# Nanomaterials, Nanotechnology and Engineering of Materials


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# Topics

- What is Nanotechnology
- What are Nanomaterials
- How this implies changes in Engineering
- Examples of Applications
- A study case of products design
- Nanotech Products
- The Promise of Tomorrow
- Toxicity
- Disadvantages

# What is Nanotechnology?

## Nanotechnology is about:

- Making small objects
- Manipulating small objects
- Creating new materials by varying the size of the objects with outstanding performances, where the effects of quantum physics become more prominent
- Building structures from small objects

# What is Nanotechnology?, Continued

**Nanotechnology provides mankind the ability to make things the way nature has been doing it for eons; atom by atom from the bottom up.**

**For example, nature takes brittle materials, but forms them together to be very strong, e.g., clam shells.**

# Nanotechnology

## TECHNOLOGIES

Nanomaterials

Nanofabrication

Scanning Probe Microscopy

Self-Assembly

●
●
●
●

## APPLICATIONS

Super strong materials

Super Slippery Materials

Tissue Engineering

Drug Delivery

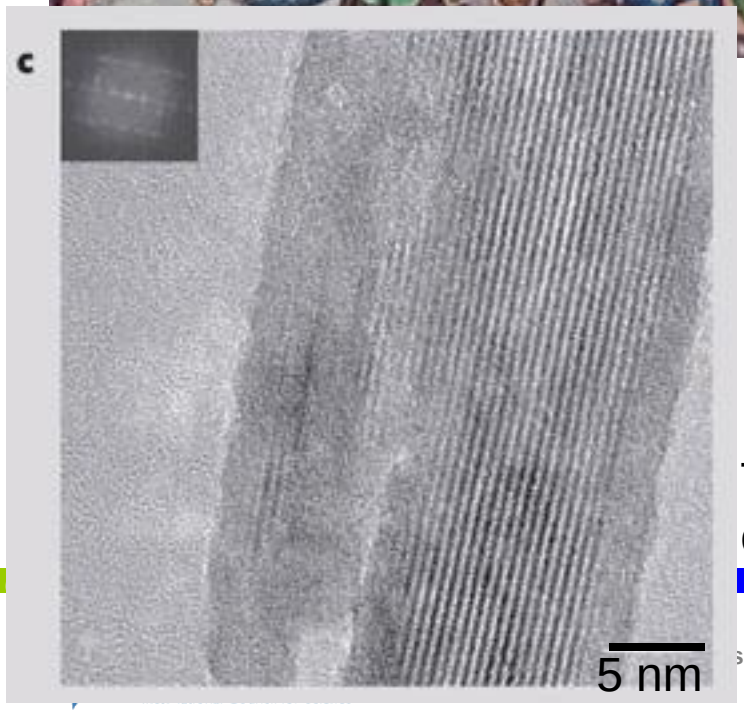
Super fast/small computers

Sensors

●
●
●

# Is Nanotechnology really new?

During the middle ages, the Muslims who fought crusaders with **swords of Damascus** steel had a high-tech edge - carbon nanotubes and nanowires in their sabres. Damascus sabres were forged from Indian steel called *wootz*. It is likely that the sophisticated process of forging and annealing the steel formed the nanotubes and the nanowires, and could explain the **amazing mechanical properties of the swords**.



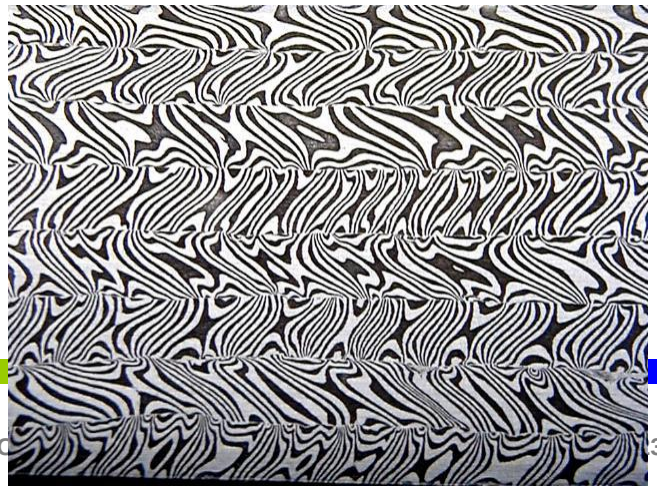

TEM image of cementite nanowires

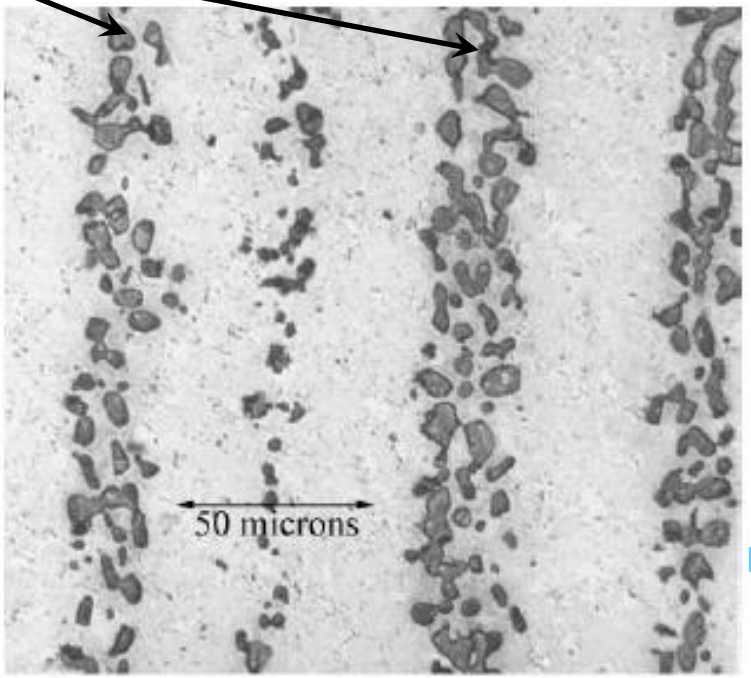
# Damascus Steel

Damascus blade showing the Damascene surface pattern containing a combined Mohammed ladder and rose pattern

http://www.tms.org/pubs/journals/JOM/9809/Verhoeven-9809.html

Cementite bands





# Is Nanotechnology really new?

- Lycurgus cup,4$^{th}$ century AD (now at the British Museum, London).

- Depicts King Lycurgus of Thrace being dragged to the underworld

- When illuminated from outside, it appears green. However, when illuminated from within the cup, it glows red.

# Is Nanotechnology really new?

Suspensions of spherical gold particles with various diameters (150, 100, 80, 60, 40, 20 nm from left to right) in water. The difference in colors is due to different scattering and absorption behaviour of small and large gold particles.

# How did it started in 20th century?

## There's Plenty of Room at the Bottom:

### An Invitation to Enter a New Field of Physics

**Richard Feynman**
**Cal Tech, 1959**

"People tell me about miniaturization, and how far it has progressed today. They tell me about electric motors that are the size of the nail on your small finger. And there is a device on the market, they tell me, by which you can write the Lord's Prayer on the head of a pin. But that's nothing; that's the most primitive, halting step in the direction I intend to discuss. It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction. *Why cannot we write the entire 24 volumes of the Encyclopedia Brittanica on the head of a pin?"*

This goal requires patterning at the 10 nanometer scale.

# Why is Small a Big Deal?

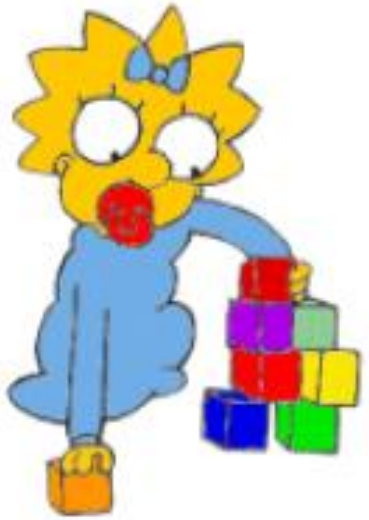
What are some advantages of making things **smaller**?

- Some extraordinary properties can be achieved (structural, electrical, etc.)
- Economic benefits - cost, quantity
- Technologic benefits - speed, power, integration, practical.

# Building Complex Structures with Small Objects

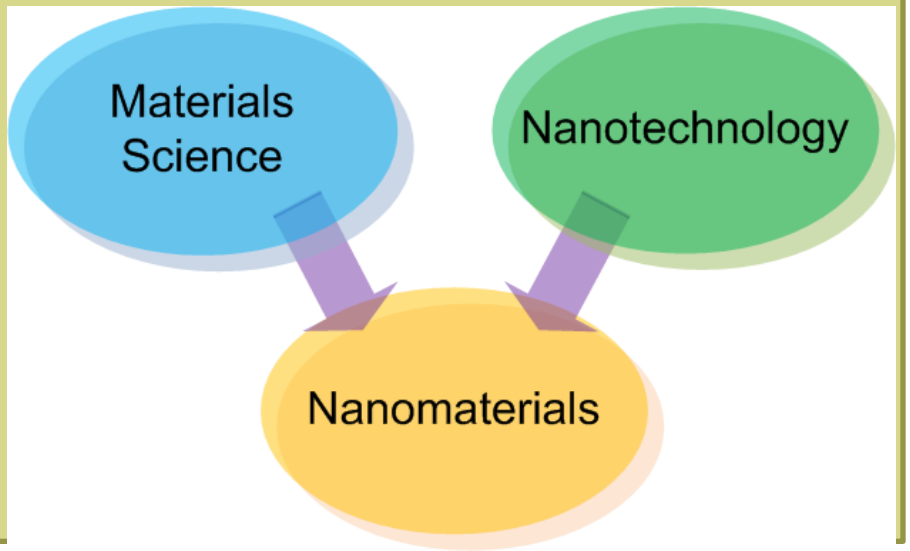
**Top-down**
**(i.e. Lithography)**

**Bottom-up**
**(i.e. Self-assembly)**

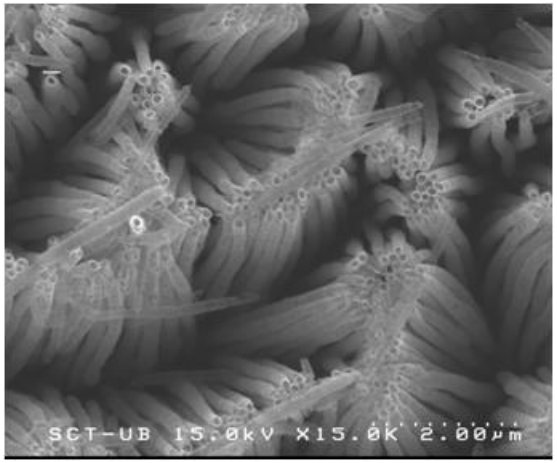


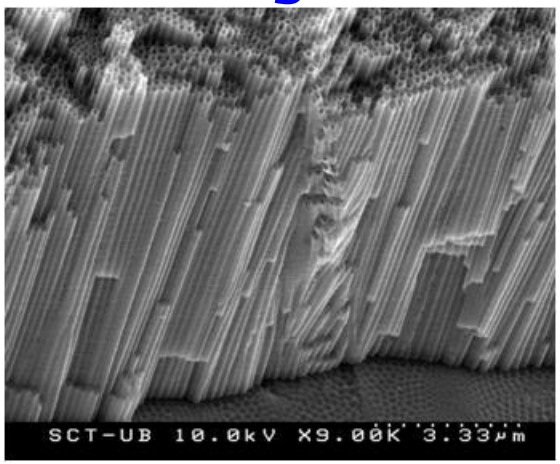
# What are nanomaterials?

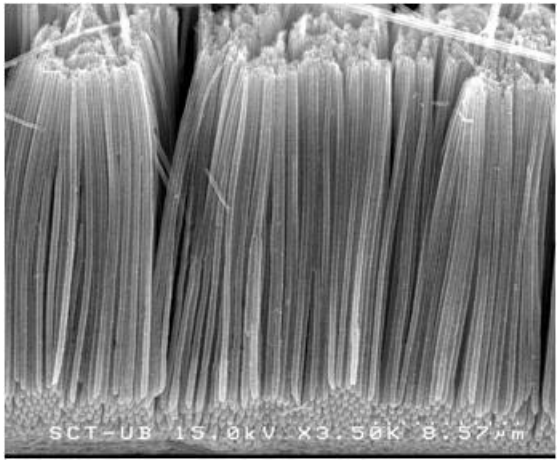
- **European Commission definition, 2011:** "***A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm – 100 nm***. *In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%.*"

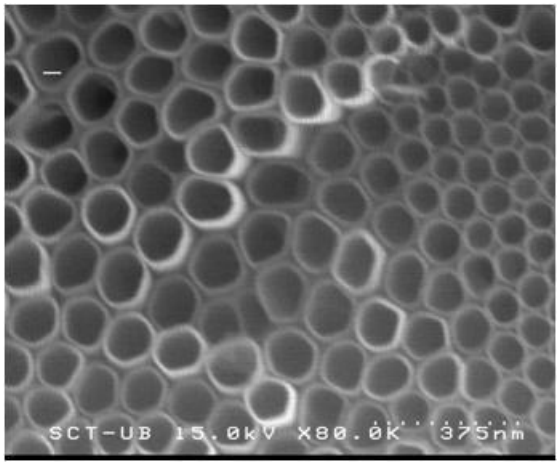


# What are Nanomaterials?: The small reference objects



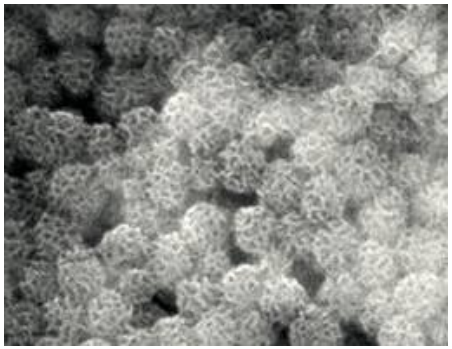

Anodic oxidation of Ti foil. Excellent electrical contact with the titanium base electrode.

# What are the relevancy of Nanomaterials?

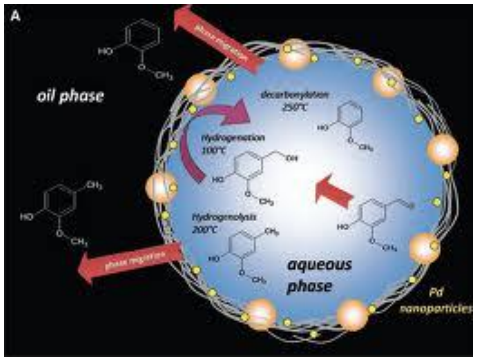

**Ex: High surface area**

**Ex: increased reactivity**

**Ex: improved catalytic** efficiency



News.sciencemag.org



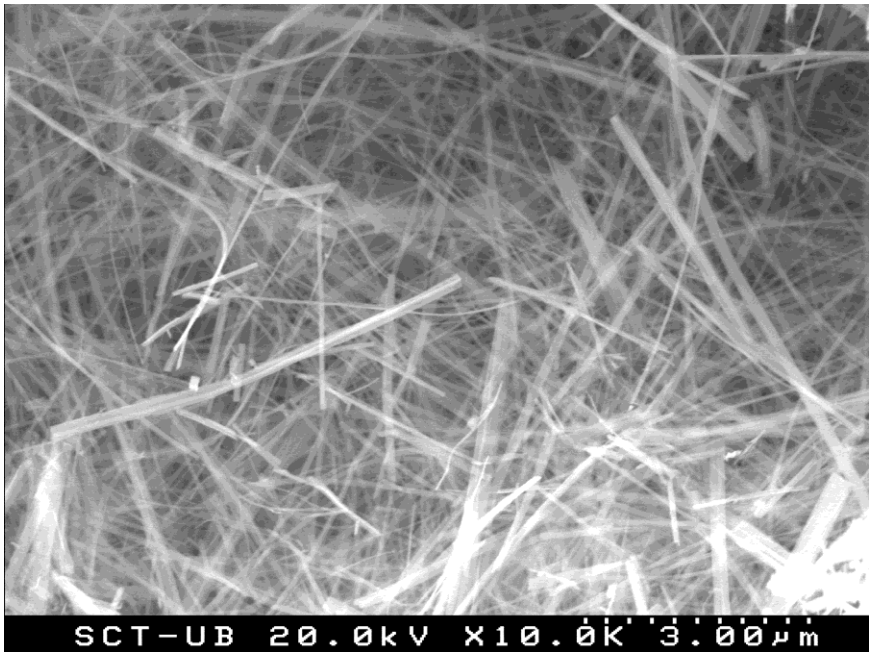

ou.edu

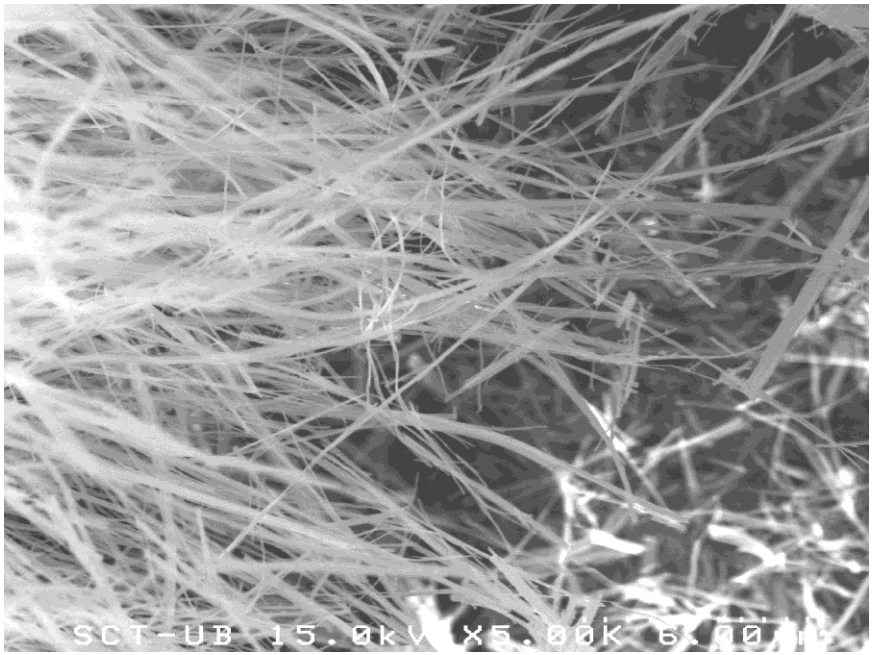
**Nanomaterials properties controlled by surface effects such as Van der Waals forces, hydrogen bonds, covalent bonds, hydrophobicity, ionic conduction or quantum mechanical tunneling.**

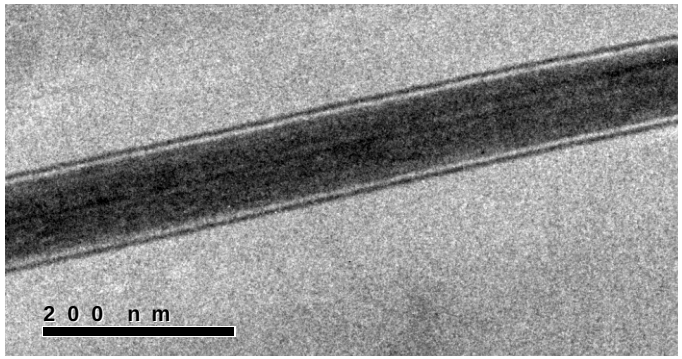
# What we can do with Nanomaterials?

## INCREMENT OF SURFACE AREA

Hydrothermal treatment with 10M NaOH



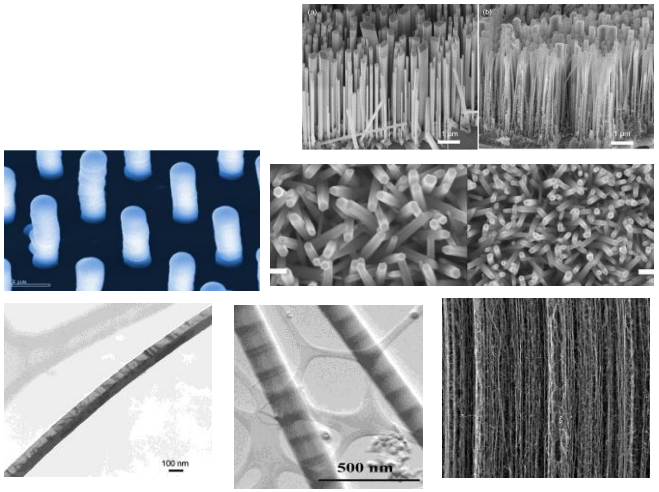



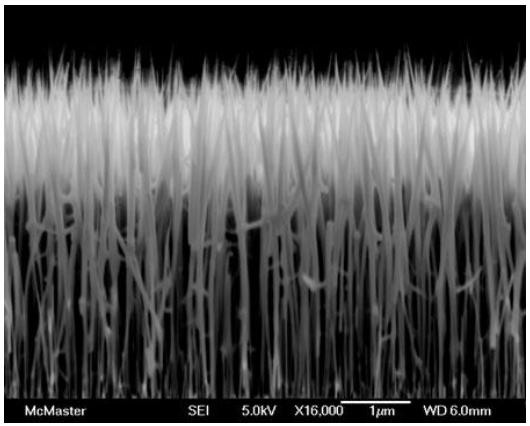



# What we can do with Nanomaterials?

## Nanowires and Nanotubes

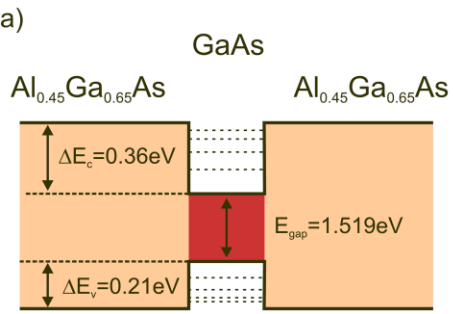
- Lateral dimension: 1 – 100 nm
- Nanowires and nanotubes exhibit novel physical, electronic and optical properties due to
  - Two dimensional quantum confinement
  - Structural one dimensionality
  - High surface to volume ratio
- Potential application in wide range of nanodevices and systems
  - Nanoscale sensors and actuators
  - Photovoltaic devices – solar cells
  - Transistors, diodes and LASERs

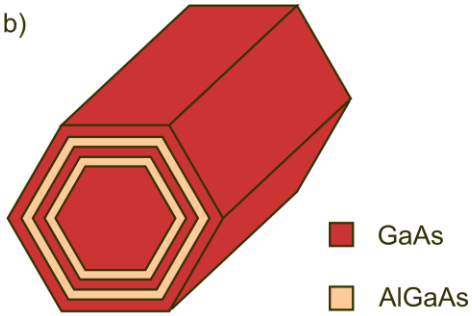


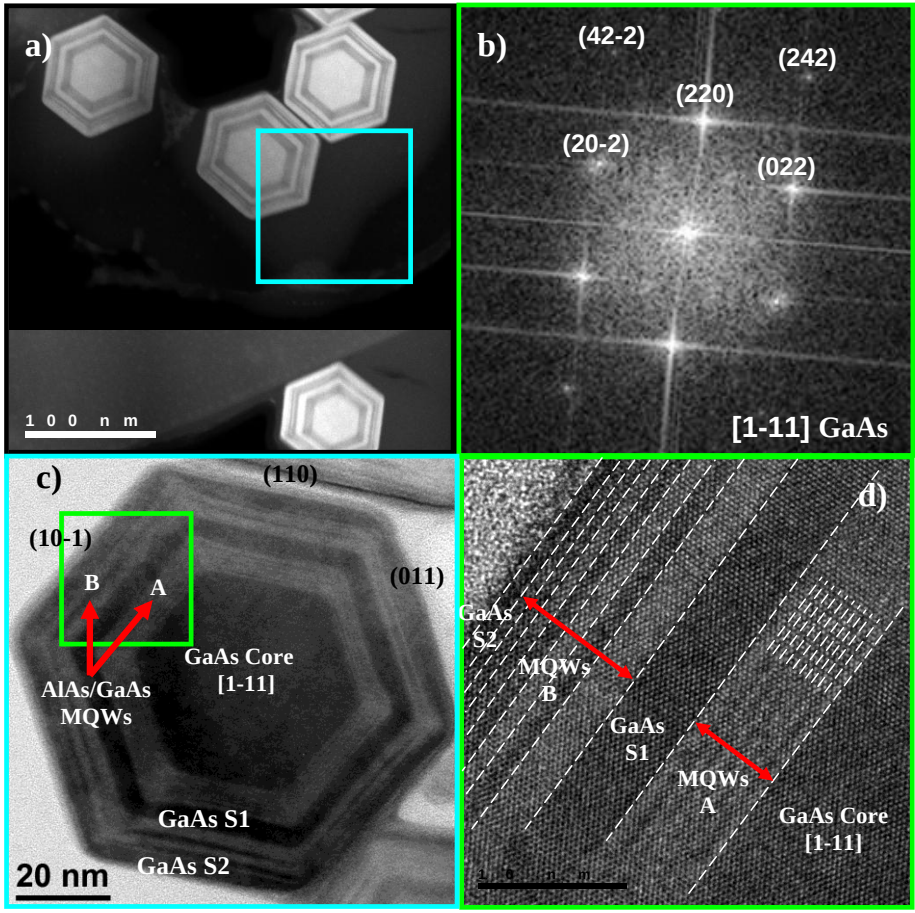




**Nanowire Solar Cell:** The nanowires create a surface that is able to absorb more sunlight than a flat surface – *McMaster Univ. 2008*

# Nanomaterials:
# Nanowires with coaxial quantum wells



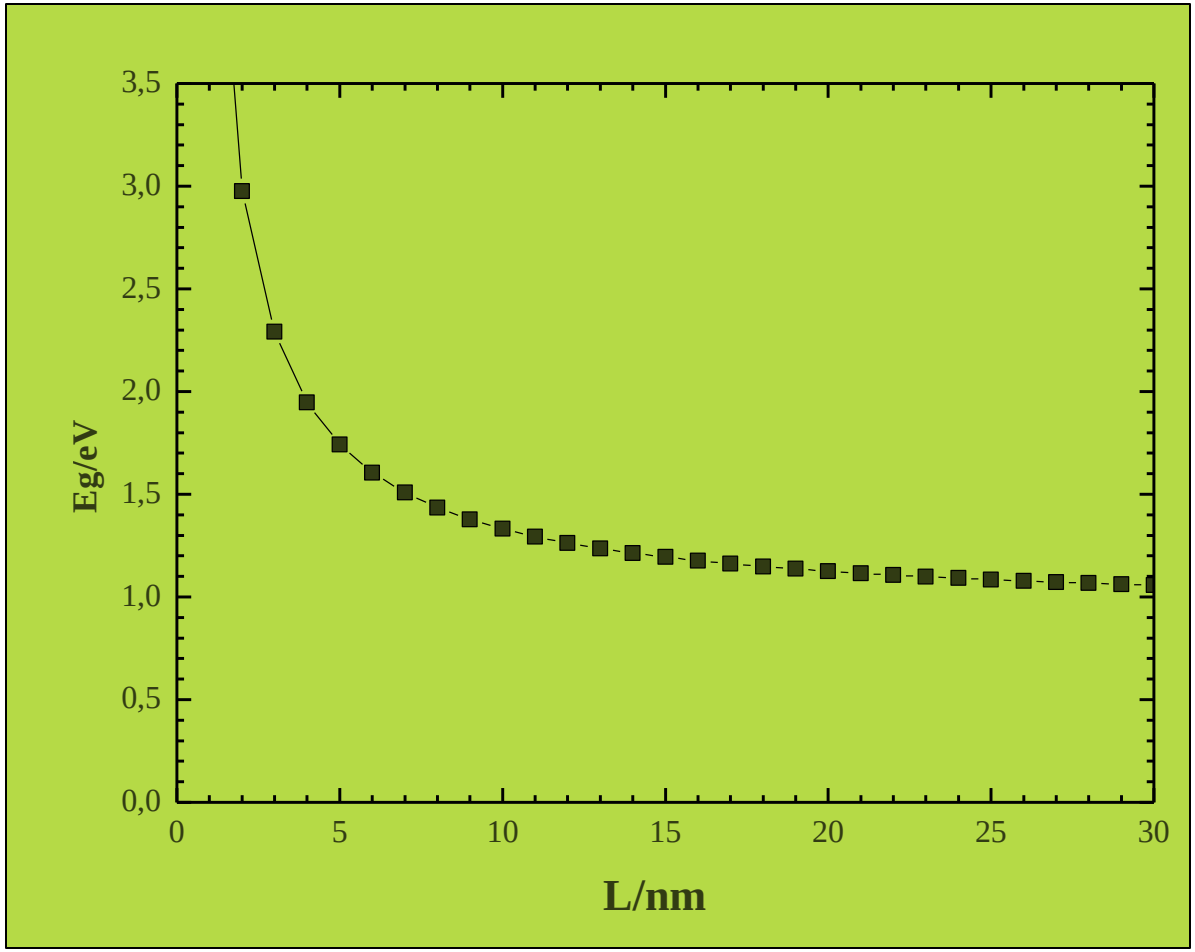




Small 4, 7, 899-903 (2008)

# What we can do with Nanomaterials?

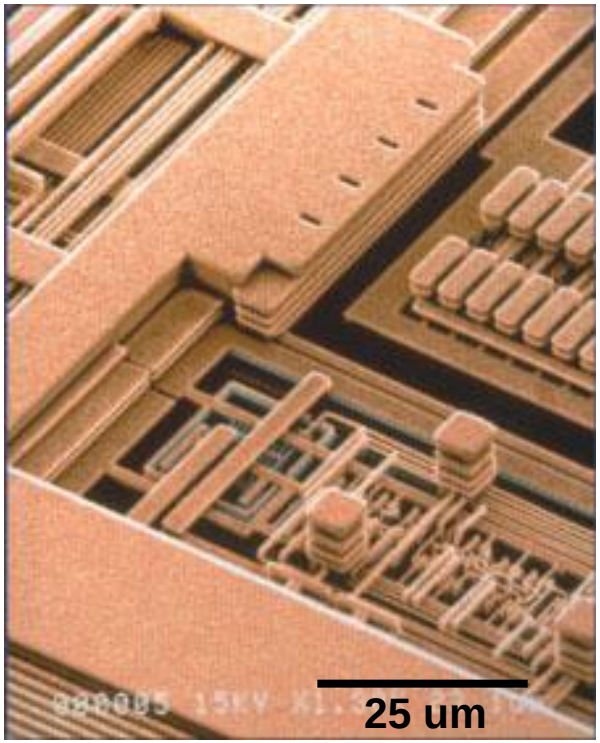
## Play with "colour": Band gap engineering



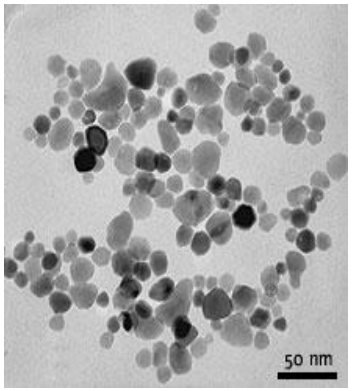

ZH Hu, et al. J. Non Cryst. Solids Vol.: 352 Issue: 9-20 Pages: 1900-1903, 2006

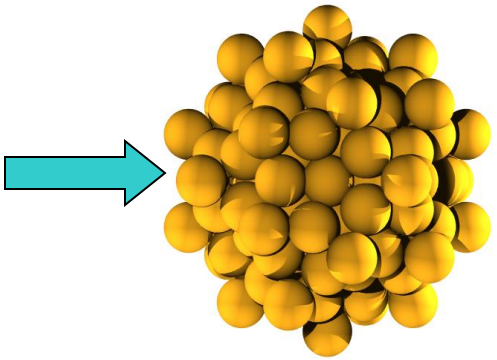
Y. Xu et al, J. Non Cryst. Solids, Vol.: 352 Issue: 9-20 Pages: 1972-1975 , 2006

# Engineering: making small objects

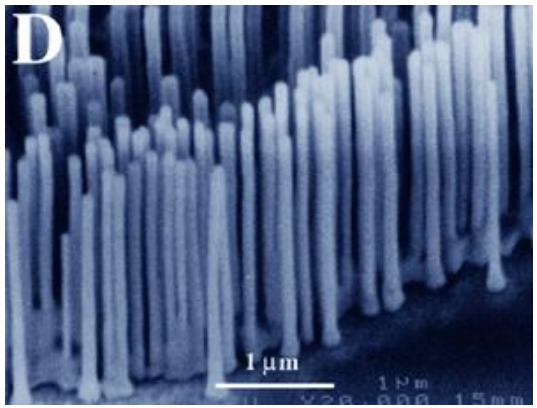



Optical lithography
Electron beam lithography
**Top-down approach**



Self-assembly of nanoparticles,
individual atoms, molecules
**Bottom-up approach**




Chemical deposition
**Bottom-up approach**

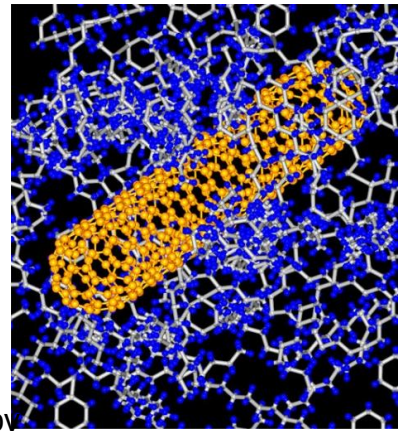
# Carbon Nanotubes in Engineering

## Composites

Polymer, ceramic or metal composites with CNT

Weight reduction and improved mechanical properties

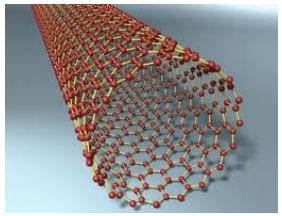
**Polymer-CNT composite simuation**



nasa.gov

**Polymer-CNT composites examples**

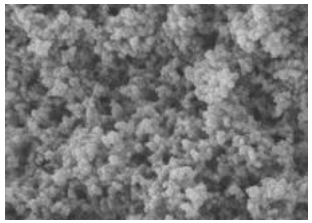
justmeans.com



**Zyvex Technologies vessel "Piranha"**

**Carbon fiber infused with CNT**
**Tensile strength 60 Gpa (60 x higher than steel)**

# Nanoporous Carbon



swissen.ch

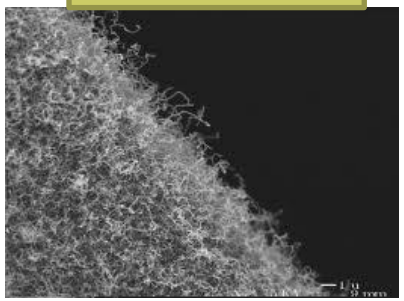
- **Supercapacitors**

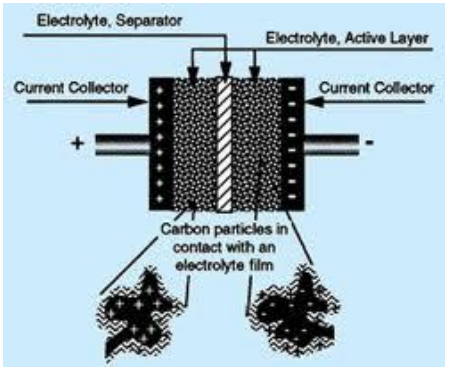
**Carbon aerogel, graphene, nanotubes**

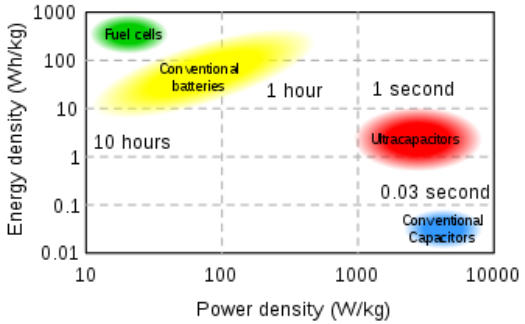
**High specific surface area**

**Huge power density**

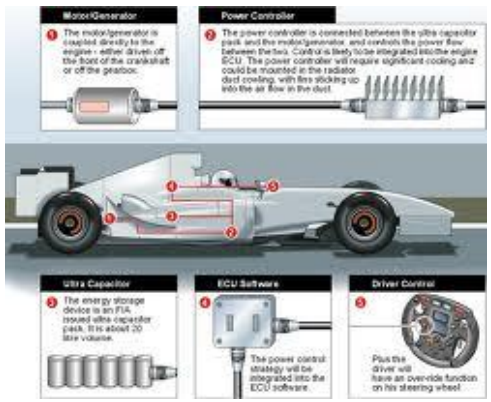
**CNT aerogel**






**Kinetic Energy Recover System:KERS system F1 cars**



**3000 F Capacitor**


stephenhobley.com

**Toyota Hybrid Race Car**

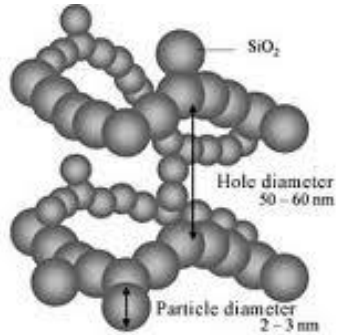
# Silicon aerogel

sennocao.com

- **Thermal insulation**

**Silica aerogel structure**

chem-eng.kyushu-u.ac.jp




**Highly porous material (nano-sized porous) just 3 times the density of the air**

**Lightweight and thermal insulation**

**Thermal insulation in space objects and clothes**

**Thermal and light control in buildings**

gsespace.com

architects24.com

**Thermal insulating panels**

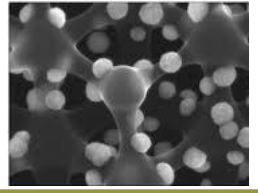
tradekey.com





International Council for Science

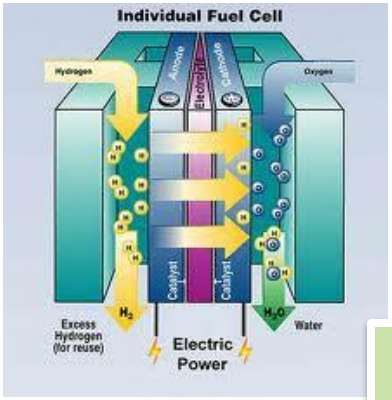
# Platinum nanostructures



ne.ucsd.edu

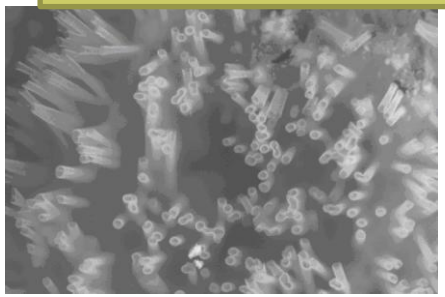
## Fuel Cells

**Increased electrode effective area**




optics.rochester.edu

**Platinum nanowires**



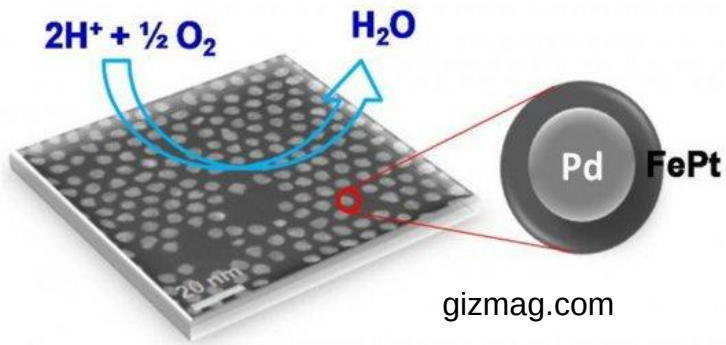
chem.stonybrook.edu

**Improved catalytic capability**

**Pt nanowires can increase the area and mass specific activities of 0.77 mA/cm$^2$ and 1.83 A/mg$_{Pt}$, respectively.**

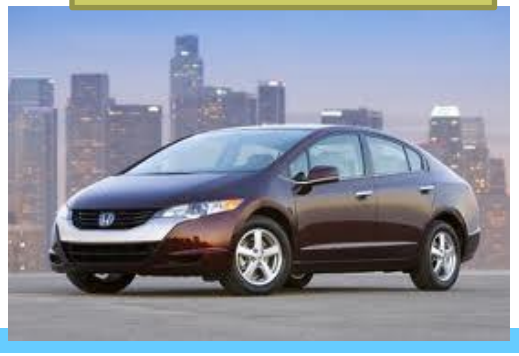
**Reduce Pt amount and/or cell size**

**FC concept**

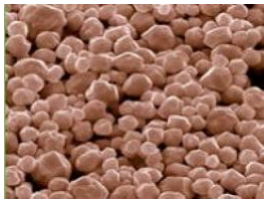



gizmag.com


**Honda electric car**



# Metallic nanoparticles: Reinforcement



printedelectronicsworld.com

## Steel reinforcement

**Reduces surface unevenness**

**Limits the number of stress risers**

**Reduced fatigue cracking**

**Cu reinforced steel**

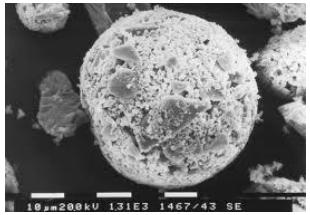
**V or Mo reinforced bolts**

**Improve the delayed fracture problems associated with high strength bolts**

**Increased safety, less need for monitoring and more efficient materials in constructions prone to fatigue issues. Structural integrity at temperatures up to 1000 F (with regular steel this happens for 750 F) combined with good formability, corrosion resistance and good surface finishing.**

# Inorganic nanoparticles

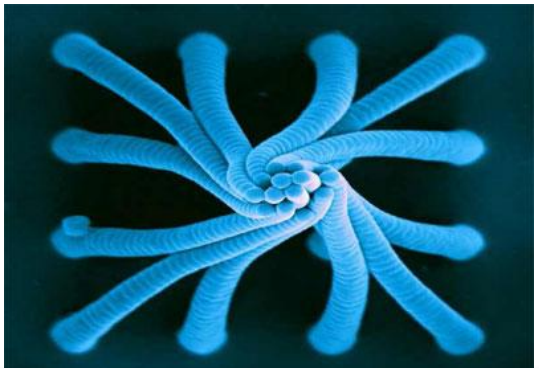
mtm.kuleuven.be



## Additives to lubricants

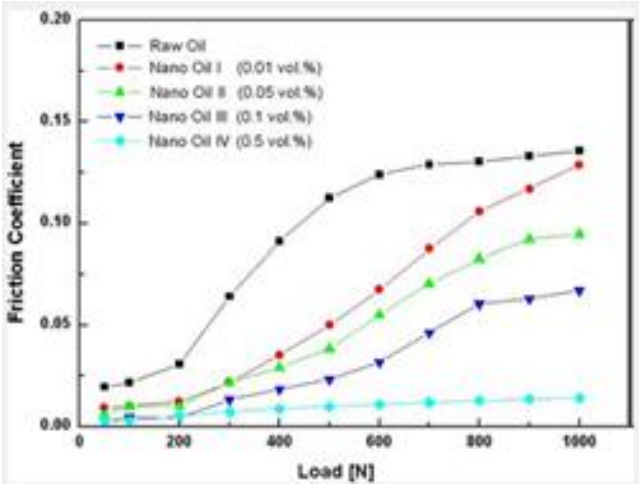
**Tungsten disulphide fullerene**

nanoprom.it



**Small and stable lubricant particles**

**Reduced wear**



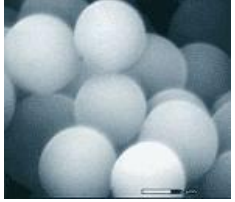

tech-star.it

**Reduced friction, noise, heat and vibration results in reduced energy consumption and decreased air pollution**

**High performance lubricants**

# Inorganic nanoparticles: Buildings

## Concrete reinforcement



capitalhplc.com

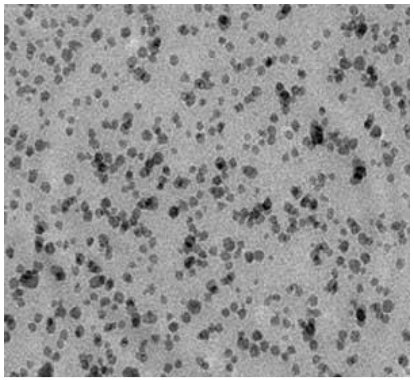
**Densification of the micro and nanosctructure**

**$TiO_2$ is a white pigment that can be used as an excellent reflective coating. Surfaces with self-cleaning properties due to its hydrophilic behavior.**

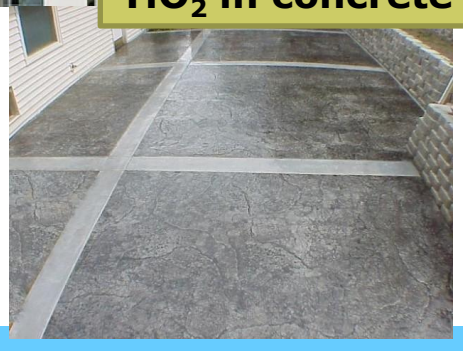
**Improved mechanical properties.**

**TEMPLE OF NANOSCIENCE**
**Rome's Dio Padre Misericordioso Church**

**Silica nanoparticles in concrete**



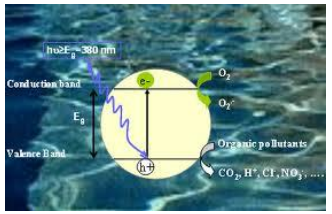
**$TiO_2$ in concrete**



**Nano-silica also helps to control the degradation of the calcium-silicate hydrate reaction of concrete caused by calcium leaching in water, as well as block water penetration, leading to improvements in durability.**

# Inorganic nanoparticles: Cleaning

- **Self-cleaning surfaces**



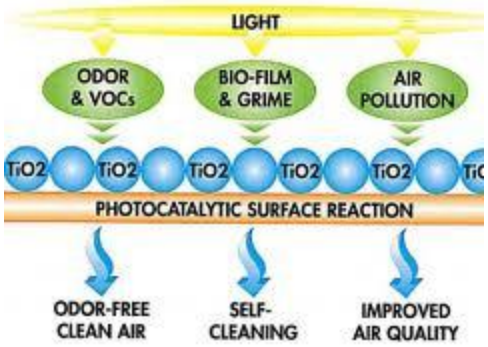

uab.es

**$TiO_2$ nanoparticles**

**Sterilizing and anti-fouling properties**

**Hydrophilic nature allows to form sheets out of raindrops, washing off the dirty particles broken down in the previous process.**

surfacesolutions.com





**Particles catalyze powerful reactions breaking down organic pollutants, volatile organic compounds and bacterial membranes.**

# Inorganic nanoparticles: S Windows

- **Glazing** ($WO_3$, $V_2O_5$,...)

**Chromogenic properties**

**Light transmittance control**

**Electrochromic technologies**

**React reversibly to changes in applied voltage, thereby becoming more opaque at the touch of a button.**

**Photochromic technologies**

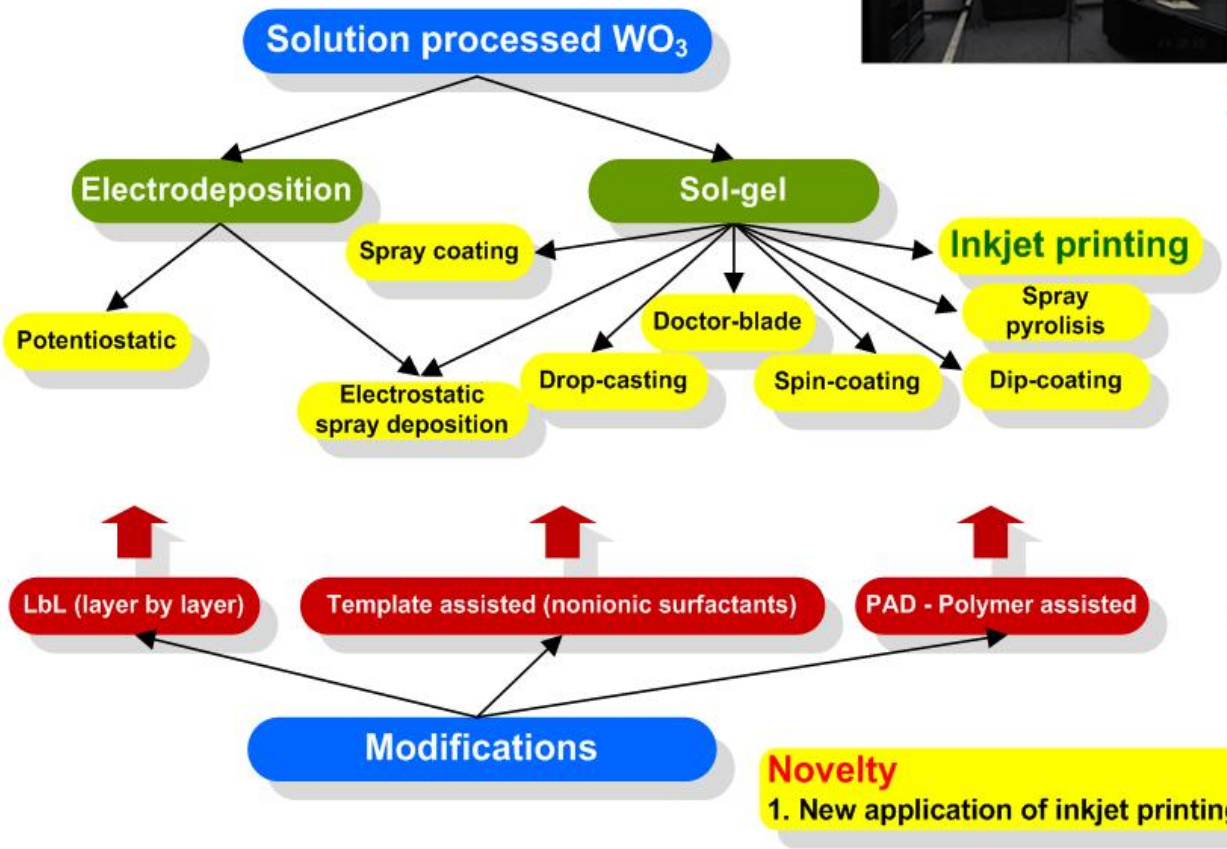
onestepahead.com

**Structures that react to changes in light intensity, changing reversibly their color.**

# Examples of nanoparticles formulation

## Solution-processed $WO_3$

**Electrochromism** is a persistent but reversible optical change produced electrochemically in selected thin films compounds.





Canon Thermal DOD (FINE)™


Piezo MEMS DOD Glass & Silicon

**Novelty**
1. New application of inkjet printing

# Electrochromic ink formulation

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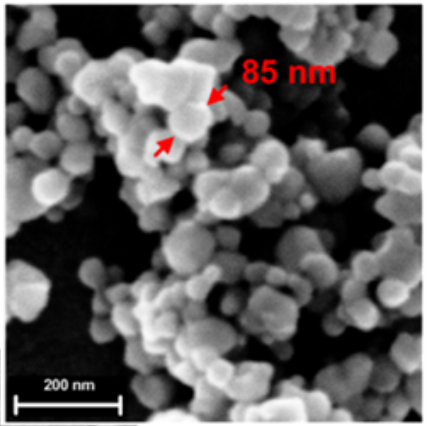
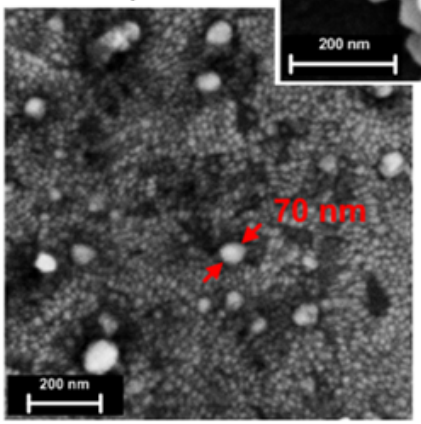
# Electrochromic ink formulation

SEM - $WO_3$ *yellow* nanopowder




SEM – $WO_{2.9}$ *blue* nanopowder




**Why dual-phase is better than amorphous?**

1. Better chemical stability
2. Superior electrochromic performance
3. Better cyclic stability

**Printable sol**
**PTA**
**+**
**$WO_X$ nanopowder**

$WO_X$ nanopowder

dual-phase *a*-$WO_3$/$WO_X$ film

Inkjet Printing

Annealing 120 C

**Tungsten metal powder** → $H_2O_2$ → **Peroxotungstic acid (PTA)**

$WO_3$ precursor preparation (State-of-the-Art)

Oxalic Acid
$H_2O$
Isopropyl alcohol

**Printable $WO_3$ precursor**

Inkjet Printing

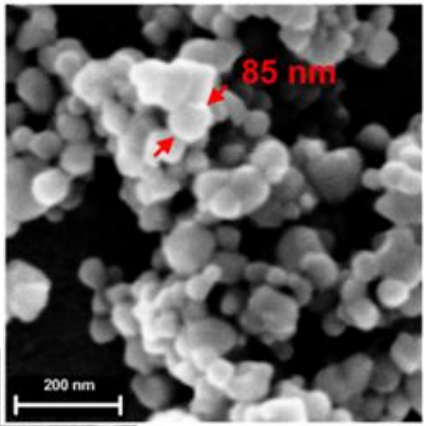
**$WO_3$ gel film**

Annealing 120 C

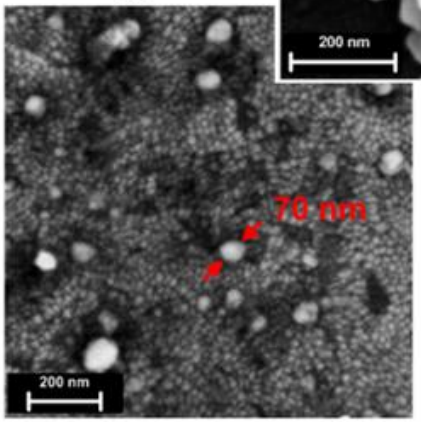
**Amorphous *a*-$WO_3$ film ($WO_3 \cdot aH_2O \cdot bH_2O_2$)**

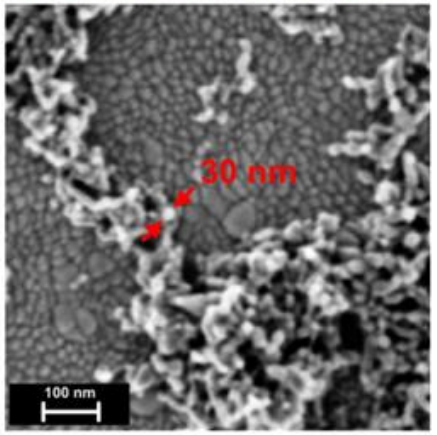
# Electrochromic ink formulation

SEM - $WO_3$ *yellow* nanopowder




SEM – $WO_{2.9}$ *blue* nanopowder




SEM – $TiO_2$ nanopowder

dual-phase *a*-$WO_3$/$TiO_2$/$WO_X$ film

Inkjet Printing
Annealing 120 C

Printable sol
PTA
+
$WO_X$ nanopowder

$WO_X$ nanopowder

$TiO_2$ nanopowder

Printable sol
PTA
+
$TiO_2$ nanopowder

Tungsten metal powder → $H_2O_2$ → Peroxotungstic acid (PTA)

$WO_3$ precursor preparation (State-of-the-Art)

Oxalic Acid
$H_2O$
Isopropyl alcohol

Printable $WO_3$ precursor

Inkjet Printing

$WO_3$ gel film

Annealing 120 C

Amorphous *a*-$WO_3$ film ($WO_3 \cdot aH_2O \cdot bH_2O_2$)

**Novelty**
**1. Mixture composition**



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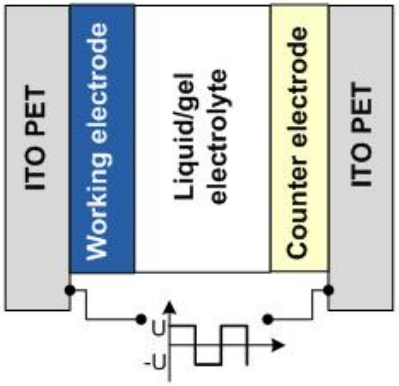
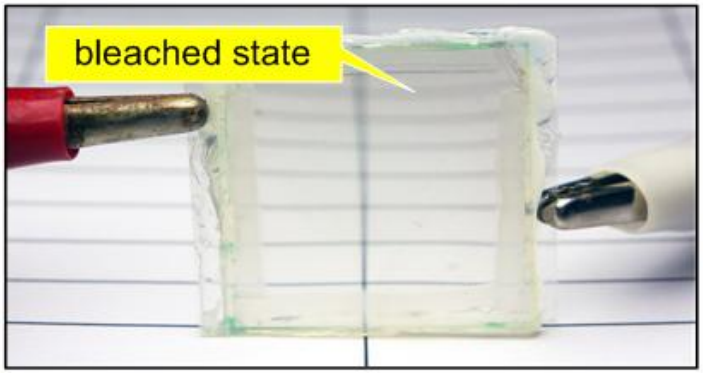
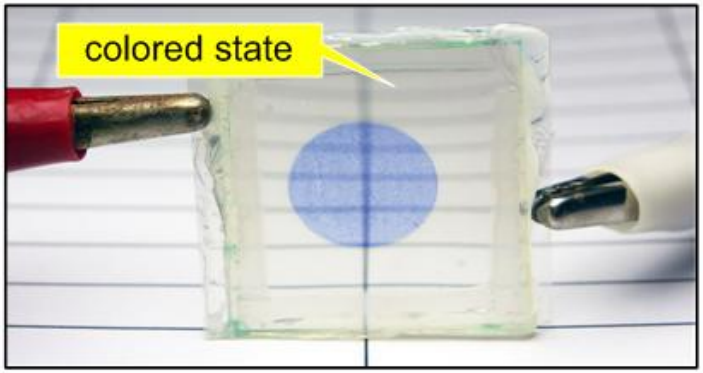
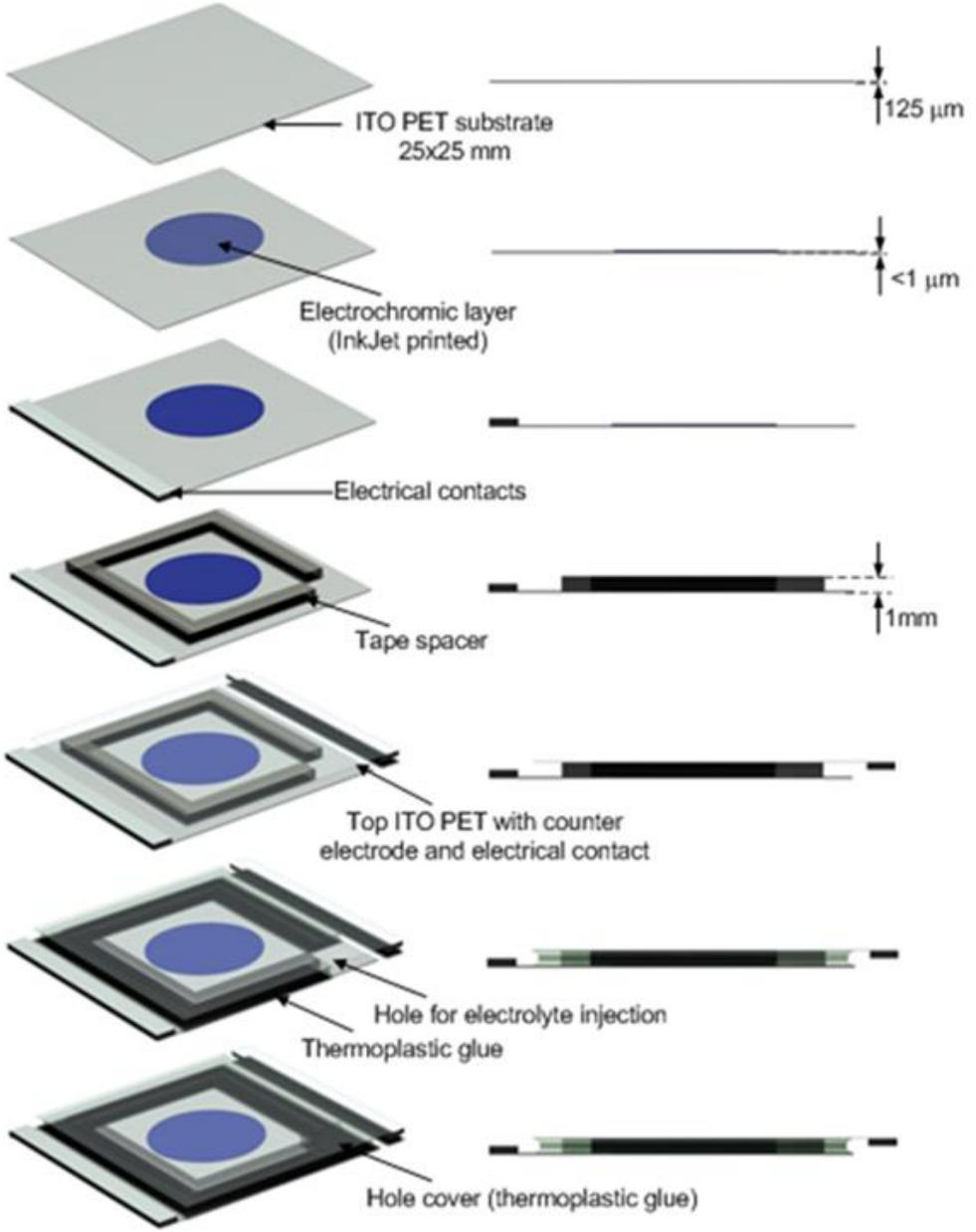
# Encapsulation

**EC performance was measured in device**



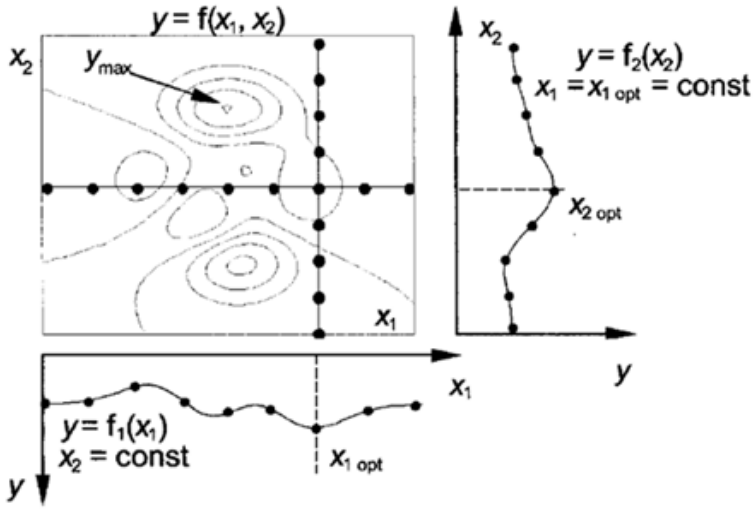



# Methodology -classically

## Factors to be studied:

$w_{PTA}$ - Peroxotungstic Acid content;
$w_{OAD}$ - Oxalic Acid content;
$w_{TiO2}$ - amount of $TiO_2$ nanoparticle dispersion;
$w_{WOX}$ - amount of $WO_X$ nanoparticle dispersion;
$WO_X$ - stoichiometry of tungsten oxide nanoparticles;
$w_{iso/water}$ - base solution content.

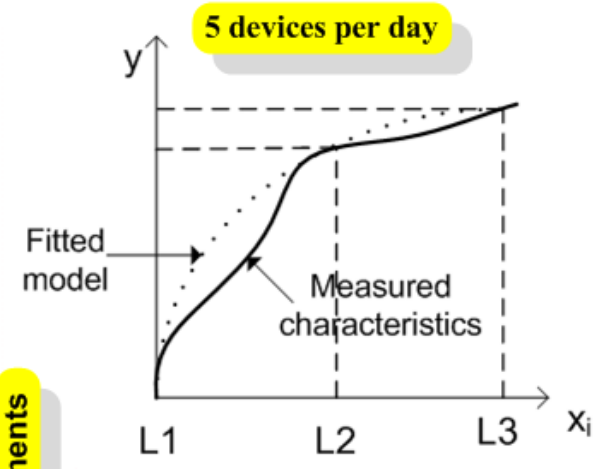
**Monoselective method**



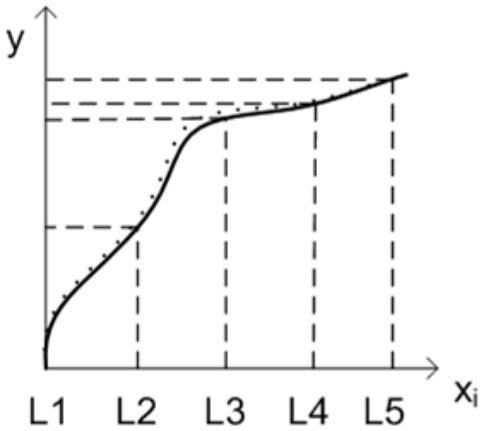

For $L=3$
$n = 2(3 + (5-1)(3-1)) = \boxed{22}$
$t \approx \boxed{5\ days}$

For $L=5$
$n = 2(5 + (5-1)(5-1)) = \boxed{42}$
$t \approx \boxed{9\ days}$

**Complete measurements**




For $L=3$
$n = L^p = 3^5 \cdot 2 = \boxed{486}$
$t \approx \boxed{4.8\ months}$




For $L=5$
$n = L^p = 5^5 \cdot 2 = \boxed{6250}$
$t \approx \boxed{5.1\ years}$

# Methodology -classically

## Factors to be studied:

$w_{PTA}$ - Peroxotungstic Acid content;
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$w_{TiO2}$ - amount of $TiO_2$ nanoparticle dispersion;
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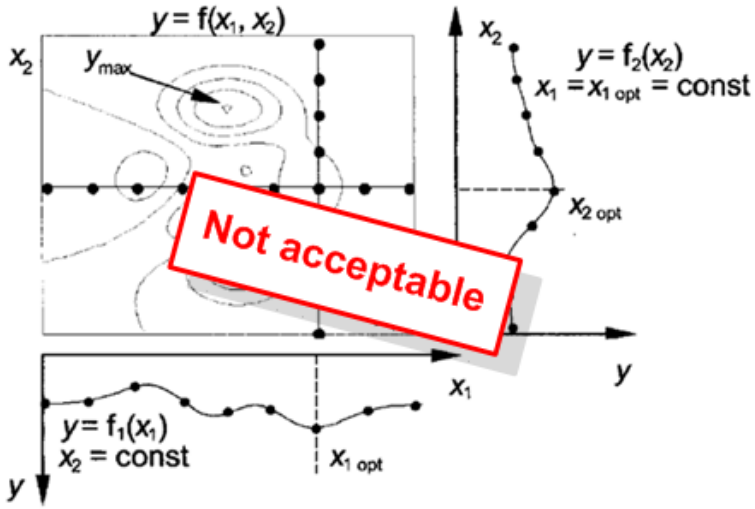


For $L=3$
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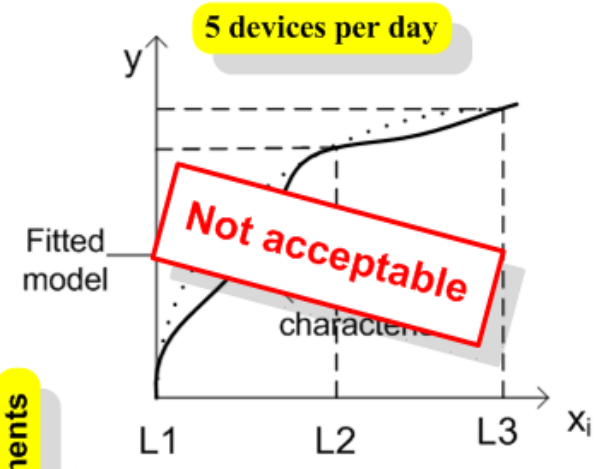
**Complete measurements**

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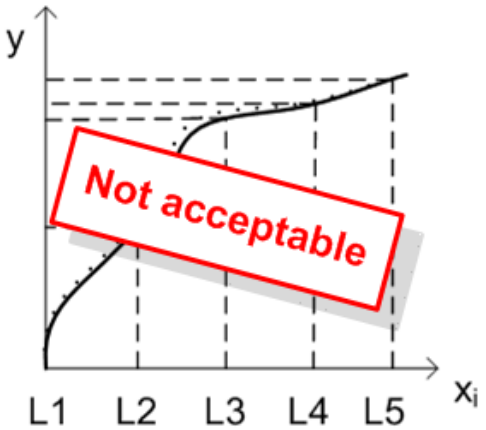
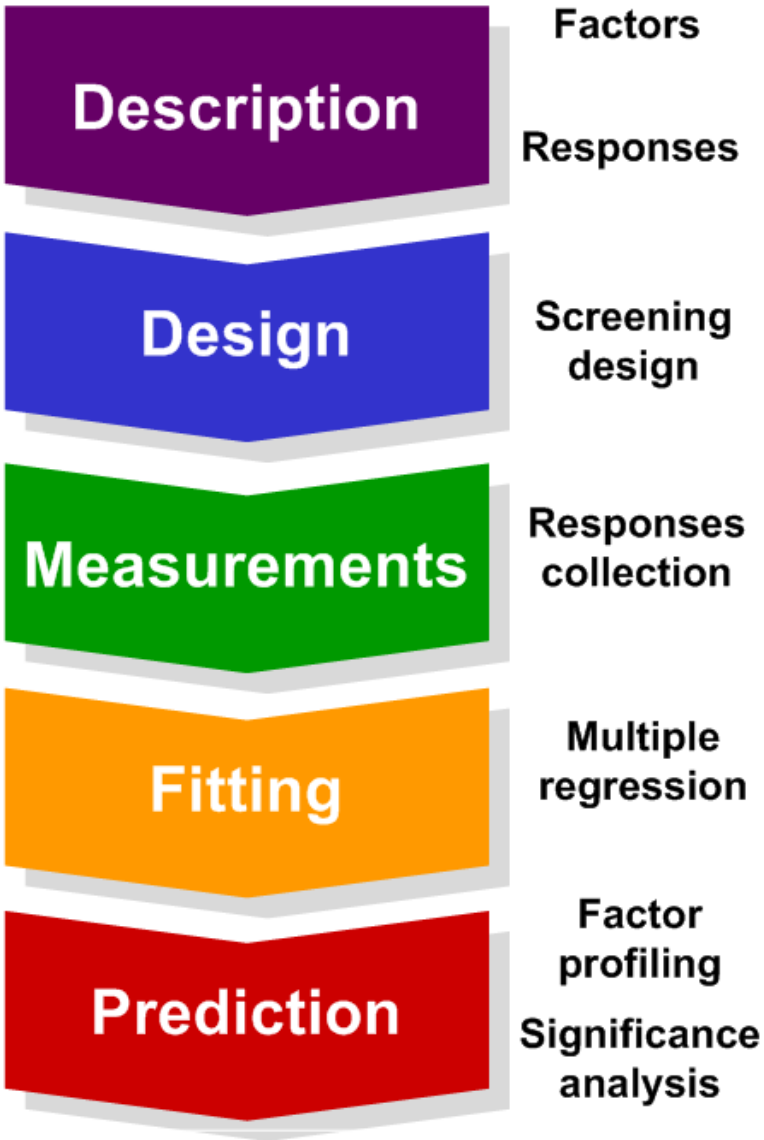



For $L=5$
$n = L^p = 5^5 \cdot 2 = \boxed{6250}$
$t \approx \boxed{5.1\ years}$

# Methodology -Design of Experiment (DOE)




Supported by SAS JMP software

**Novelty**

1. Sophisticated statistical technique applied to complex electrochromic studies

# Design of Experiment

**Description**

**Factors**
- mixture components (continuous factors);
- type of particles (categorical factors);

**Responses**
- mechanical, optical and electrical properties of EC layer;
- fluid (ink) parameters;

**Design**

**Screening design**
- determination of mixture formulations for all devices in a test;

**D-Optimal designs are most appropriate for screening experiments because the optimality criterion focuses on precise estimates of the coefficients**

**Recipes for 30 mixtures (30 devices)**

**Measurements**

**Responses collection**
- measurements of responses for each device;

# Design of Experiment -mathematical model

## Fitting

**Multiple regression**

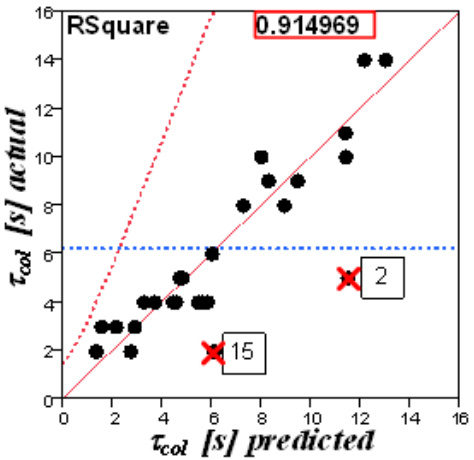
- computing the best fit of mathematical model to collected data;

$$y = f(x_1, x_2, \ldots, x_p) + \varepsilon$$

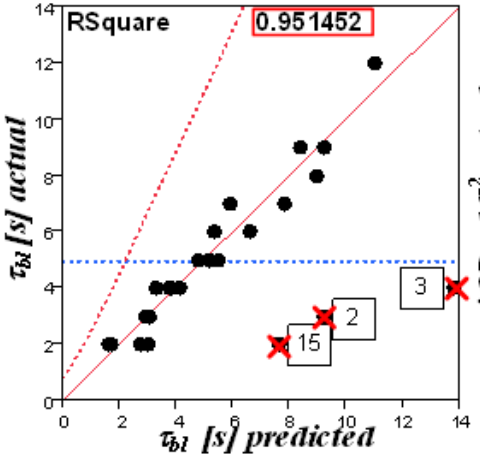
**First order polynomial function**

$$y = a_0 + \sum_{i=1}^{p} a_i x_i + \sum_{i=1}^{p} \sum_{j=i+1}^{p} a_{ij} x_i x_j + \varepsilon$$

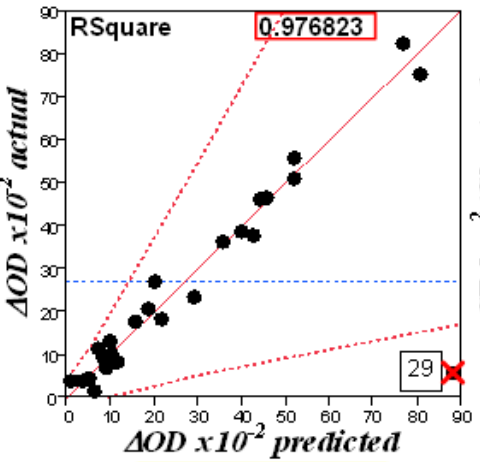
$a_i x_i$ – main effect; $a_{ij} x_i x_j$ - interaction components effect



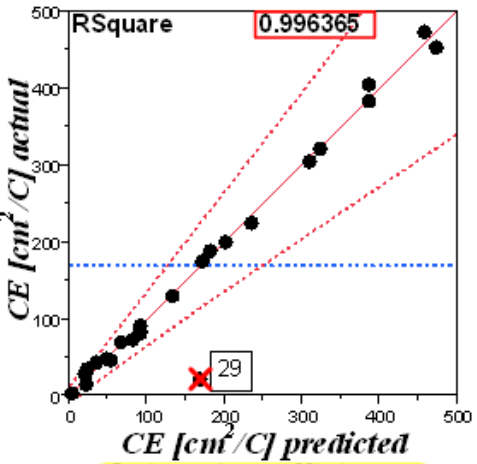

Coloration time




Bleaching time




Optical density




Coloration efficiency

## Prediction

**Factor profiling**

- finding the best factor setting for on-target responses and minimum variability;



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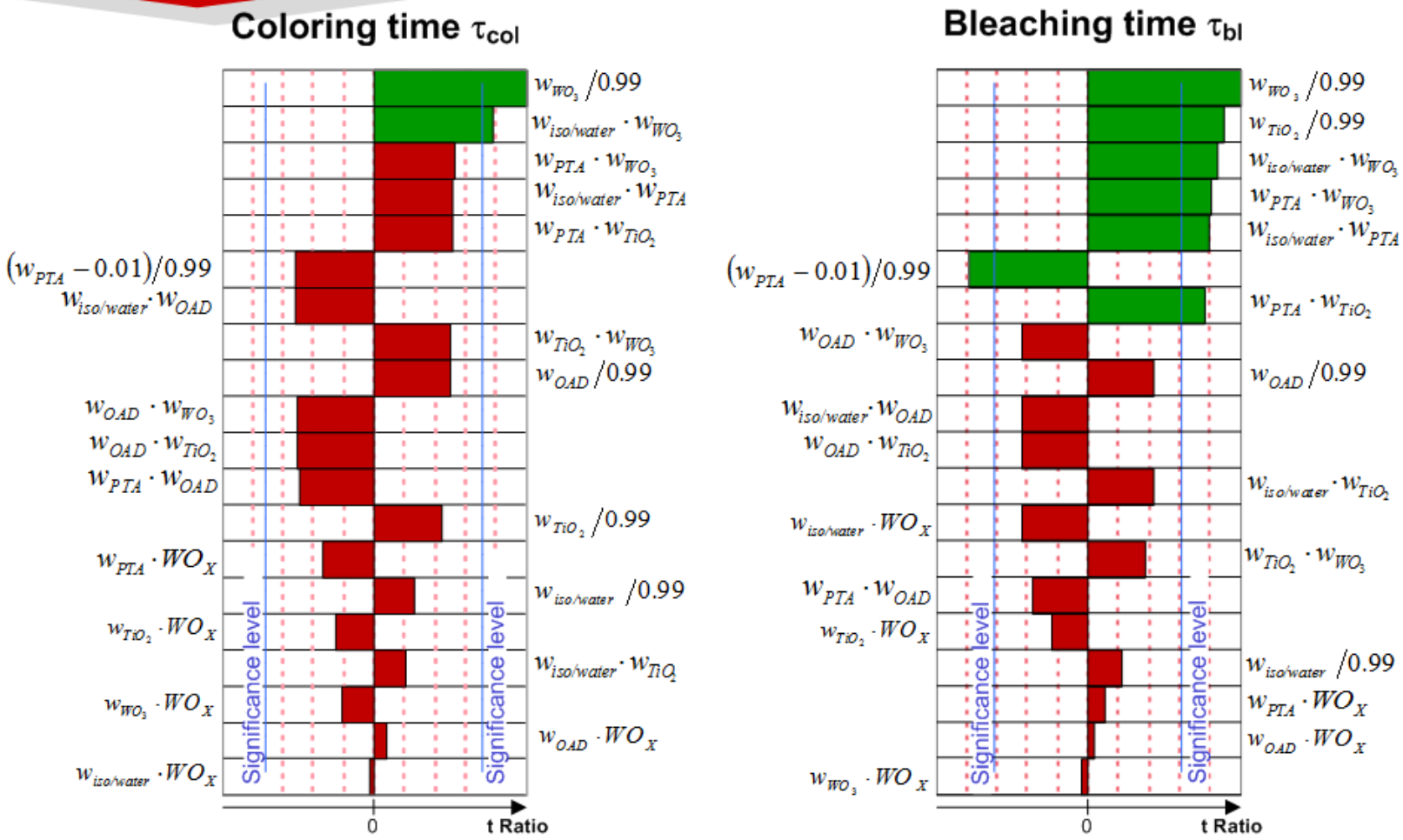
# Design of Experiment -significance analysis

**Prediction**

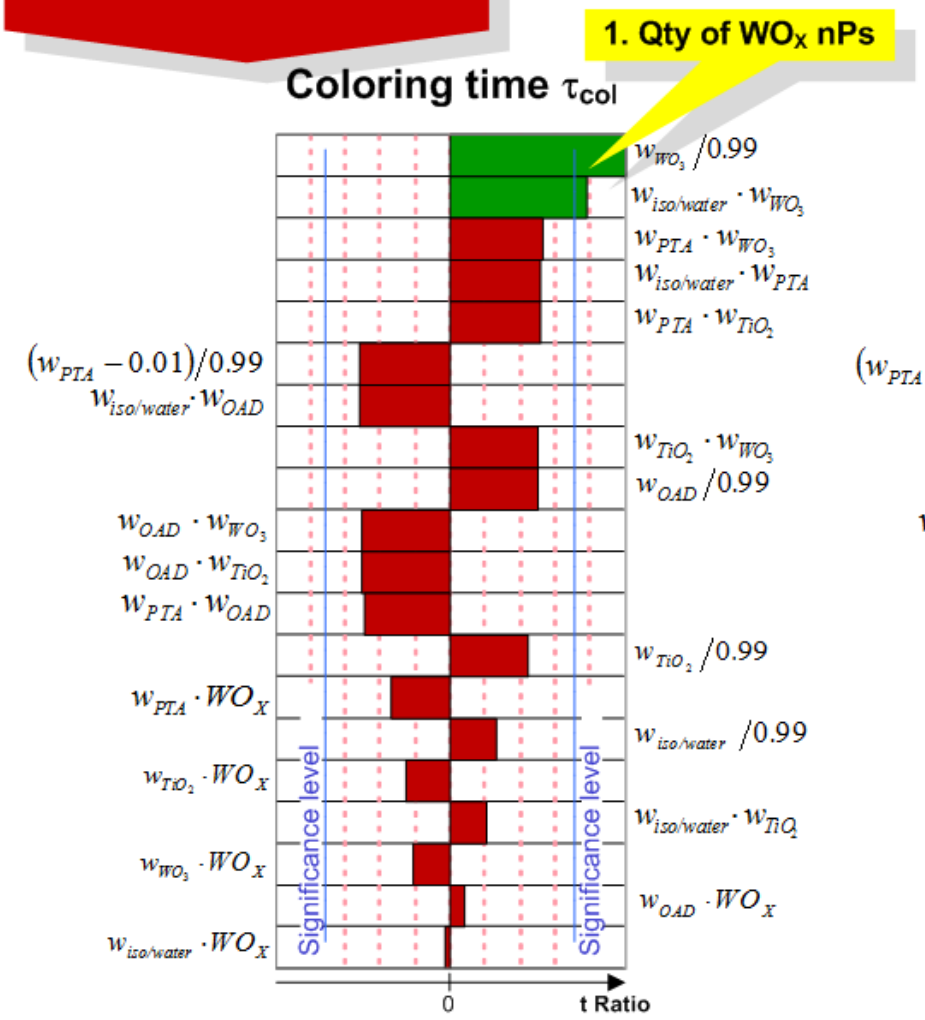
**Significance analysis** ▪ examination of many factors to see which have the greatest effect on the response

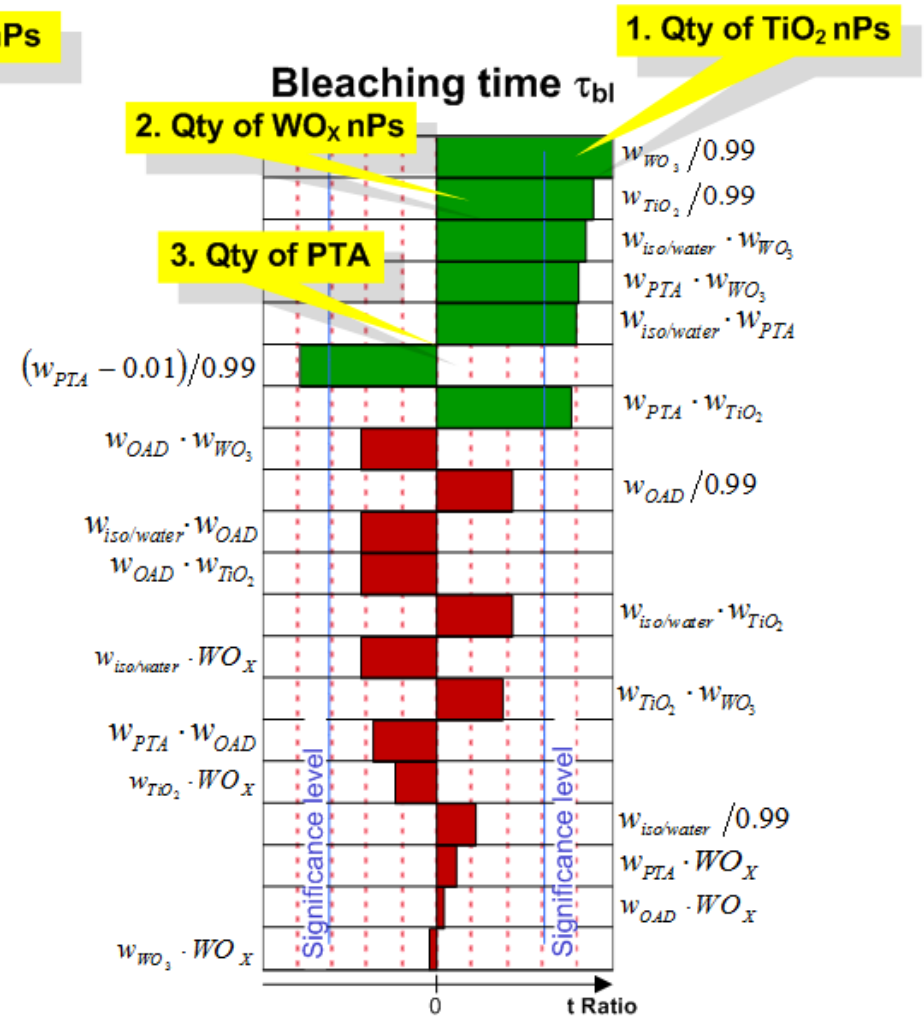


# Design of Experiment -significance analysis

**Prediction**

**Significance analysis** ▪ examination of many factors to see which have the greatest effect on the response



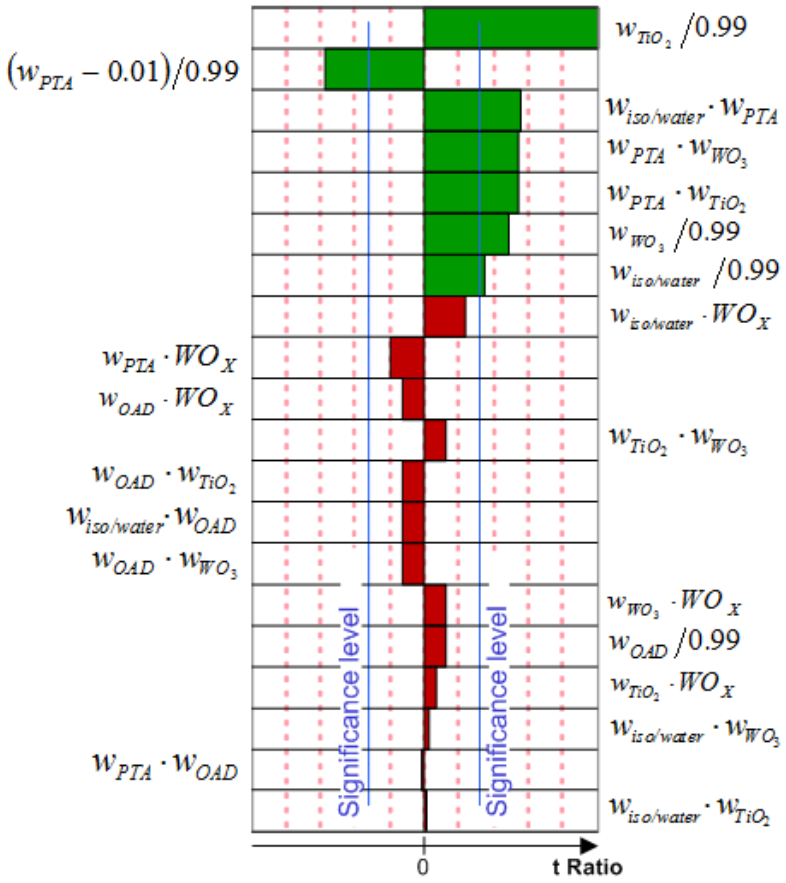



# Design of Experiment -significance analysis

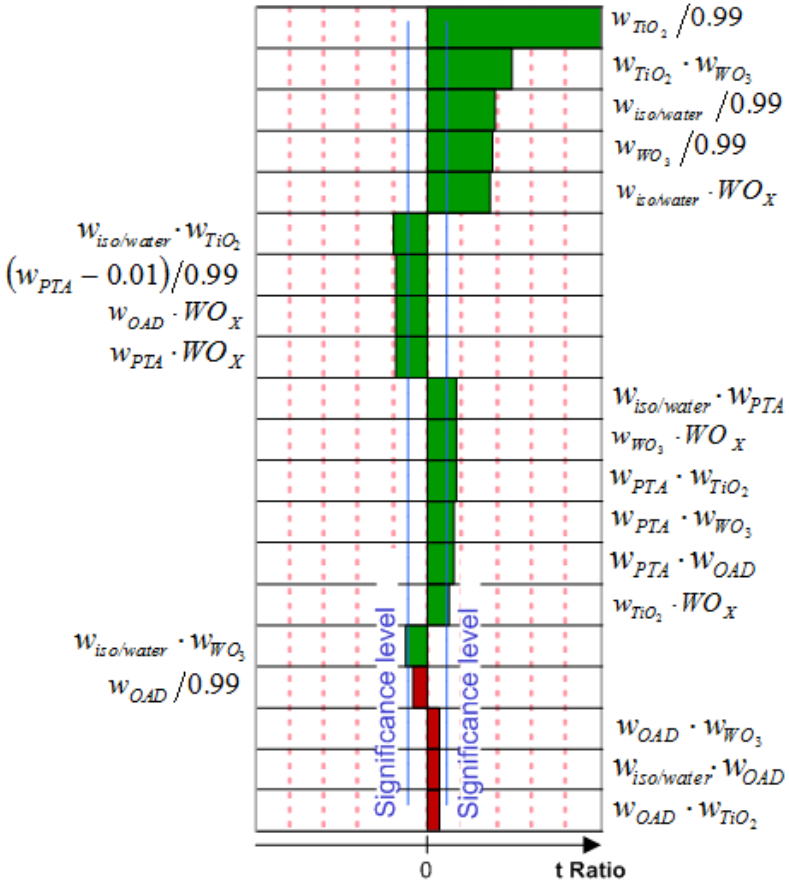
**Prediction**

**Significance analysis** ▪ examination of many factors to see which have the greatest effect on the response

## Optical density (*OD*)




## Coloration efficiency (CE)



# Design of Experiment -significance analysis

**Prediction**

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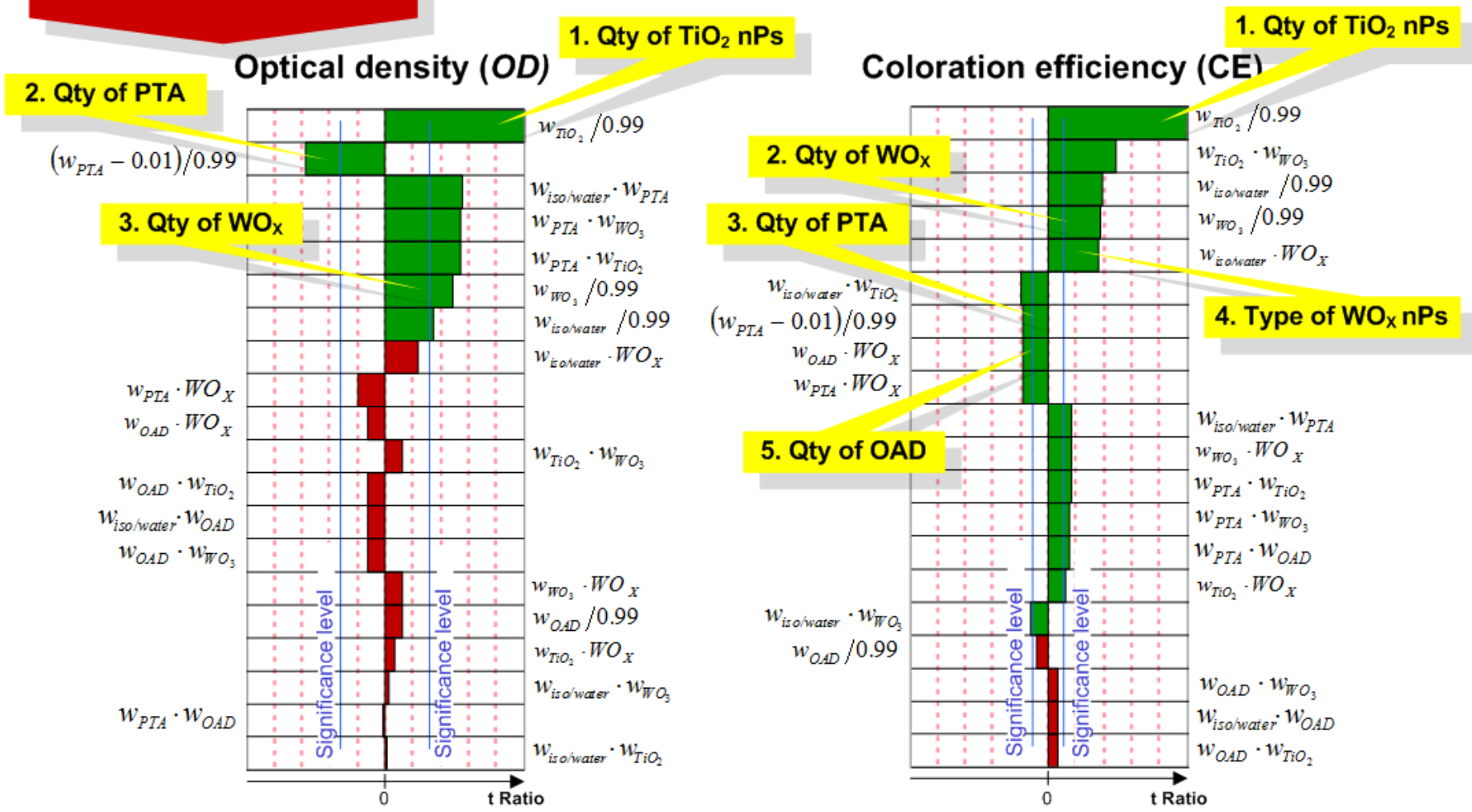
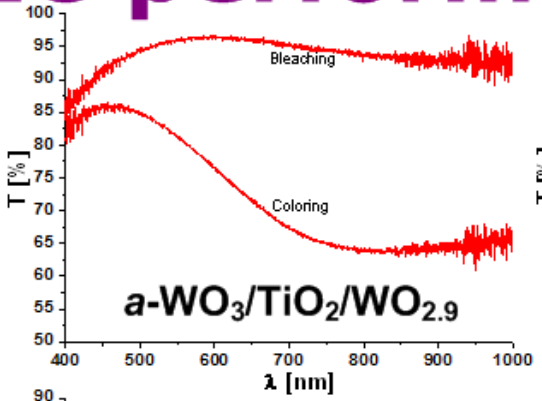
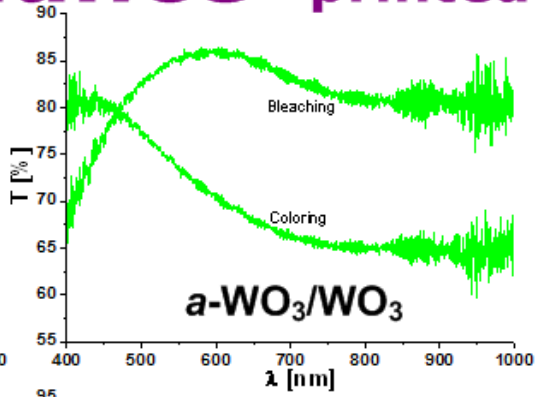
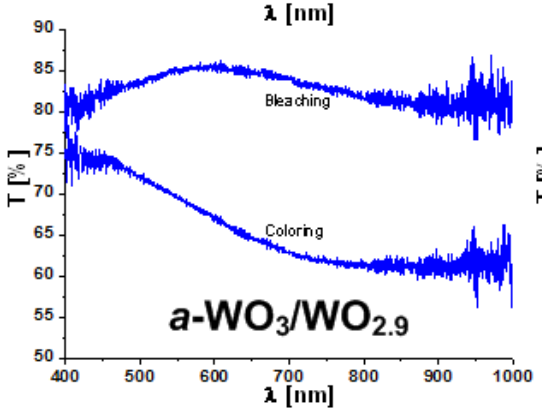
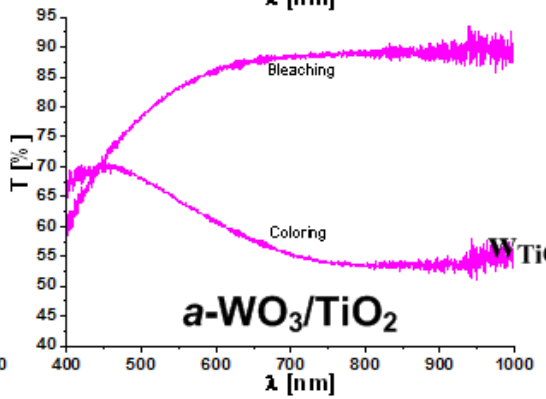


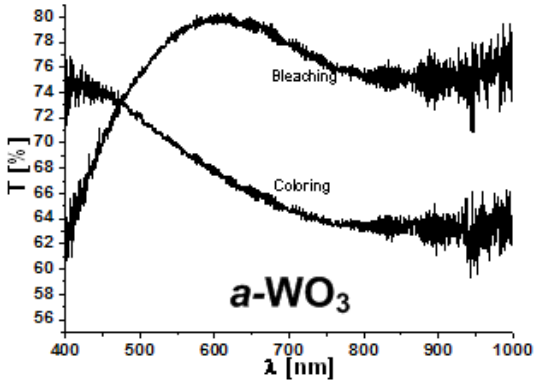
# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films



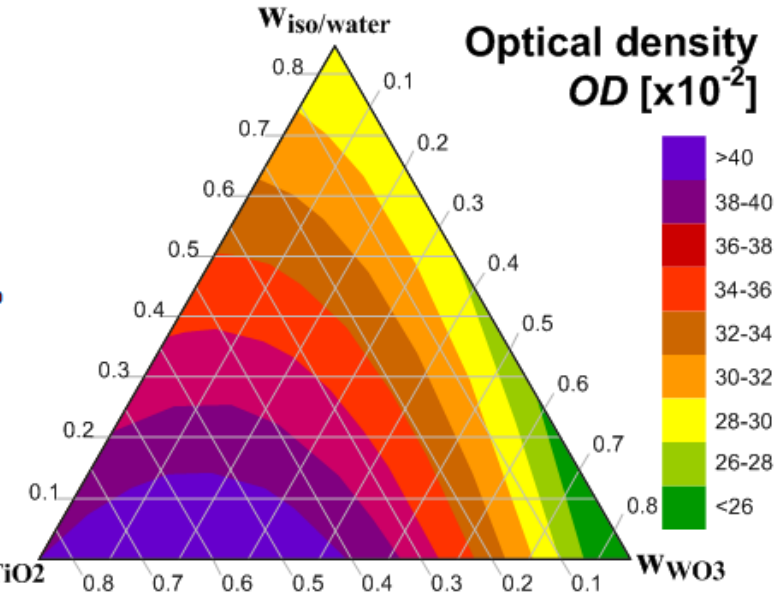



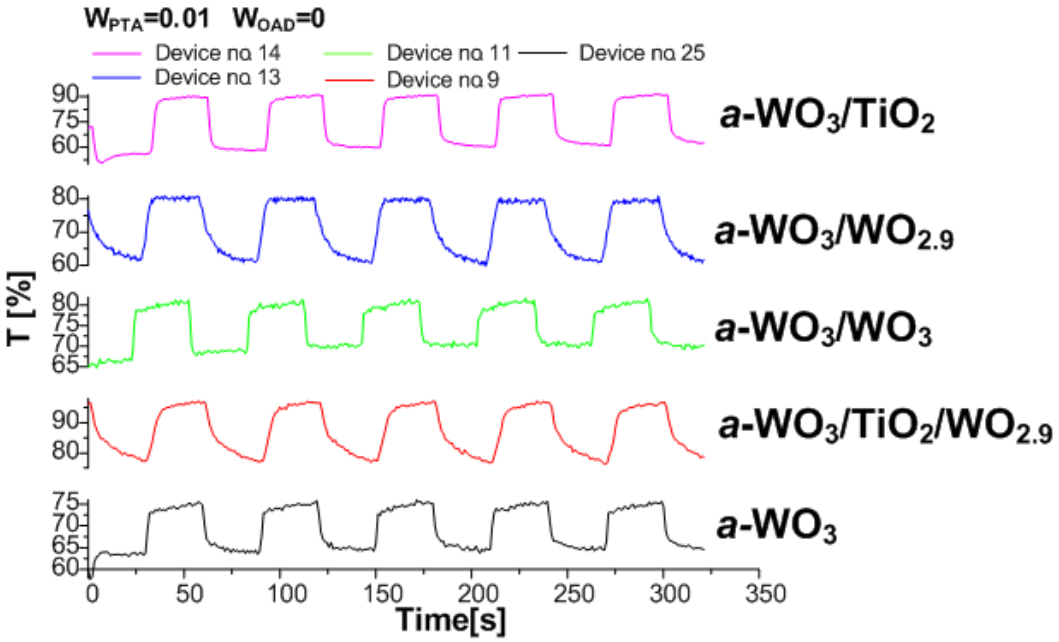

**Transmission modulation spectra**

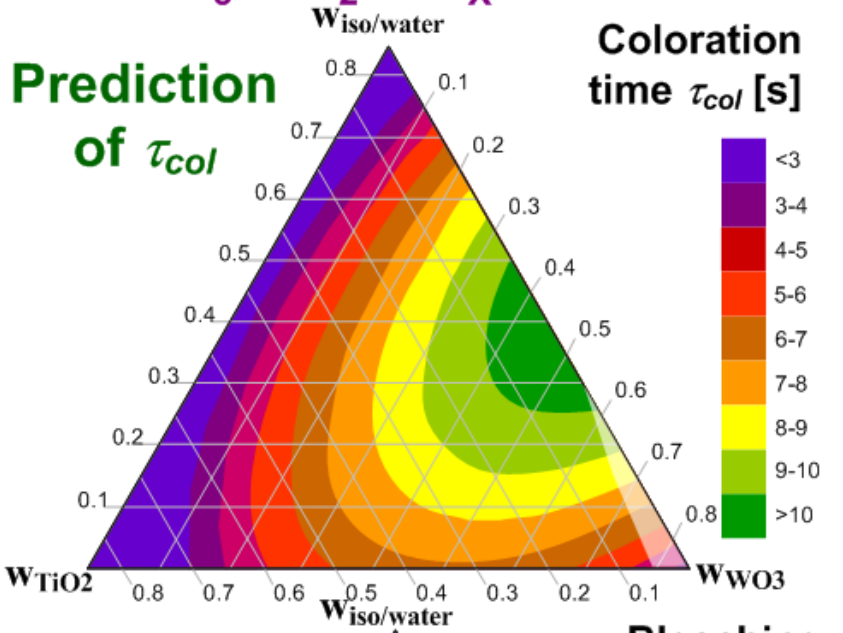


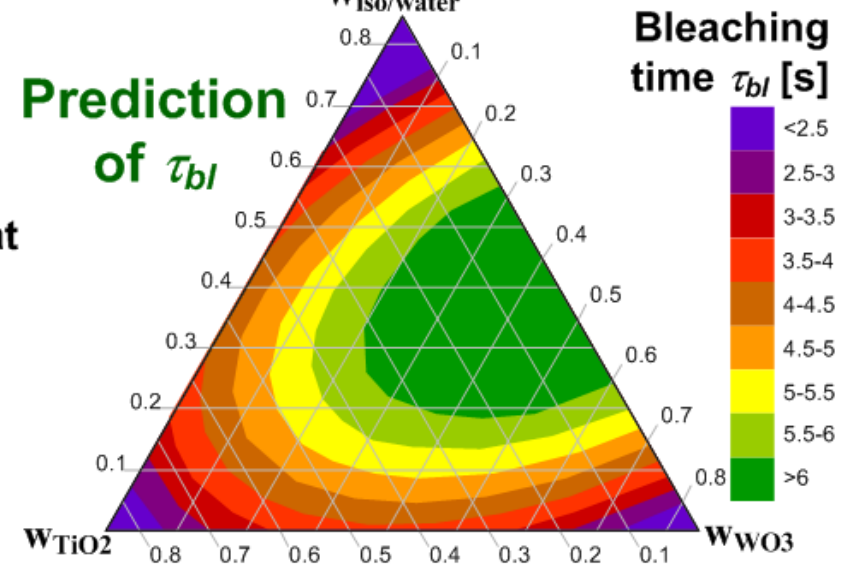

## Prediction of *OD*

$$OD = ln\left(\frac{T(t_1,\lambda)}{T(t_2,\lambda)}\right)$$

# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films



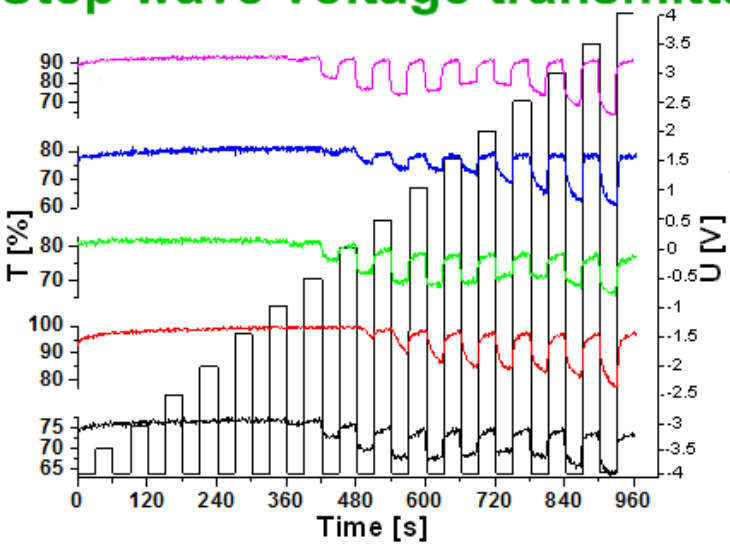




**Color-bleached characteristics** recorded at 900 nm under a square wave potential of 4V at a frequency of 0.016 Hz in a first 5 cycles.

# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films

## Step wave voltage transmittance




*a*-$WO_3/TiO_2$

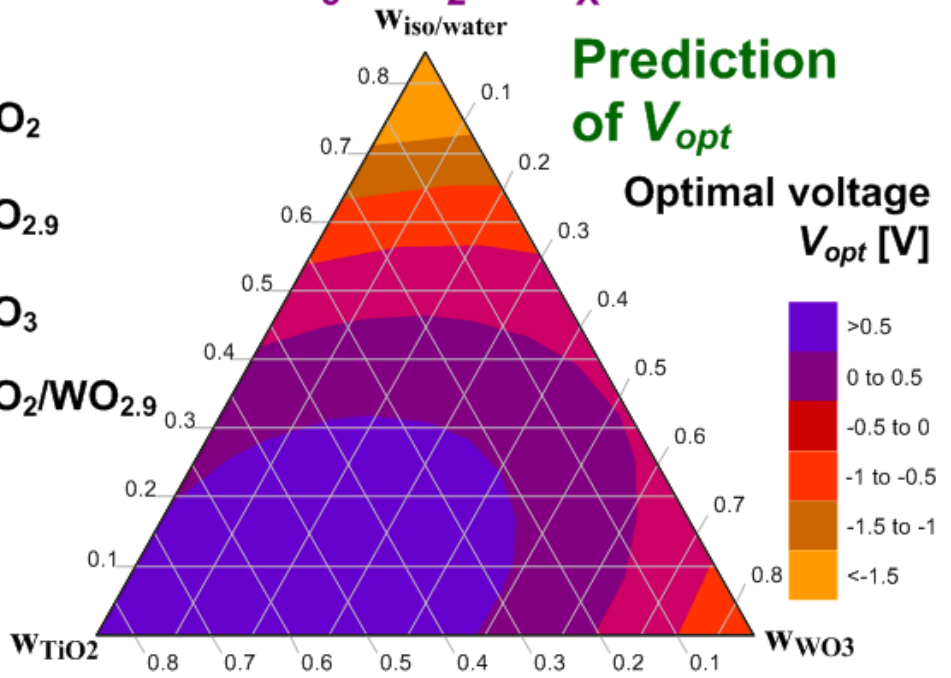
*a*-$WO_3/WO_{2.9}$

*a*-$WO_3/WO_3$

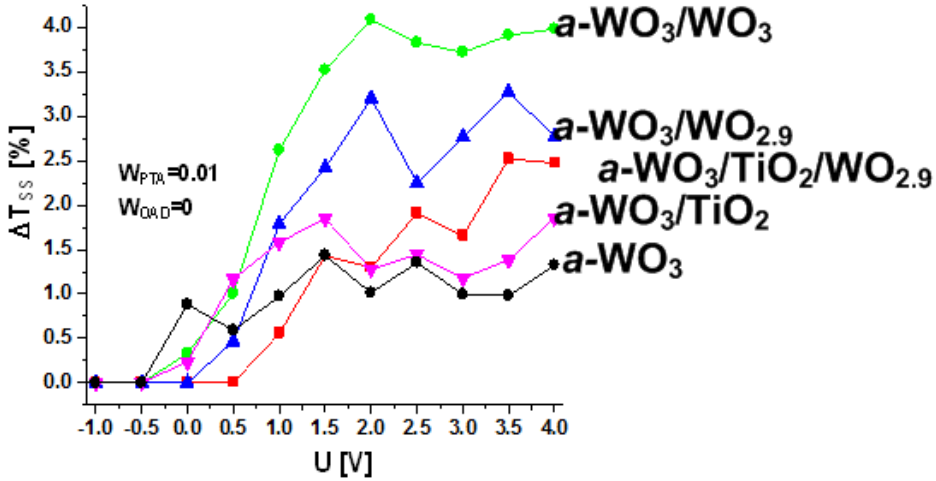
*a*-$WO_3/TiO_2/WO_{2.9}$

*a*-$WO_3$

## Prediction of $V_{opt}$




## Site saturation




*a*-$WO_3/WO_3$

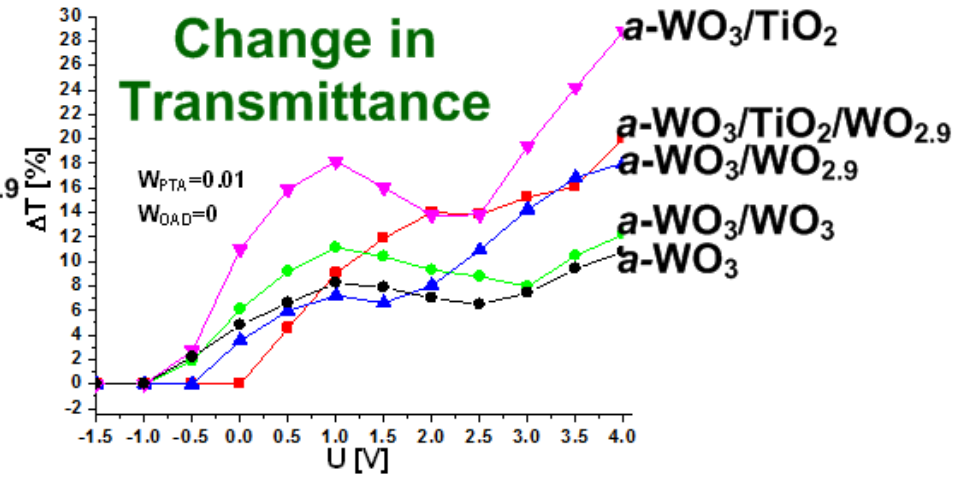
*a*-$WO_3/WO_{2.9}$

*a*-$WO_3/TiO_2/WO_{2.9}$

*a*-$WO_3/TiO_2$

*a*-$WO_3$

## Change in Transmittance




*a*-$WO_3/TiO_2$

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*a*-$WO_3$

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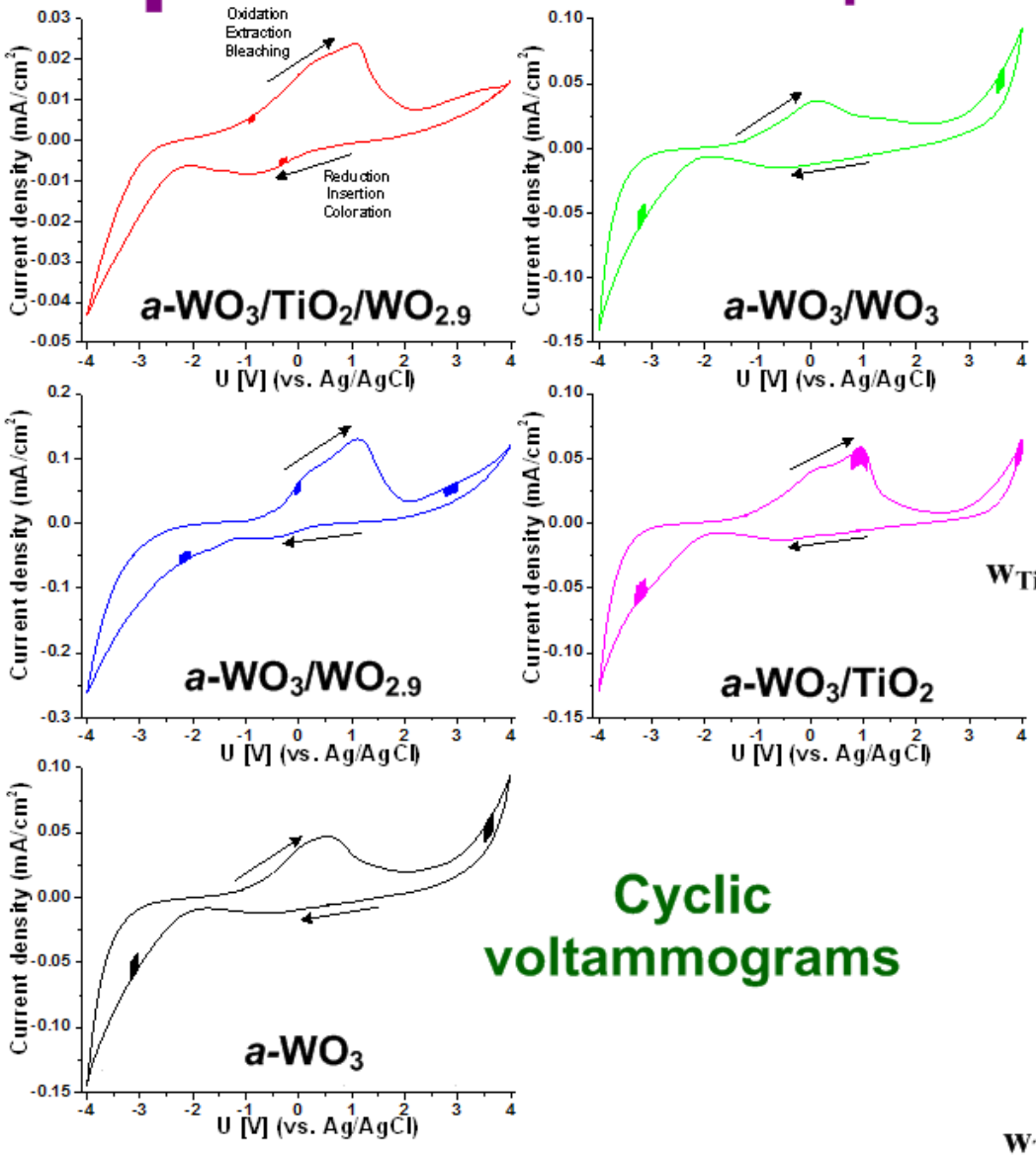
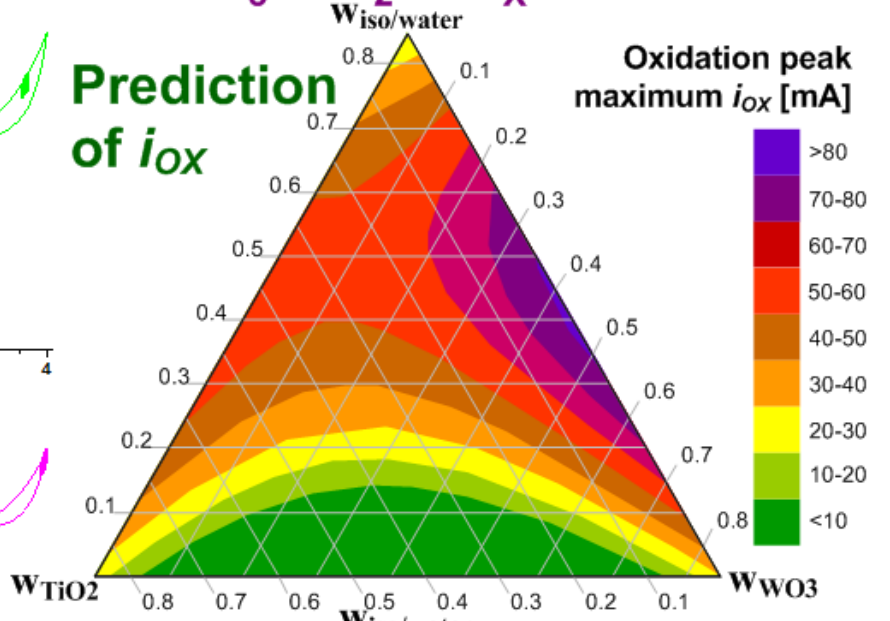
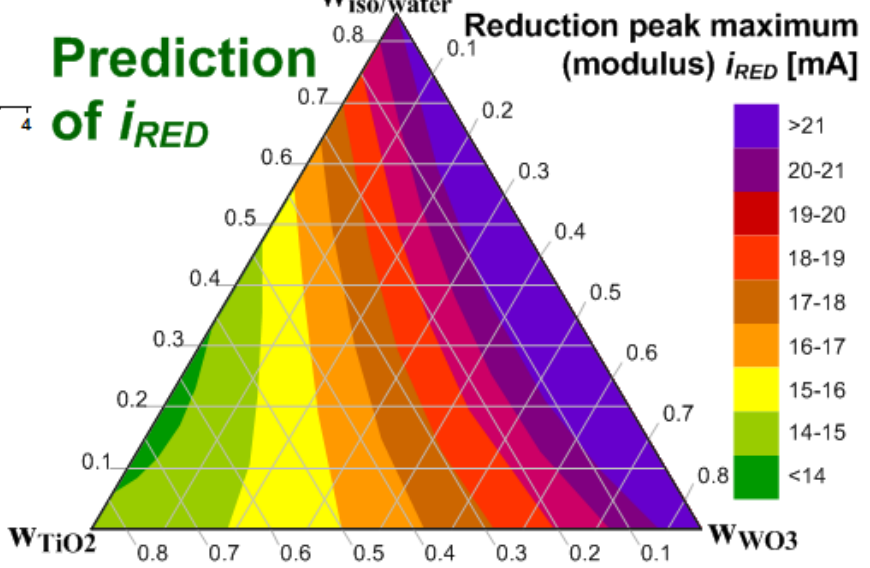



**Cyclic voltammograms**

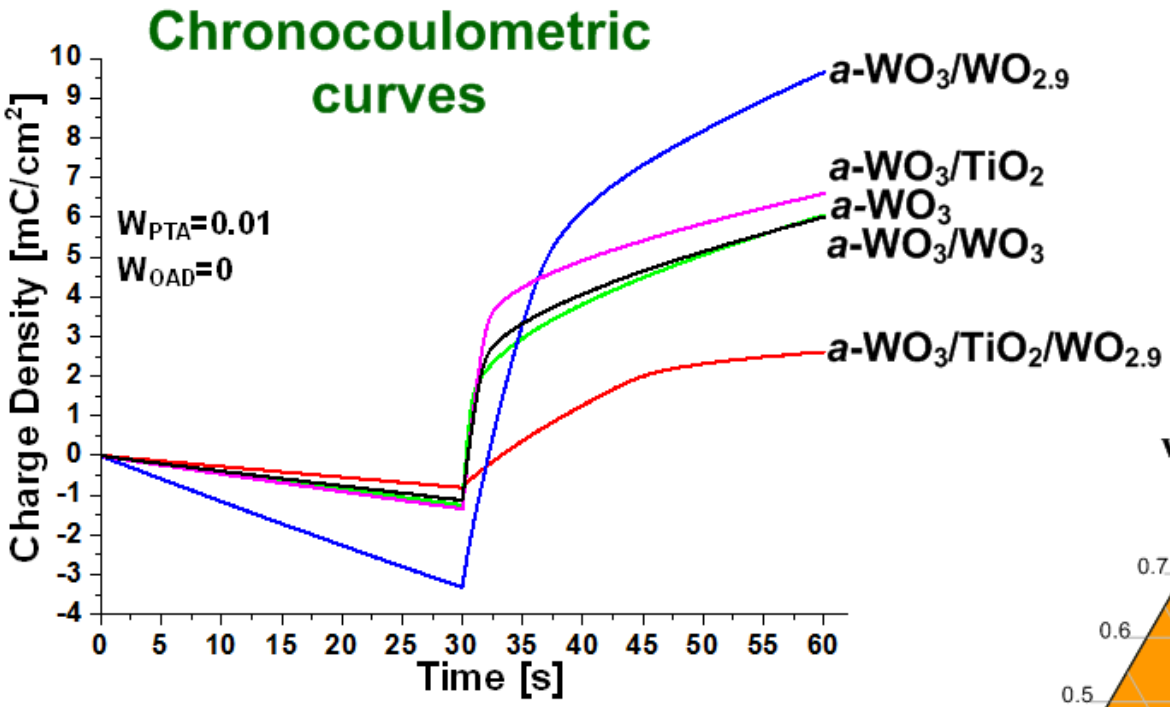
**Prediction of $i_{OX}$**

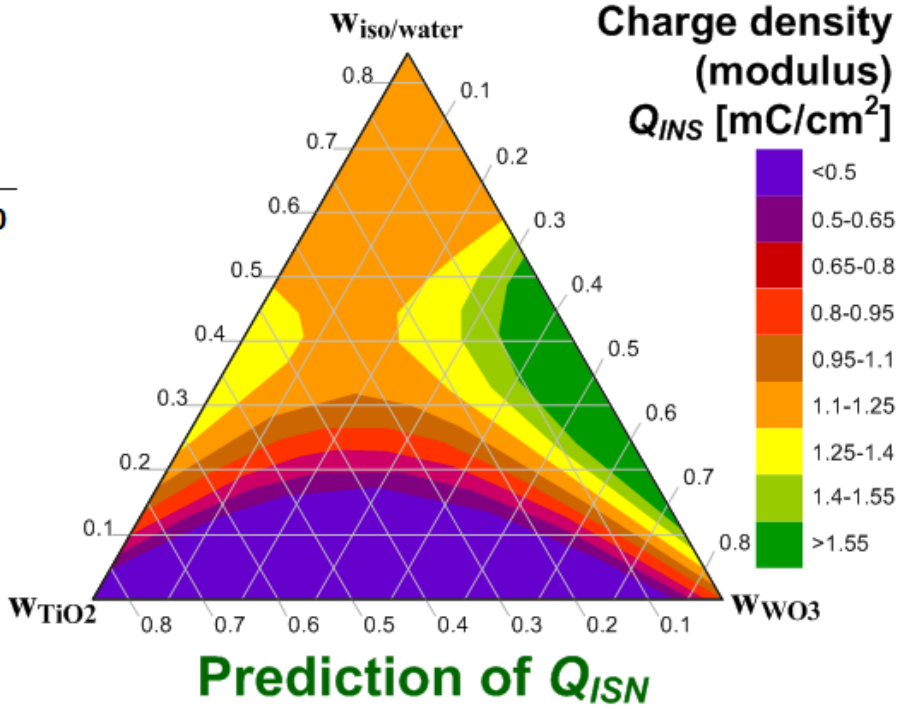



**Prediction of $i_{RED}$**



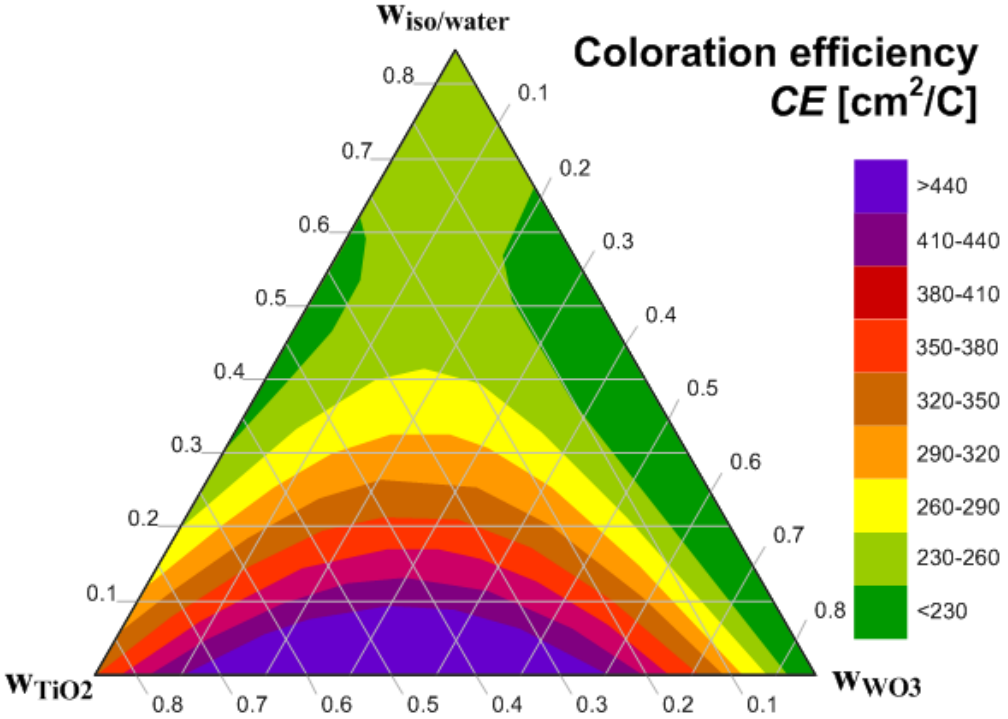
# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films




Prediction of $Q_{ISN}$

# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films




**Prediction of *CE***

## Overall performance

$$CE = \frac{\Delta OD}{Q_{INS}/A}$$

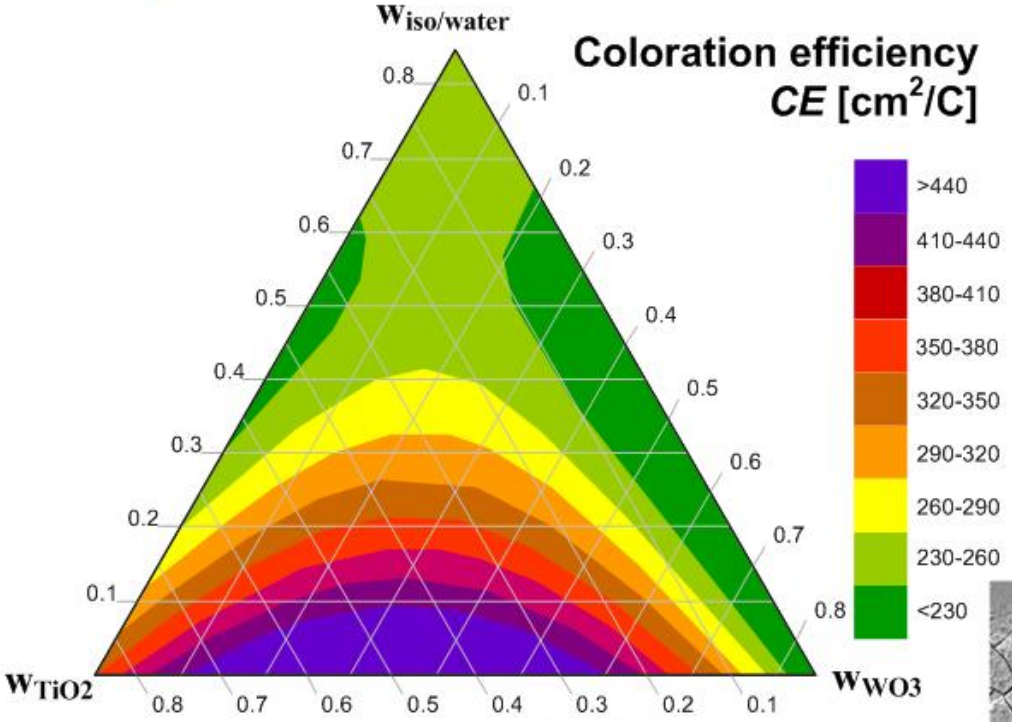
**In State-of-the-Art for PTA based EC devices:**

***CE*<120[cm²/C]**



49

# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films



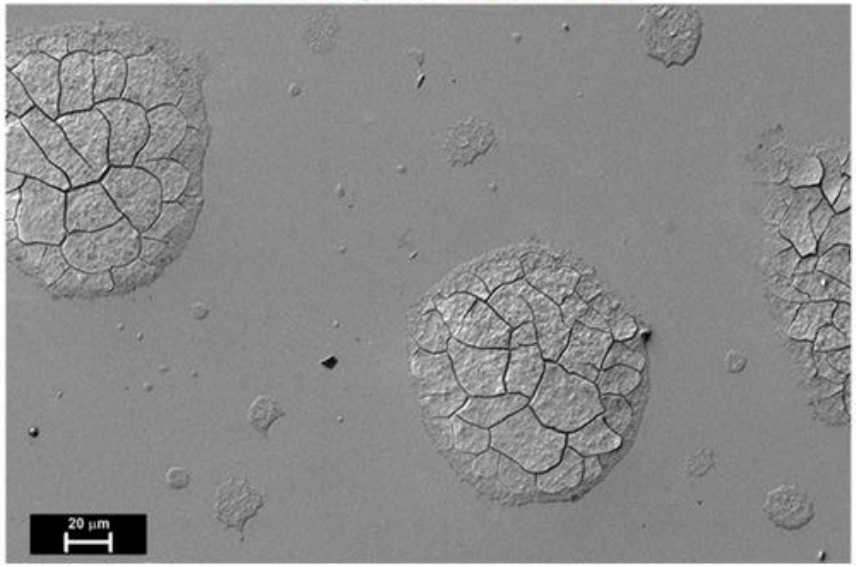

Prediction of *CE*

## Overall performance

$$CE = \frac{\Delta OD}{Q_{INS}/A}$$

Surface area (A) is overestimated

## SEM picture of a printed *a*-$WO_3/TiO_2/WO_X$




**In State-of-the-Art for PTA based EC devices:**

***CE*<120[cm²/C]**

# EC performance -printed *a*-$WO_3/TiO_2/WO_X$ films

## Factors

$w_{PTA}$ - Peroxotungstic Acid content;
$w_{OAD}$ - Oxalic Acid content;
$w_{TiO2}$ - amount of $TiO_2$ nanoparticle dispersion;
$w_{WOX}$ - amount of $WO_X$ nanoparticle dispersion;
$WO_X$ - stoichiometry of tungsten oxide nanoparticles;
$w_{iso/water}$ - base solution content.

**We can plot and predict any relation between factors and responses**

**We can test any hypothesis**

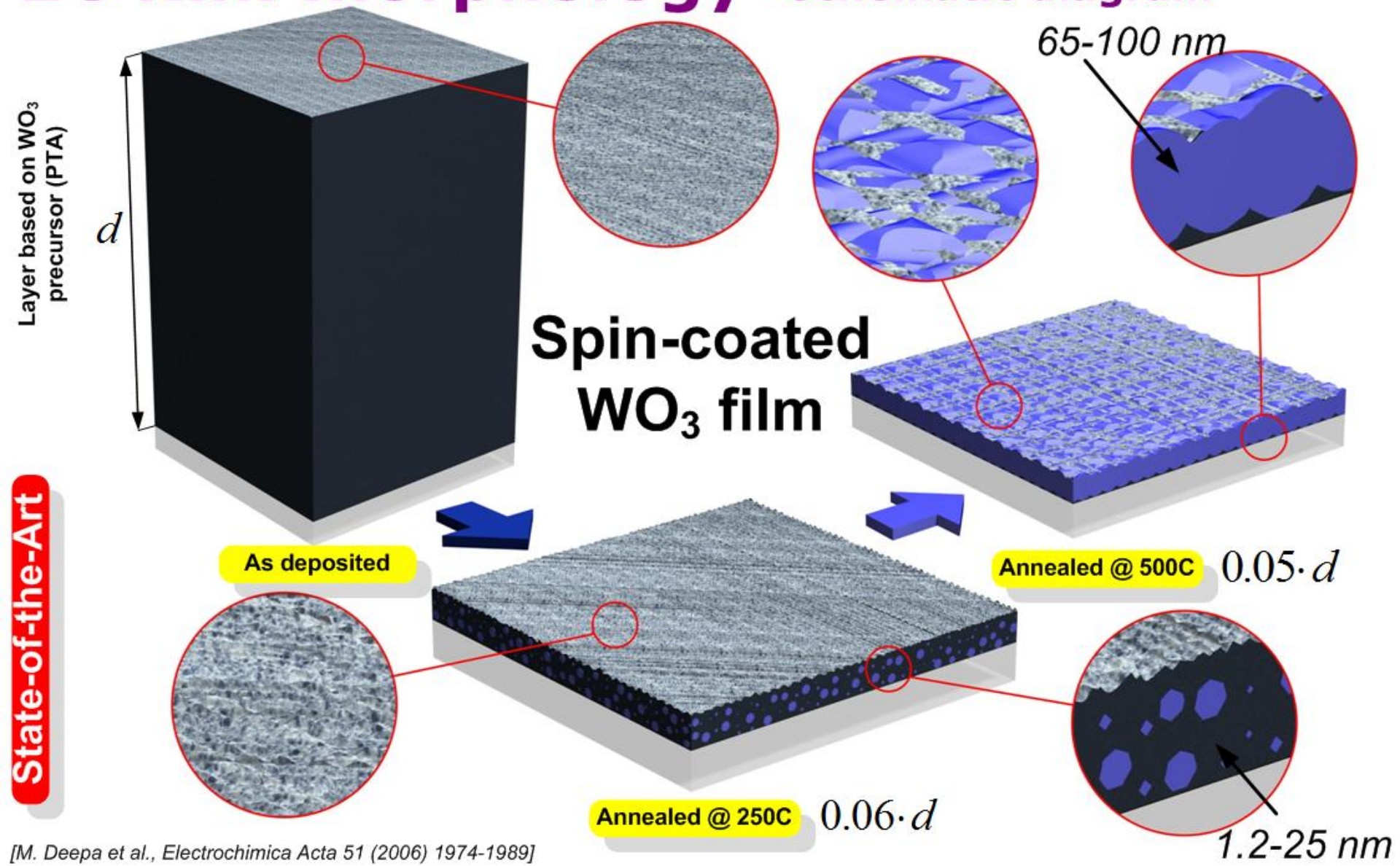
**We can design device with desired preformance**

**Prediction accuracy < 10%**

## Responses

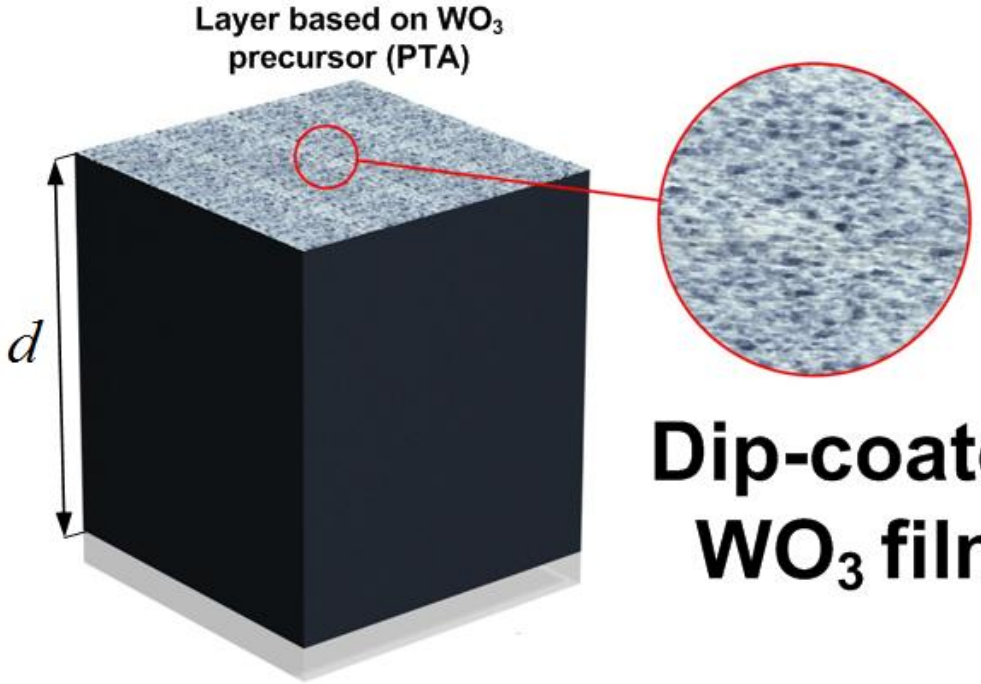
1. **Mechanical parameters**
   - *d* - film thickness;
   - $R_q$ - film roughness;
2. **Optical parameters defined for =*900nm***
   - $\tau_{col}$ - coloration time;
   - $\tau_{bl}$ - bleaching time;
   - *OD* - change in optical density;
   - $T_{col}$ - transmittance in coloration state;
   - $T_{bl}$ - transmittance in bleaching state;
   - $\alpha$ – optical absorption coefficient;
3. **Electrical parameters**
   - $i_{RED}$ - reduction peak max.
   - $i_{OX}$ - oxidation peak max.
   - $Q_{ins}$ - Charge inserted to the device
4. **Fluid parameters of the ink**
   - $\upsilon$- ink viscosity;
   - $\gamma$- ink surface tension;
   - $\theta$- ink contact angle on ITO PET substrate;
   - $\rho$- ink density;
5. **Overall performance defined for =*900nm***
   - *CE* - coloration efficiency

# EC film morphology -schematic diagram




[M. Deepa et al., Electrochimica Acta 51 (2006) 1974-1989]

# EC film morphology -schematic diagram

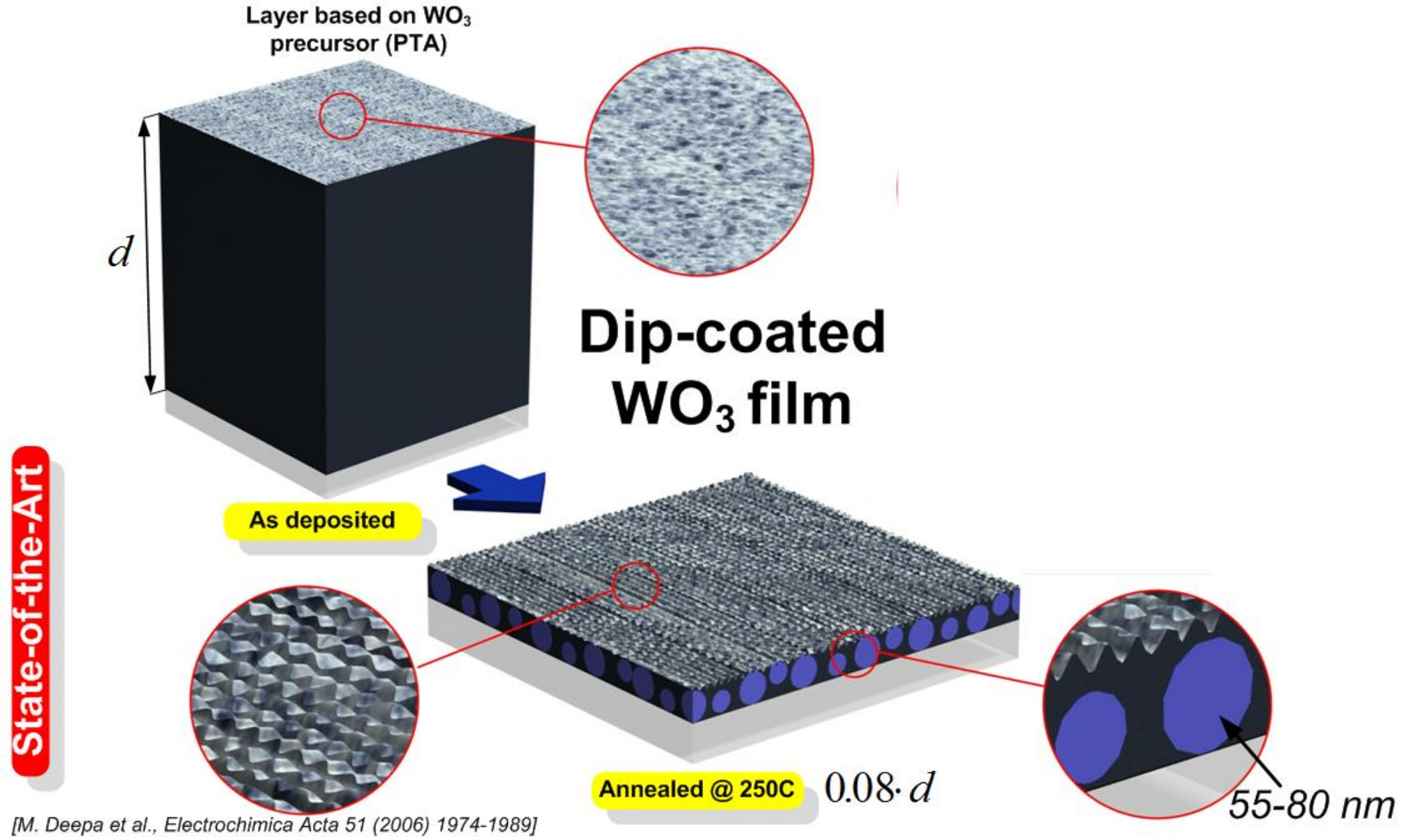



**Dip-coated $WO_3$ film**

State-of-the-Art

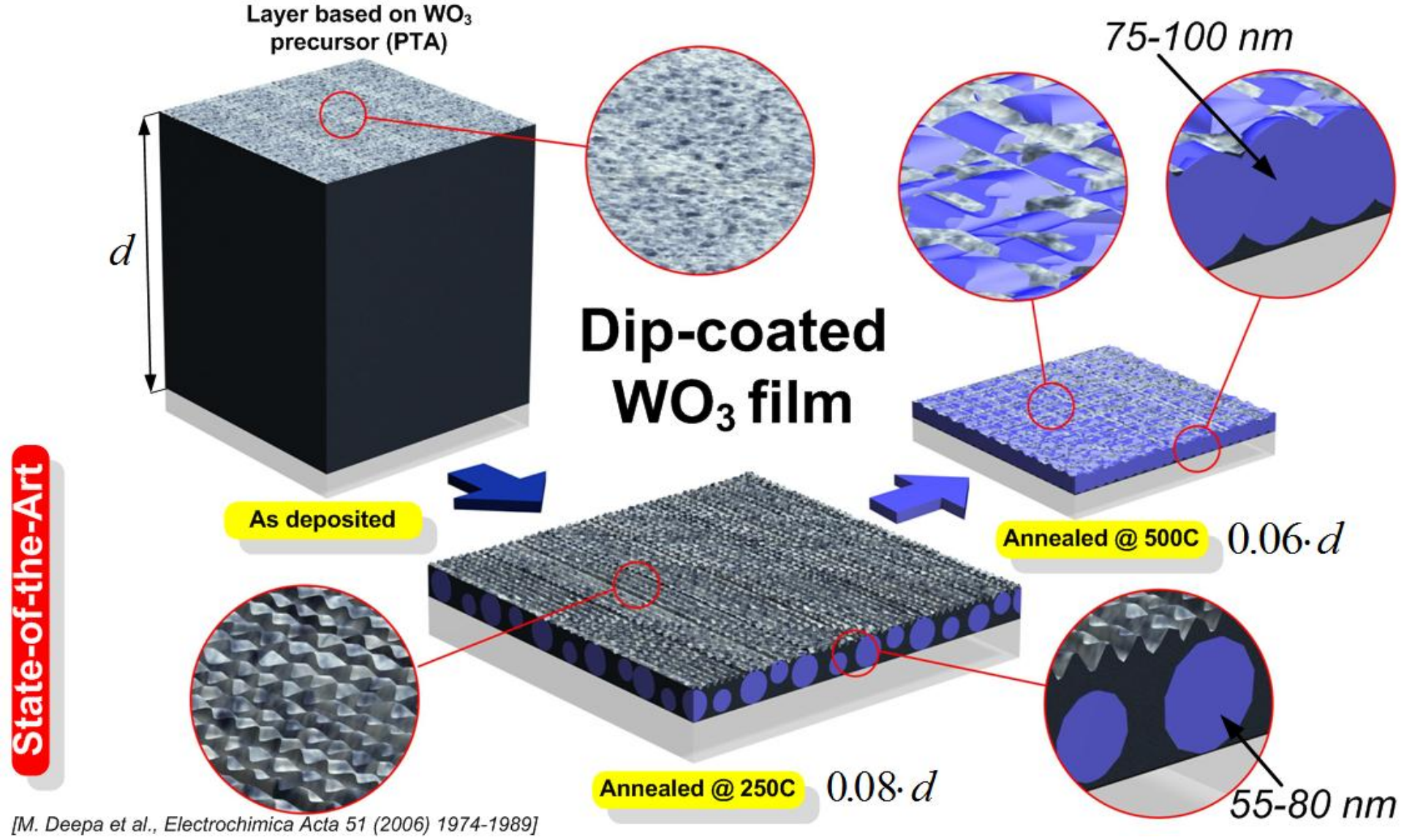
*[M. Deepa et al., Electrochimica Acta 51 (2006) 1974-1989]*

# EC film morphology -schematic diagram



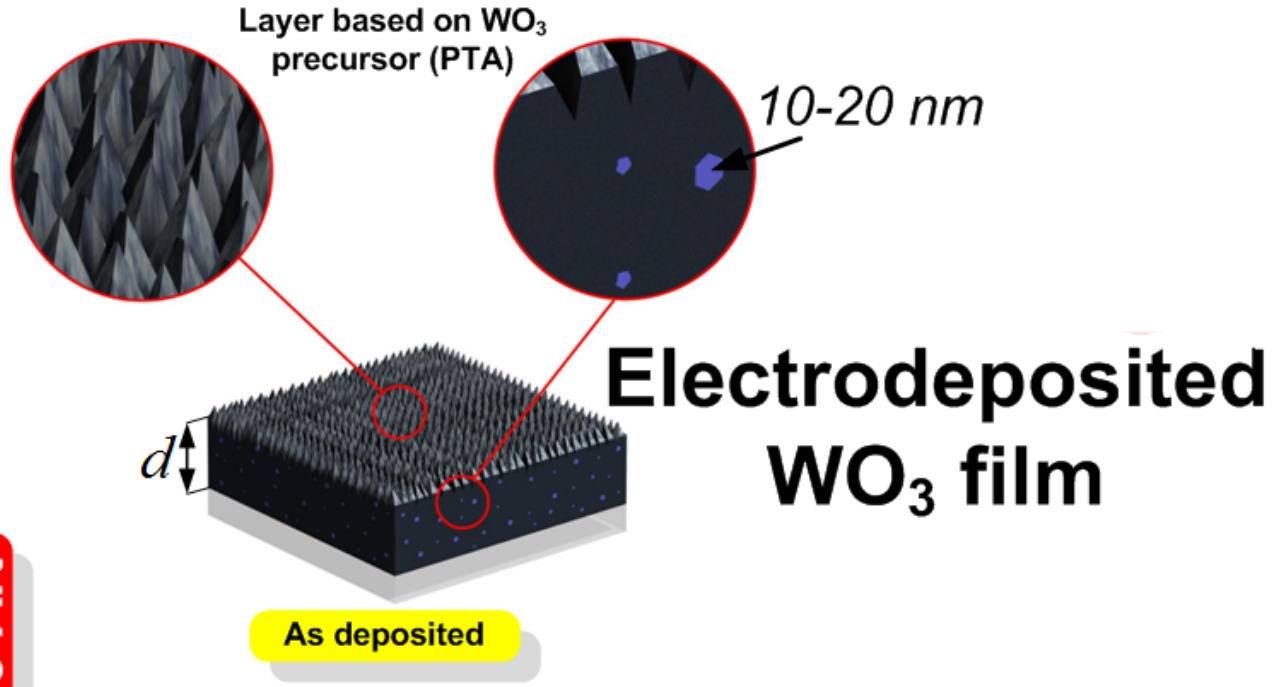

[M. Deepa et al., Electrochimica Acta 51 (2006) 1974-1989]

# EC film morphology -schematic diagram




[M. Deepa et al., Electrochimica Acta 51 (2006) 1974-1989]

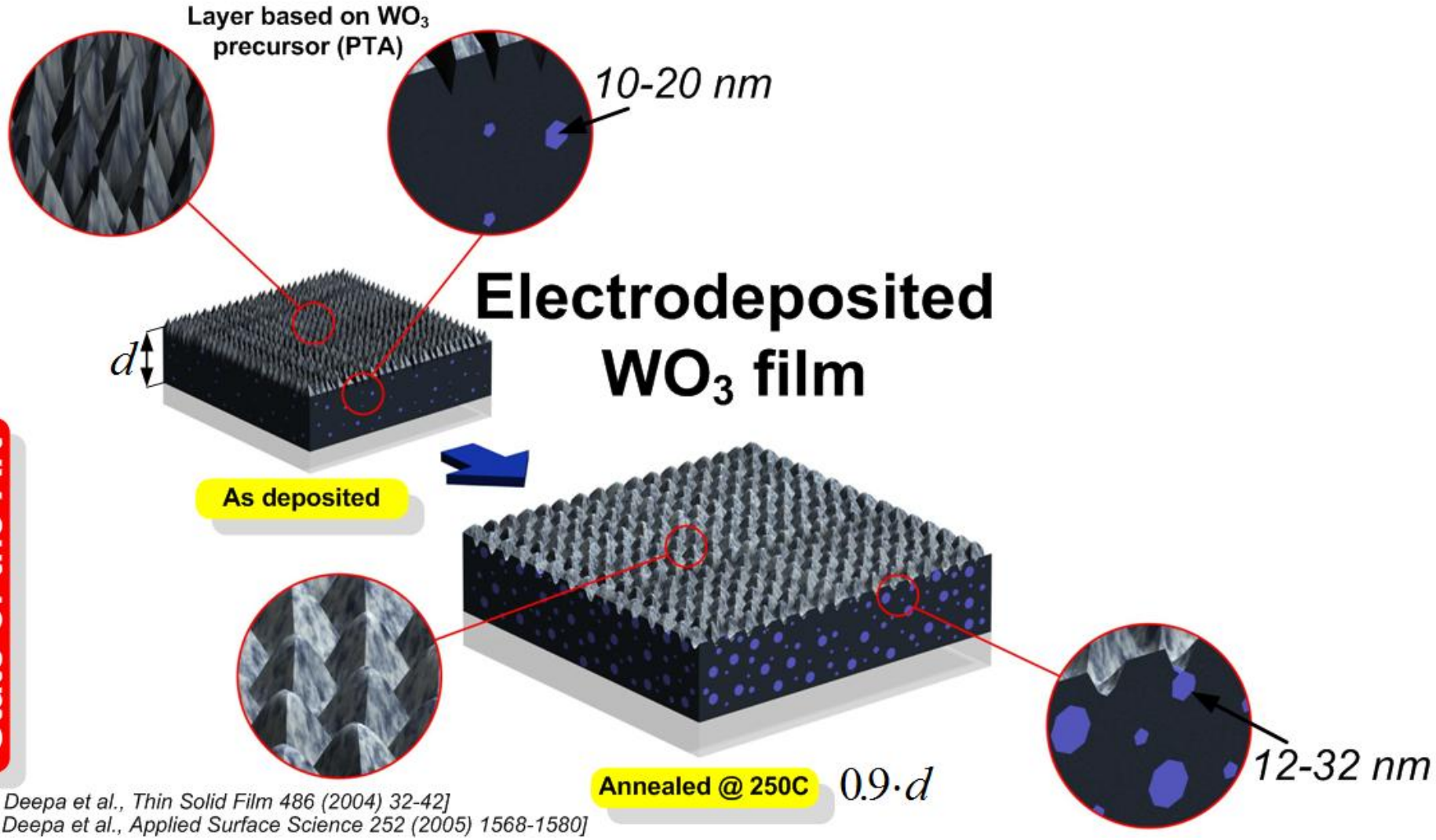
# EC film morphology -schematic diagram




State-of-the-Art

*[M. Deepa et al., Thin Solid Film 486 (2004) 32-42]*
*[M. Deepa et al., Applied Surface Science 252 (2005) 1568-1580]*

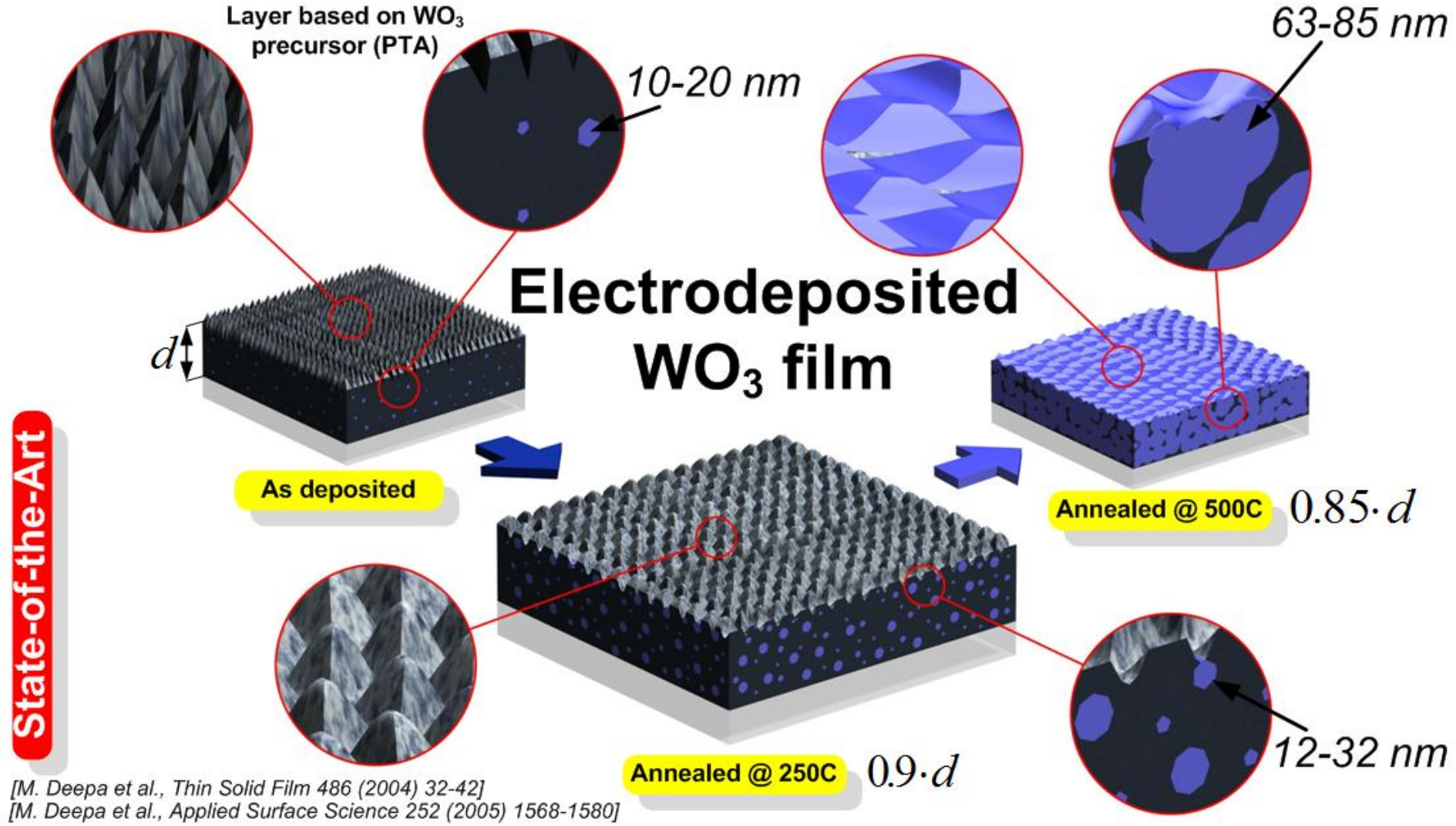
# EC film morphology -schematic diagram




State-of-the-Art

[M. Deepa et al., Thin Solid Film 486 (2004) 32-42]
[M. Deepa et al., Applied Surface Science 252 (2005) 1568-1580]

# EC film morphology -schematic diagram

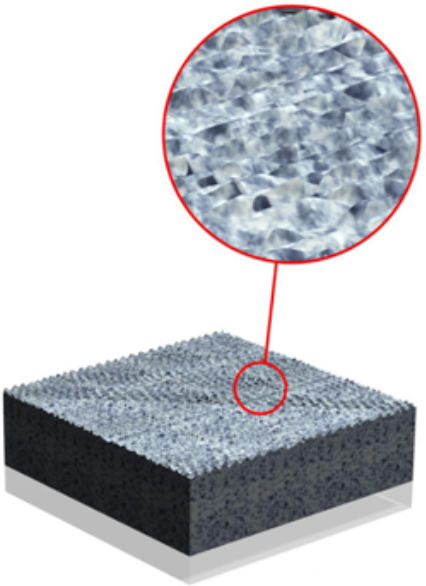


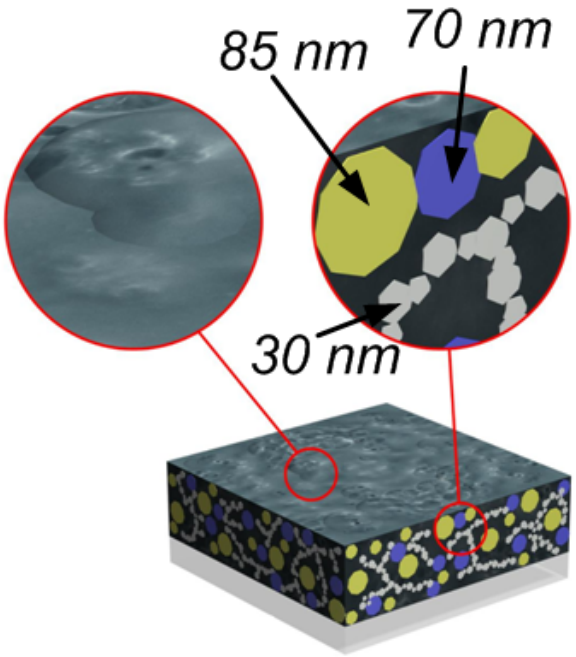

[M. Deepa et al., Thin Solid Film 486 (2004) 32-42]
[M. Deepa et al., Applied Surface Science 252 (2005) 1568-1580]

# EC film morphology -schematic diagram

**Present work**

## Inkjet printed *a*-$WO_3$ and *a*-$WO_3/TiO_2/WO_X$

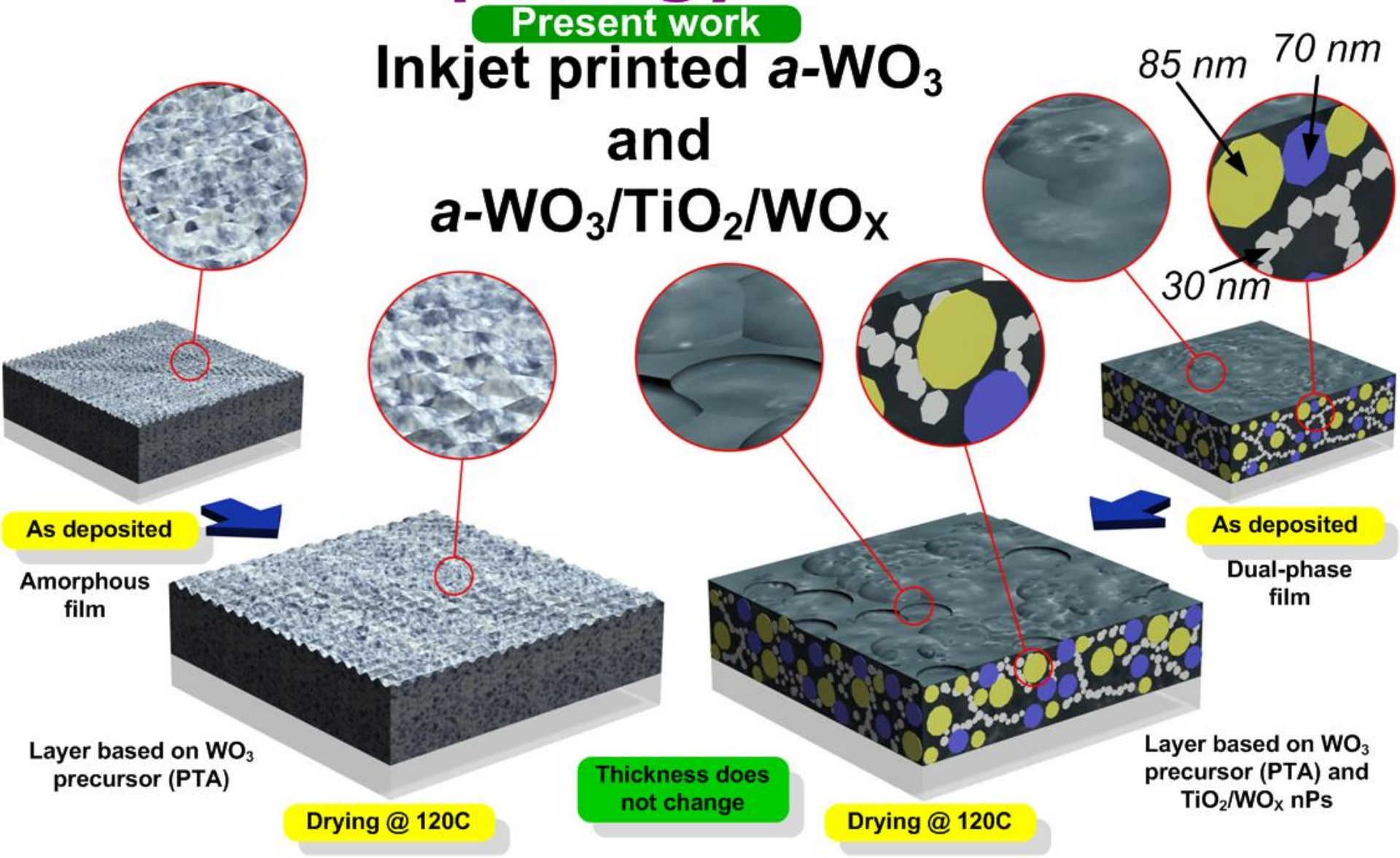







59

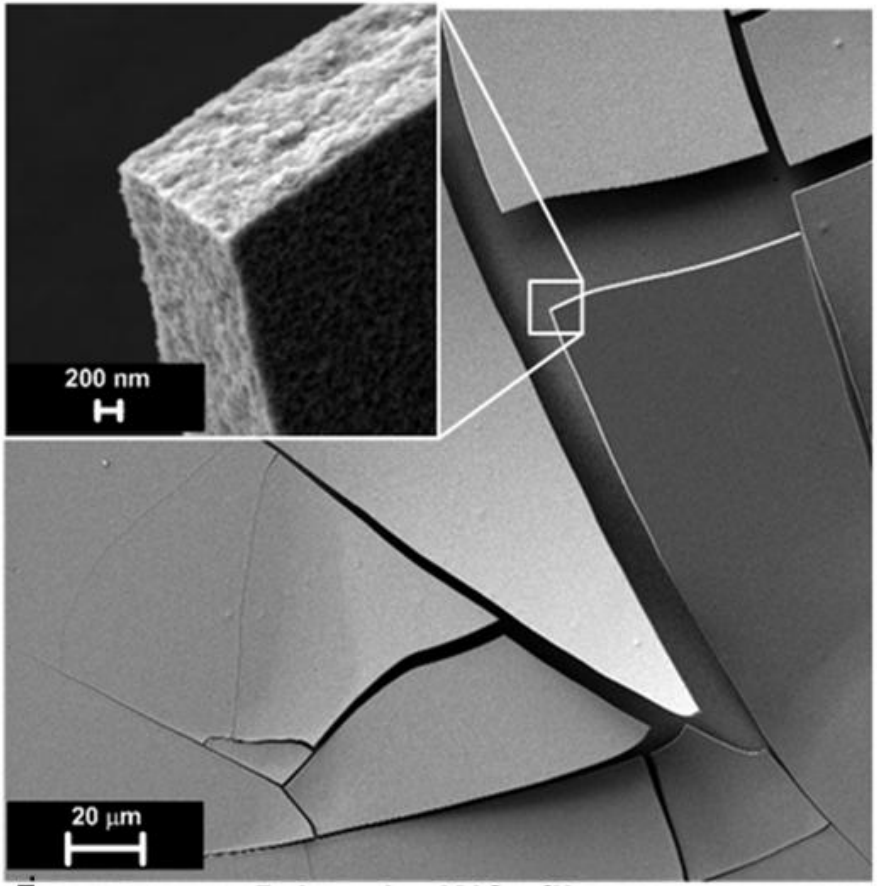
# EC film morphology -schematic diagram





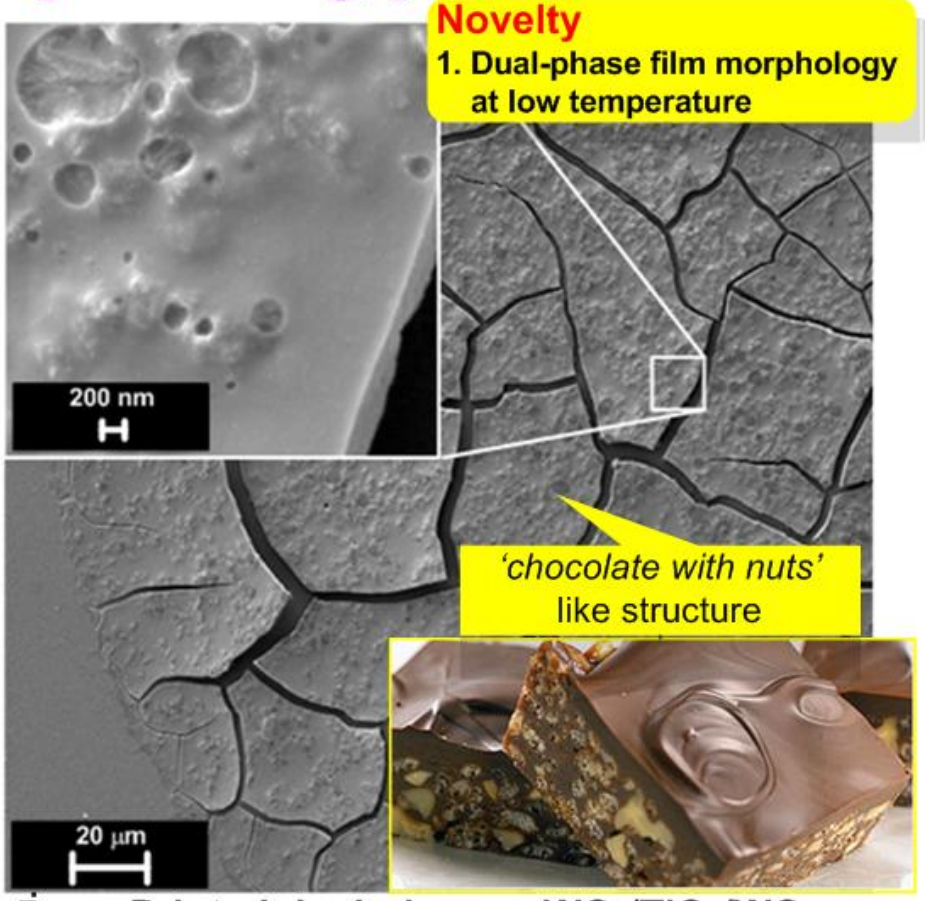

60

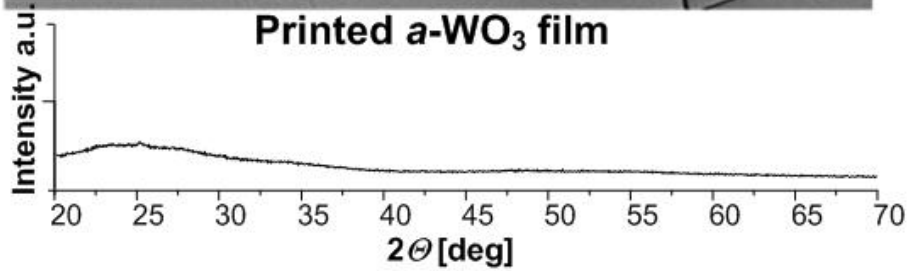
# Printed EC film morphology -SEM,XRD

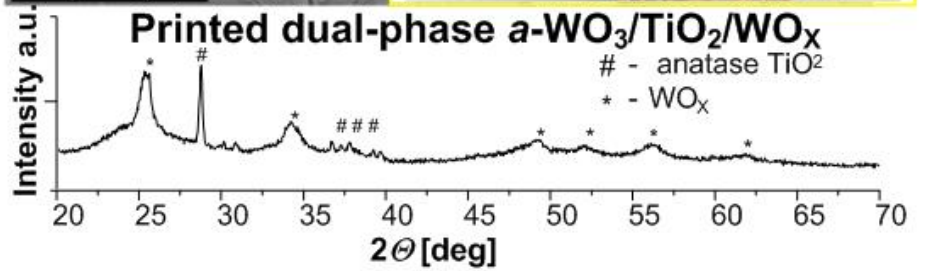



**Novelty**

1. Dual-phase film morphology at low temperature



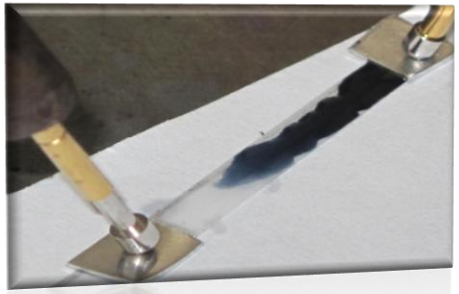



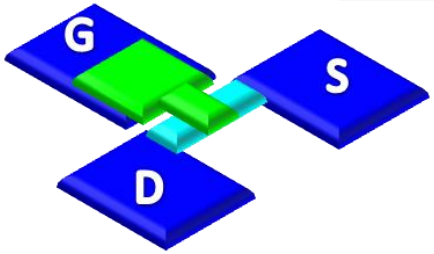



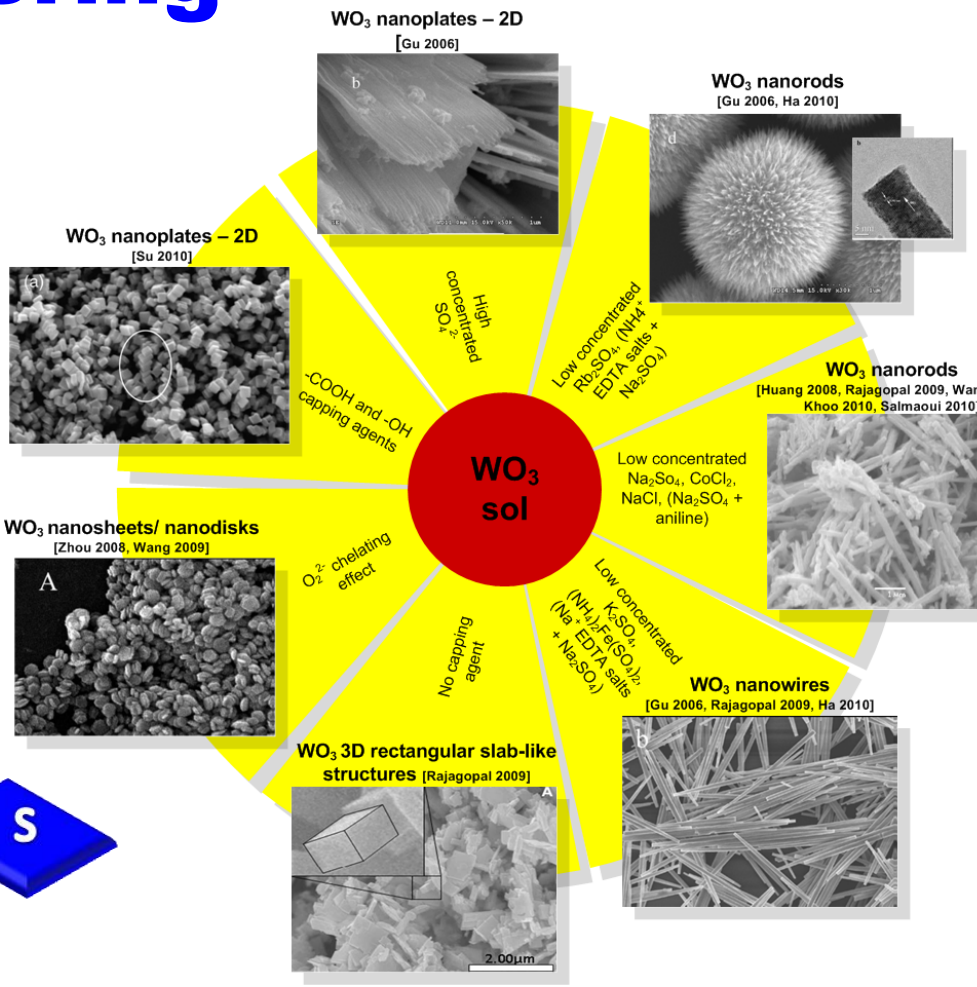
# Devices engineering

**Electrochromic nanomaterials for smart labels**

**Electrochromic transistors produced by ink-jet**



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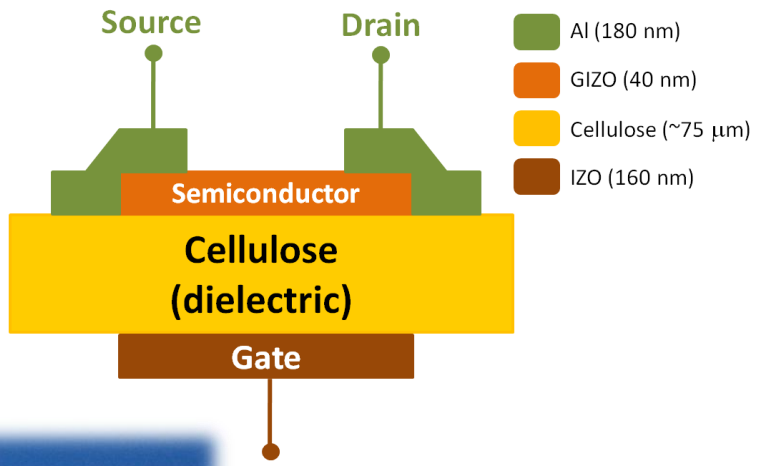
SEVENTH FRAMEWORK PROGRAMME

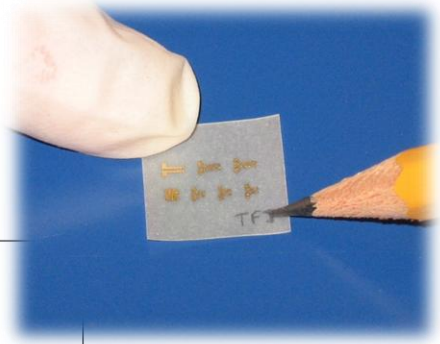
# Devices engineering: Paper electronics




Large Electronics

Flexible Electronics

Printed Electronics



Disposable electronics

Tags (RFID)

food industry

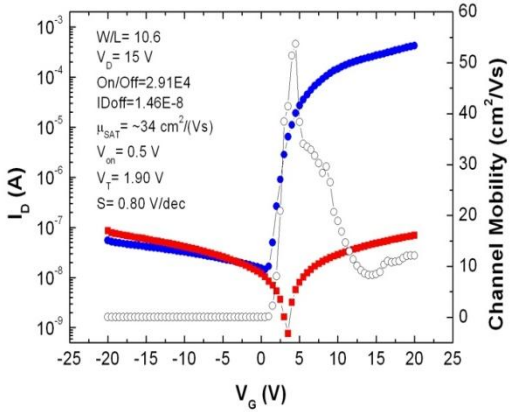
pharmaceutical industry

...

Safety

Medicine

IDs




Paper-e®

Paper - e

Green electronics for the future

SEVENTH FRAMEWORK PROGRAMME

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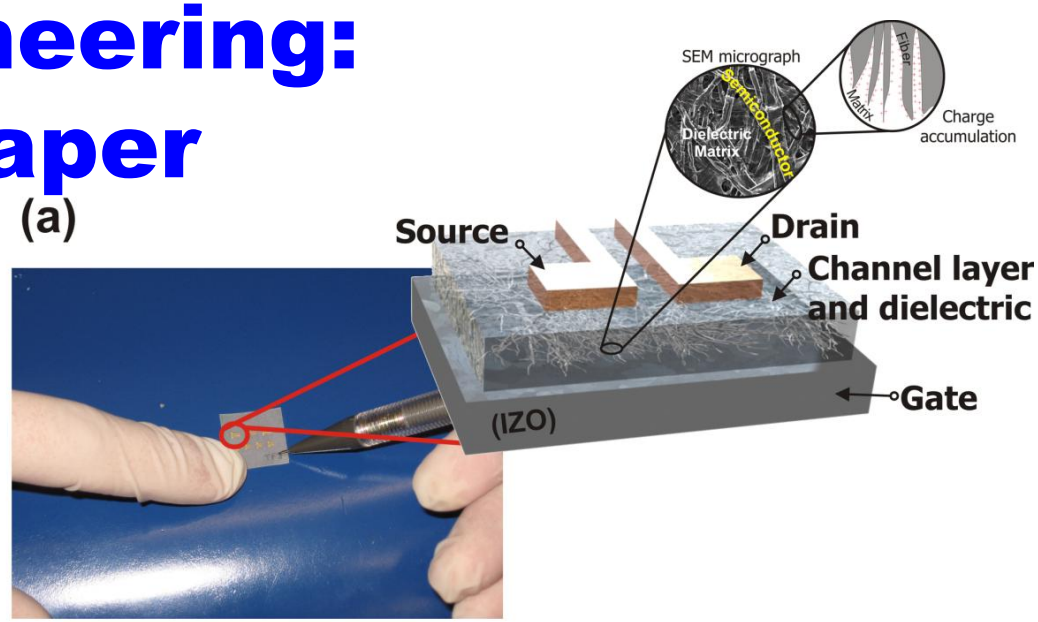
ICSU International Council for Science



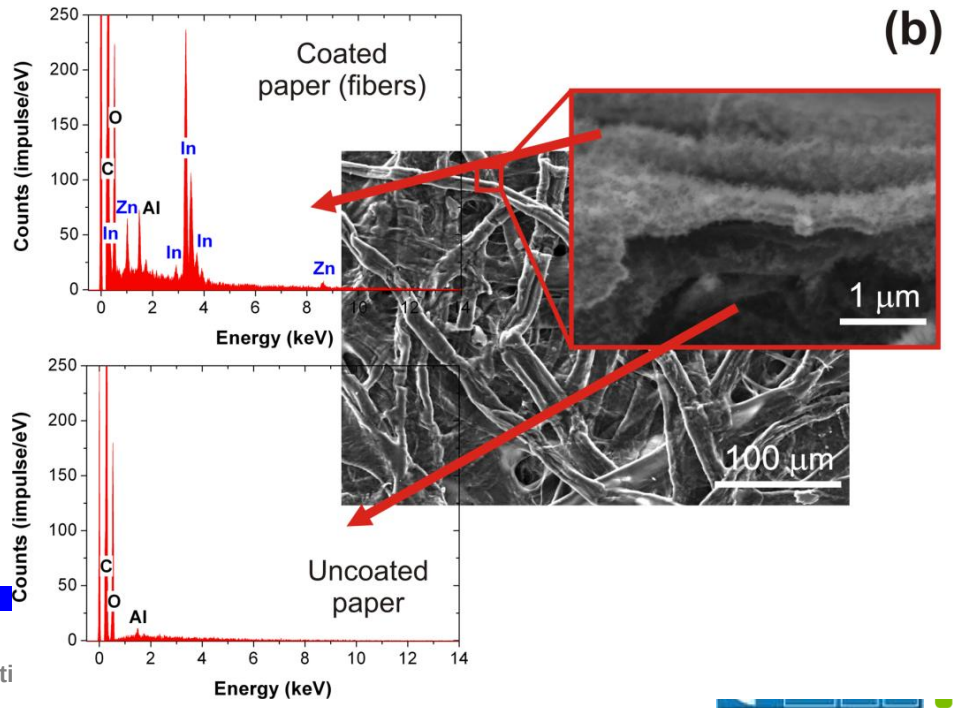
E-MRS FCT

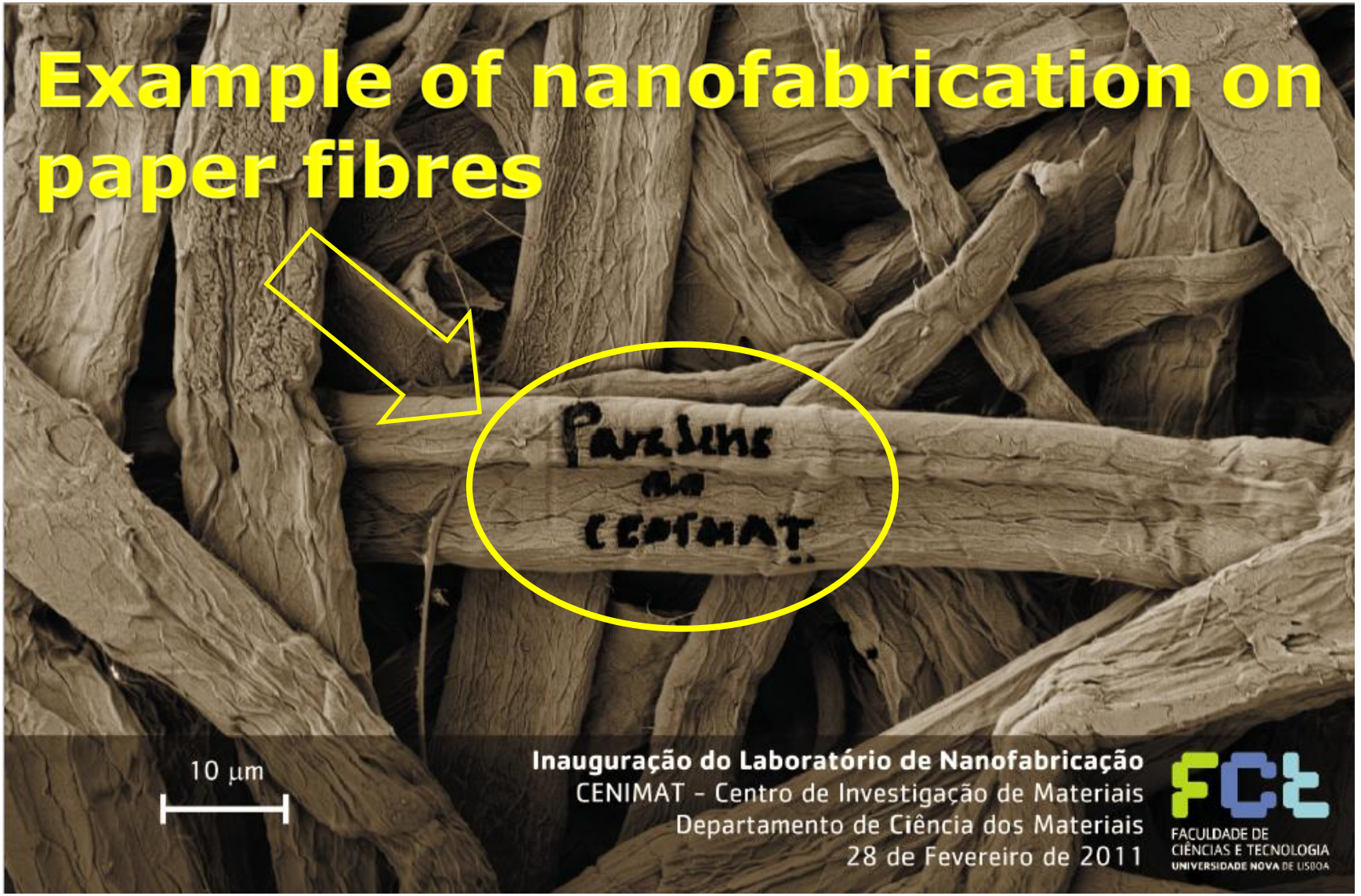
# Devices engineering: memory paper

Sketch of the device structure, showing the different layers. The magnified inset shows the fiber based dielectric structure and how carriers are accumulated along the fibers;




SEM image and XPS of the paper oxide coated



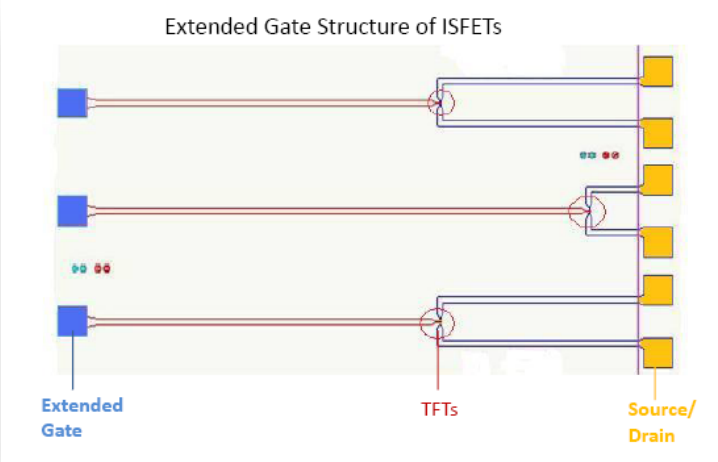

Example of nanofabrication on paper fibres
10 µm
Inauguração do Laboratório de Nanofabricação
CENIMAT - Centro de Investigação de Materiais
Departamento de Ciência dos Materiais
28 de Fevereiro de 2011
FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

# Devices engineering. Bio-batteries

**Enzyme biosensors based on ion-selective field-effect transistors**

**Inkjet printed and "doctor blade" $TiO_2$ photodetectors for DNA biosensors**

**Flexible electrochemical device able to generate electrical energy from physiological fluids**

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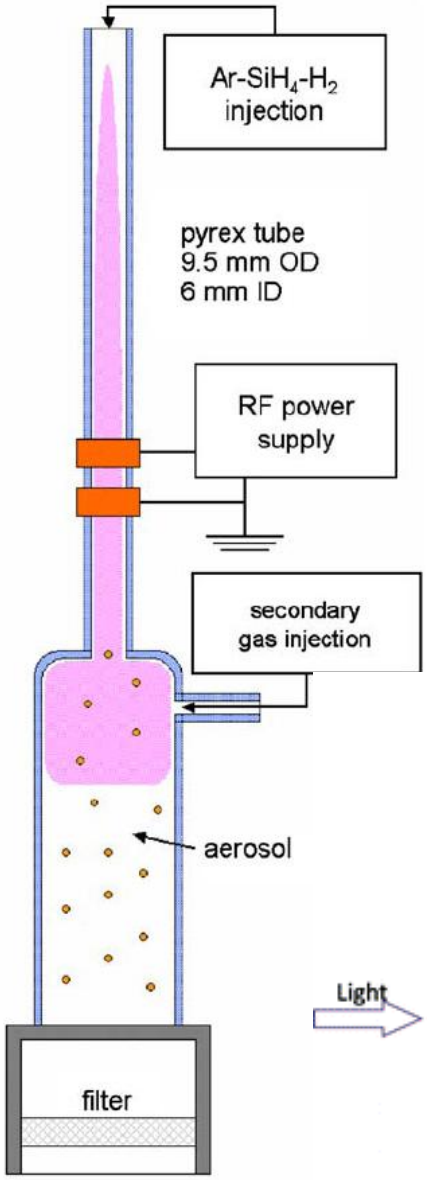
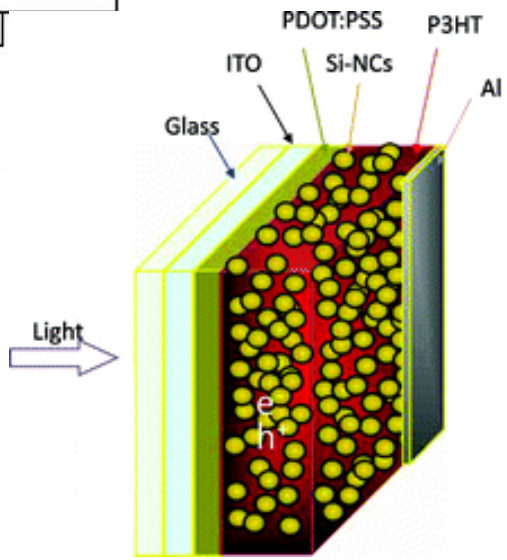
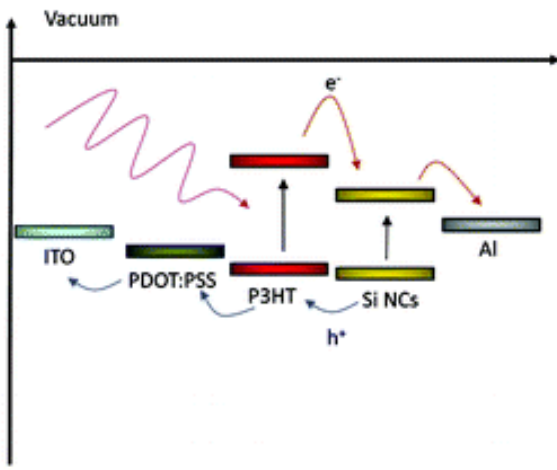
*I. Bernacka-Wojcik et al., Biosensors & Bioelectronics, 25 (2010) 1229-1234*

# Hybrid Solar

***Hybrid Si-nanoparticle/polymer layers for solar cell applications***

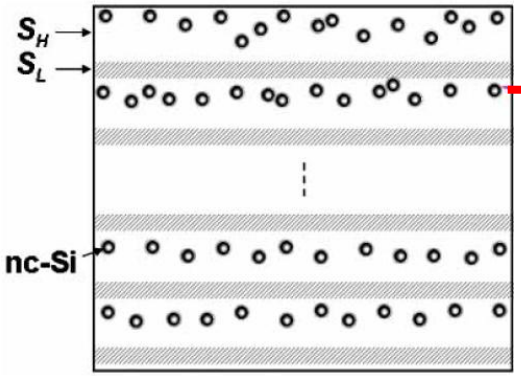


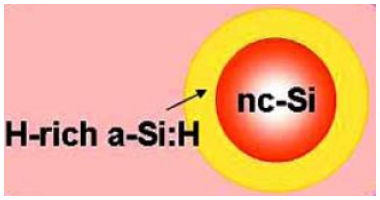



# Devices engineering: Nanoscale base solar cells

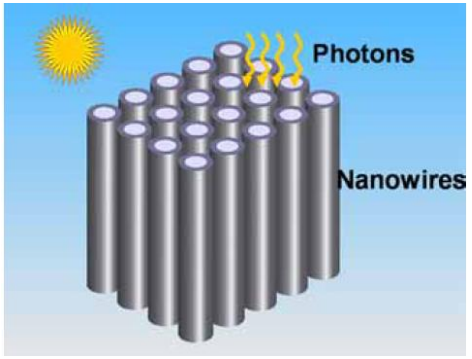
**0D (Quantum Dot)**




**Protocrystalline Si:H**

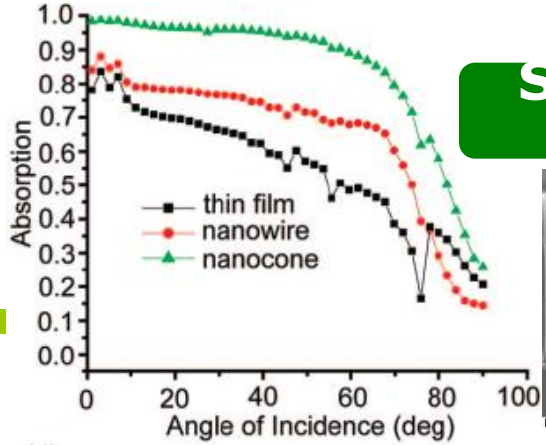
**1-D (Quantum Wire)**

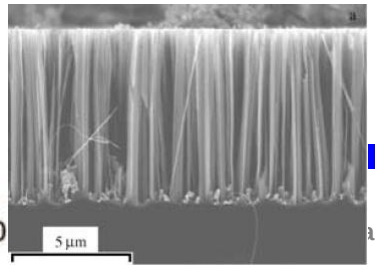


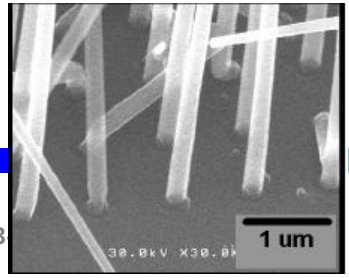

**Si Nanowires (SiNW)**

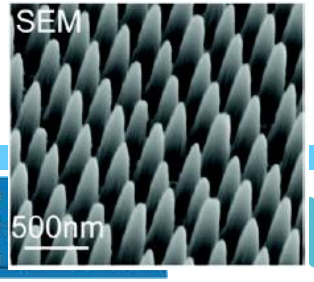
**Si Nano-Rodes**

**Si Nano-Cones**




anomaterials, 23

# Nanotech Products

Examples include

- ICT applications
- Sporting Goods
- Clothing and Fabrics
- Medical
- Other

Buckyball sculpture created by former physicist Julian Voss-Andreae.

# The Promise of Today

# Nanotech Products

Other Products, Continued

- Window Coatings

  **Pilkington** (www.pilkington.com) creates a coating for window glass that uses a chemical reaction to breakdown and loosen organic dirt particles from the glass when activated by the ultraviolet rays from natural daylight and the oxygen in the air.

Glass coating is hydrophillic.

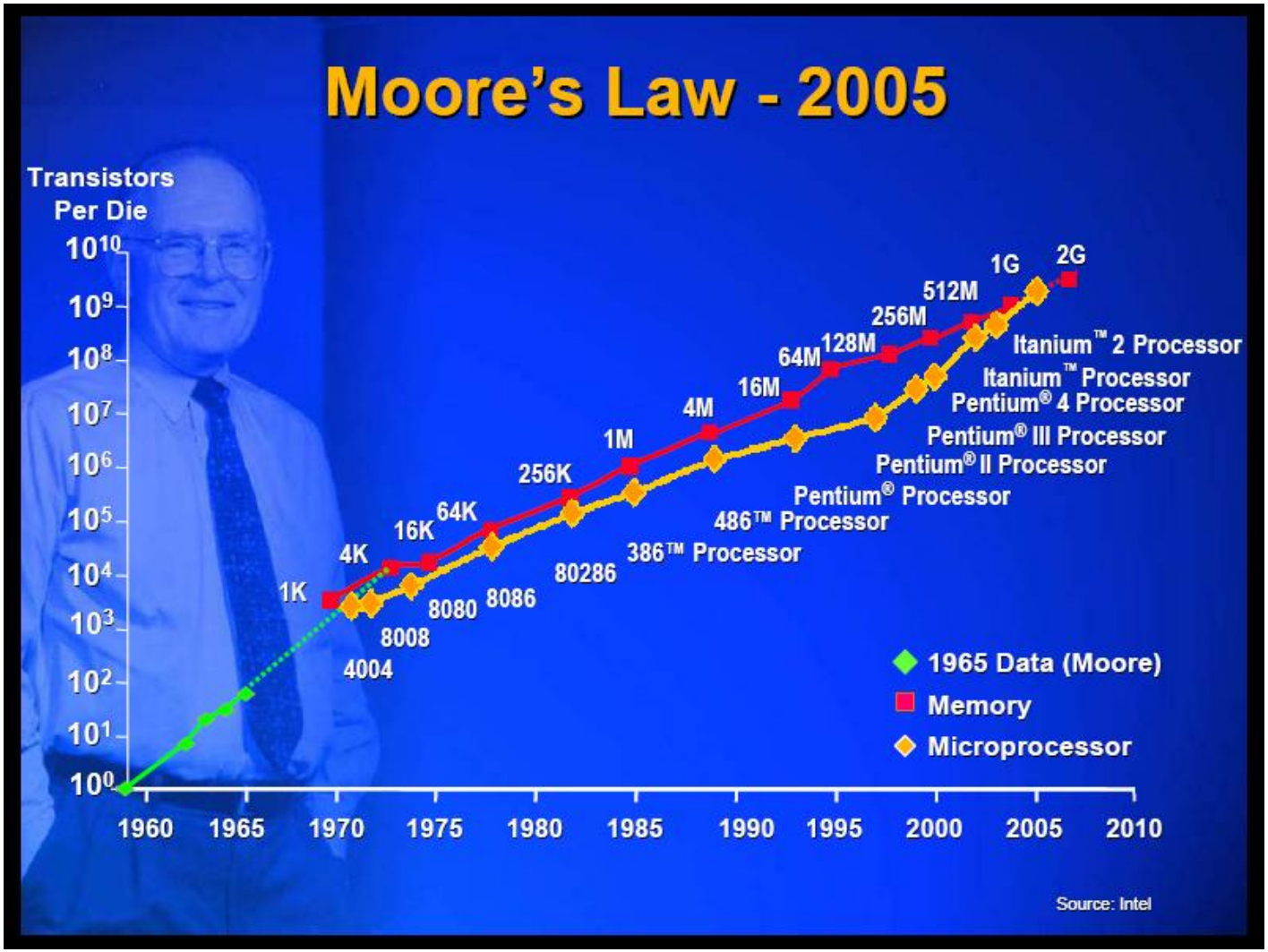
# The Promise of Tomorrow

**Nanotechnology & Nanomaterials has the potential to:**

- **To promote new outstanding Materials performances**
- **Solve Information Speed Limitations**
- **Solve Energy Problems**
- **Cure Cancer**
- **Eradicate Disease**
- **Slow Down Aging**
- **Solve World Hunger**
- **Colonize Space**

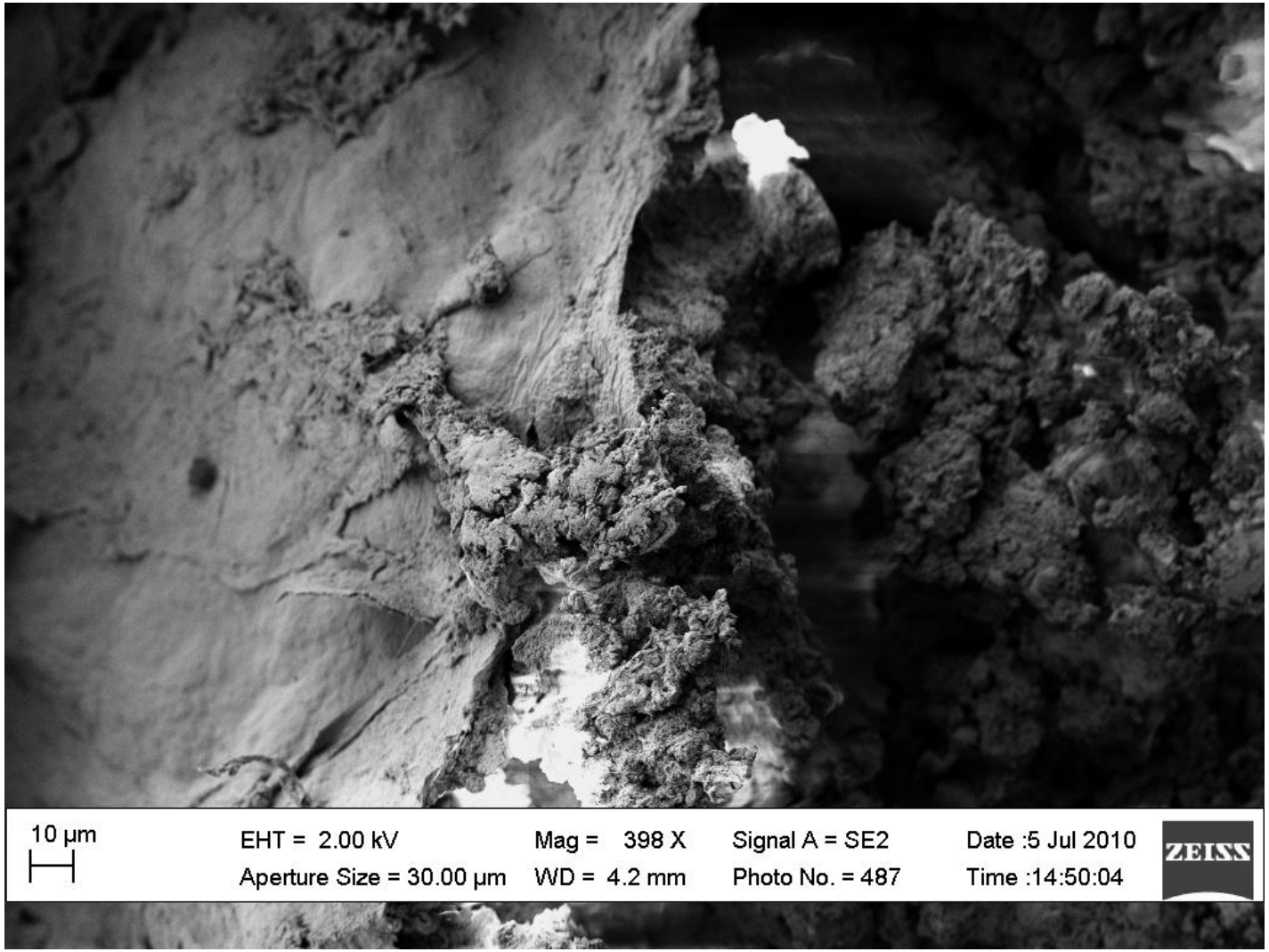
**Without nanotechnology, it is likely none of these are possible.**

# The First “Law” of Small(er)

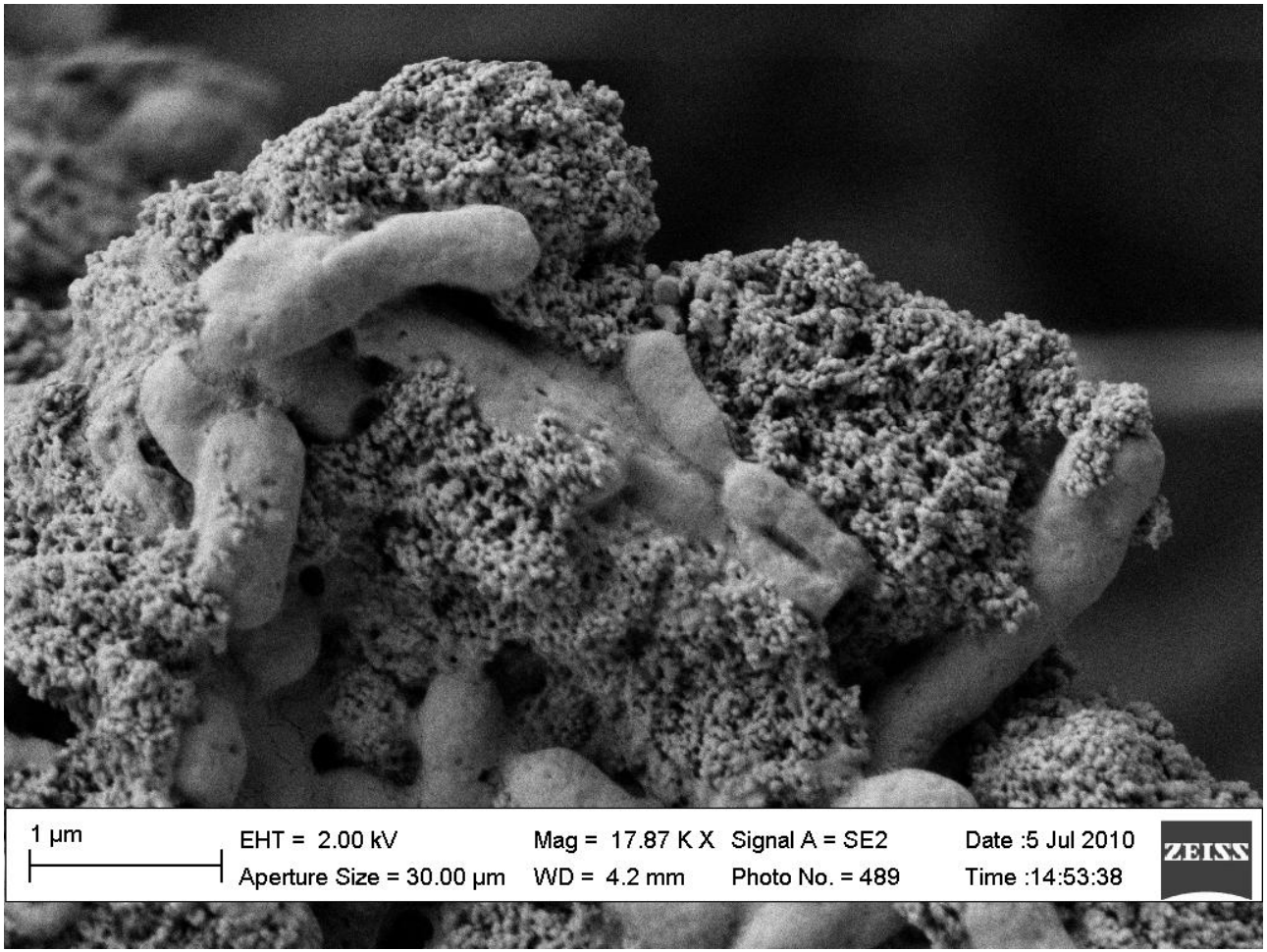



The rapid (exponential) rate of miniaturization of semiconductor devices is unprecedented for any technology or business.

# Toxicity: Liver of a Zebra Fish



# Toxicity: Accumulated $TiO_2$ nanoparticles on the fish leaver



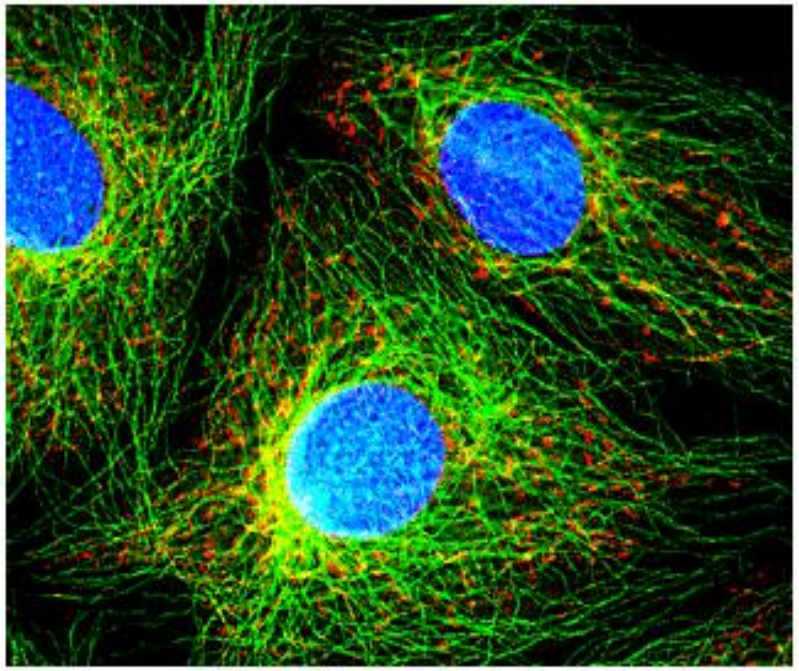
# Disadvantages

- Safety hazards with nanomaterials (size?)
- Some studies detected possible cancer-causing properties of carbon nanotubes
- Some nanomaterials bounded with other materials or components (?)

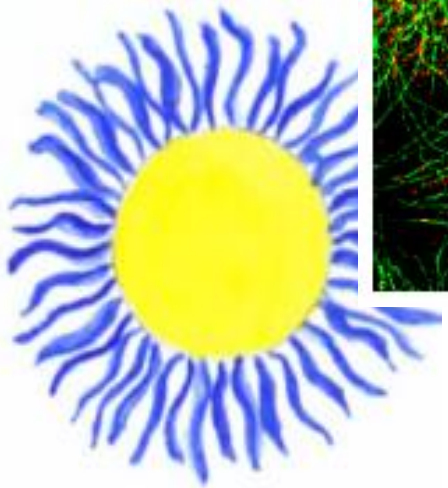
# Nanomaterials - Biomarkers

## Metal and semiconductor nanoparticles are used to label biological samples

Semiconductors are great for fluorescence labeling. Gold is an excellent stain for electron microscopy.



Attach to different structures such as cancer cells by using different molecules on the surface



# Nanomaterials - Biomarkers

- 15nm dia FeO nanoparticles injected directly into tumor site.
- Alternating magnetic field (similar to MRI) heats up nanoparticles, destroying tumor from inside with minimal damage to sur

magforce® NANOTECHNOLOGIES

# Thanks to all from all of us: CENIMAT/PORTUGAL and E-MRS!