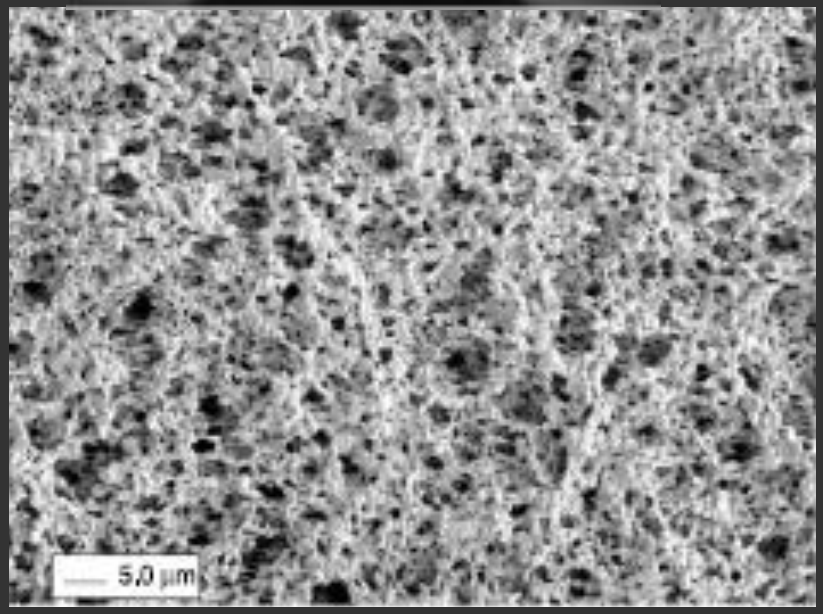
Loto





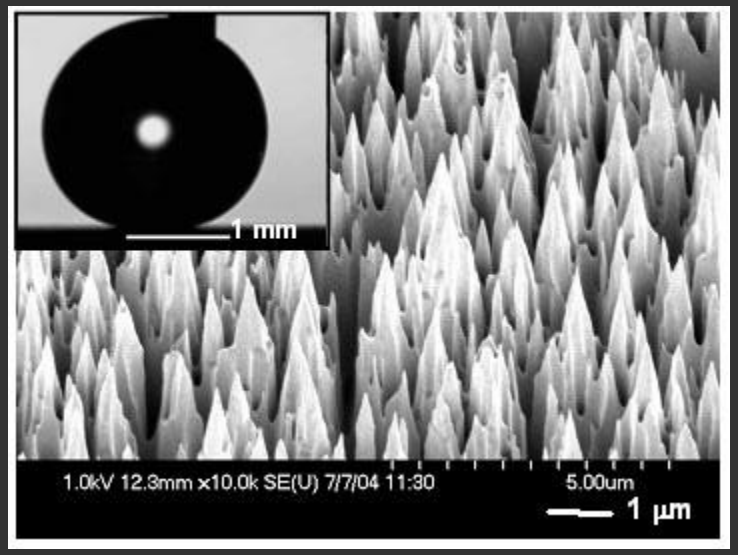


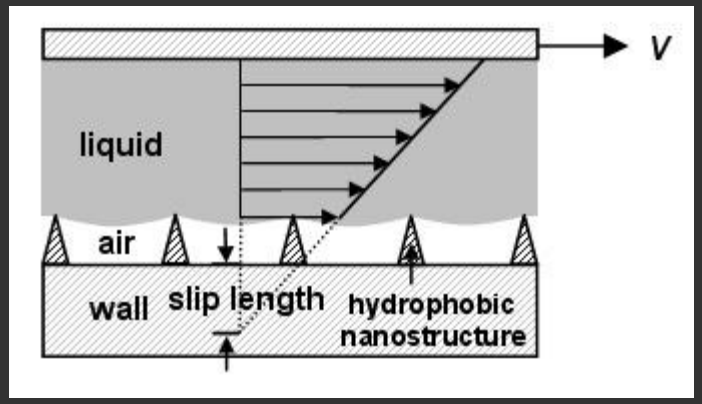




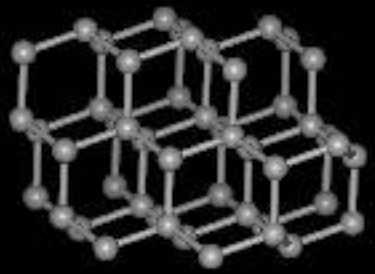
H.Y. Erbil et al,
“Transformation of a Simple Plastic into a Superhydrophobic Surface”
Science 299, 1377 (2003)

Superhydrophobic Surface

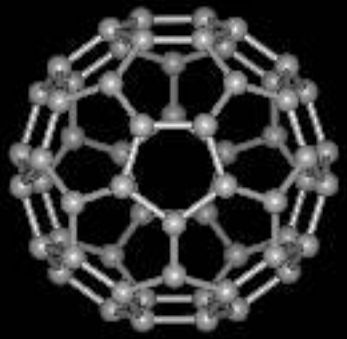




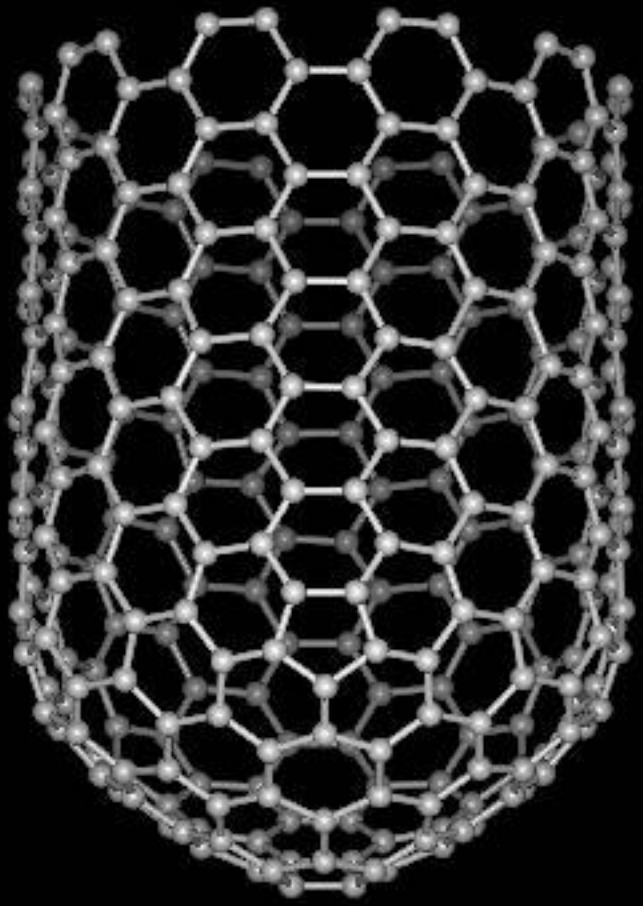
Choi and Kim, Physical Review Letters 2006



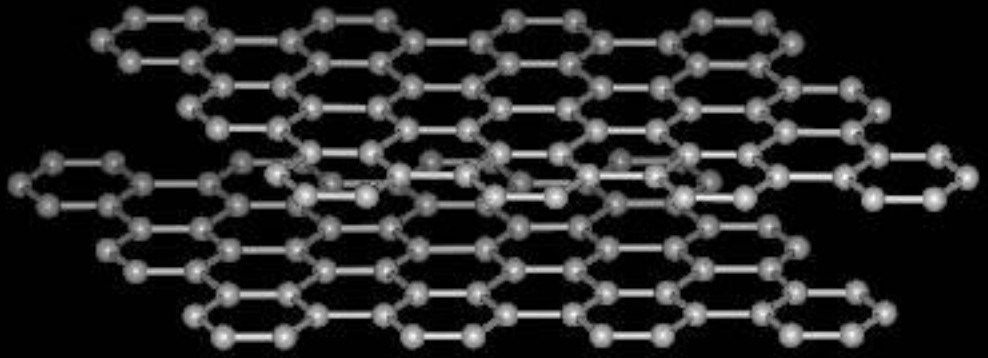
diamante



fullerene

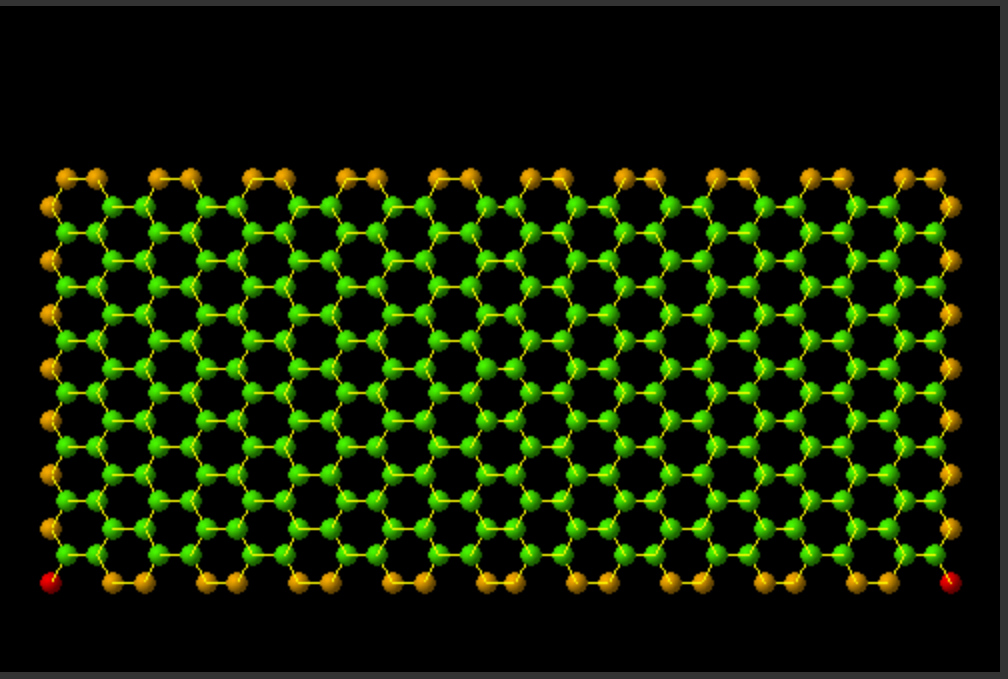


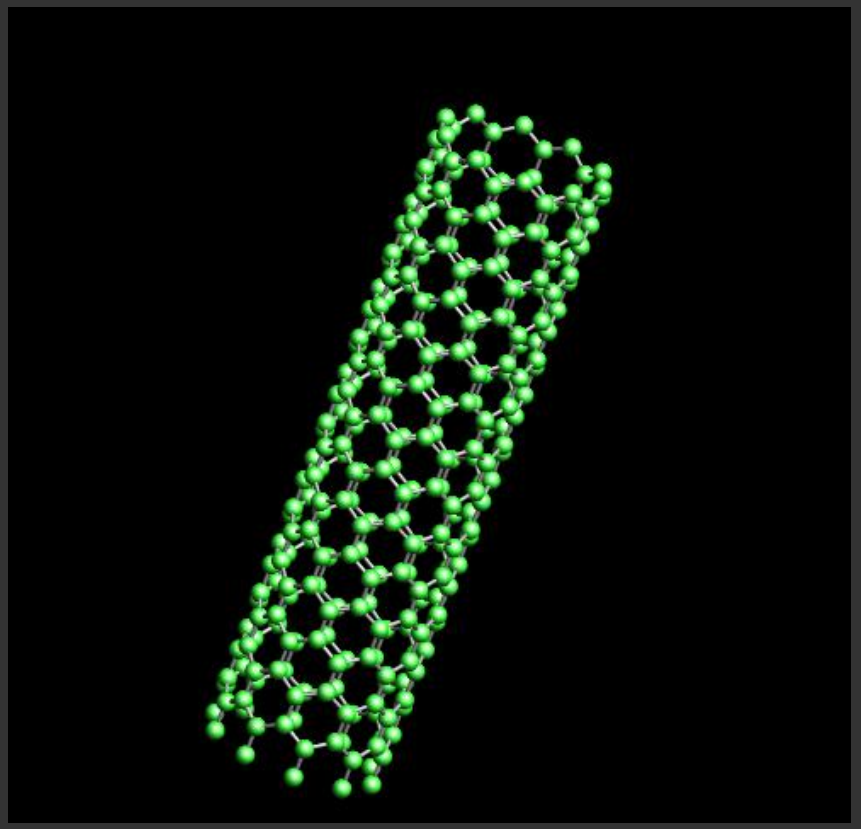
nanotubo

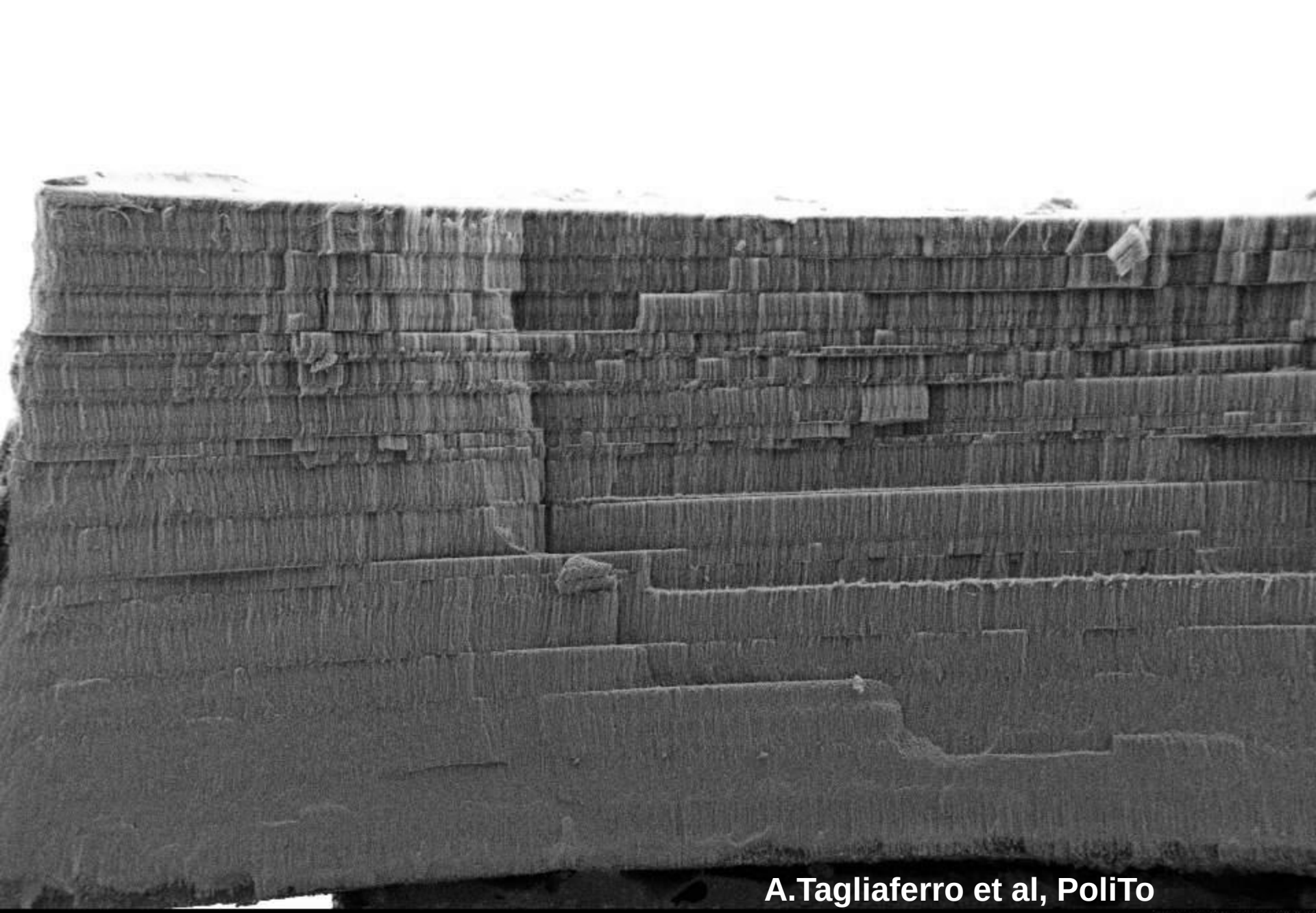


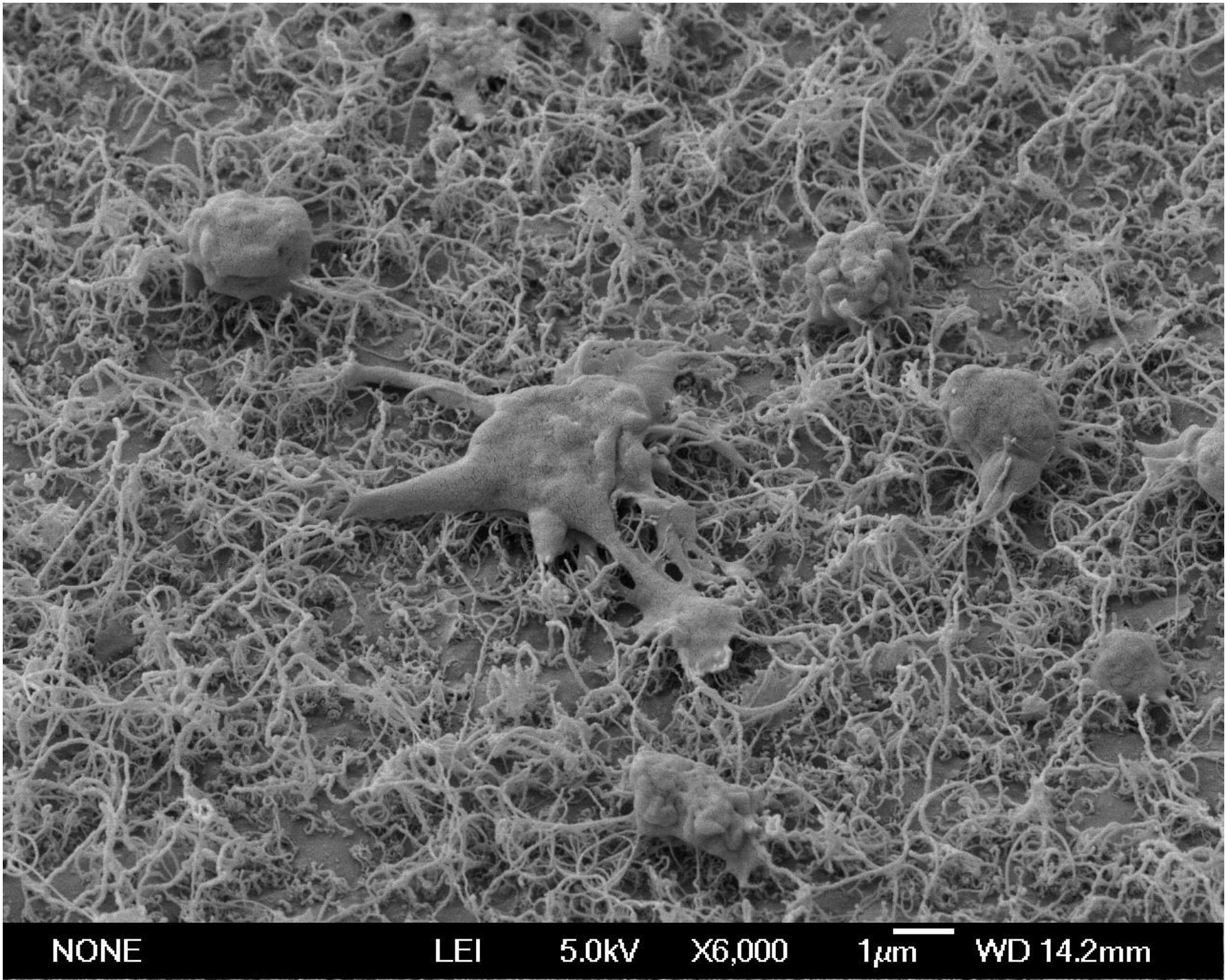
grafite

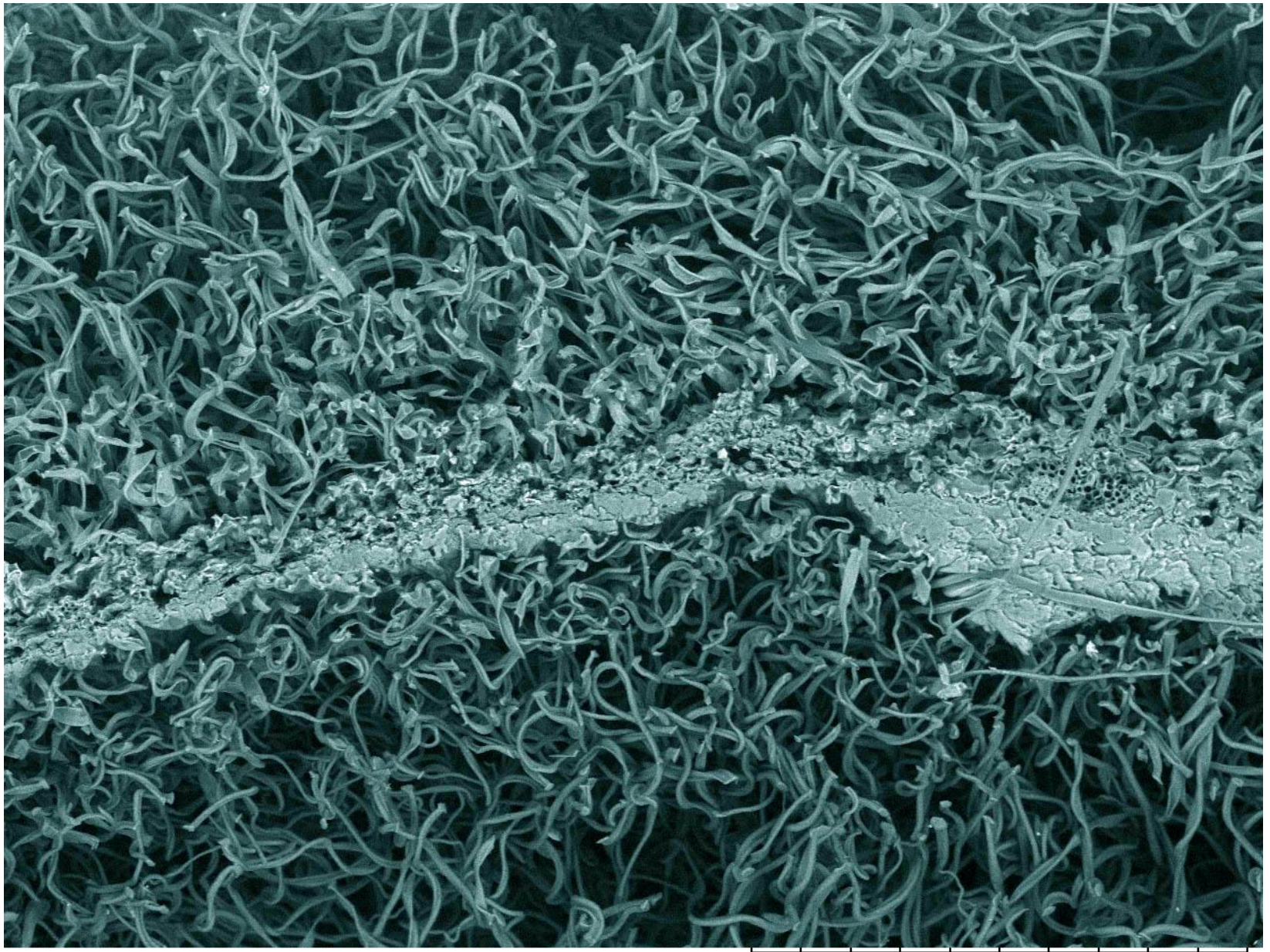
Nanotubi di carbonio





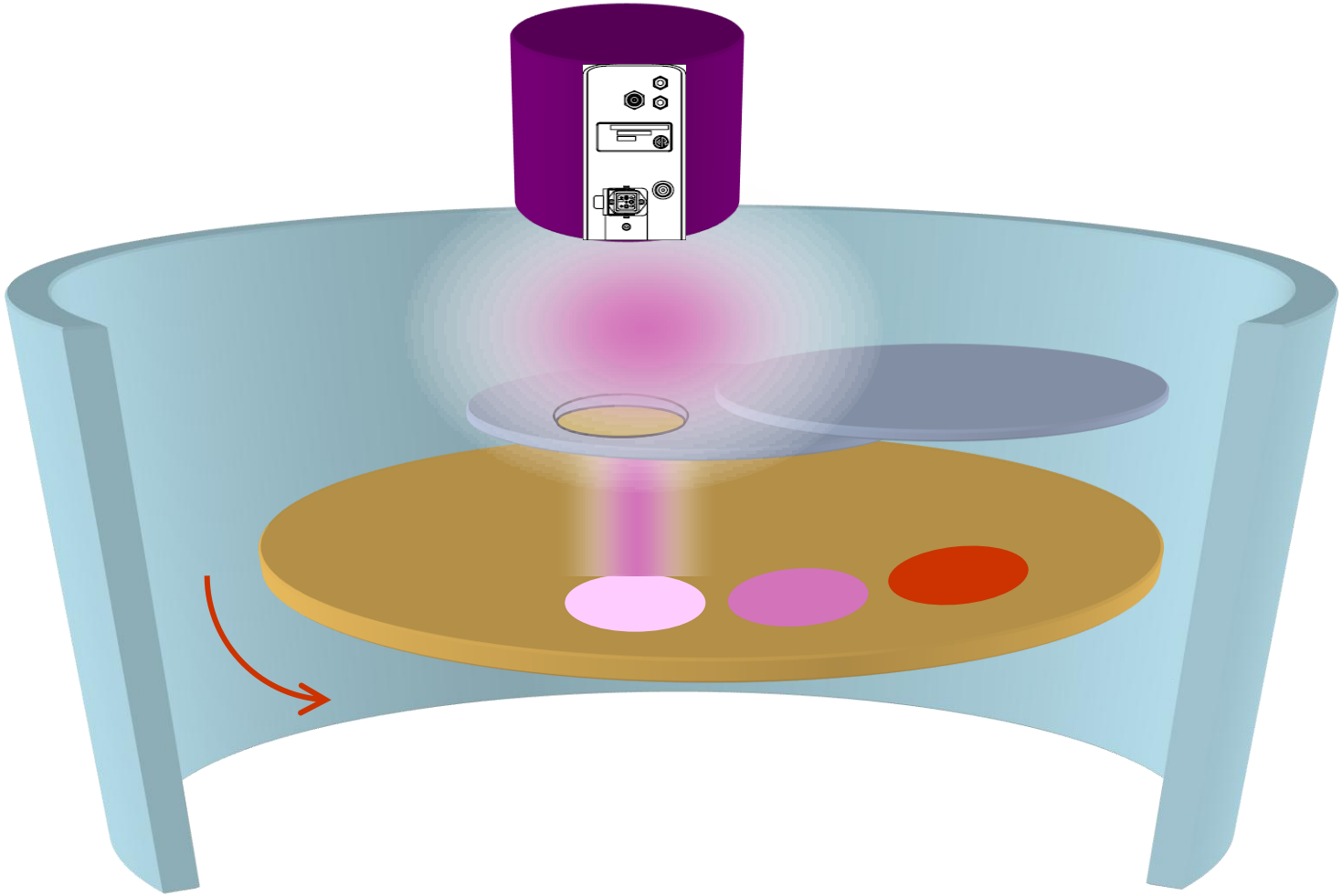

A.Tagliaferro et al, PoliTo
200µm
VVD = 5 mm
Mag = 87 X
Aperture Size = 20.00 µm
EHT = 5.00 kV
Signal A = SE2
Stage at T = 45.0 °
Date :27 Mar 2006
Time :11:51:03
User Name = ANGELI


NONE
LEI
5.0kV
X6,000
1μm
WD 14.2mm

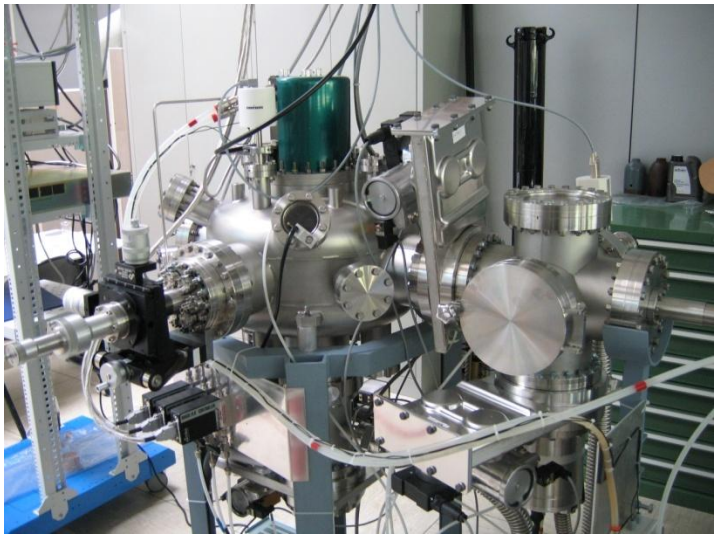


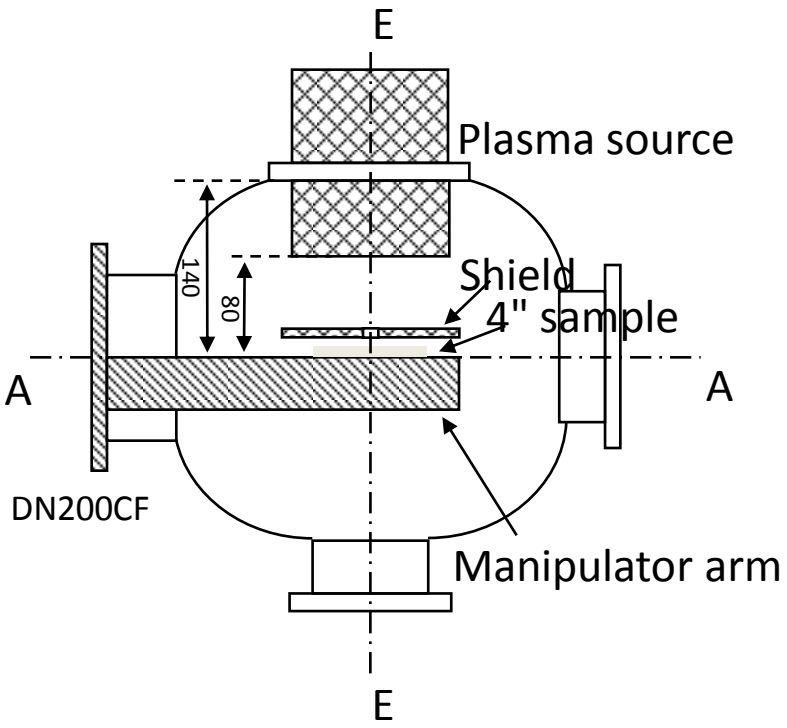
CEALP_1709 L x250 300 um

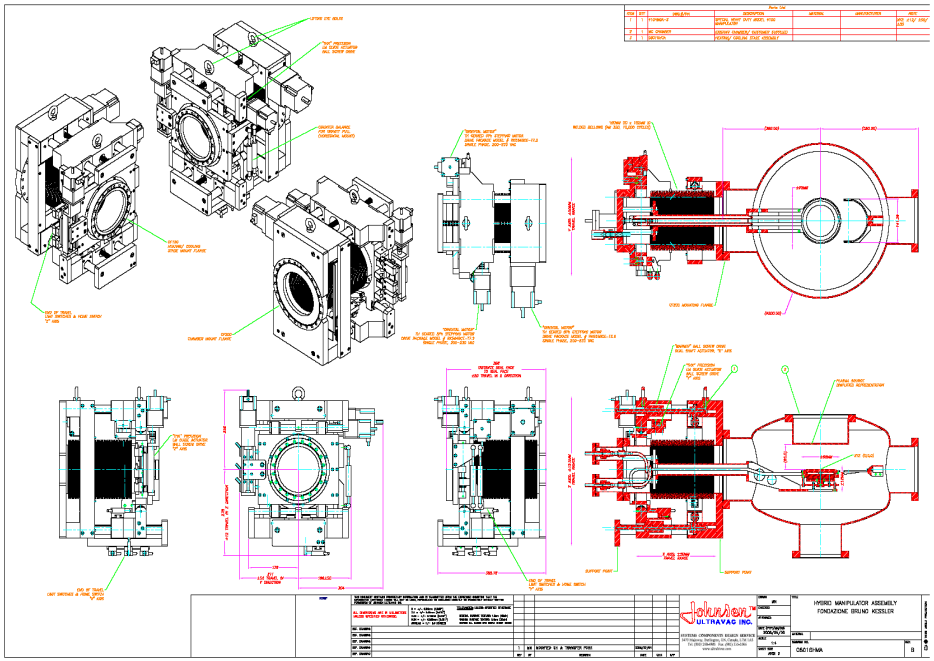
Dolomiti Invisibili 2006



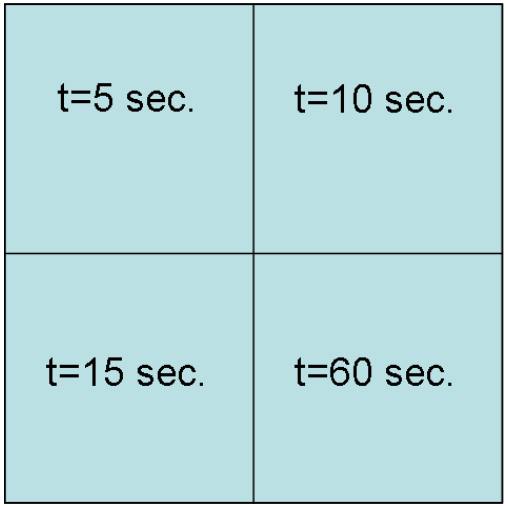
Combi Approach to Biosurfaces

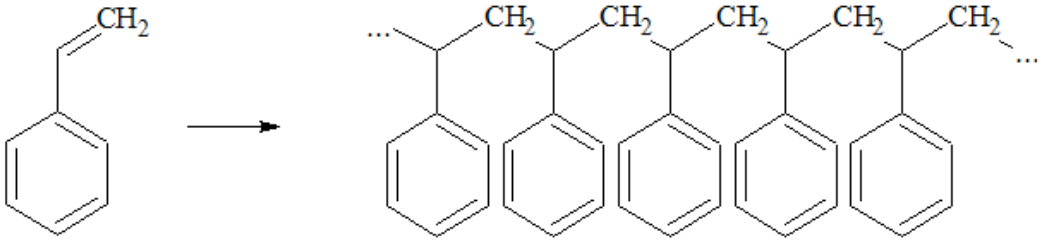



E
Plasma source
140
80
Shield
4" sample
A
A
DN200CF
Manipulator arm
E



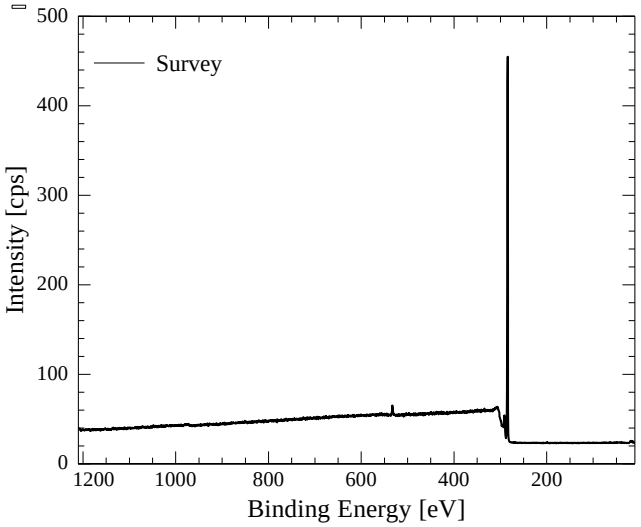
Substrate Size	Ø 50 mm (recommended)
	2x10-4 to 5x10-2 mbar
Plasma Density	109 to 1012 cm-3
Ion Current Density	0,01 to 1,0 mA/cm2
Ion Energy	30 to 200 eV
Frequency	13,56 MHz
Max Power	600 W
Process Gas	O_2, N_2, CO_2, NH_3, Ar and other
Uniformity	± 10%



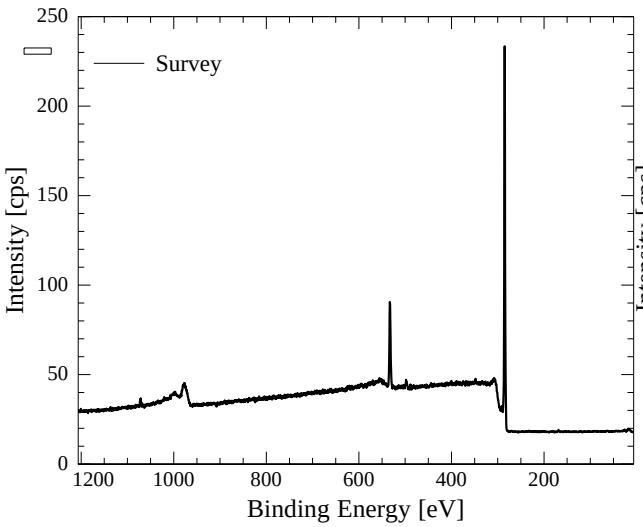


FONDAZIONE
BRUNO KESSLER

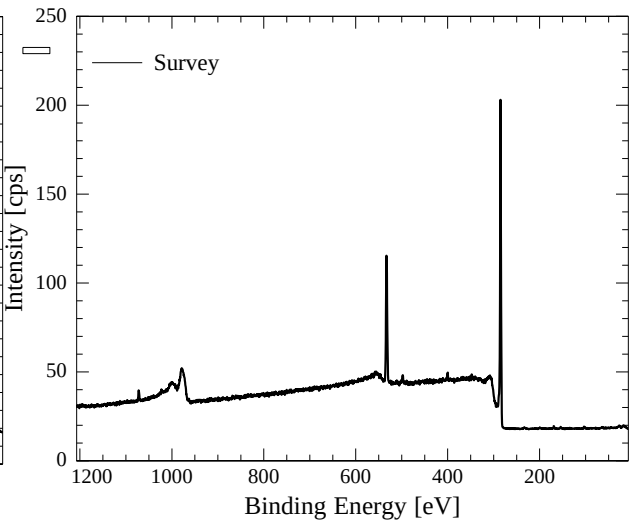
Filename: COMBIREF



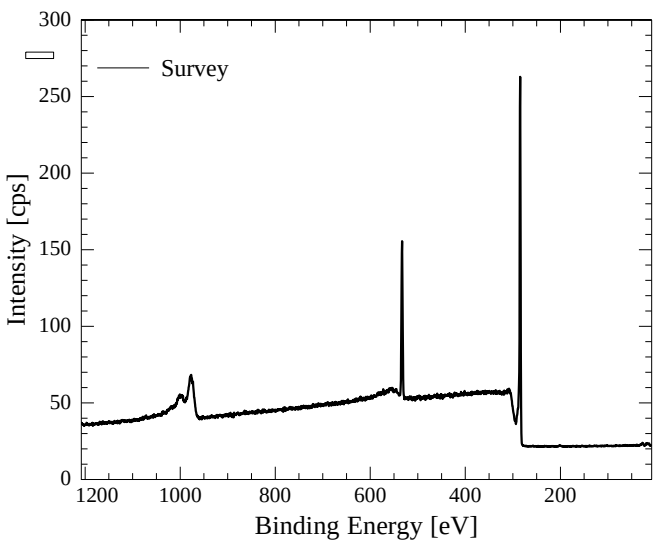
Filename: COMBI44



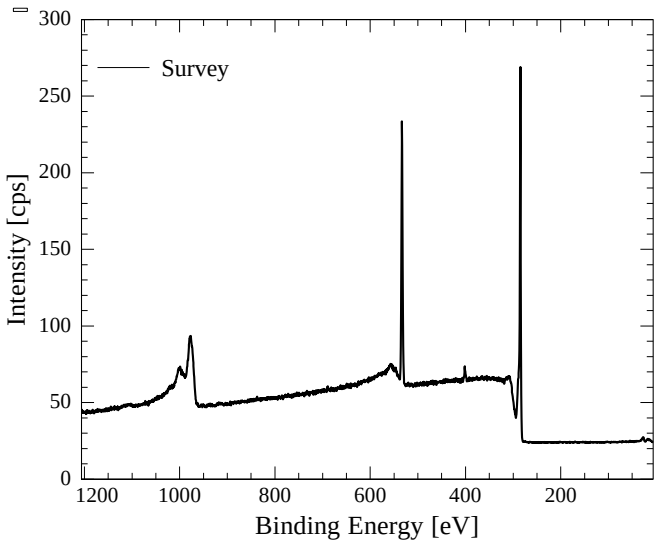
Filename: COMBI41



Filename: COMBI21

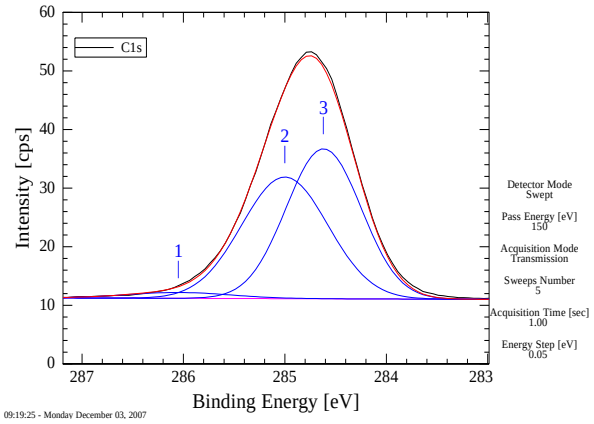


Filename: COMBI1

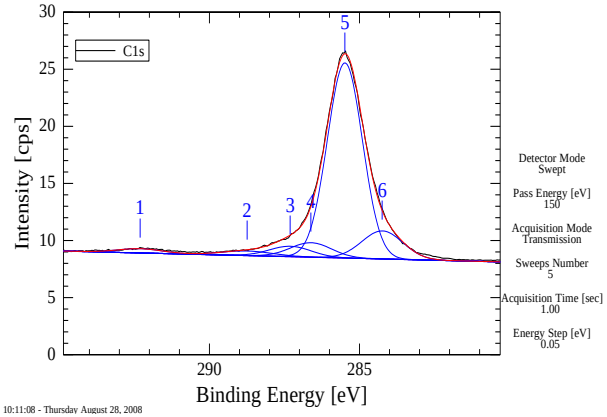


FONDAZIONE
BRUNO KESSLER

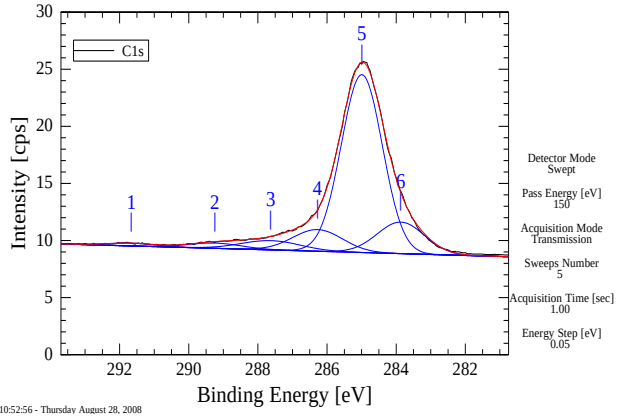
FileName: COMBIREF.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : C1s001	25.161	286.05	0.996	1.20	1.00	0.00	2.62
Componente : C1s002	441.683	285.00	20.747	1.00	1.00	0.00	46.04
Componente : C1s003	474.260	284.62	25.606	0.87	1.00	0.00	49.43



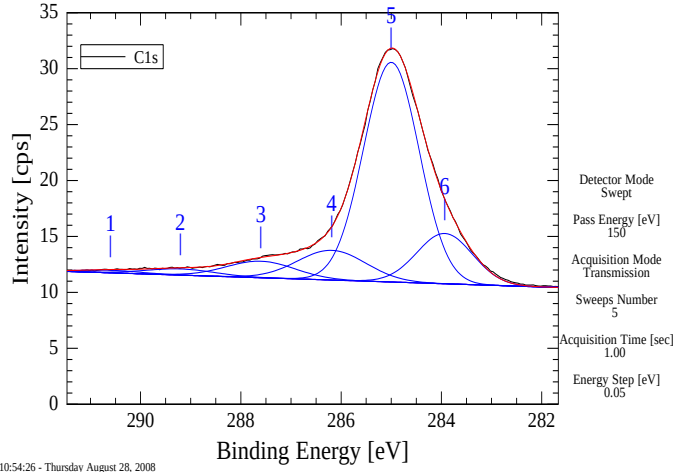
FileName: COMBI44.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : C1s001	13.497	292.31	0.373	1.70	1.00	0.00	1.91
Componente : C1s002	17.007	288.74	0.399	2.00	1.00	0.00	2.40
Componente : C1s003	31.613	287.30	0.911	1.63	1.00	0.00	4.47
Componente : C1s004	43.127	286.61	1.266	1.60	1.00	0.00	6.10
Componente : C1s005	499.122	285.49	17.088	1.37	1.00	0.00	70.55
Componente : C1s006	83.625	284.24	2.455	1.60	1.00	0.00	11.82



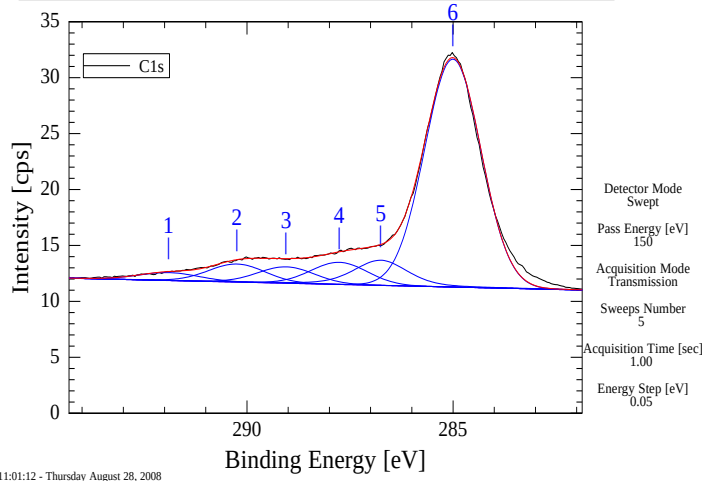
FileName: COMBI41.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : C1s001	8.300	291.66	0.244	1.60	1.00	0.00	1.20
Componente : C1s002	17.698	289.24	0.460	1.81	1.00	0.00	2.56
Componente : C1s003	34.637	287.63	0.814	2.00	1.00	0.00	5.02
Componente : C1s004	68.018	286.27	1.896	1.69	1.00	0.00	9.86
Componente : C1s005	462.535	284.99	15.577	1.39	1.00	0.00	67.02
Componente : C1s006	94.103	283.87	2.763	1.60	1.00	0.00	13.63



FileName: COMBI21.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : C1s001	6.319	290.60	0.226	1.41	1.00	0.00	0.76
Componente : C1s002	18.793	289.21	0.552	1.60	1.00	0.00	2.25
Componente : C1s003	50.335	287.60	1.478	1.60	1.00	0.00	6.02
Componente : C1s004	90.482	286.19	2.656	1.60	1.00	0.00	10.81
Componente : C1s005	543.707	285.00	19.645	1.30	1.00	0.00	64.97
Componente : C1s006	124.446	283.93	4.497	1.30	1.00	0.00	14.87

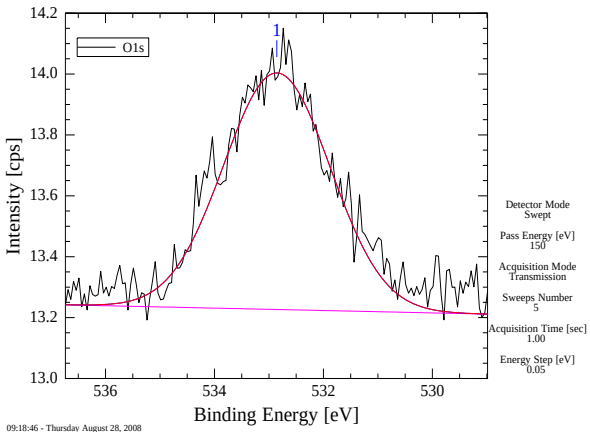


FileName: COMBI1.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : C1s001	25.433	291.90	0.703	1.70	1.00	0.00	2.57
Componente : C1s002	54.858	290.25	1.610	1.60	1.00	0.00	5.54
Componente : C1s003	49.713	289.05	1.459	1.60	1.00	0.00	5.02
Componente : C1s004	67.200	287.76	1.973	1.60	1.00	0.00	6.78
Componente : C1s005	79.468	286.75	2.247	1.50	0.70	0.00	8.02
Componente : C1s006	694.055	285.01	20.376	1.60	1.00	0.00	70.04

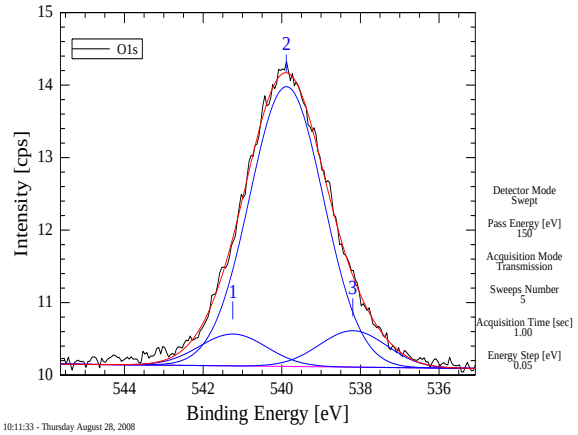


FONDAZIONE BRUNO KESSLER

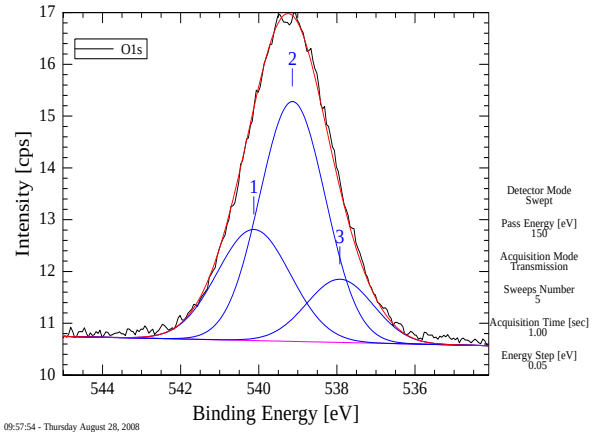
FileName: COMBIREF.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : O1s001	41.431	532.85	0.777	2.30	1.00	0.00	93.96



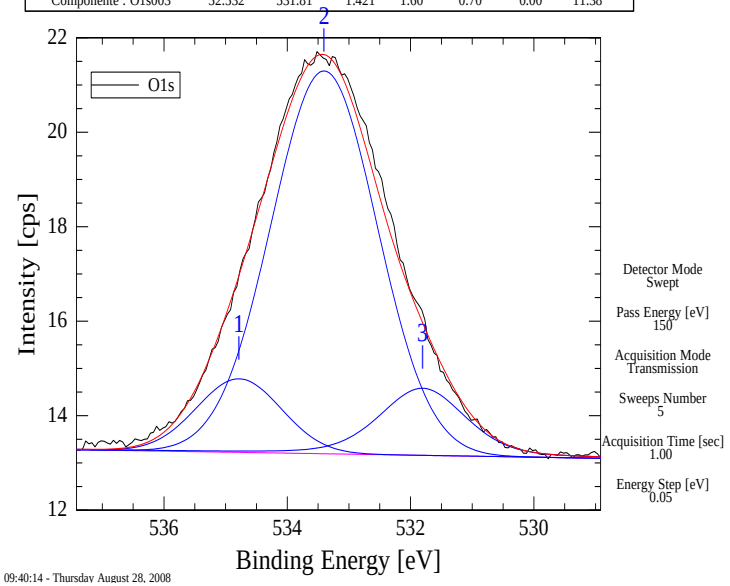
FileName: COMBI44.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : O1s001	18.695	541.24	0.439	2.00	1.00	0.00	8.23
Componente : O1s002	180.766	539.88	3.860	2.20	1.00	0.00	79.53
Componente : O1s003	21.385	538.19	0.502	2.00	1.00	0.00	9.41



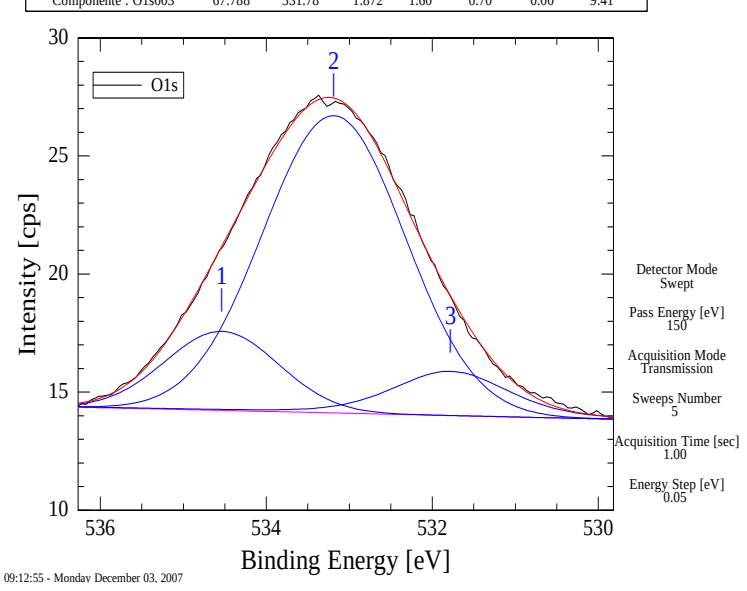
FileName: COMBI41.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : O1s001	100.472	540.13	2.145	2.20	1.00	0.00	27.96
Componente : O1s002	194.617	539.14	4.632	1.97	1.00	0.00	54.16
Componente : O1s003	51.962	537.92	1.220	2.00	1.00	0.00	14.46

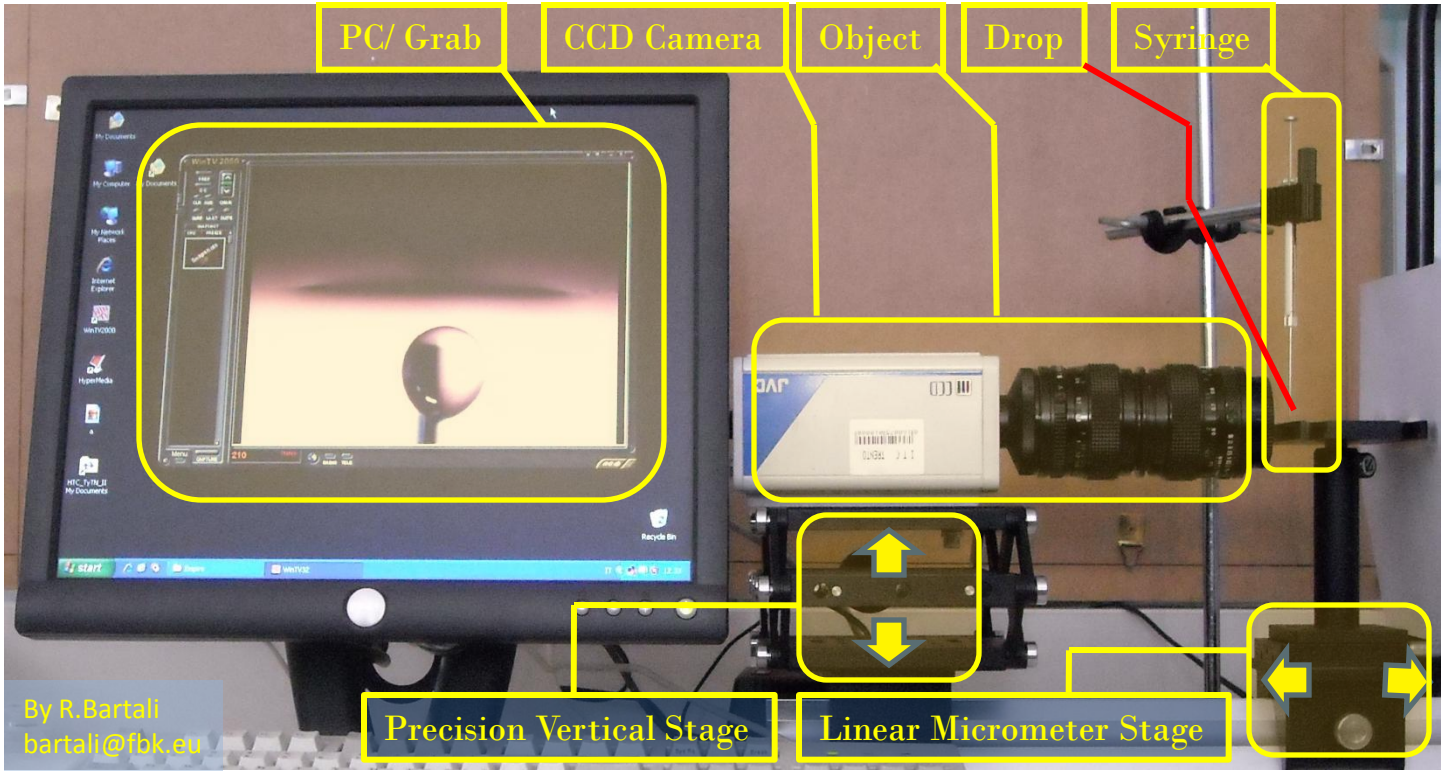


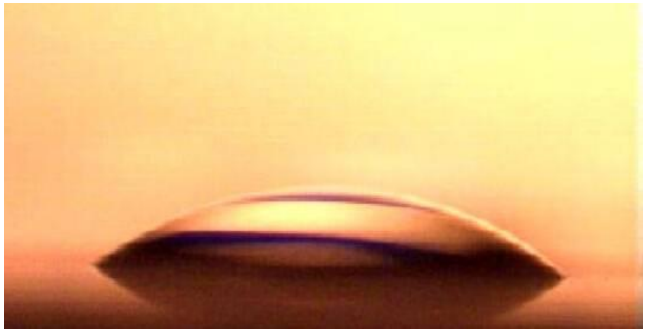
FileName: COMBI21.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : O1s001	53.031	534.78	1.557	1.60	1.00	0.00	11.49
Componente : O1s002	345.128	533.40	8.106	2.00	1.00	0.00	74.79
Componente : O1s003	52.532	531.81	1.421	1.60	0.70	0.00	11.38



FileName: COMBI1.PXT	Area (cps)	BE(eV)	Height	Fwhm	MixGL	Asym	% Tot.
Componente : O1s001	113.383	534.54	3.345	1.60	1.00	0.00	15.73
Componente : O1s002	535.809	533.19	12.586	2.00	1.00	0.00	74.34
Componente : O1s003	67.788	531.78	1.872	1.60	0.70	0.00	9.41

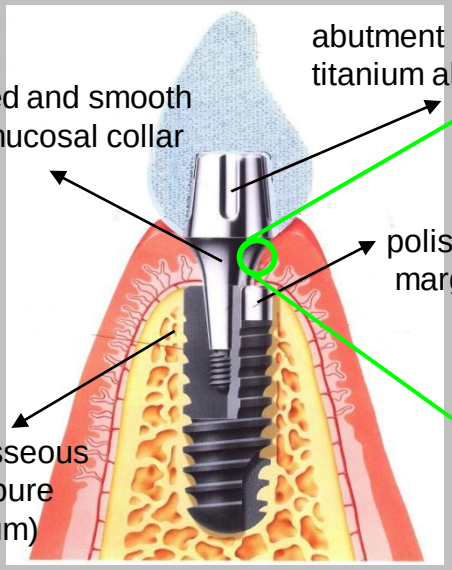


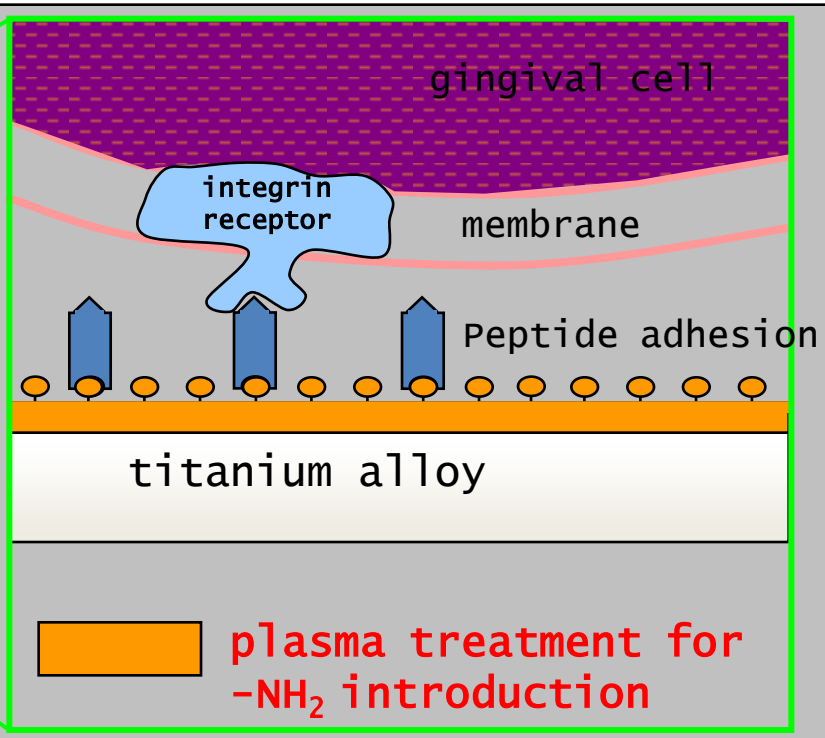

PC/ Grab
CCD Camera
Object
Drop
Syringe
By R.Bartali
bartali@fbk.eu
Precision Vertical Stage
Linear Micrometer Stage

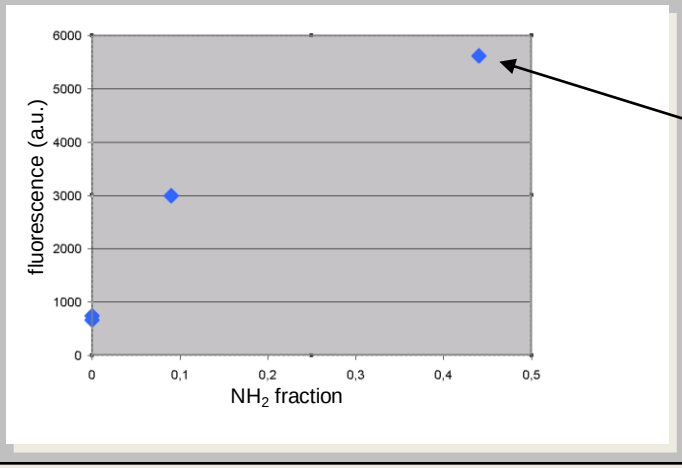


ADESIONE DELLA GENGIVA AD UN PROTESI DENTALE

Implanted titanium screw







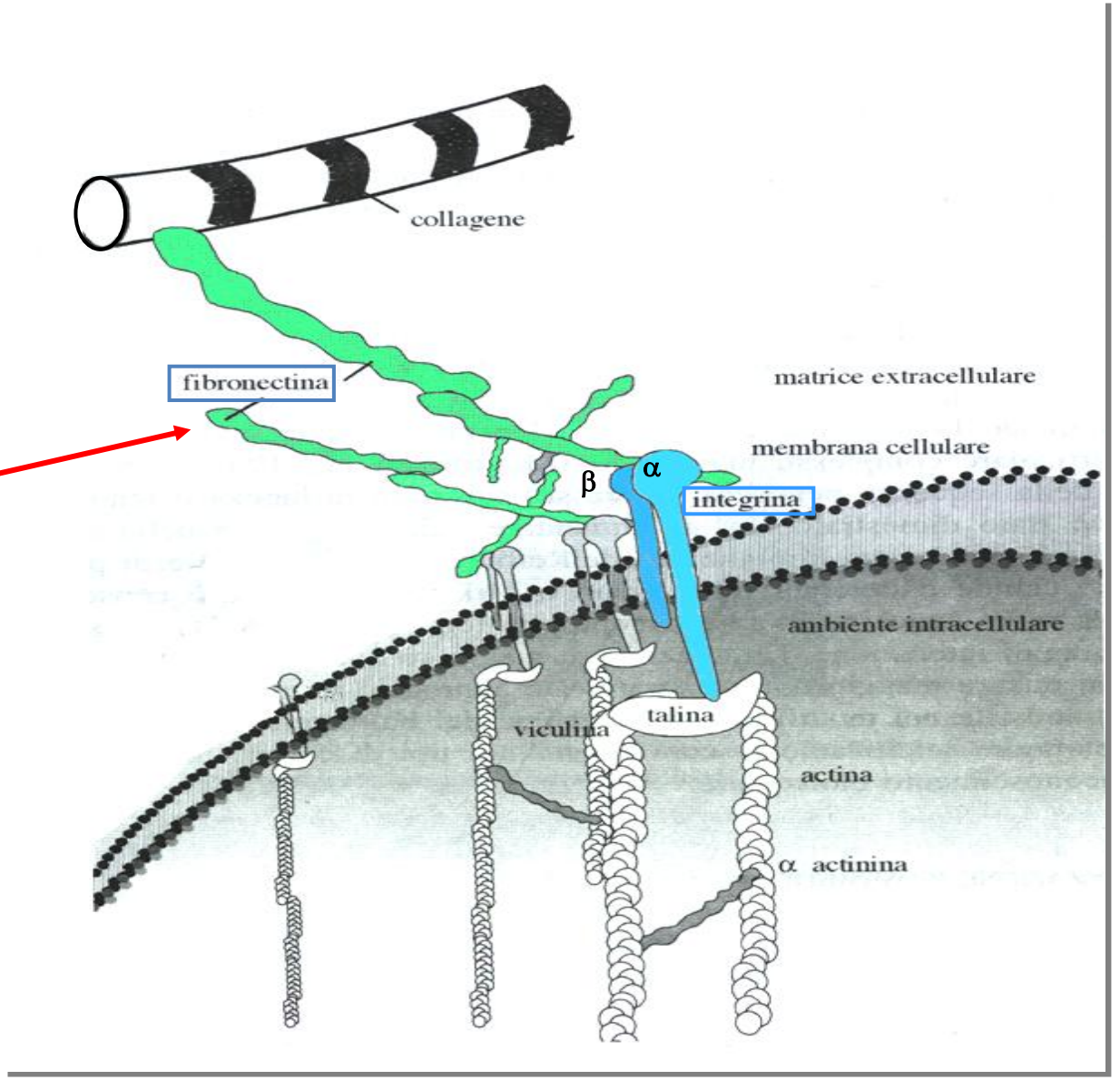
$4 \cdot 10^{13}$ mol/cm^2

ECM proteins and integrin receptors

Fibronectin

GLY-ARG-GLY-ASP-SER-TYR-CYS

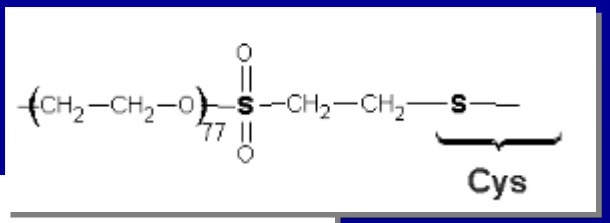
RGD Adhesion Peptide

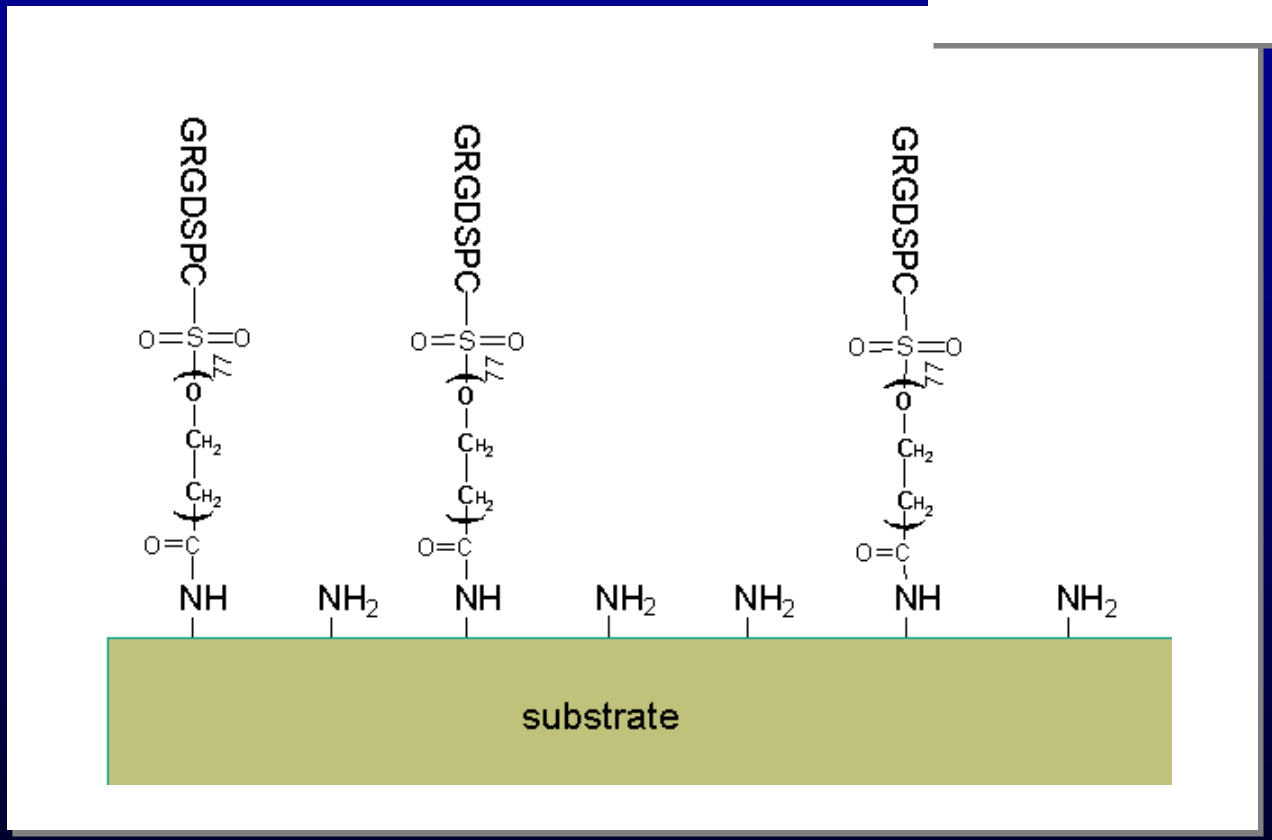


Titanium alloy functionalization: Overview

Step 1: amide bond through the N-hydroxysuccinimide ester *(NHS)*

Step 2: thiol chemistry *(Vinylsulfone)*

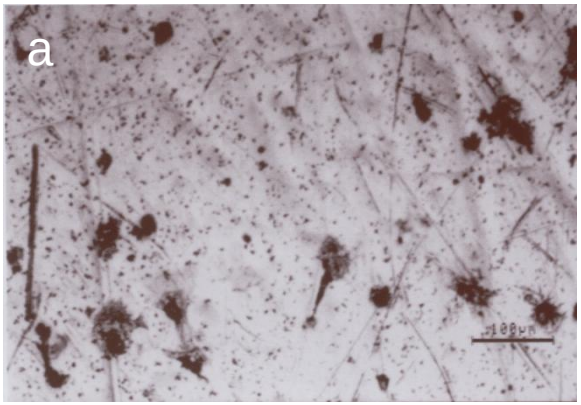


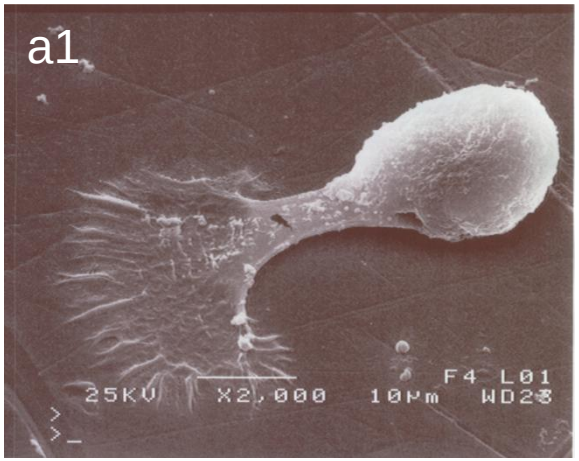


Fluorescent derivative PEG: $5.5 \cdot 10^{13}$ molecules/cm^2

Titanium alloy functionalization 3: Human gingival cells (HGF-1) adhesion

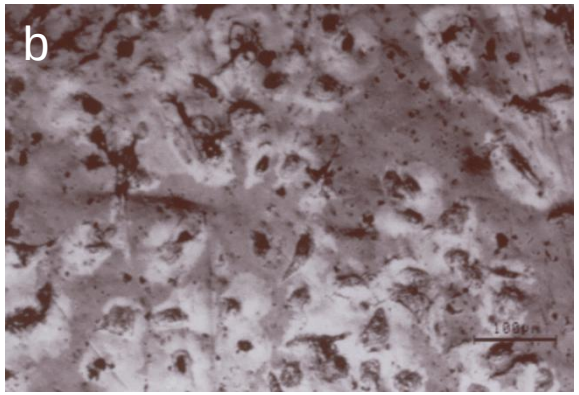
titanium alloy

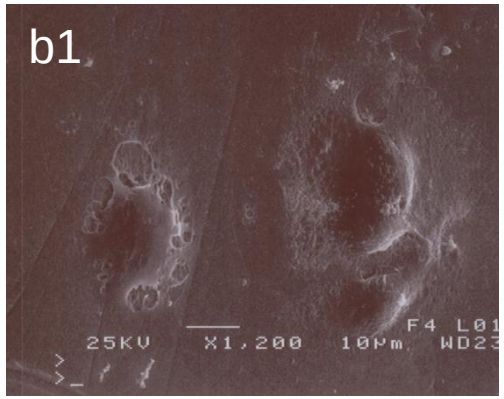


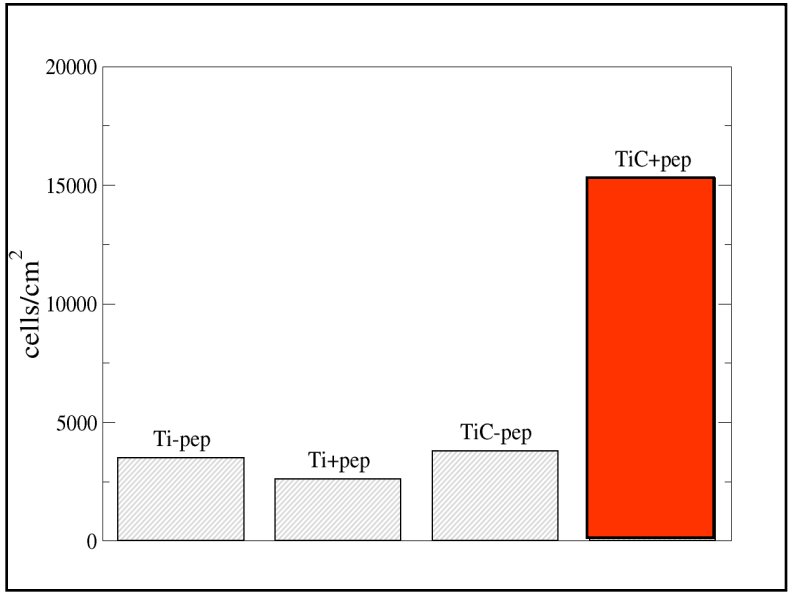


Cell images obtained with a laser scan microscope (a and b) and with a scanning electron microscope (a1 and b1)

RGD modified titanium alloy



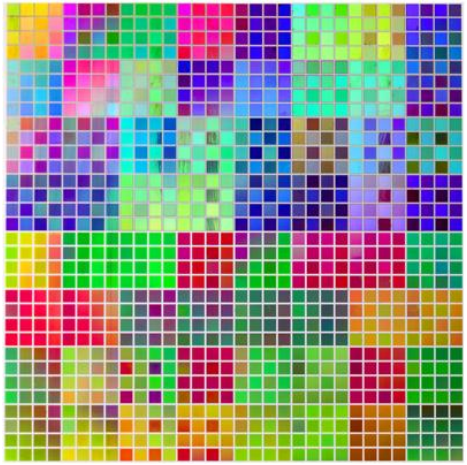


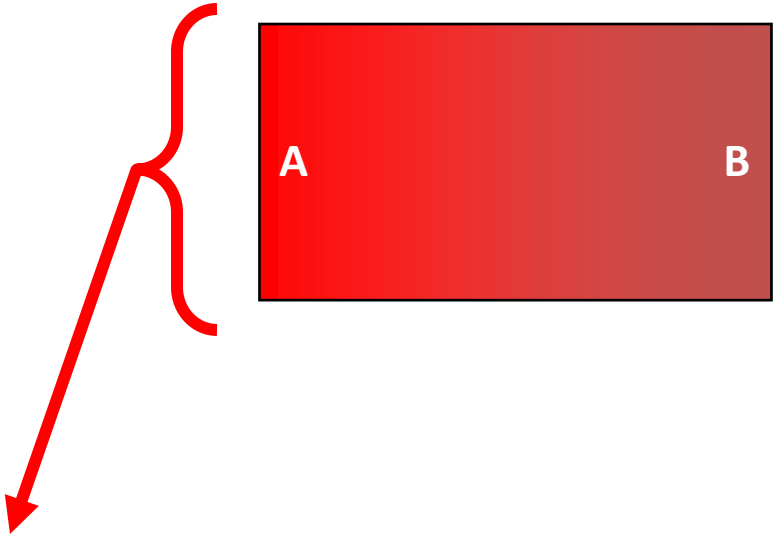


17.500 cell/cm^2
Incubation 24 h in serum free medium plus cycloheximide (25 ug/ml)

Various combinatorial experimental designs

discrete libraries vs composition spreads

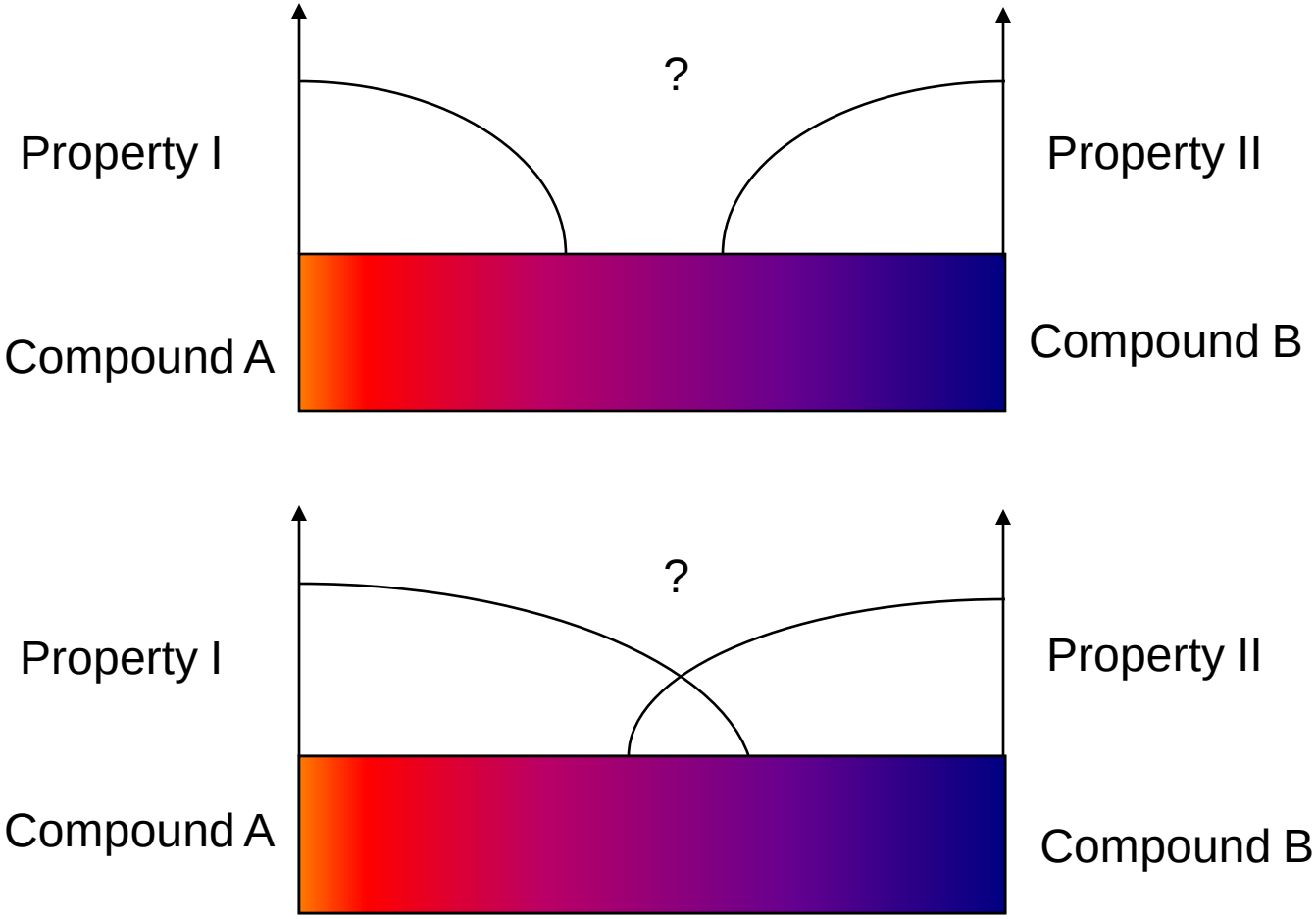




Composition spreads allow continuous mapping of physical properties and phase boundaries

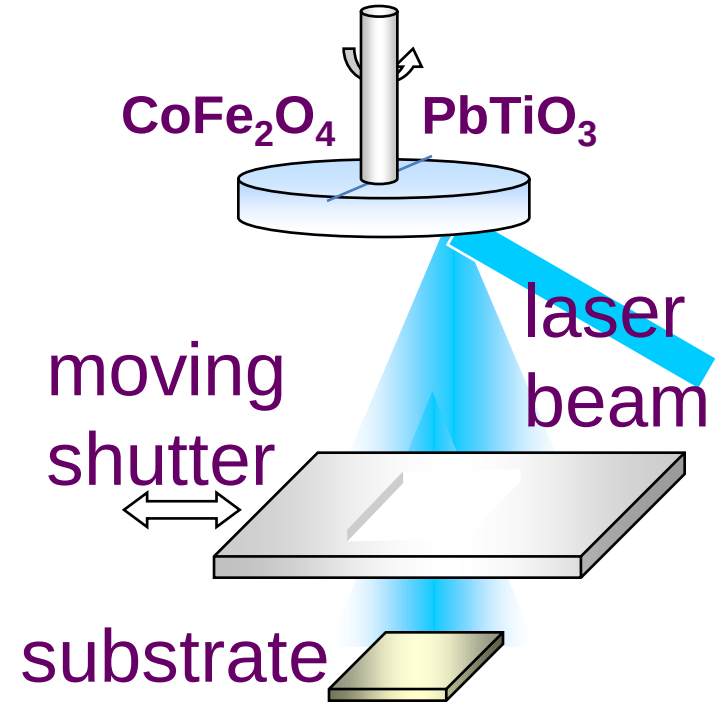
Using composition spreads to design multifunctional materials

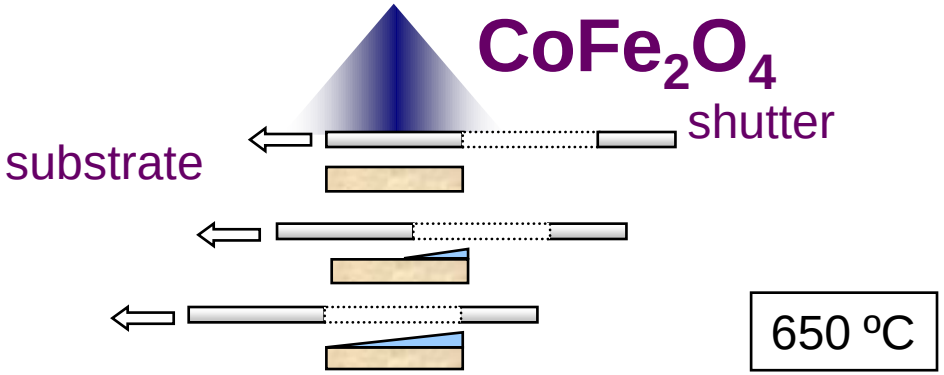
Mixing properties: ferromagnetism, ferroelectricity, ferroelasticity, superconductivity, hydrogen storage capabilities, optical transparency, band gap, catalytic properties, various sensing, biological …, …

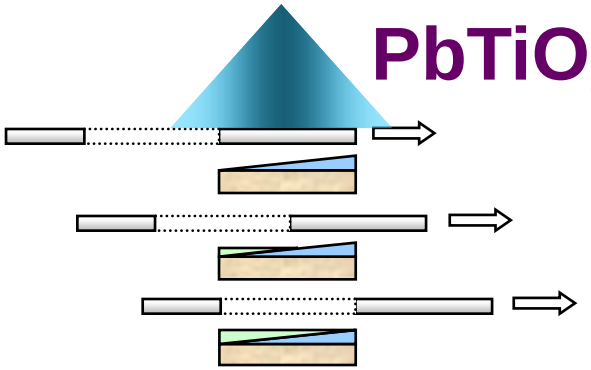


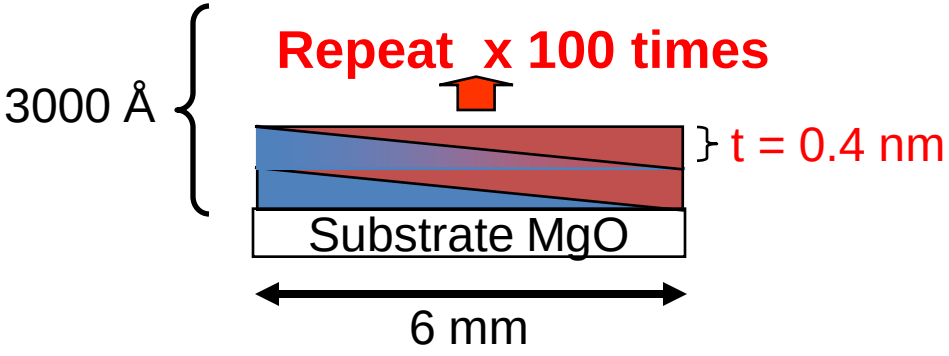
Microstructure: composites, nanocomposites, solid solutions

Fabrication of epitaxial continuous composition spread





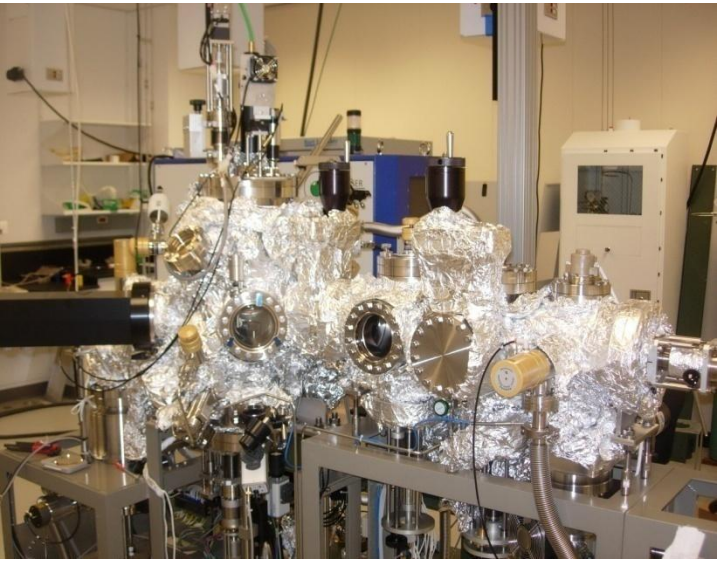


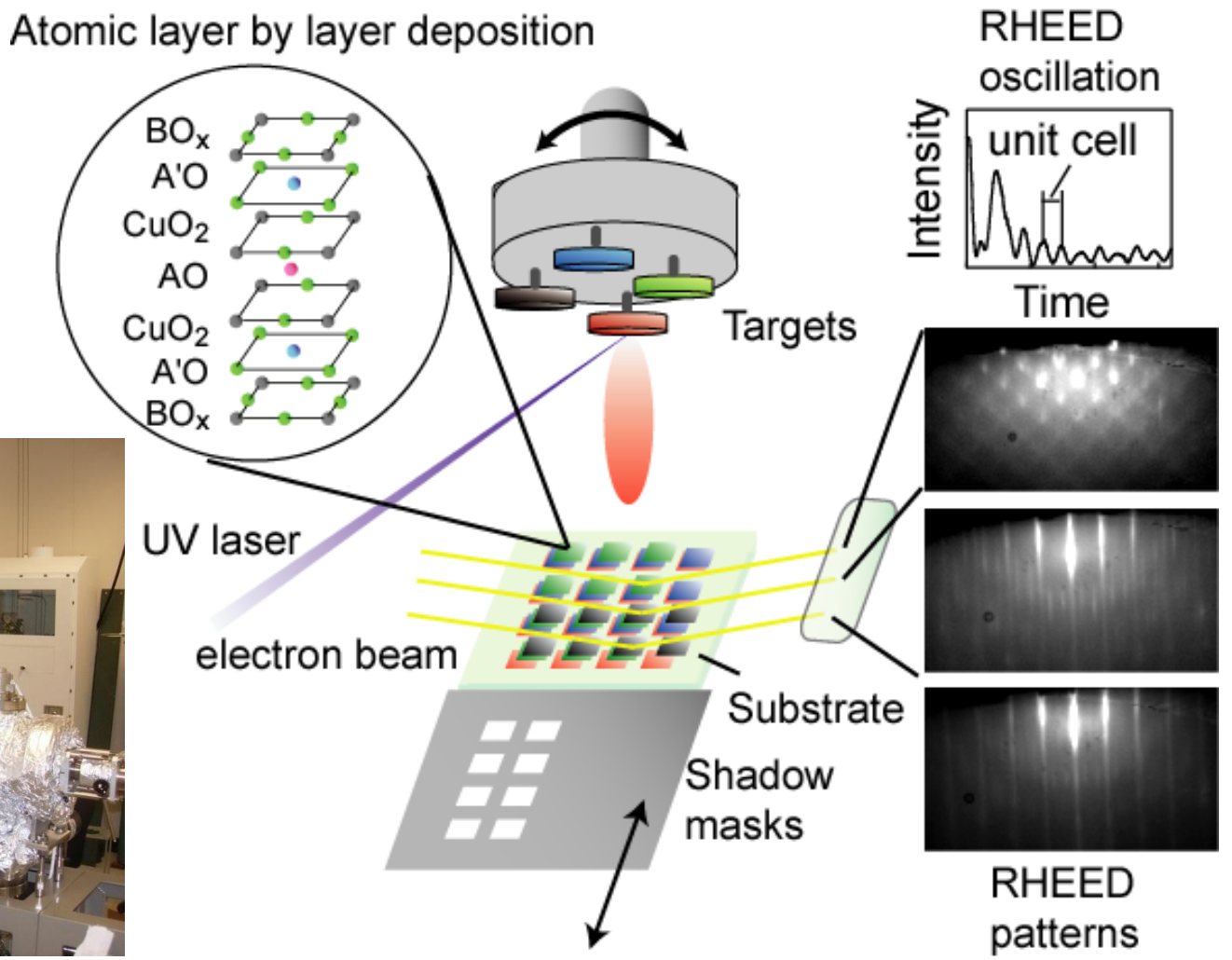


W. M. Keck Laboratory for Combinatorial Nanosynthesis and Multiscale Characterization

Ichiro Takeuchi, Gary W. Rubloff, Ellen D. Williams

Combinatorial laser MBE for creating arrays of atomically controlled crystal structures

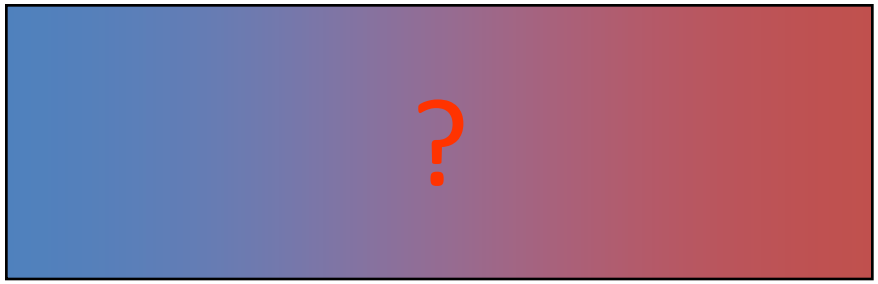




Designing new functional materials using composition spreads

Ferroelectric-Ferromagnetic composition Spread

Top view



Deposition on MgO substrate at 650C

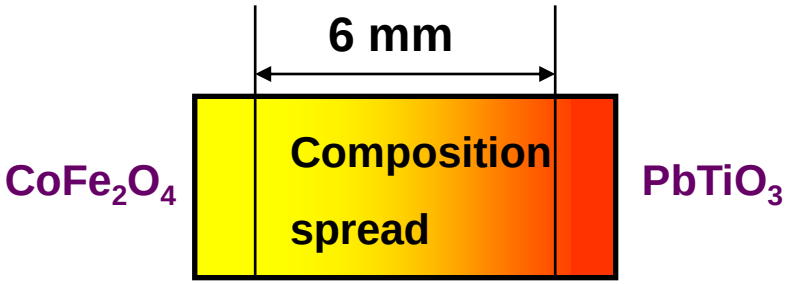
Ferromagnetic ($CoFe_2O_4$)

Ferroelectric ($PbTiO_3$)

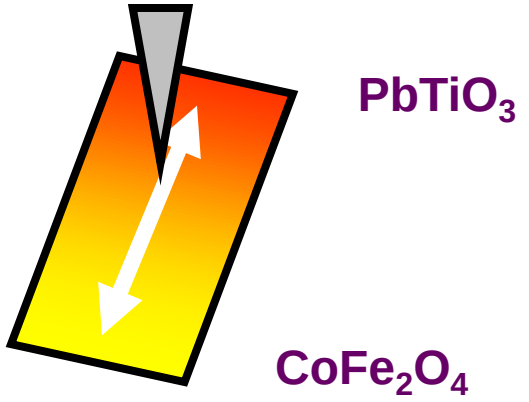
composition variation

What do we get in the middle?

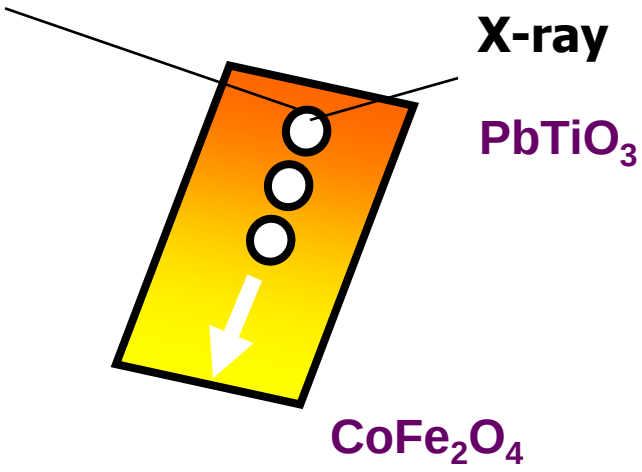
Composition spread characterization technique



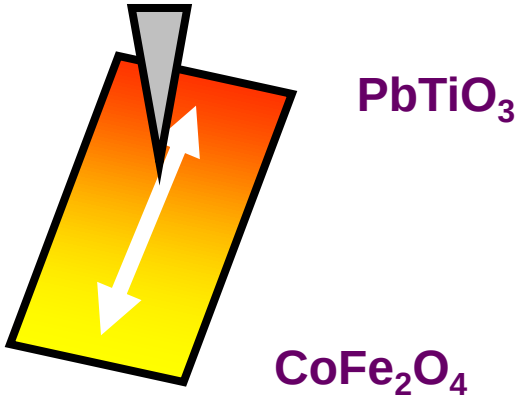
Scanning Microwave Microscope (SMM)



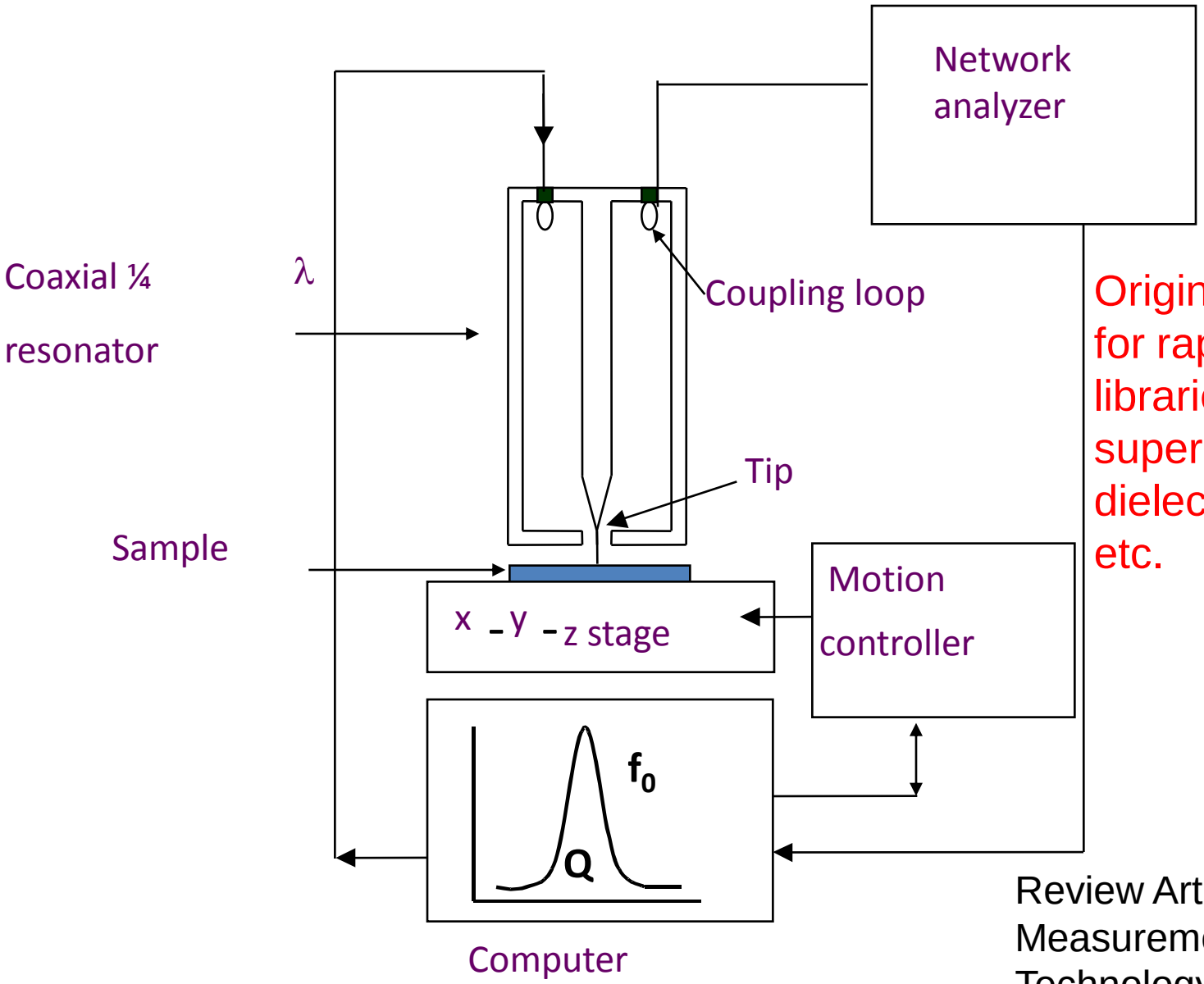
X-ray micro-diffraction



Scanning SQUID Microscope (SSM)



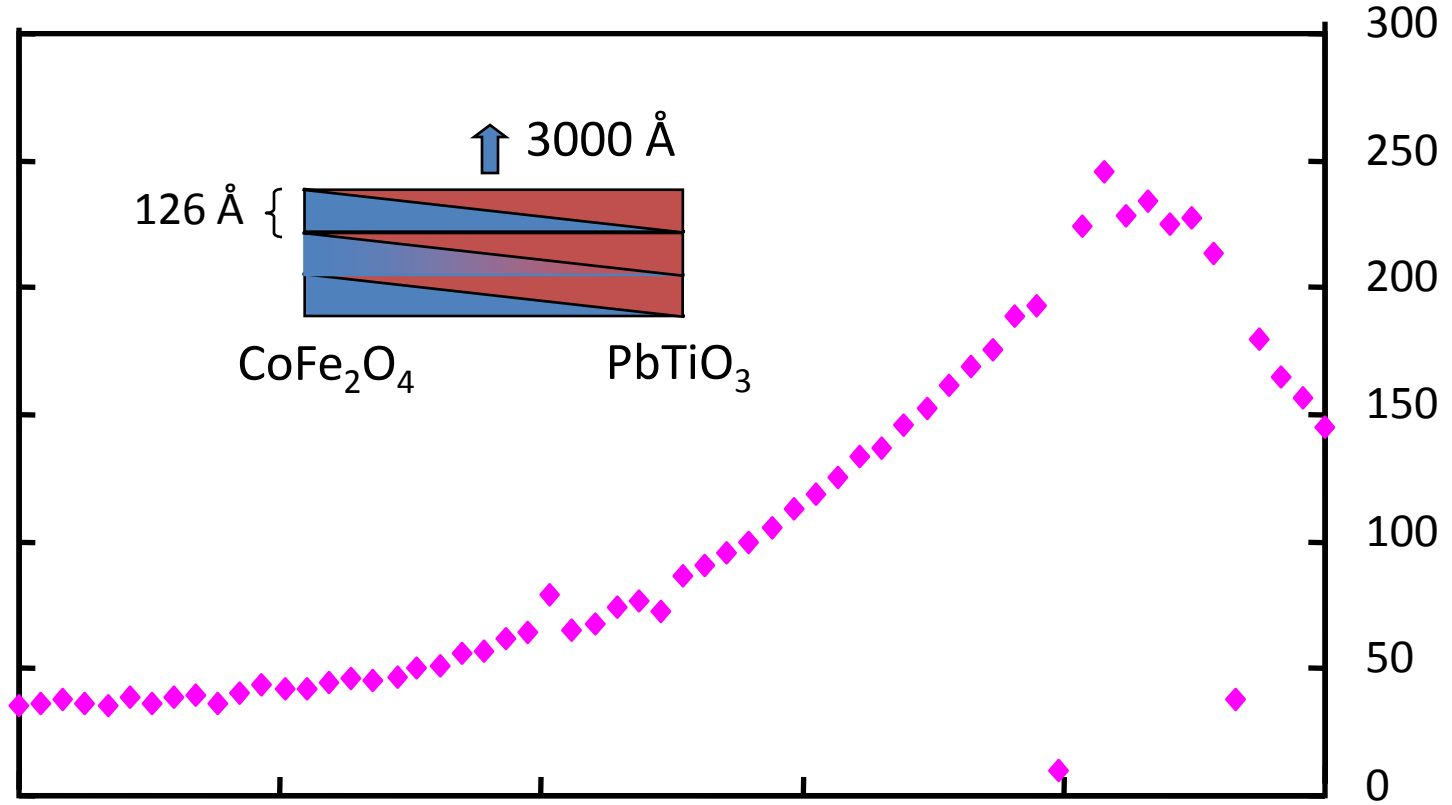
Scanning Microwave Microscope



Originally developed for rapid screening of libraries of superconductors, dielectric materials, etc.

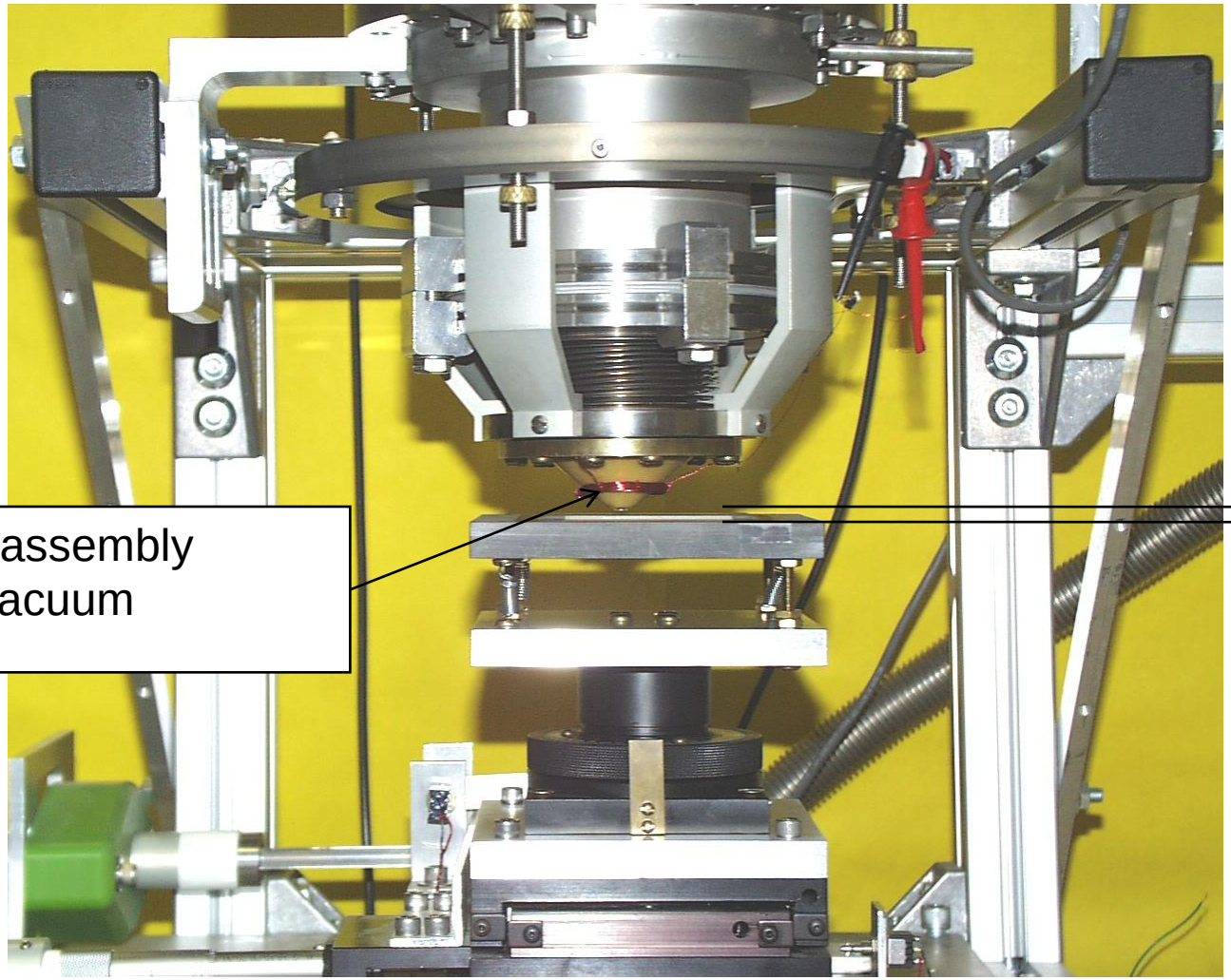
Review Article: Gao, *et al*., Measurement Science and Technology **16**, 248 (2005)

Dielectric constant characterization using microwave microscope



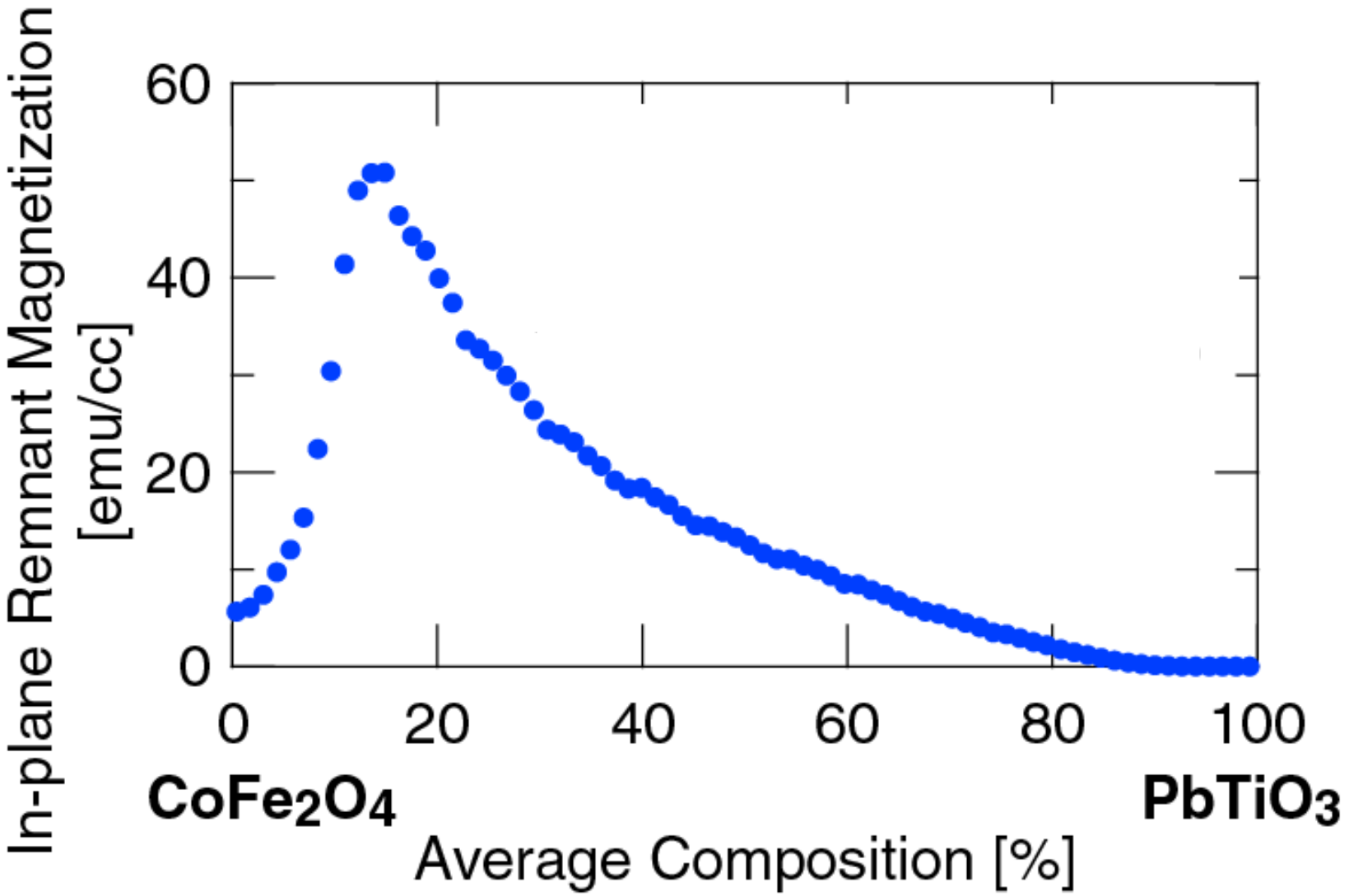
$CoFe_2O_4$ $PbTiO_3$

Scanning SQUID microscope based on $YBa_2Cu_3O_7$ thin film (F. Wellstood, UMD)

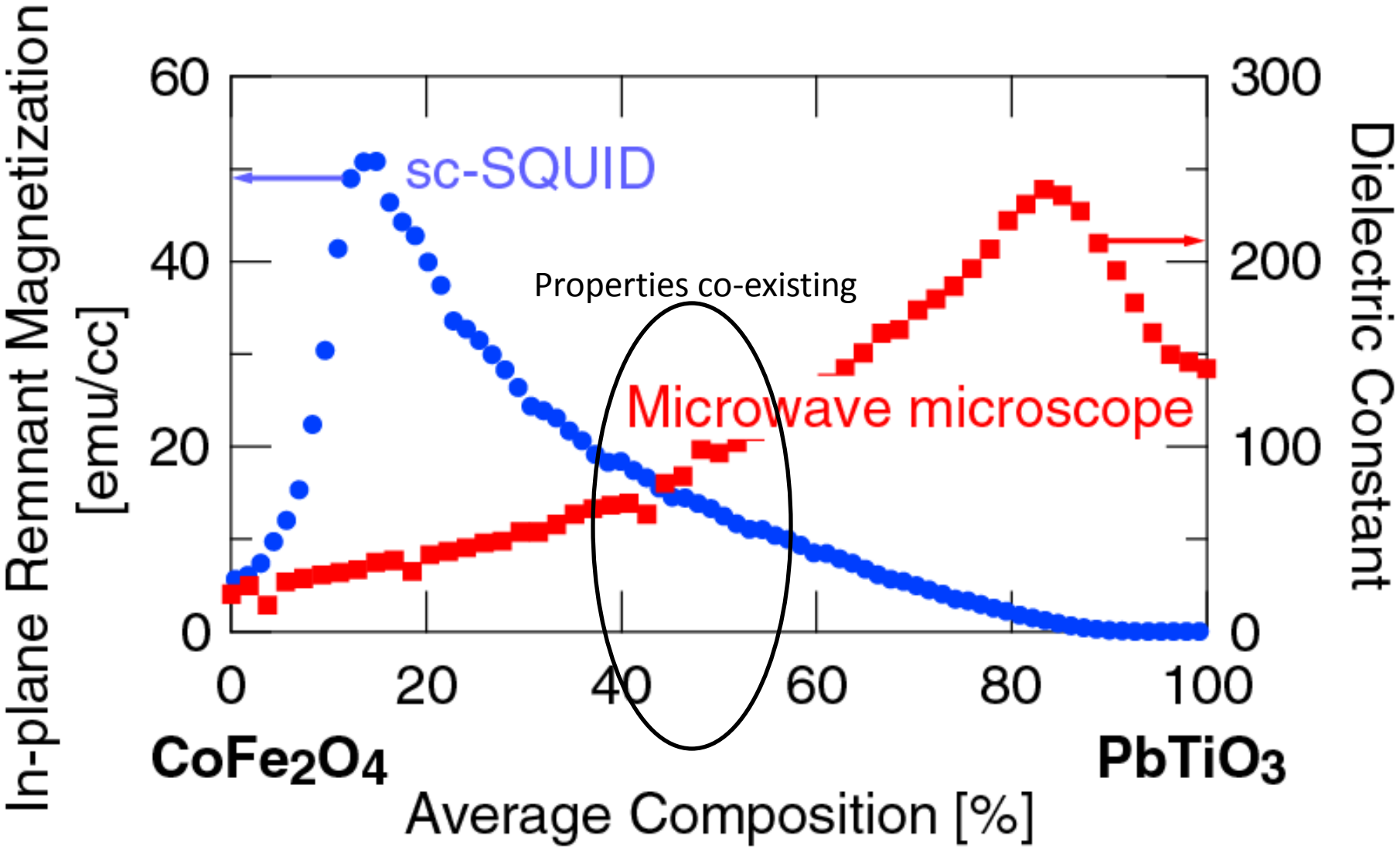


Room temperature samples are measured

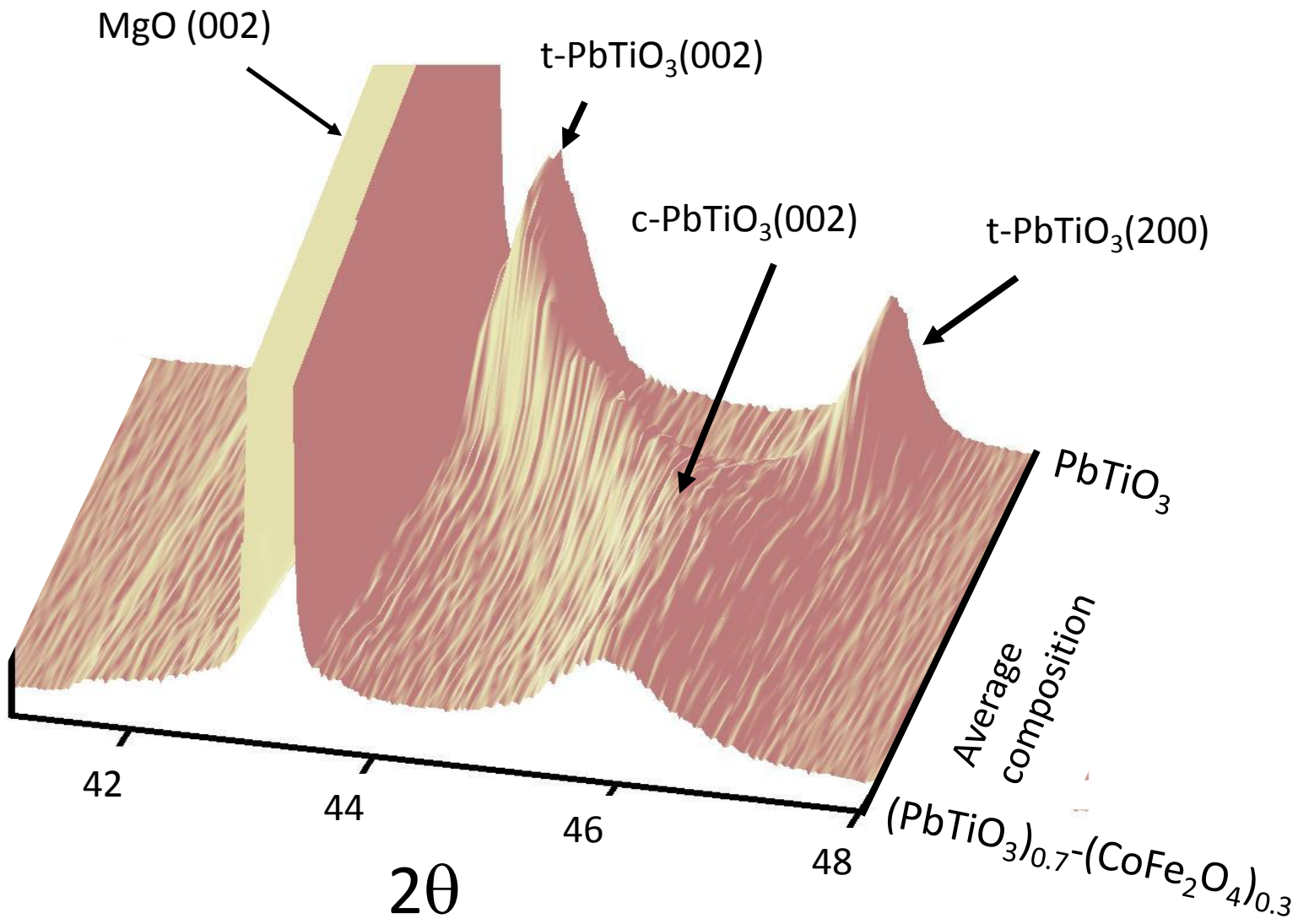
Magnetic property characterization using a scanning SQUID microscope



Magnetic and dielectric properties of $PbTiO_3$-$CoFe_2O_4$ system



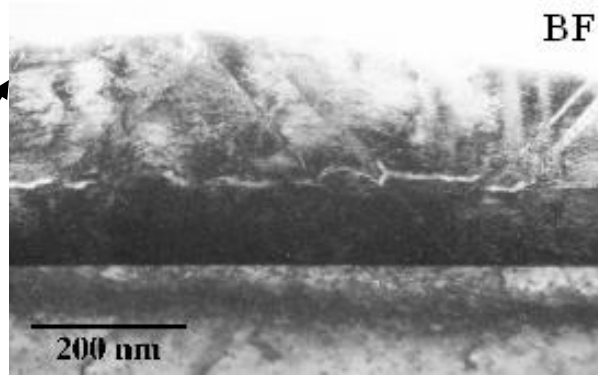
Scanning X-ray microdiffraction



Room Temp.

Continuous change in nanostructure across the nanocomposite spread

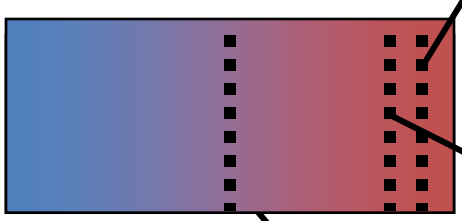
TEM micrographs of different compositions of $xPbTiO_3$-$(1-x)CoFe_2O_4$



X=0.9

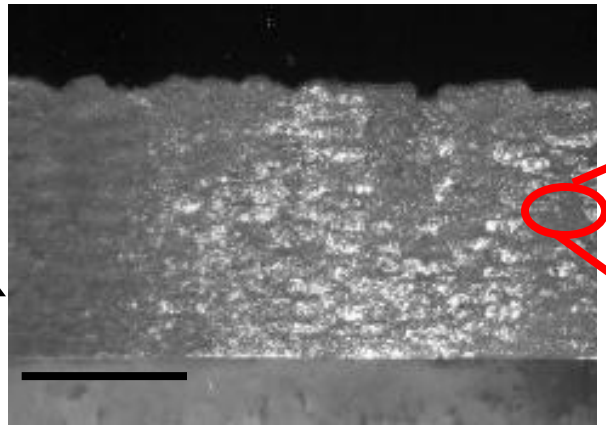
Solid solution

$PbTiO_3$:Co,Fe



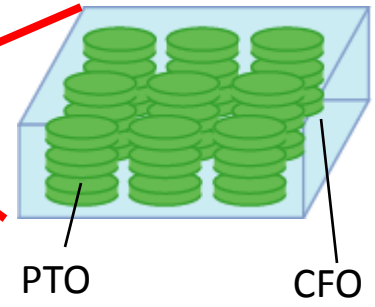
$CoFe_2O_4$

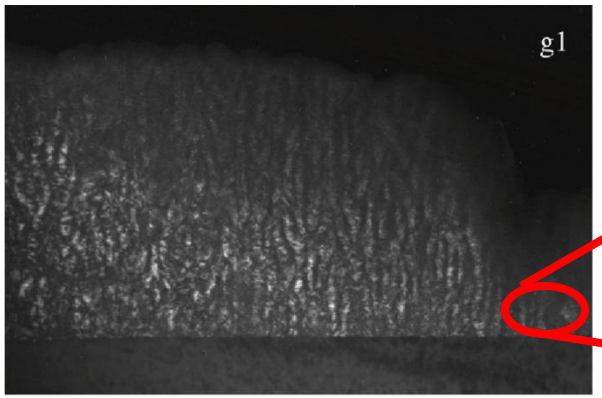
$PbTiO_3$



X=0.8

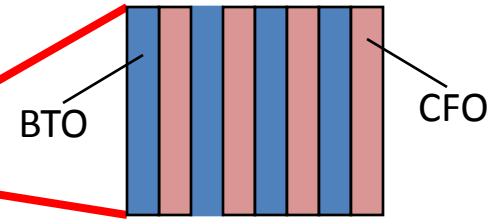
Nanopancakes





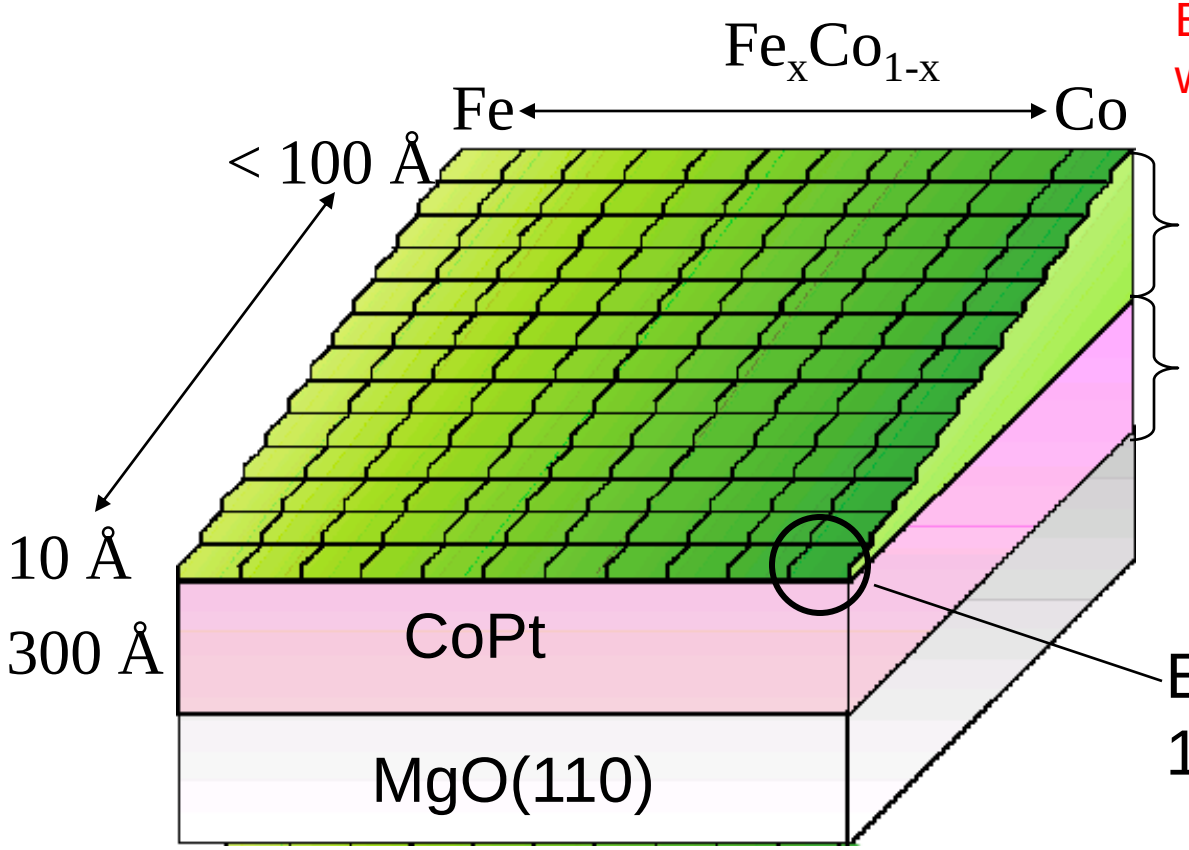
X=0.5

Nanopillars



Combinatorial Library

Systematic study of the exchange coupling with small changes of the magnetic parameters



By changing the composition we are changing the magnetic parameters of the soft layer

Soft layer

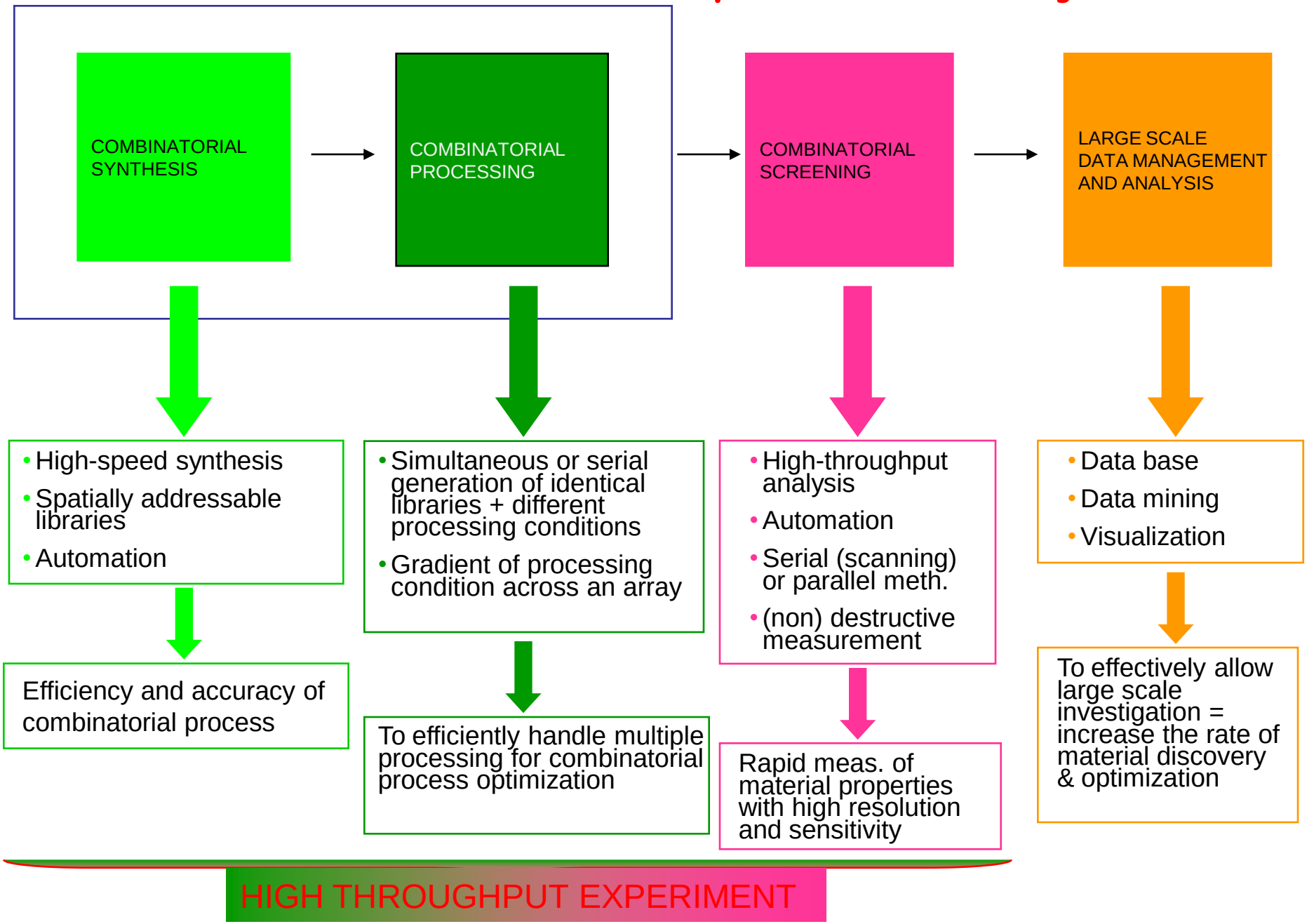
Hard layer

Each rectangle is 1 mm x 0.5 mm

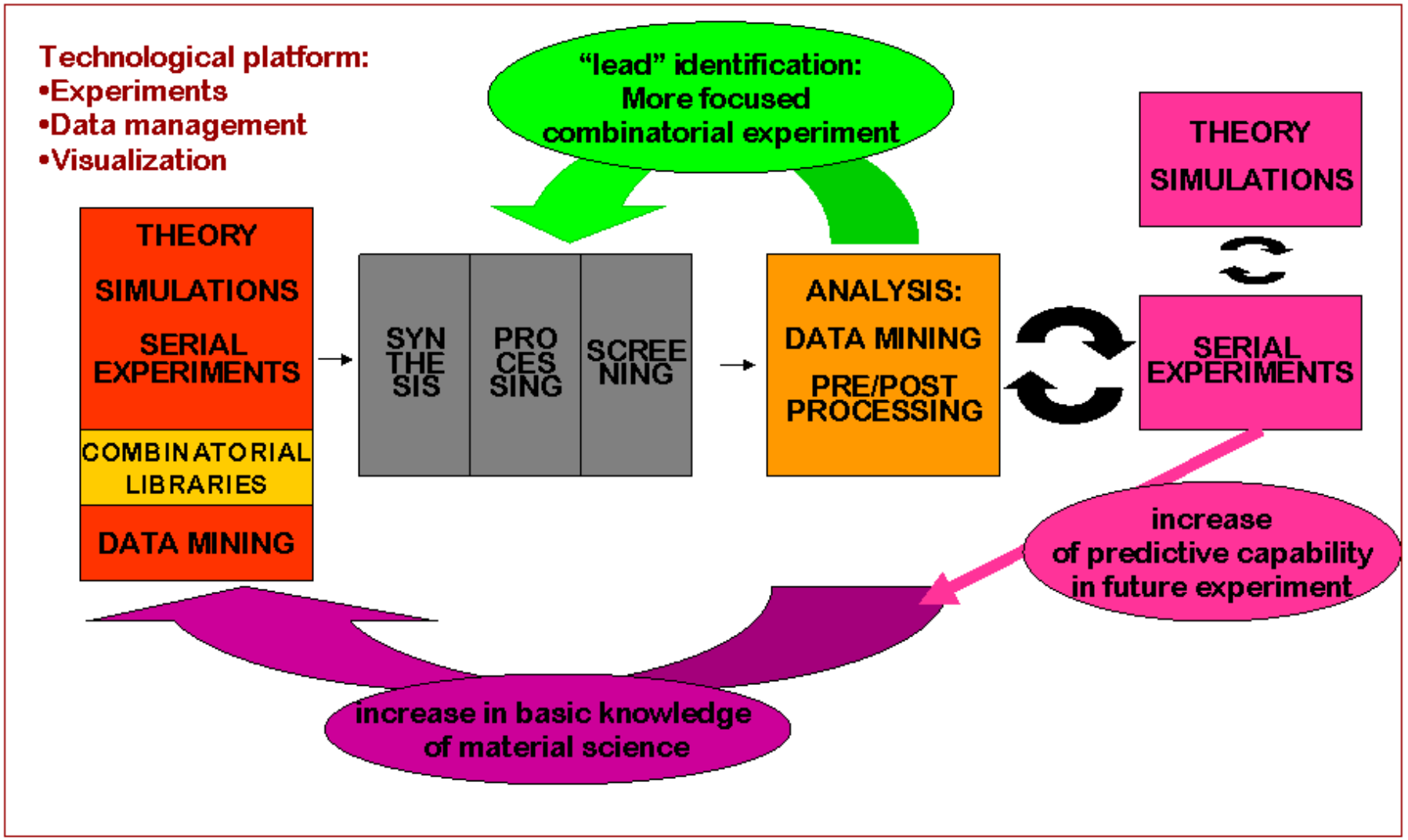
12.5 mm x 12.5mm Substrates

Ming-hui Yu, Jason Hattrick-Simpers, Ichiro Takeuchi, Jing Li, Z. L. Wang, J.P. Liu, S.E. Lofland, Somdev Tyagi, J. W. Freeland, D. Giubertoni, M. Bersani, M. Anderle, "Inter-phase Exchange Coupling in Fe/Sm-Co Bilayers with Gradient Fe Thickness" Journal of Applied Physics 98, 063908 (2005).

Combinatorial material experiment & analysis



The material discovery/optimization PROCESS



"Data analysis in combinatorial experiments: applying supervised principal components to predict thin film ternary composition spreads from TOF-SIMS spectra"

R. Dell'Anna, P. Lazzeri, R. Canteri,C.J. Long, J. Hattrick-Simpers, I.Takeuchi and M. Anderle

QSAR & Combinatorial Science **2008**, 27, 171-178

Ringraziamenti

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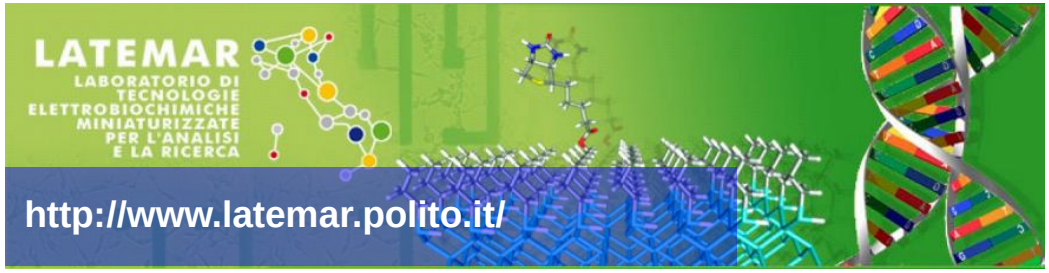
Rossana Dell'Anna, Ruben Bartali
Nadhira Laidani



Fabrizio Pirri

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