Workshop on
Advanced Materials and Surfaces

G. Benvenuti, E. Wagner, C. Sandu, S. Harada

CERN 19-11-2013

VERTICALLY INTEGRATED

BIO
OPTICS
PHOTONICS
ELECTRONICS
DECORATIVE
SECURITY
ENERGY

SINGLE Multi-Functional CHIPS

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Company Information

Company activity start: 2010

Staff 2013: 6 persons

Turnover 2012: 0.65 M€ services + 0.2 M€ subsidies

Locations:

St. Genis-Pouilly (F)	(Headquarters + R&D lab thin films)
Tours (F)	(R&D lab spectroscopy)
Le Bélieu (F)	(R&D lab equipment testing)
Magurele (Ro)	(Daughter company)

Goals and Purposes

Develop complex multifunctional thin films

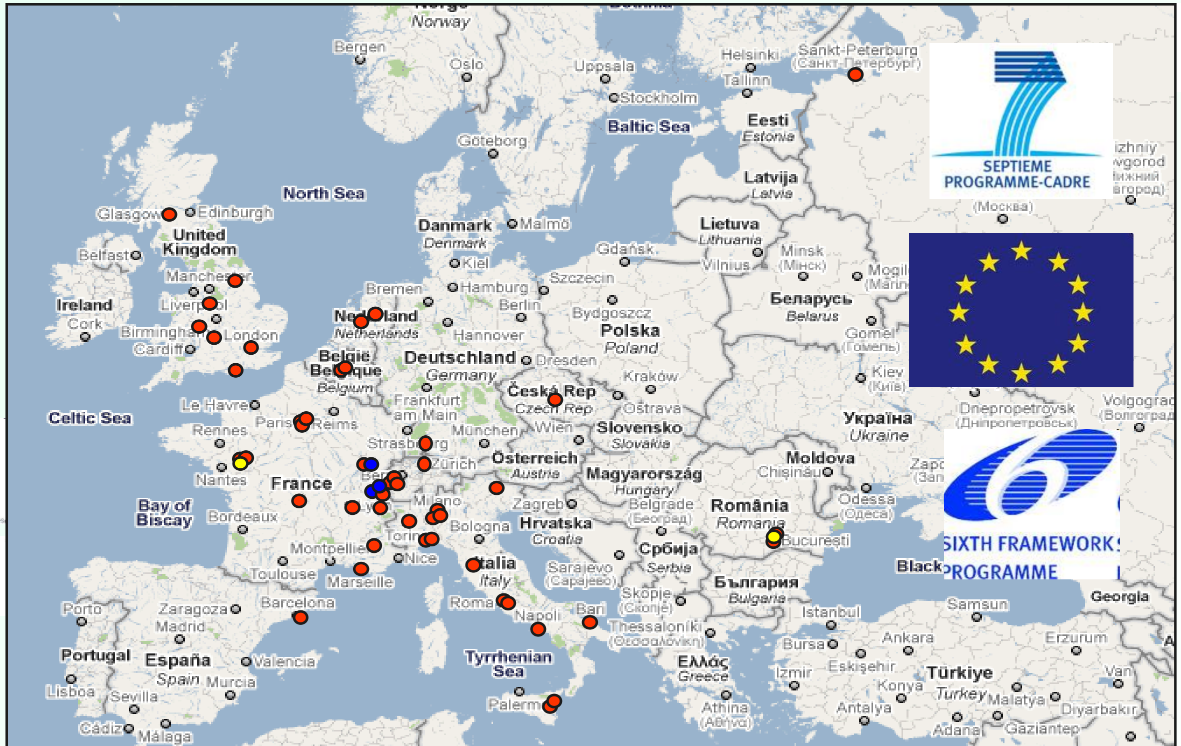
1. Multi-element oxide thin films
2. 3D-patterned thin films
3. New properties and architectures

3D-Oxides targets and develops disruptive solutions

R&D Network

3D OXIDES

University of Glasgow
epichem group
saes getters
ABCD
UNIVERSITY OF CAMBRIDGE
Leibniz Universität Hannover
UNIVERSITY OF OXFORD
The University Of Sheffield
THE UNIVERSITY OF WARWICK
KATHOLIEKE UNIVERSITEIT LEUVEN
UNIVERSITY OF Southampton
CITY UNIVERSITY LONDON
SOCRATE industrie
University of BRISTOL
UNIVERSITÉ FRANÇOIS - RABELAIS TOURS
cea
THALES
CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE



PhoeniX Software
Solutions for Micro and Nano Technologies
NXP founded by Philips
MAX-PLANCK-GESELLSCHAFT
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
INFLPR
SCHOLA GENEVENSIS 1559
FONDAZIONE BRUNO KESSLER
imec
hepia
Haute école du paysage, d'ingénierie et d'architecture de Genève
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ICFO Institut de Ciències Fotòniques
Consiglio Nazionale delle Ricerche
SELEX Sistemi Integrati A Finmeccanica Company
SAPIENZA UNIVERSITÀ DI ROMA
iit ISTITUTO ITALIANO DI TECNOLOGIA
ÉCOLE POLYTECHNIQUE ParisTech
Micron
SPECS
IBM
UNIVERSITÀ DEGLI STUDI DI GENOVA
STVDIVM GENERALE SICILIAE 1434
STMicroelectronics
UPMC PARIS UNIVERSITAS
POLITECNICO DI BARI
ΔΗΜΟΚΡΙΤΟΣ
Masdar INSTITUTE

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www.3D-

Thin films objectives

Improve sustainability, robustness, transportability

1. Miniaturization and integration of new functionalities
2. Optimize raw material use
3. Replace and/or minimize scarce and/or toxic elements

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Markets & Applications

COST EFFECTIVE MASS PRODUCTION
Less Resources, Robust devices, Transportability

Micro-electronics

- Memories
- …
- …
- Chips

Clean-Tech

- Photovoltaic
- H_2 generation
- Catalysis
- Fuel cells
- …

MEMS

- Inkjet heads
- Actuators
- Sensors
- …

Optics

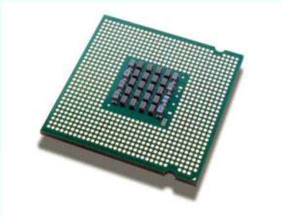
- Integrated optics
- Photonics
- Sensors
- Security
- …

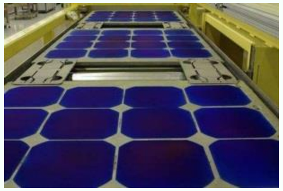
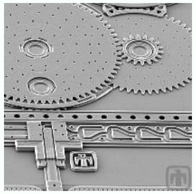
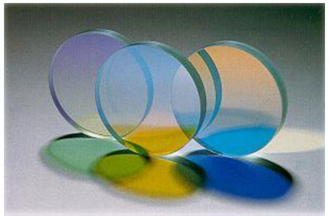
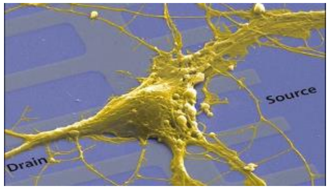
Biotech

- Bio-interfaces
- Bio-photonics
- Lab-on-chip
- …







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Oxide thin films

OPPORTUNITIES

- ✓ Eco-sustainable
- ✓ A wider number of possible functionalities
- ✓ Robust materials
- ✓ Multi-functional materials for monolithic integration

+

High added-value products

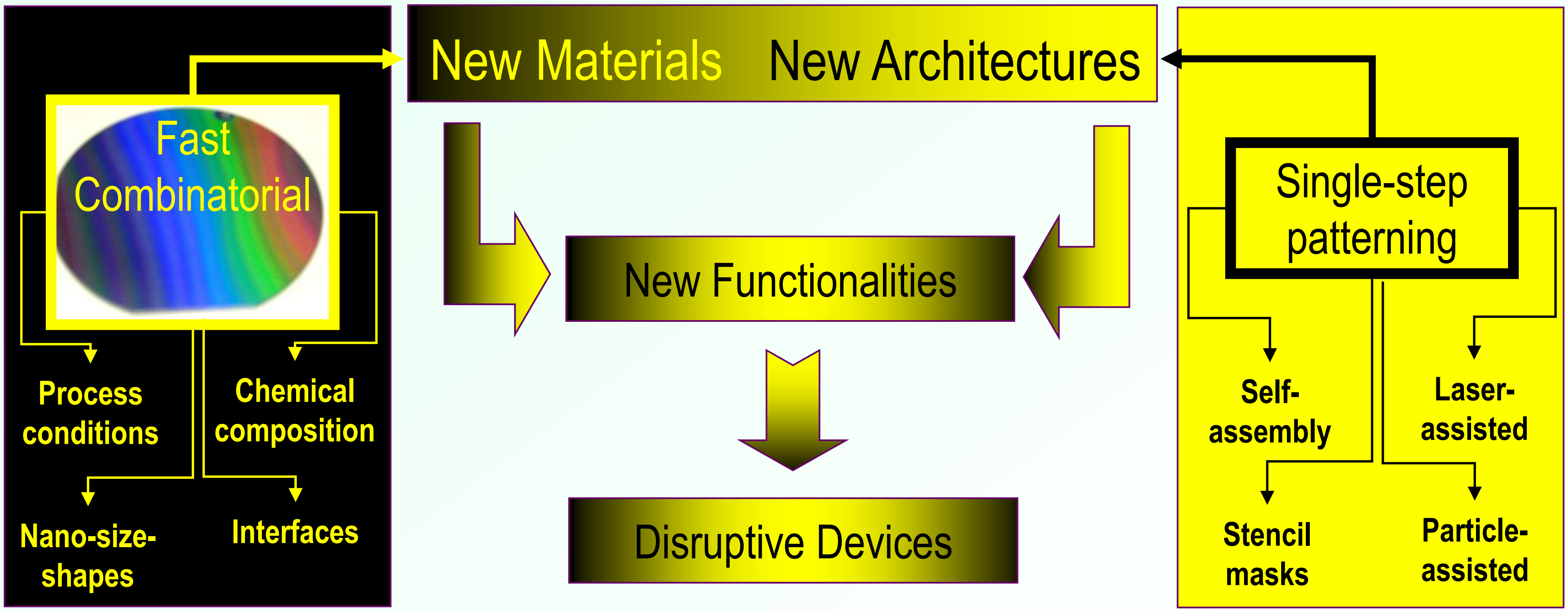
BOTTLENECKS

- ✓ Endless number of possible elemental compositions
- ✓ High process temperatures
- ✓ Properties strongly process-dependent
- ✓ Materials difficult to pattern after deposition

-

Complex materials and industrial up-scaling

3D-Oxides disruptive solution



FAST TECHNOLOGICAL APPROACH SIMULTANEOUSLY ADDRESSING SEVERAL MATERIALS-PROPERTIES-MARKETS

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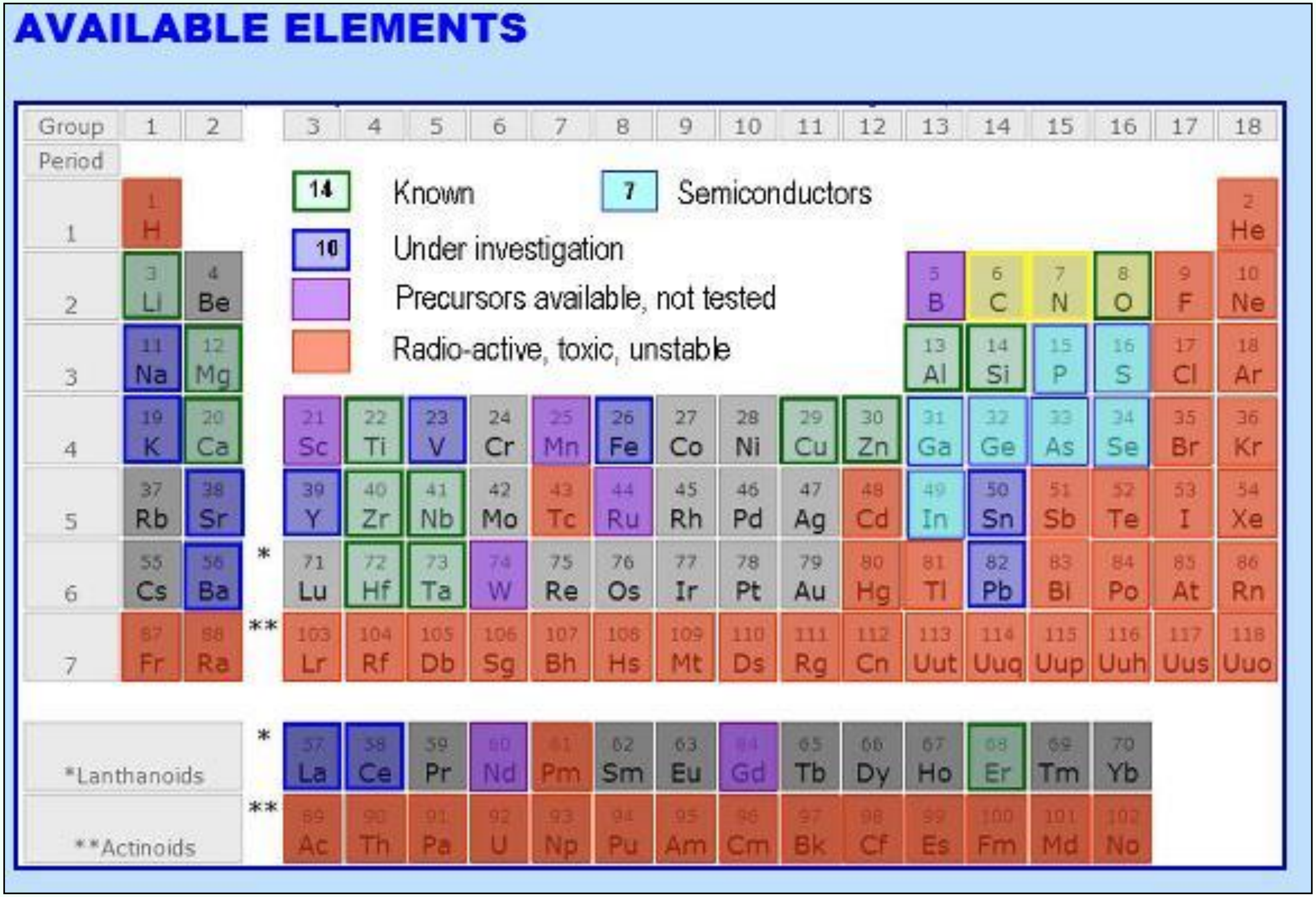
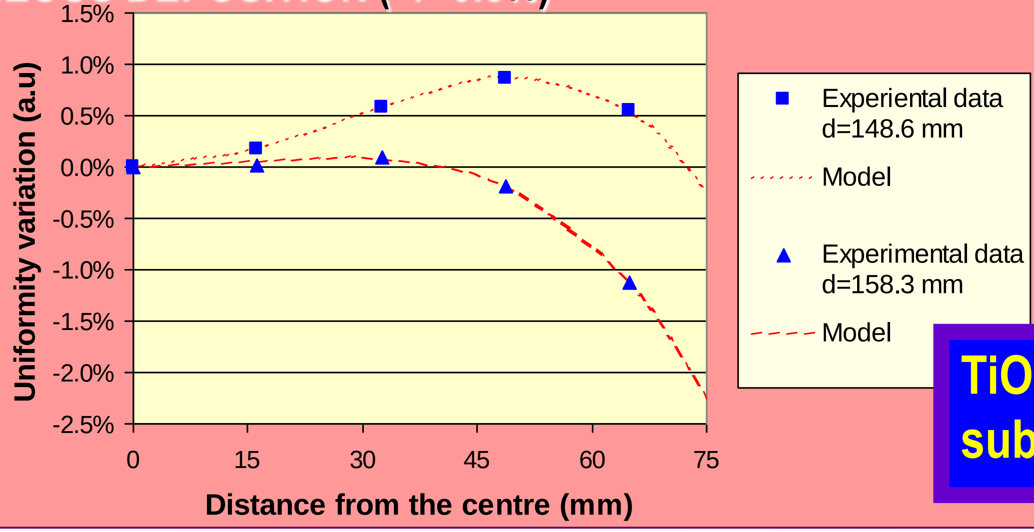
Multi-element thin films



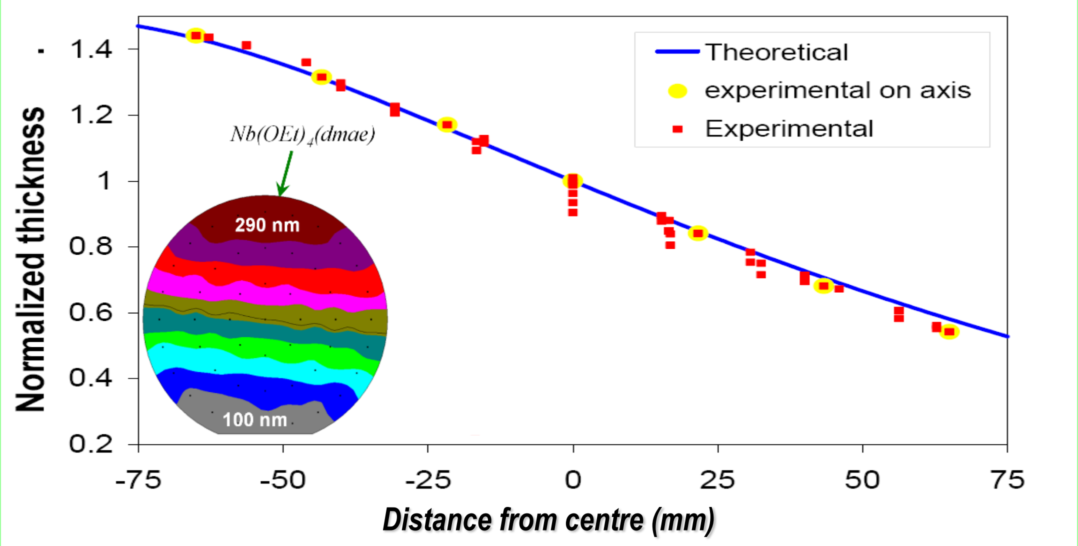
Macroscopic homogeneous or graded flows

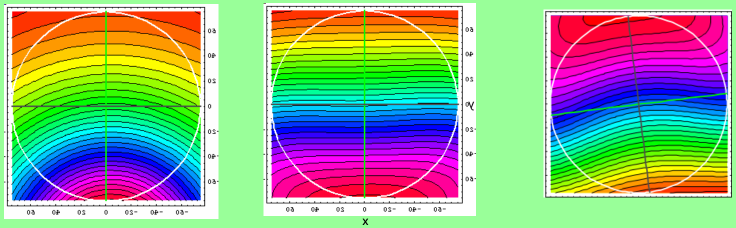
HOMOGENEOUS DEPOSITION (+/- 0.5%)

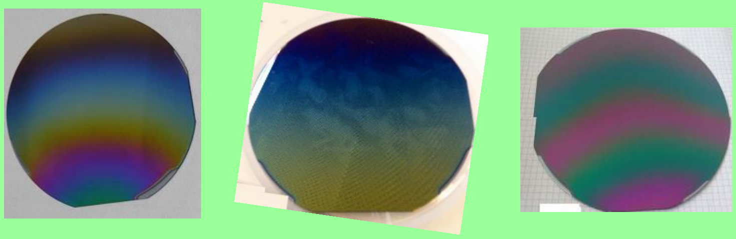


TiO_2 on 6" Si substrates

CONTROLLED GRADIENTS (variation x6)







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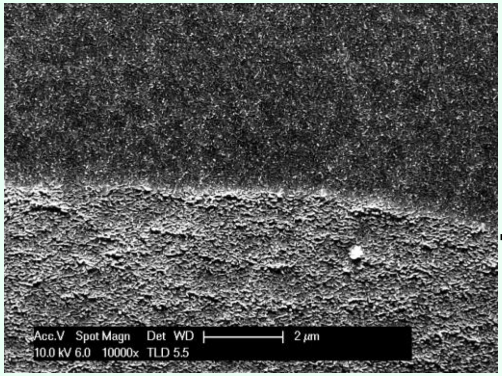
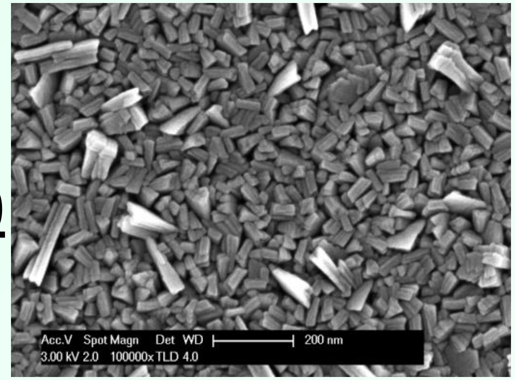
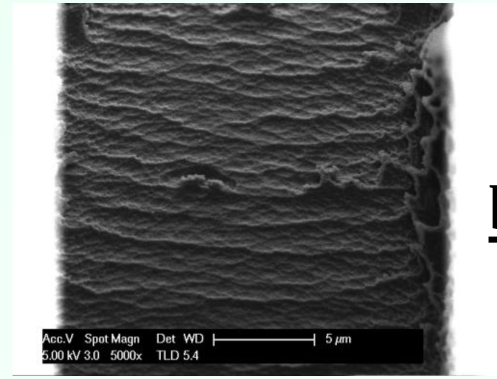
Process optimization (morphology)



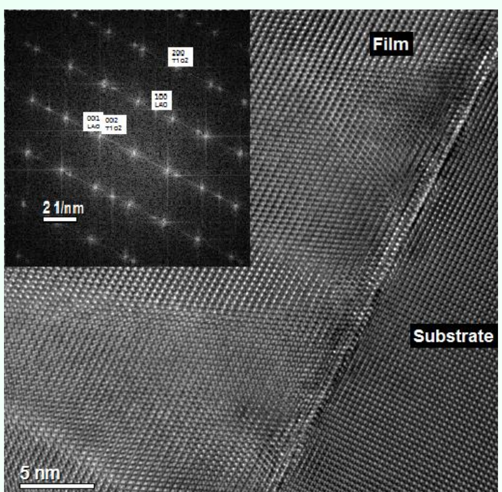
a)



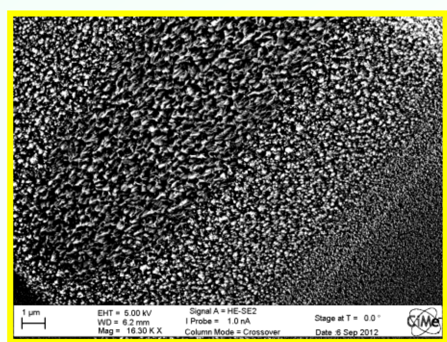


b)

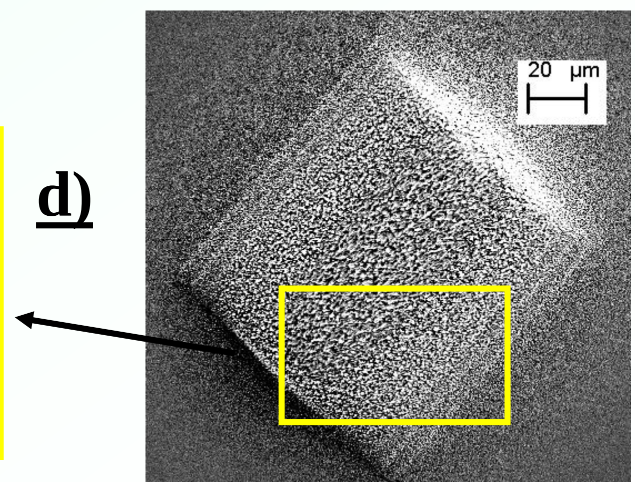
Growth rates influence on TiO_2 layers morphology



c)



d)



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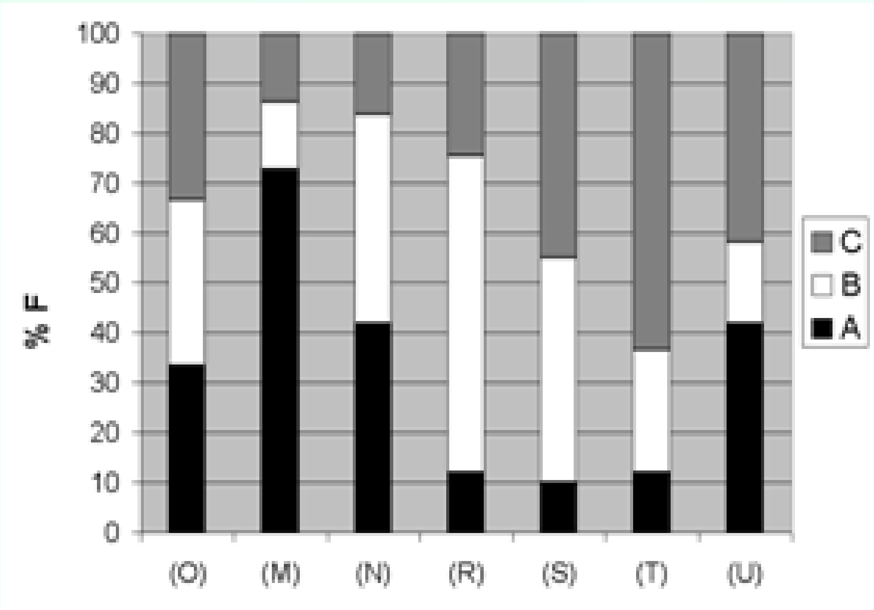
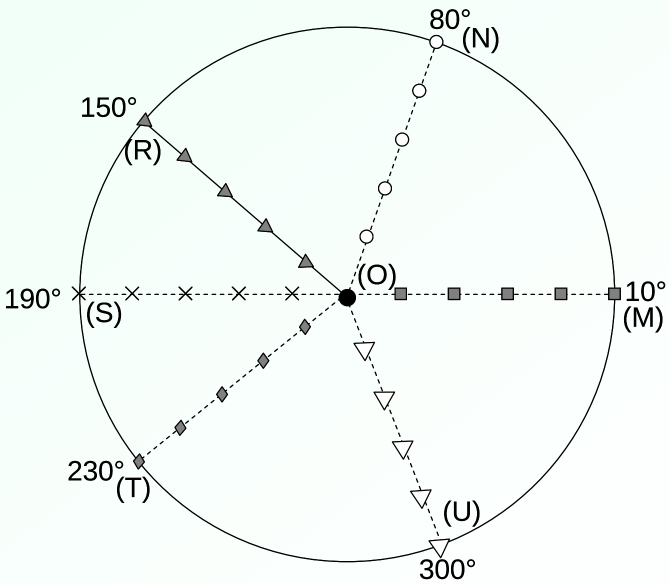
Combinatorial and phase diagrams

3 element combinatorial deposition : phase diagrams





Elemental composition ratios on a 150 mm wafer substrate @ different positions for a ternary oxide thin film of the form $A_xB_yC_zO_n$

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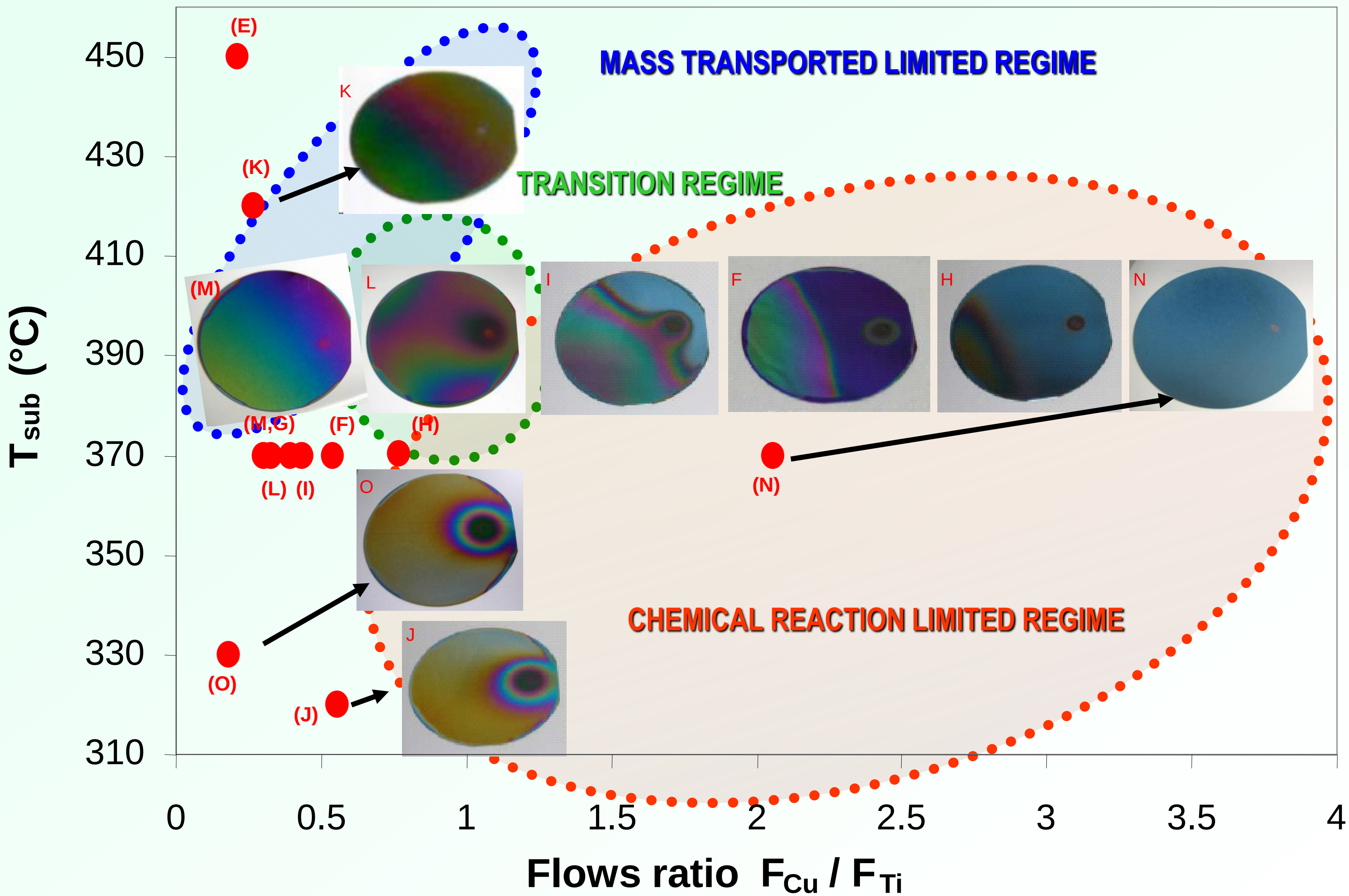
Process optimization (chemistry)

Process diagram (substrate temperature vs precursors flow ratios)



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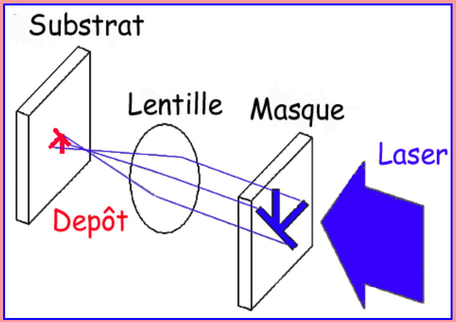
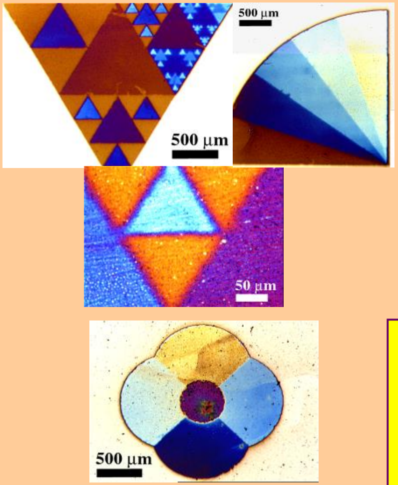
Single step patterning by laser

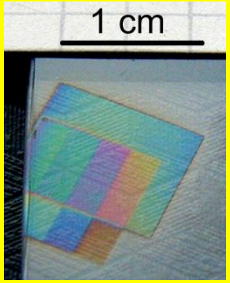
Deposition/ablation/etching is limited to the irradiated area:





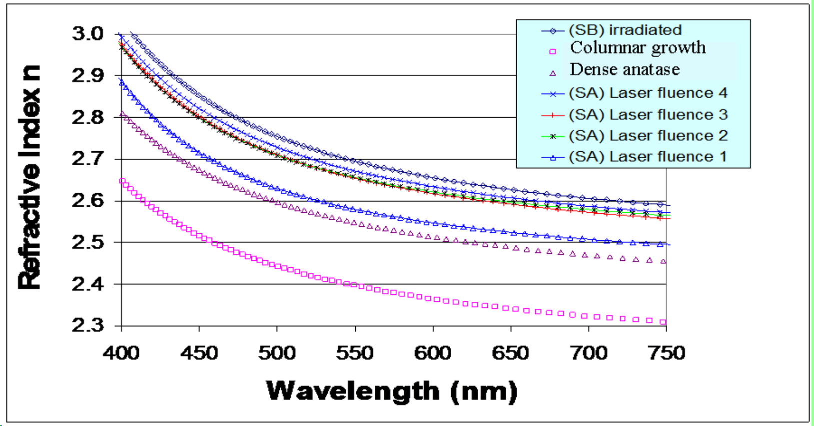
Selective deposition for real 3D patterned films

Deposition at lower temperature even on polymers

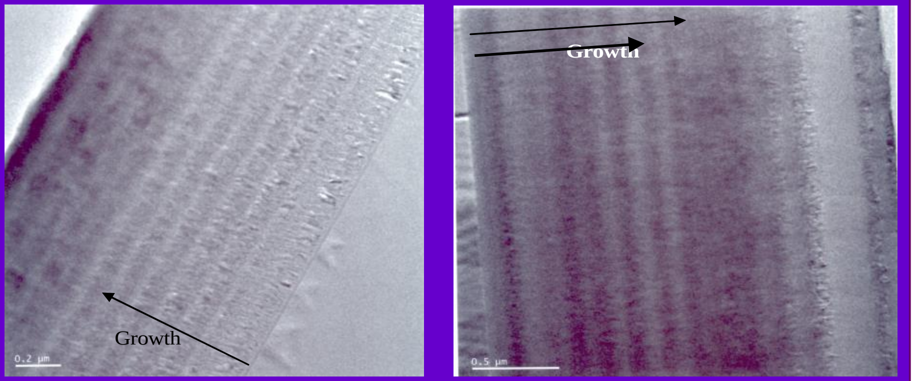


TiO_2 on various substrates

Film densification and refractive index fine tuning



Selective doping during the growth



Thermal and laser assisted deposition of same sample $Ti-(Ti_{(1-x)}Si_xO_2)$ multi-layers

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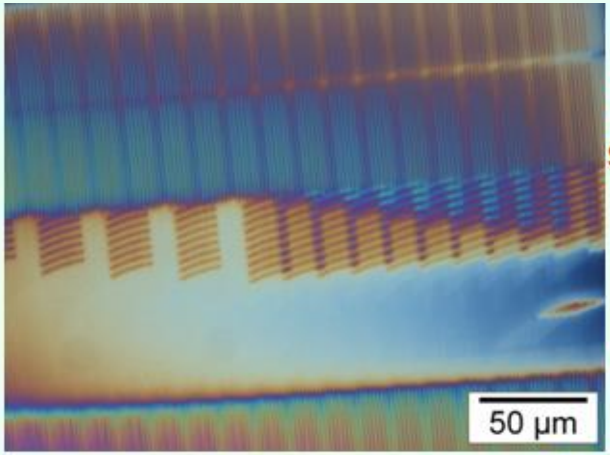
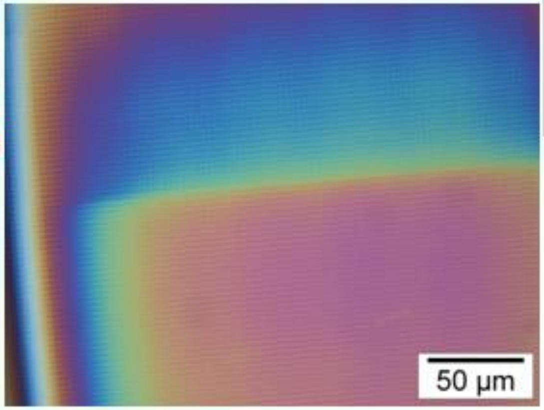
Stencil mask thin film patterning



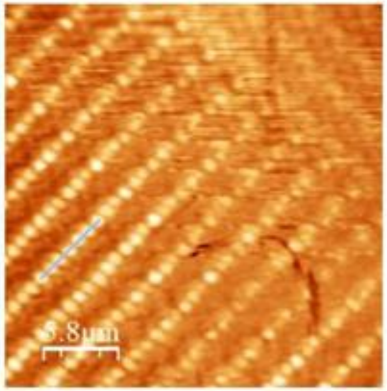
Real colors
Optical microcopy images showing interference colors due to TiO_2 different thickness

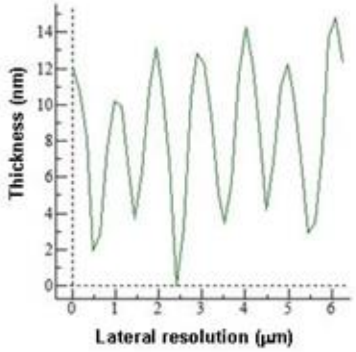


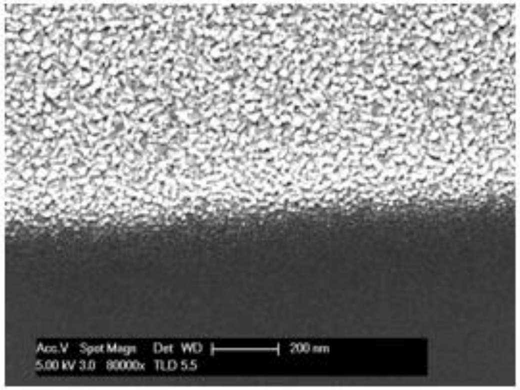
AFM Measurements showing dots with 500 nm resolution

Complex materials with graded composition and thickness can be achieved by superposition of 2 or more elemental patterns

SEM measurements showing very high border resolution (<100 nm)







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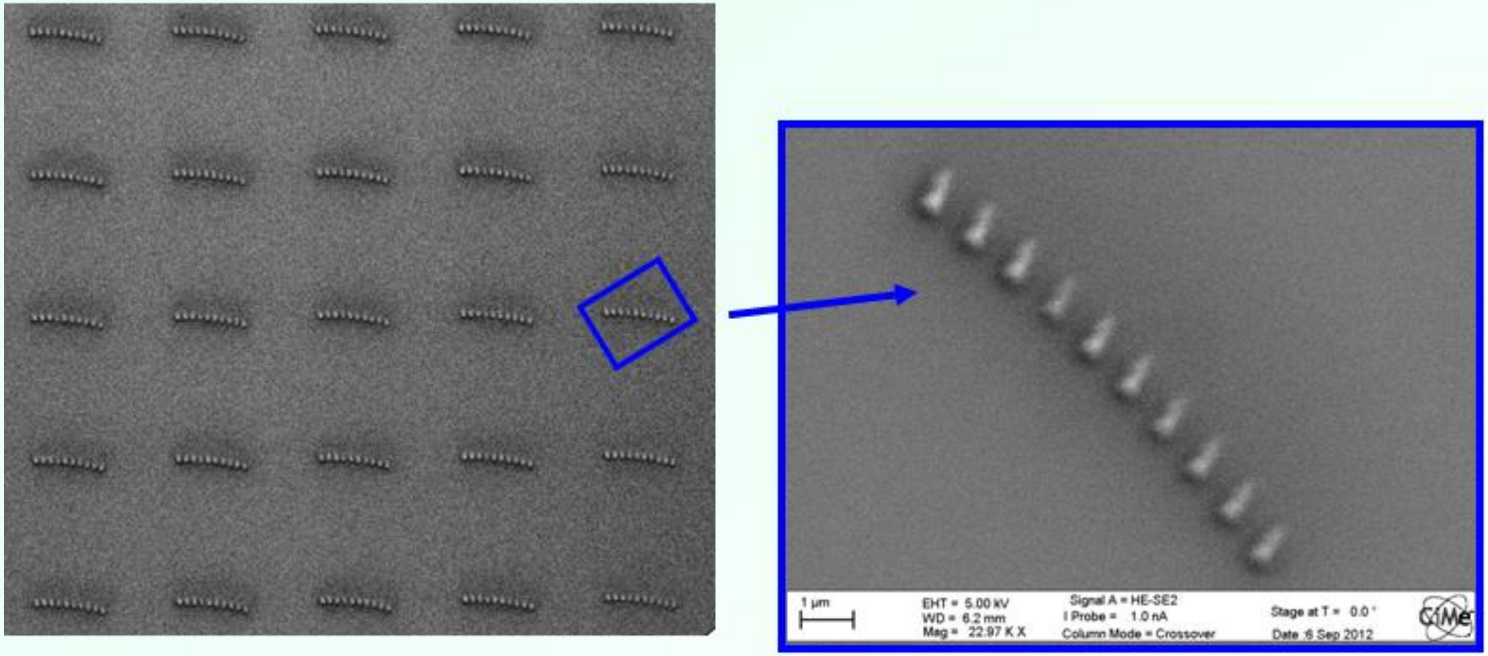
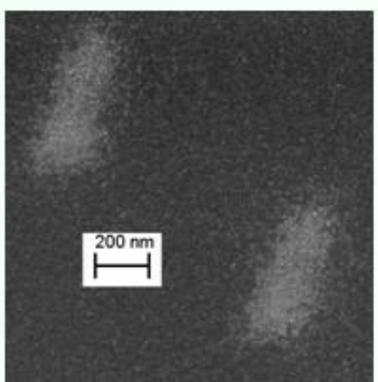
3D submicron structures





Best resolution achieved around 200 nm

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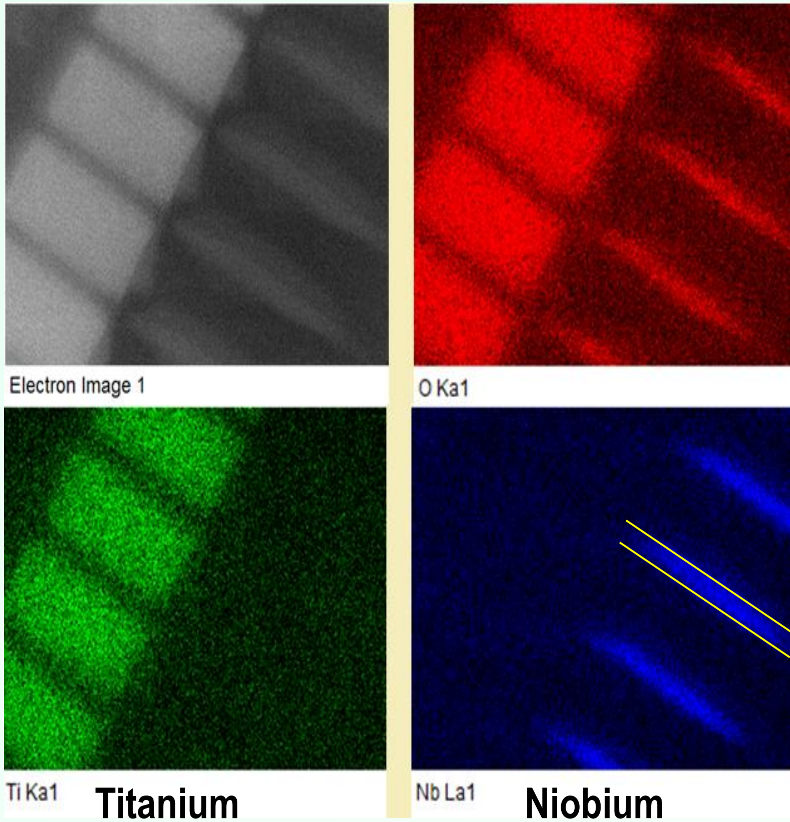
Chemical patterning: separated elements

SEM image | 50 μm | Oxygen mapping

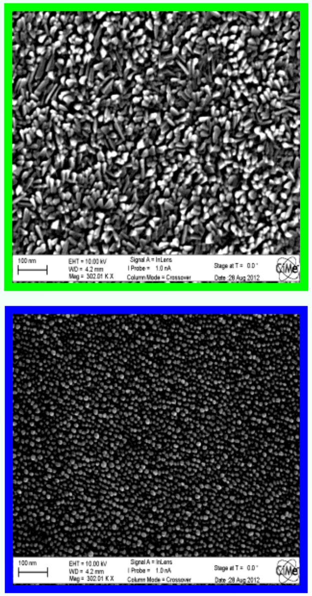


5 μm

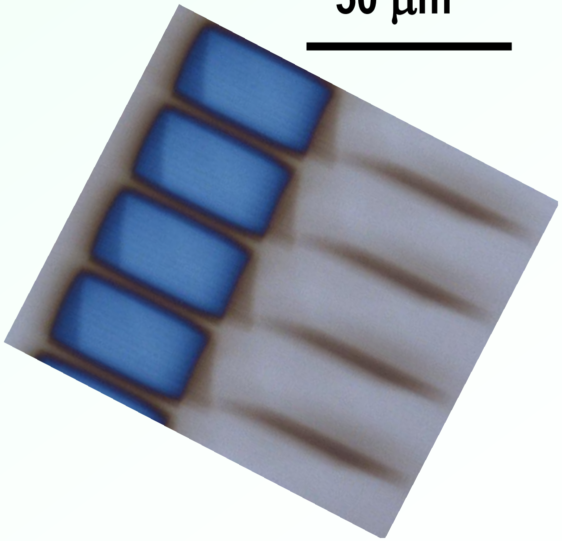
Titanium mapping | Niobium mapping

SEM top-view

500 nm



50 μm



Variable chemical composition from 95-5% to 5-95% Ti/Nb ratio by EDX

Optical microscope picture of the layer thickness 80 nm for TiO_2, 40 nm for Nb_2O_5

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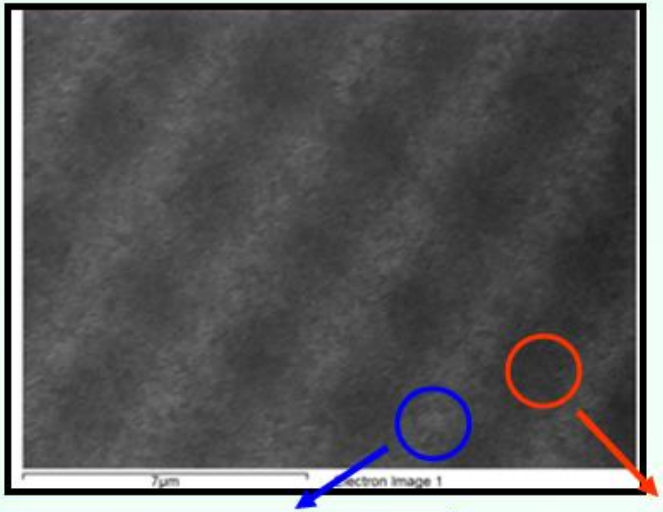
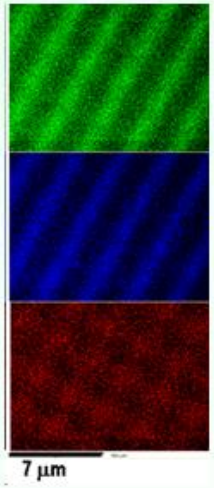
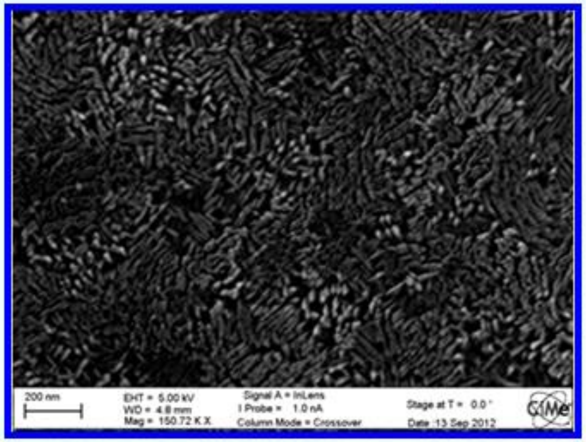
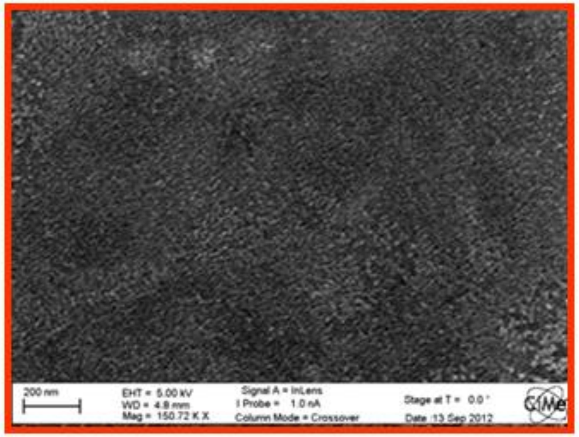
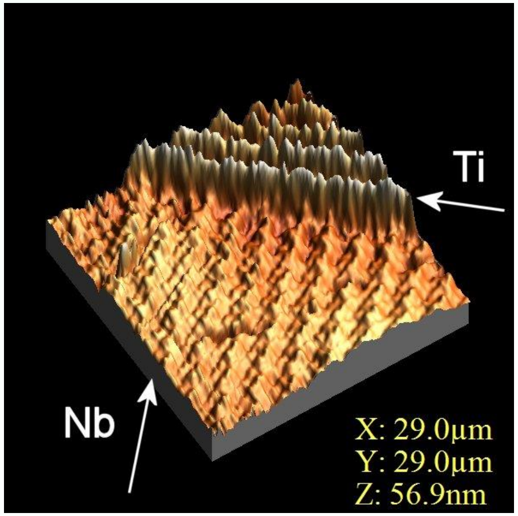
Chemical patterning: superposed elements











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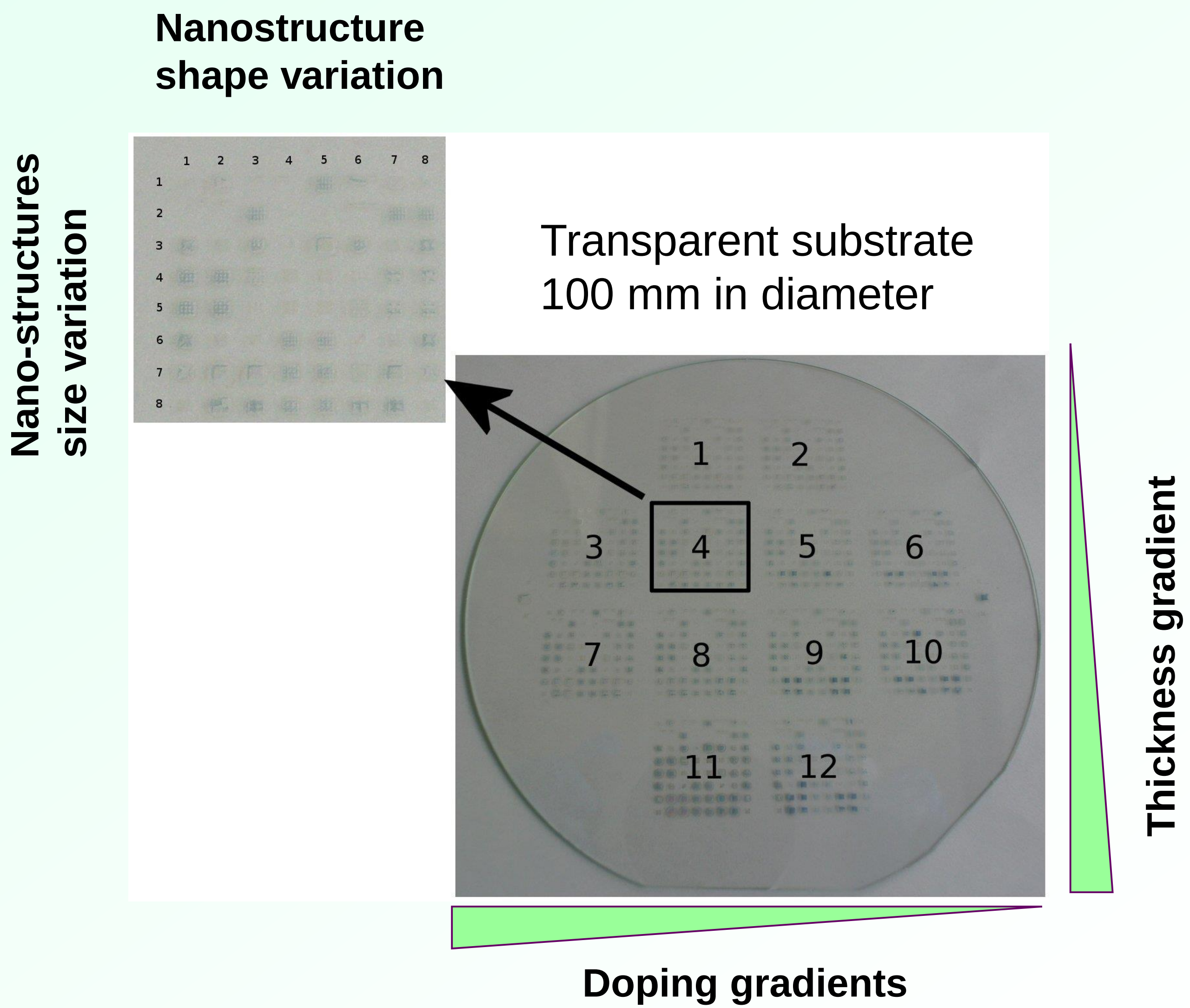
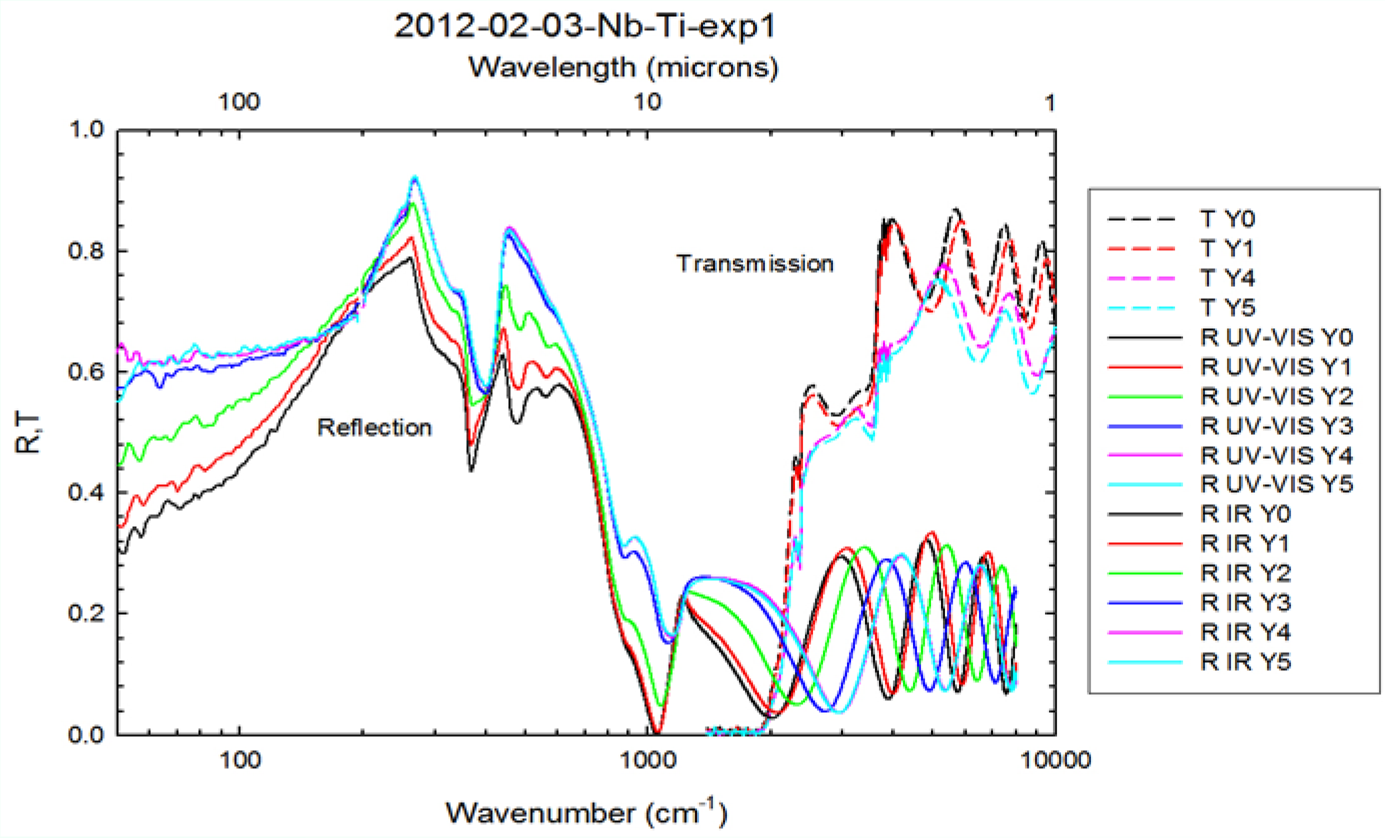
Disruptive nano-combinatorial



UV-Vis-IR Spectroscopy



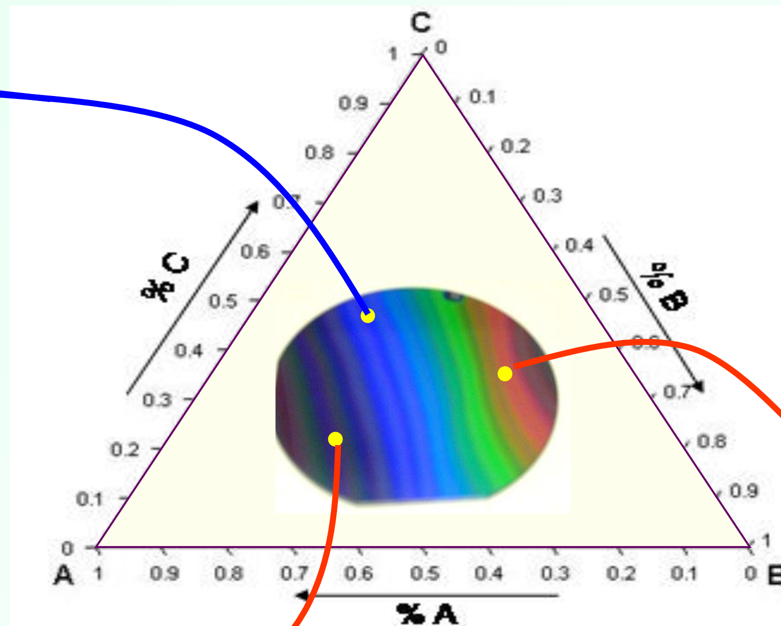
Disruptive combinatorial approach

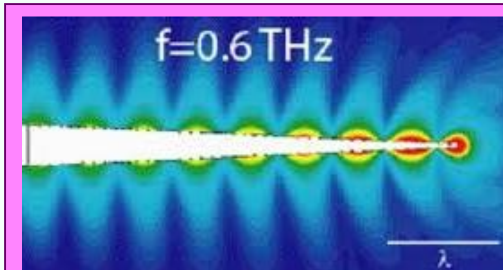
Main Application

Patterning-Architecture

Photovoltaic panels

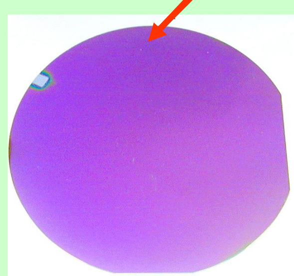
COMPLEX PHASE DIAGRAM
Chemical composition, size, shape, phase





Lasers and light sources

Secondary Applications



Memories
CPUs

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Conclusions

R&D and Production assets

<u>Flexibility, reliability and cost efficient</u>

Growth rates:	5 nm h^{-1} up to 20 µm h^{-1}
Layer Quality:	Epitaxy to highly porous thin films
Substrate size:	Scalable to any size
Number of elements:	Actually 3-5, but scalable to 6 or even more
R&D results uptake:	Very fast as the same equipment is used
Process modification:	Very fast: process is not geometry dependent
Precursors use:	Even a high as 65%
Equipment life-time:	Extensive (different materials/applications)
Costs of ownership:	Possibly down to a few 10’s € / m^2
Combinatorial production:	Possibility to produce ≠ pieces in the same run

Enabling disruptive thin films…

SYBILLA EQUIPMENT

Multi-element oxide thin films even on large substrates

Complex material stacks with modified properties via beam assistance

Single step 3D-patterned thin films with complex shapes and gradients

Unique combinatorial facility for fast and massive development of new materials

Acknowledgements

Prof Paul Muralt & Dr Veronica Savu @ EPFL

Thank you for your attention!

SIMILAR SHAPES, SIMILAR APPLICATIONS, SIMILAR BUSINESS,
BUT A TOTALLY DIFFERENT WAY TO BUILD…

We await you at our stand for further discussion

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