EMPA
Materials Science & Technology

Materials meet Life

Alex Dommann,

INNO TECH EXPO 2014 Kielce, POLAND

Lerchenfeldstrasse 5, 9014 St. Gallen
www.empa.ch

Empa within the ETH Domain

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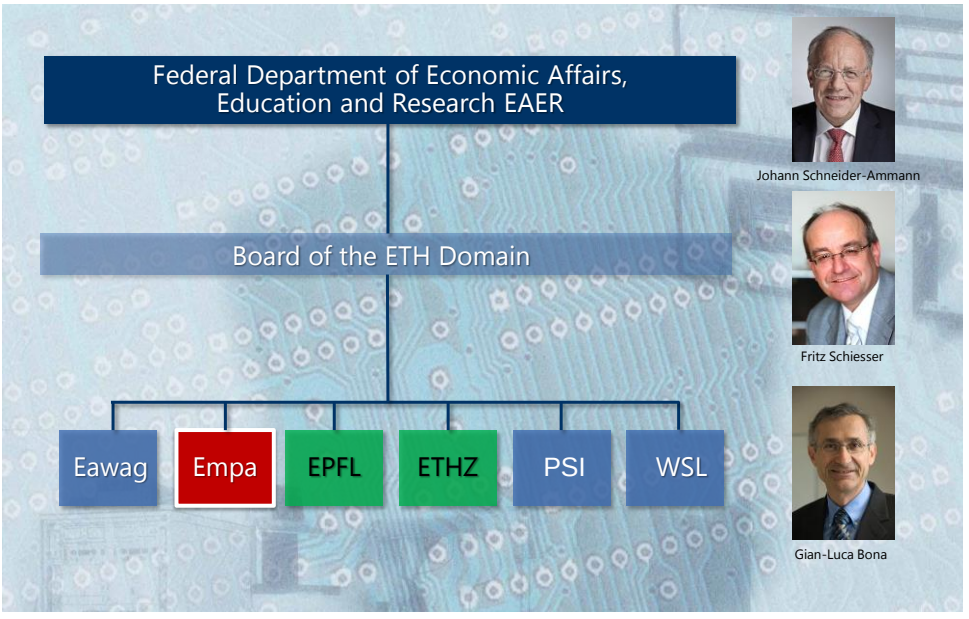


Johann Schneider-Ammann

Fritz Schiesser

Gian-Luca Bona

Mission

Empa – Bridging Research and Applications

- Use-inspired Materials Science & Technology Development
- Interdisciplinary Know-how
- Efficient Technology Transfer
- For the Benefit of Industry
- For the Welfare of Society
- Committed to Excellence in all our Activities

Switzerland in a Globalized World

Switzerland in a Globalized World
Empa-Eawag-Campus Dübendorf

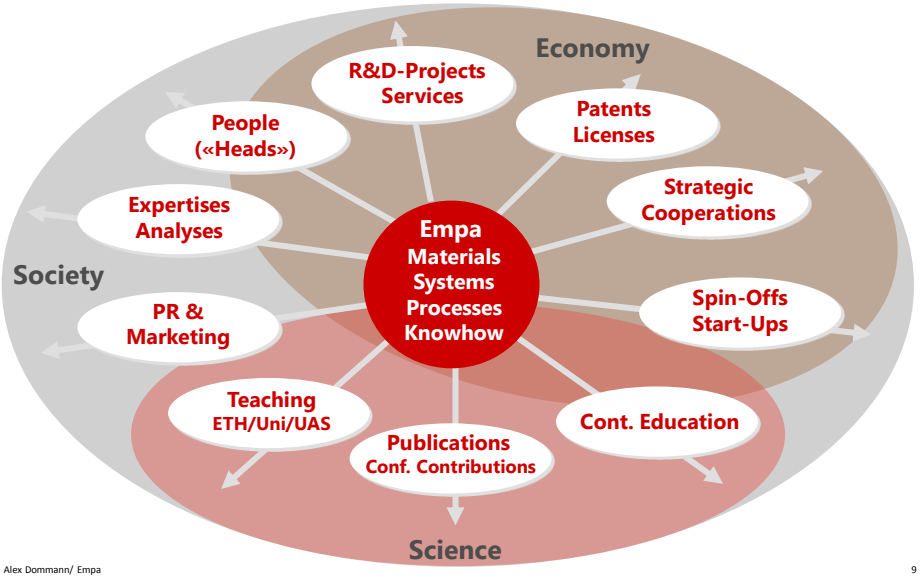
Switzerland in a Globalized World
Empa Site St. Gallen

Switzerland in a Globalized World
Empa Site Thun

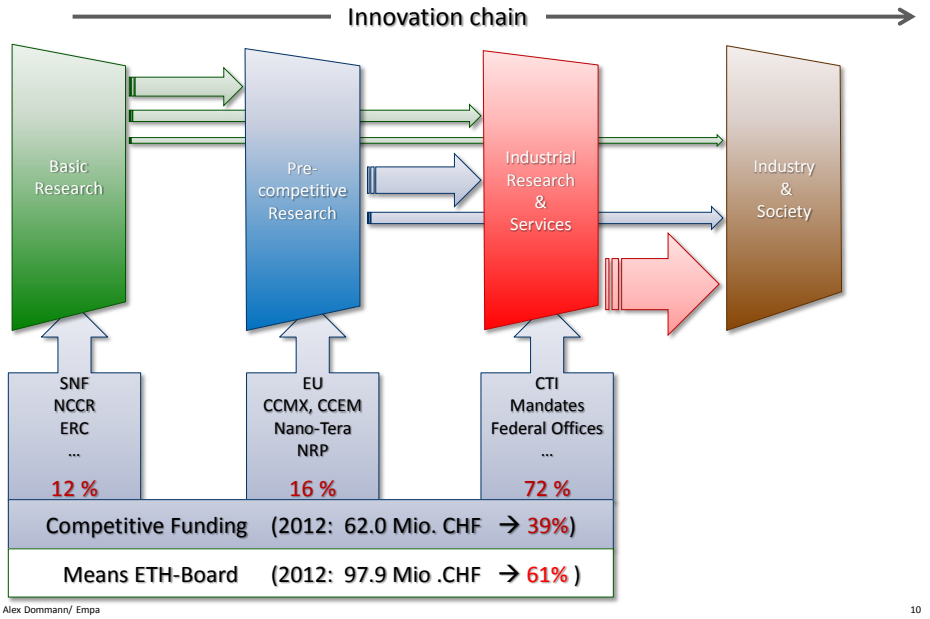
Empa in Numbers (2012)

3 Sites	Dübendorf, St. Gallen, Thun
5 Departments	30 Laboratories
	950 Employees (860 FTE; about 30% Women)
	160 PhD Students
	40 Apprentices
	plus 200 Master Students & Interns
Budget	98 Mio. CHF Public Funding
	62 Mio. CHF Second/Third Party Means
Scientific Output	> 500 Peer-reviewed ISI-Publications
	90 Seminars & Conferences at Empa-Academy
Third Party Projects	> 60 running EU-funded Projects
	around 100 running SNSF Projects
	around 110 running CTI Projects

Integrated Knowledge & Technology Transfer From Science to Business



From Basic Science to Innovation



Leiden Ranking*: *MNCS of the top 25 Universities*

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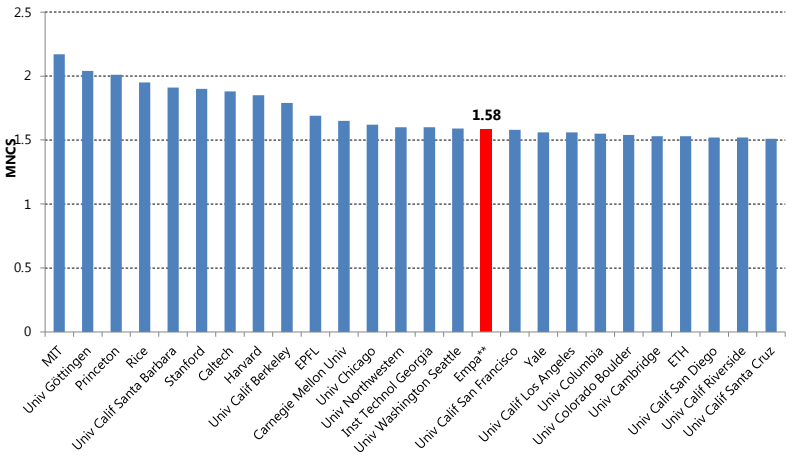
MNCS=Mean Normalized Citation Score



* The Leiden Ranking 2011/2012 measures the scientific performance of 500 major universities worldwide (Publications 2005-2009)

Global Challenges

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… also for material science

Research Focus Areas (RFA's)

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Materials meet Life

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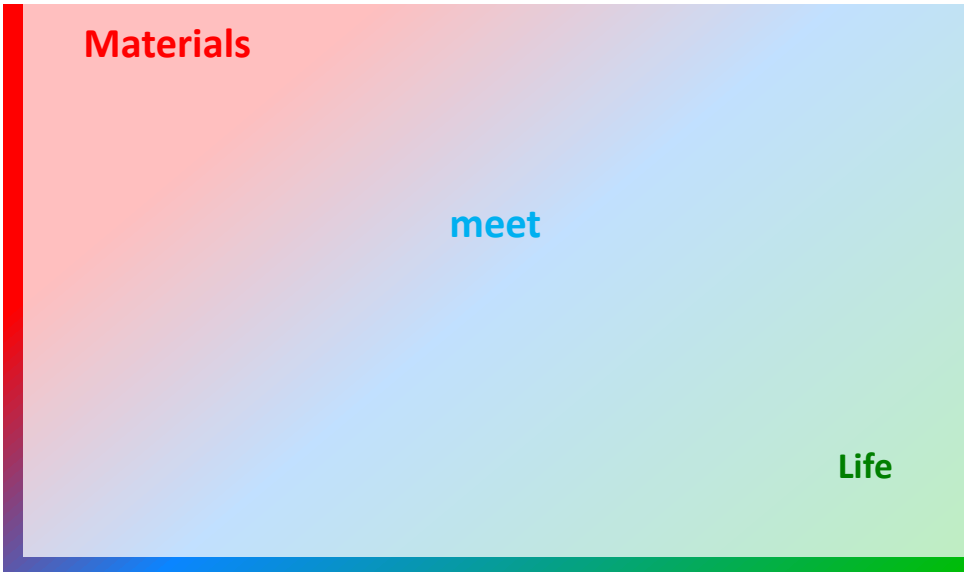

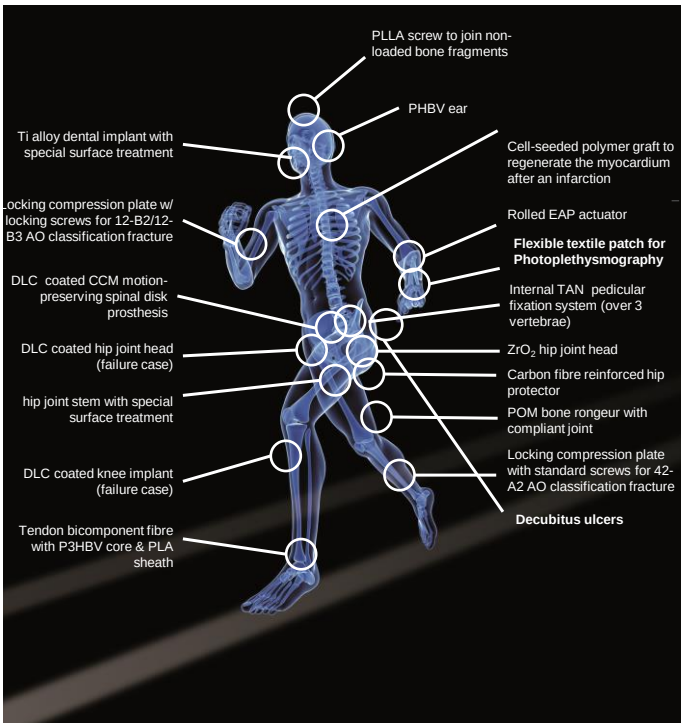

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MedTech

Combining the expertise of more than 10 Empa laboratories

15

R&D: Materials meet Life

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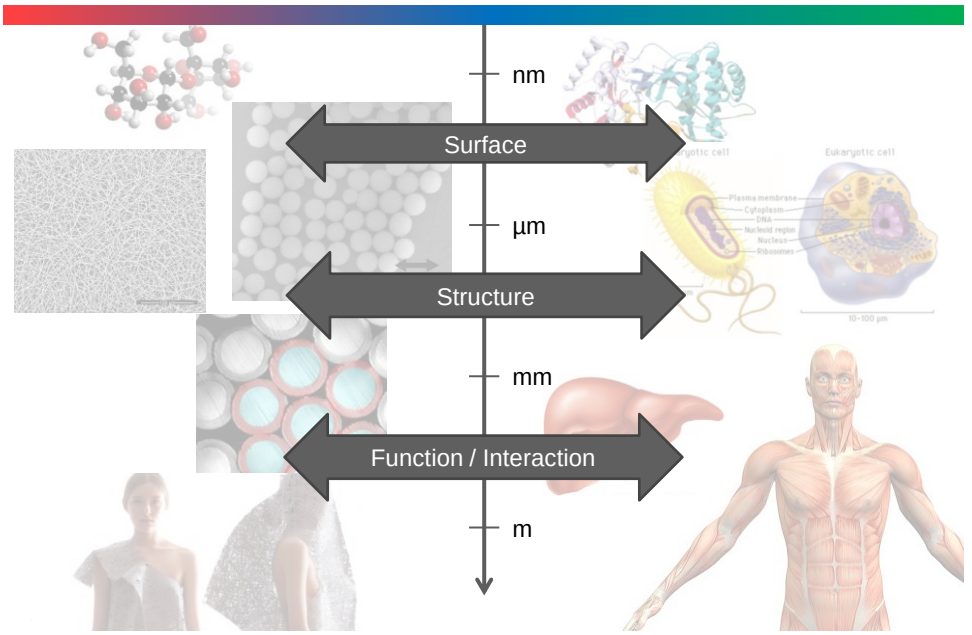
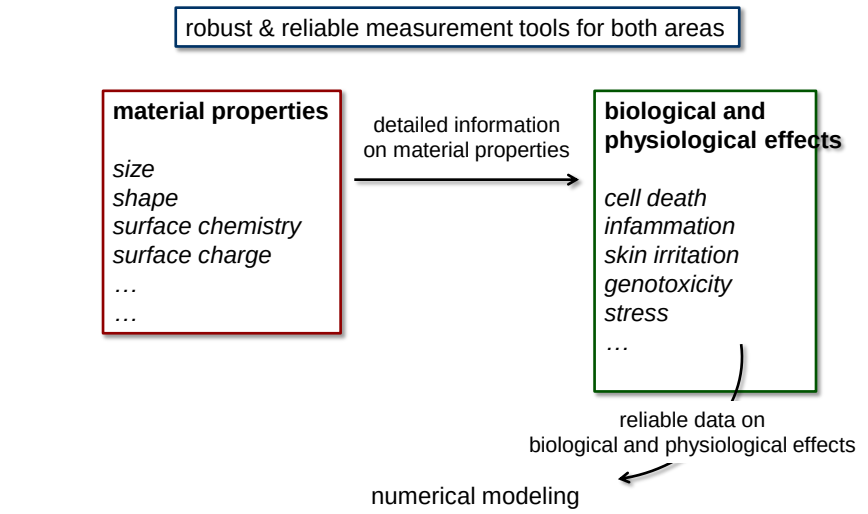
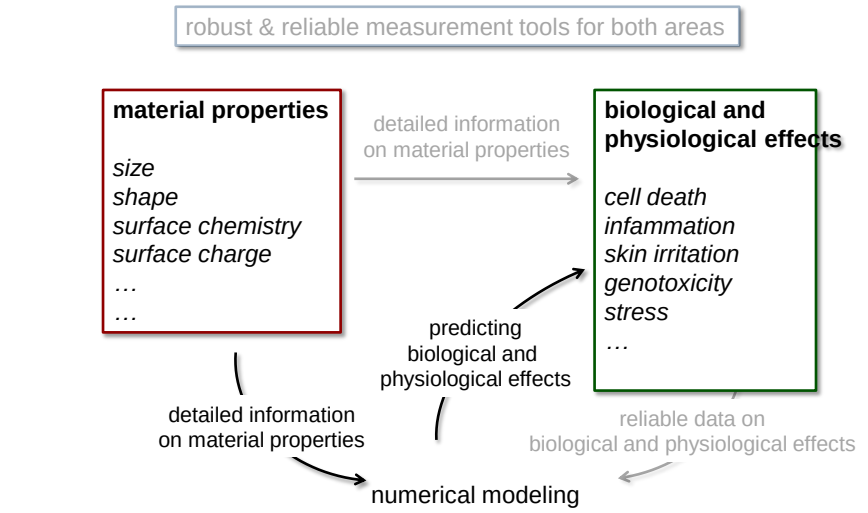


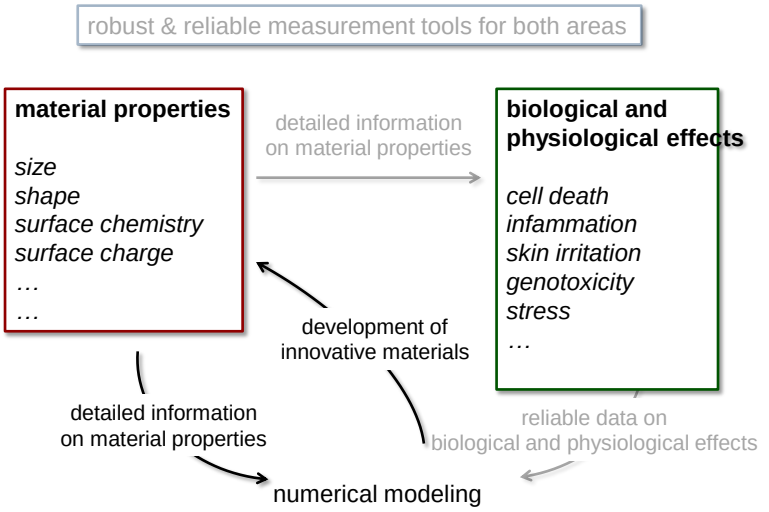
Modeling materials – life interactions



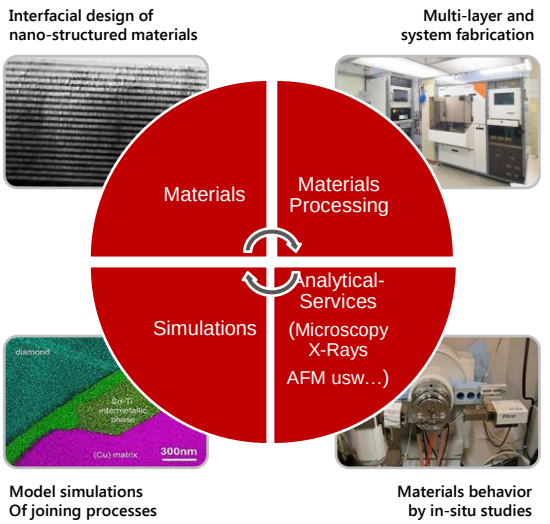
Modeling materials – life interactions



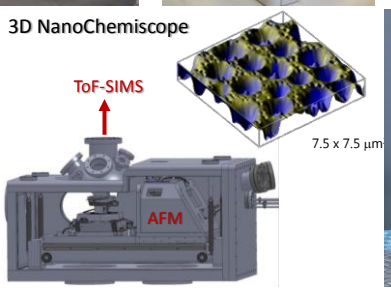
Modeling materials – life interactions

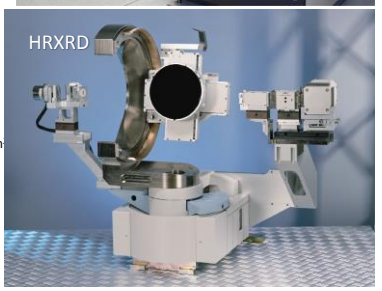


Empa-Accelerate Progress by sharing know how



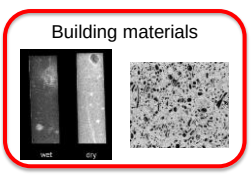
Surface Analytics @ Empa

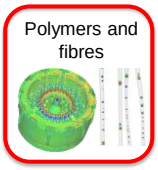


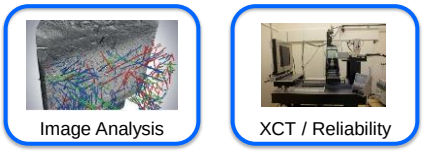


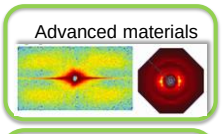
Center for X-ray analytics

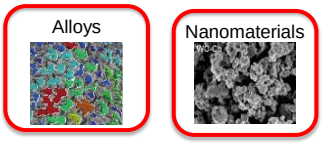
We develop novel X-ray technologies from nanometer to meter scale

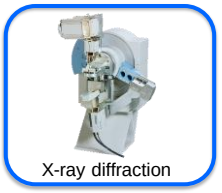


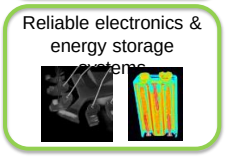






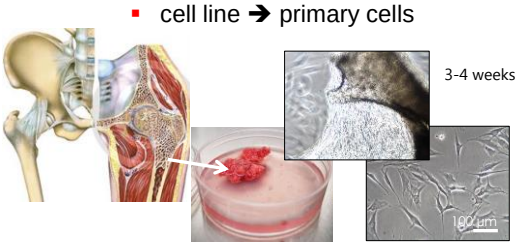






Advanced *in vitro* models

- cell line ➔ primary cells

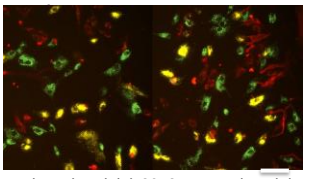


Born et al 2012; J Cell Biochem

- Static ➔ perfused

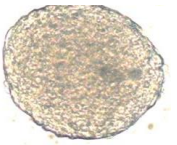
Perfused transwell system

- Monoculture ➔ co-



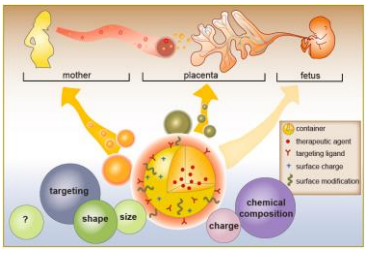
Wein and Bruinink 2013; Intergative Biol

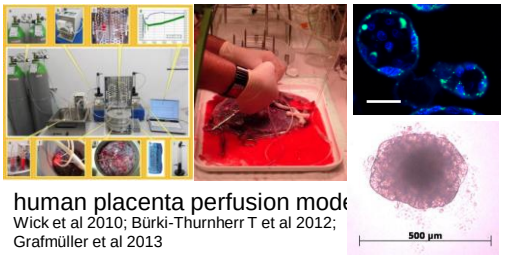
- 2 dimensional culture ➔ 3D culture



3D placenta microtissue

NANOMATERIALS AT HUMAN PLACENTA BARRIER





human placenta perfusion mode
Wick et al 2010; Bürki-Thurnherr T et al 2012; Grafmüller et al 2013

Aim:

- Achieve a better understanding of NP-placenta interaction throughout pregnancy
- Provide a versatile and predictive placenta models that covers the entre gestational period as well as different potential uptake routes

In collaboration with:

- Frauenklinik KSSG
  Prof. Dr. R. Hornung
- Institut für Pathologie KSSG
  Prof. Dr. W. Jochum
- Institut für Immunbiologie KSSG
  Prof. Dr. B. Ludewig
- Hirslandenklinik Stephanshorn

Kantonsspital St.Gallen

Support of Empa research with clinical expertise

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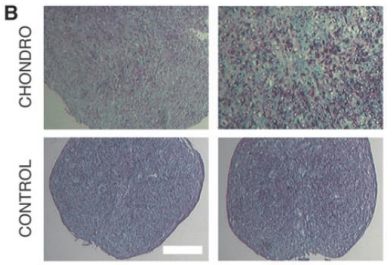
Histology know-how and expertise

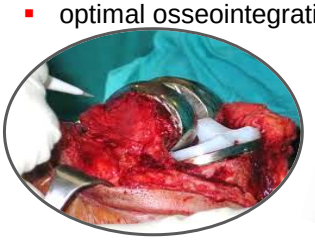
Kantonsspital St.Gallen



Studer D, Lischer S, Jochum W, Ehrbar M, Zenobi-Wong M, Maniura-Weber K. Tissue Eng Part C Methods. 2012 Oct;18(10):761-71.

Bone marrow samples for in vitro studies of diverse projects

- new implant materials/ surfaces
- optimal osseointegration



Materials-Biology Interactions

understanding the structure-function relationship of nanomaterials on human cells and tissues for human health

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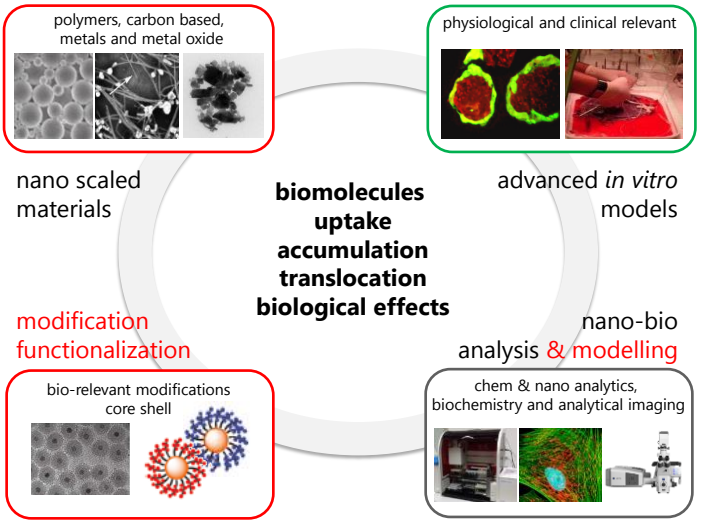

NanoMedicine

Advanced analytical research

Measurement science in biology
Insights from interlaboratory comparisons

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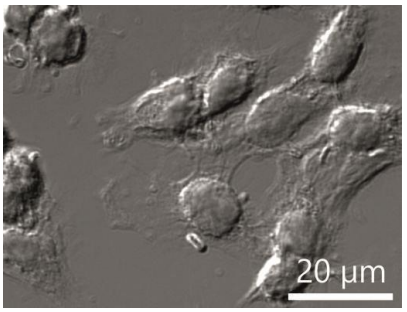
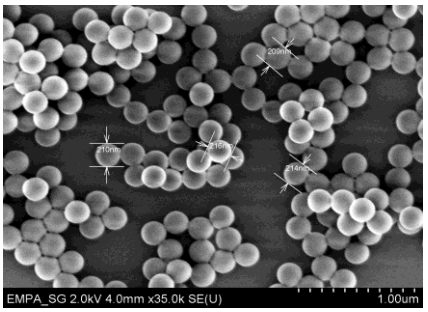
A549 cells:
subclone-A
subclone-B

amine-modified **Polystyrene beads**





NIST National Institute of Standards and Technology U.S. Department of Commerce
KRISS Korea Research Institute of Standards and Science
JRC EUROPEAN COMMISSION
NANOTEC a member of NSTDA

Modelling Body Functions – Textiles and Sensors

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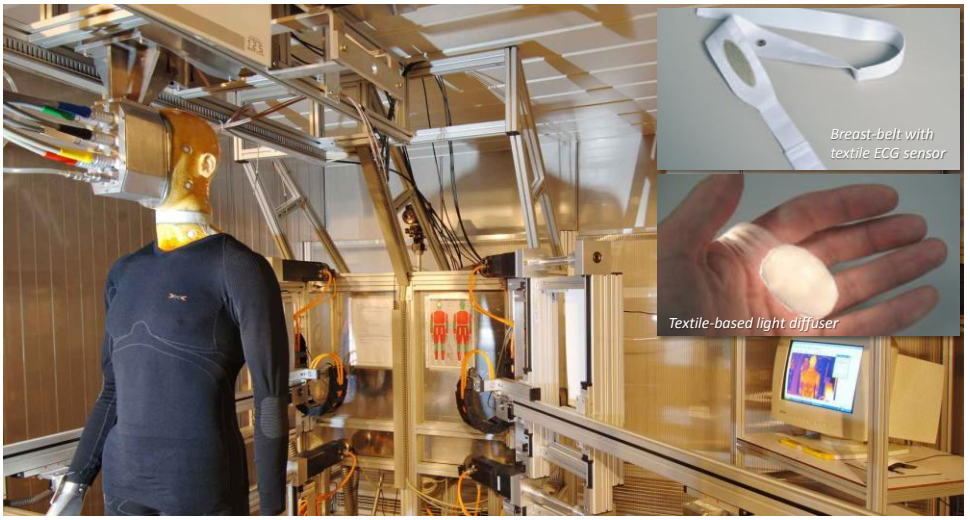
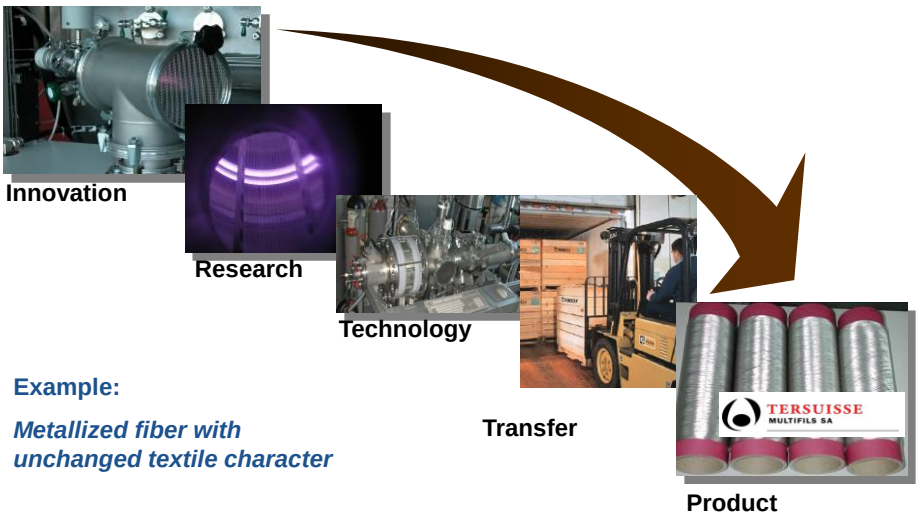


Plasma Metallization transferred to industry



Example:

Metallized fiber with unchanged textile character

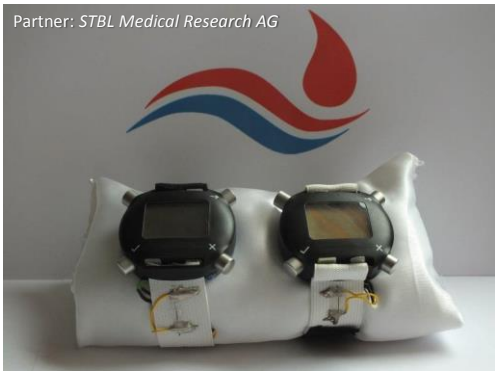
Textile embedded electrodes

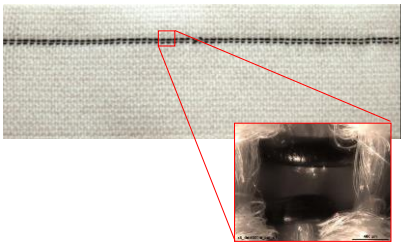
MedTech Award 2006: ECG sensor shirt

- **Electrocardiogram (ECG) measurements**
- **Muscle stimulation**

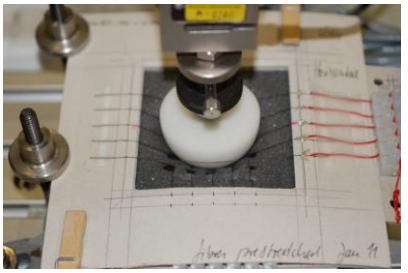
Wristband for blood pressure measurement

Partner: *STBL Medical Research AG*

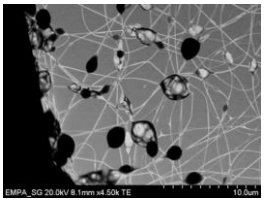


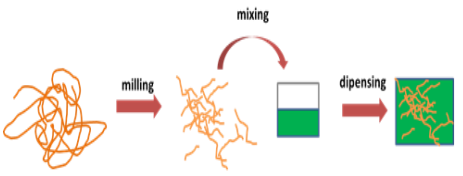


Pressure Sensor based on Piezo-resistive fibres



Nanospider (Electrospinning-Anlage)





Nanostructured Thin Films and Coatings

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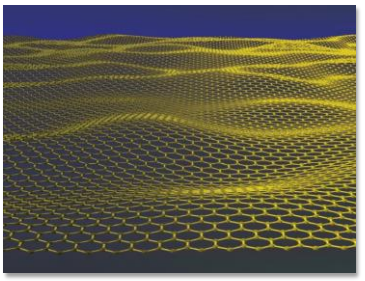
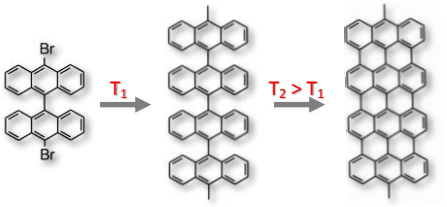
Atomically Precise Graphene Nanoribbons



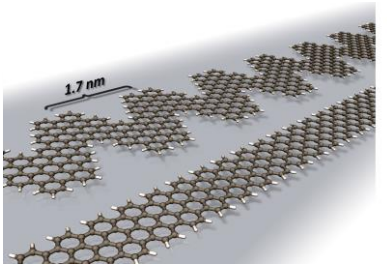
- Thermal conductivity:
  - Graphene ~ 5000 $Wm^{-1}K^{-1}$
  - Silicon ~ 150 $Wm^{-1}K^{-1}$
- Electron mobility:
  - Graphene < 200'000 $cm^2V^{-1}s^{-1}$
  - Silicon 1400 $cm^2V^{-1}s^{-1}$

Partners

On-Surface Synthesis of Graphene Nanoribbons



J. Chai, R. Fasel et al., Nature, **466** (2010) 470 - 473



Lithium-Ion Batteries

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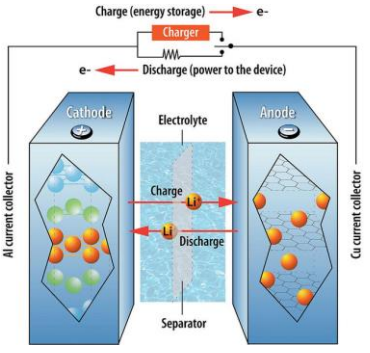


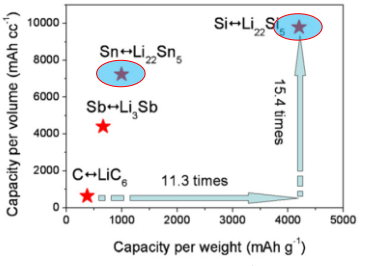
Mn, Co, Ni

C, Si, Sn, Sb

UBM Electronics

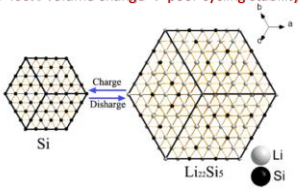
$$C_6 + LiMn_2O_4 \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} Li_xC_6 + Li_{1-x}Mn_2O_4$$

Gravimetric & volumetric capacities of anode materials



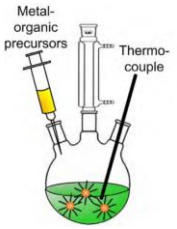
N. Ding et al., Journal of Power Sources, 192 (2009) 644

Problem:
Up to 400% volume change → poor cycling stability

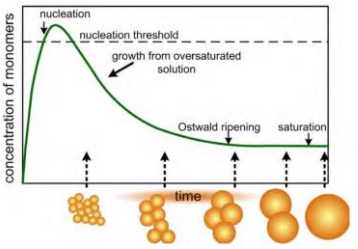


Lithium-Ion Batteries

Sn Nanocrystals as Anode Material



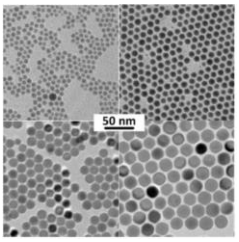
+ surfactants
(25-350°C)

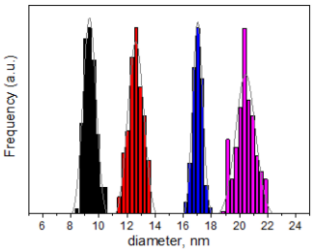


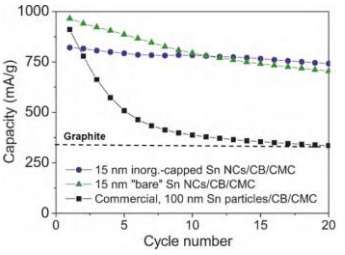
$SnCl_2$ —(DIBAH, OLA; 100 – 180°C)→ Sn (NCs)

DIBAH: Diisobuthylalluhydride
OLA: Oleylamine

Sn Nanocrystals



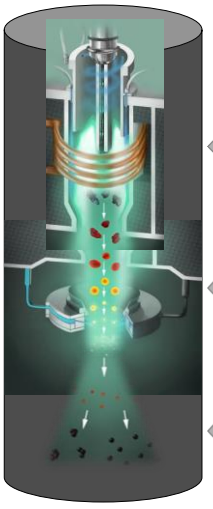




Lithium-Ion Batteries

Si Nanoparticles as Anode Material

Inductively Coupled RF Plasma (ICP)

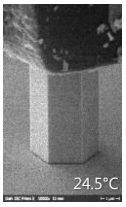


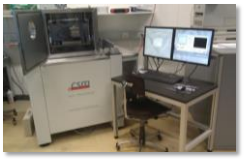
Plasma Diagnostic
- Optical Emission Spectroscopy (OES)
- Entahlpy Probe
- Calorimetry
- Fourier Transform Infrared Spectroscopy (FTIR)

Plasma/Particles Interaction
- Optical Emission Spectroscopy (OES)
- High-Speed Imaging

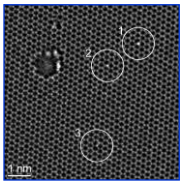
Products Characterization
- Fourier Transform Infrared Spectroscopy (FTIR)
- Light Extinction Spectroscopy
- In-Situ Sampling

Micro- and Nano-Characterisation





High-Temperature Nanoindenter
Commercialization start in 2013
(CSM instruments, CH)



Graphene Monolayer

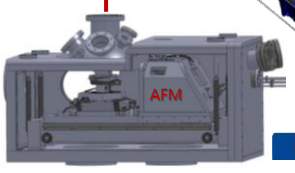
PRL, **108** (2012) 047601
Nano, **6** (2012) 7077
Nature, **470** (2011) 374

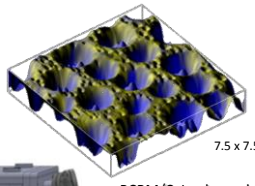
Ag NP (748 atoms)

Adv. Mat., **22** (2010) 4467
Nature Chem., **4** (2012) 287
Angw. Chem. (int. ed.) **48** (2010) 8890

3D NanoChemiscope
(EU-FP 7 project)

ToF-SIMS





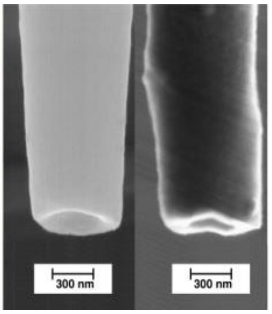
PCBM/CyI polymer blend
- PCBM (yellow)
- CyI (blue)

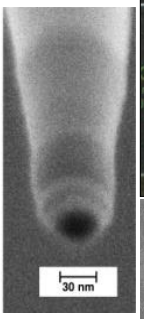
ionTOF

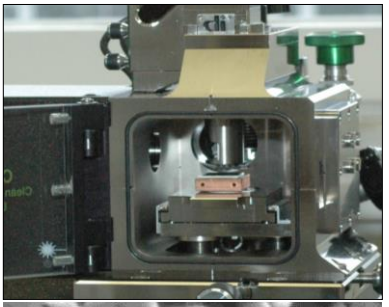
IBM/Empa joint venture
Operation of a High-end TEM
Start: 1.2.2013

Micro- and Nano-Characterisation

Electrochemical Characterisation on the Nano-Scale







Failure and Safety Analysis @ Empa

National road A9 / Jet fans of Glion Tunnel (2012)

Center for X-ray analytics

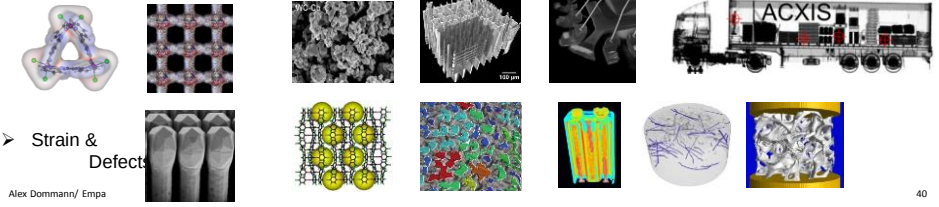
VISION: We the are the leading group in Europe in the field of novel X-ray technologies and methods for materials science and biotechnology from the Angstrom to the meter scale.

Å nm µm mm

Diffraction & Scattering	Phase Contrast & Dark Field Imaging	Micro-Tomography	Macro-Tomography
XRD / HRXRD / SAXS	XPCI	µCT	XCT

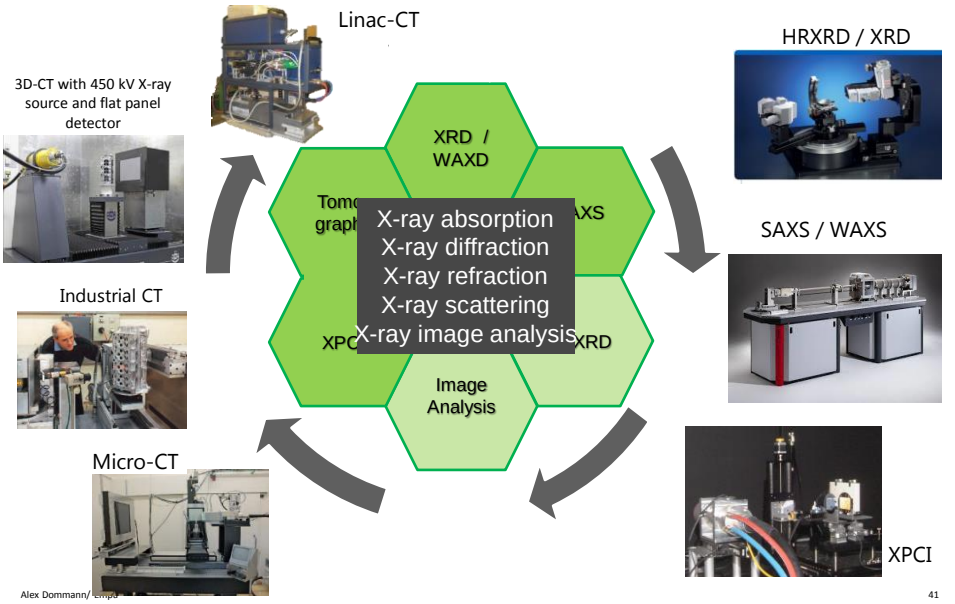
Image Analysis & Simulation

- Molecular structures and interactions
- Strain & Defects
- Nano-particles & voids (sizes and distributions)
- Interfaces
- 3D Imaging of large Objects



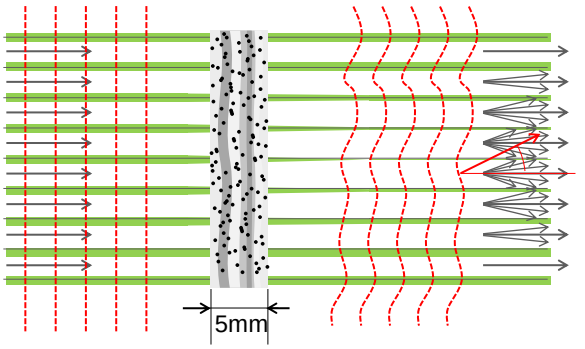
CENTER FOR X-RAY ANALYTICS

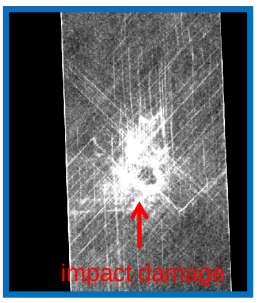
EMPA
Materials Science & Technology



Enabling New X-ray Insights

EMPA
Materials Science & Technology

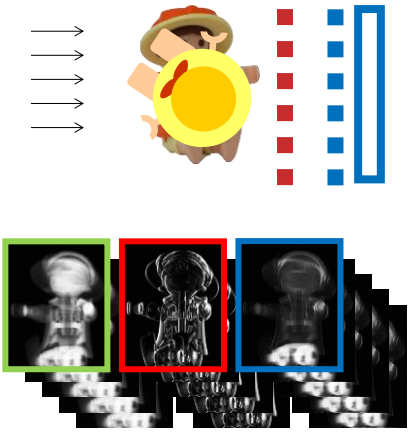




Fiber Composite Materials

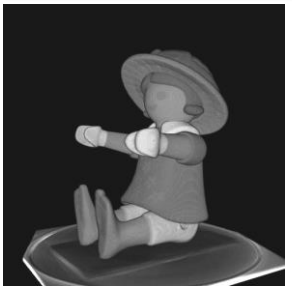
- quasi-isotropic CFRP
- lay up $[0°/+45°/90°/-45°/0°]_s$

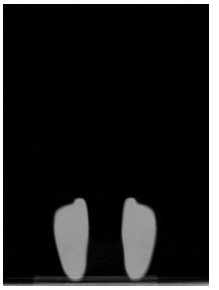
Computed Tomography CT



Individual reconstruction for each contrast!

Reconstruction of 3D Internal Volume
(same principle used for medical scanners)

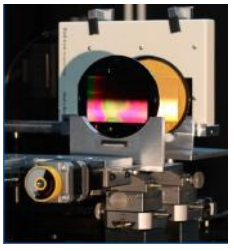


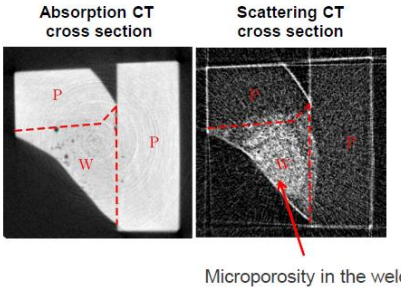


Defects analysis in light weight composites:

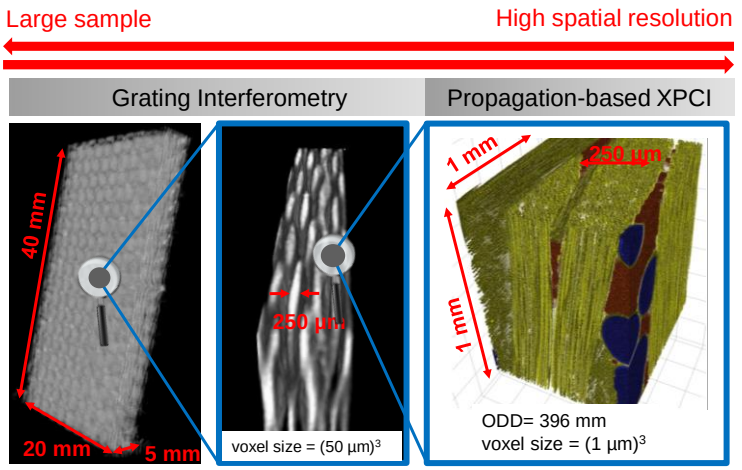
Aluminum corner weld (provided by Audi AG)

- 3D object reconstructed by Computed Tomography (CT)



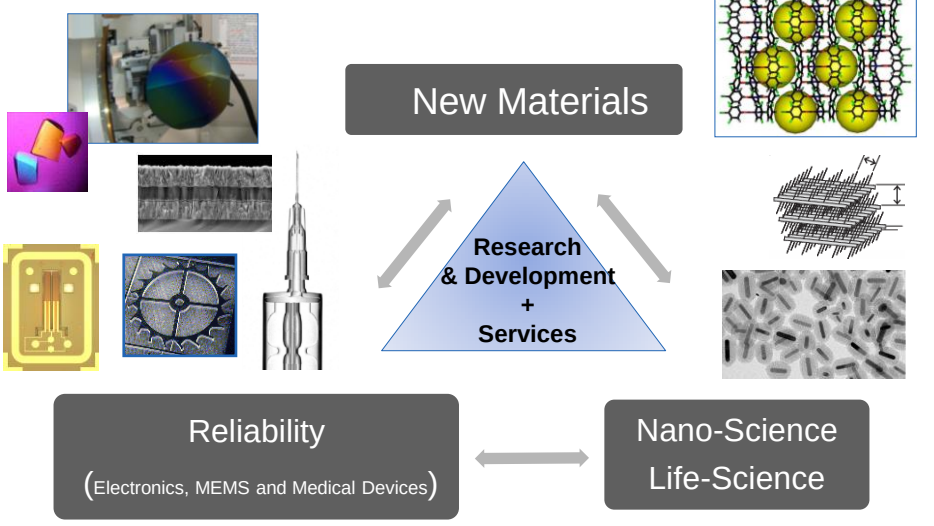


3D Visualization of fiber bundles

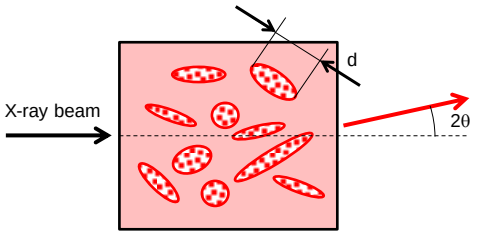


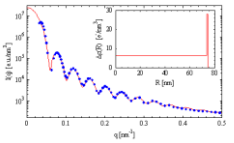
J. Kastner et al., Proc. World Conference on NDT (2012)

What we do: Domains of activities



SAXS: Principle & Opportunities

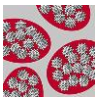




scattering at particles or electron density changes scattering angles:
2θ≈0 - 4° ↔ d≈10-100nm

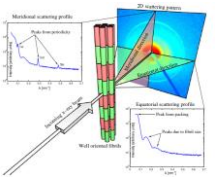
Some examples of opportunities:

Nanostructural Parameters

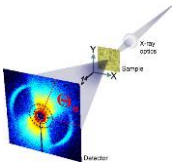


Size (mean, distribution)
Shape (spheric, cylindric, etc.,)
Inter-particle distribution

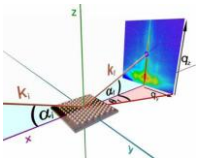
Orientation



Scanning-SAXS

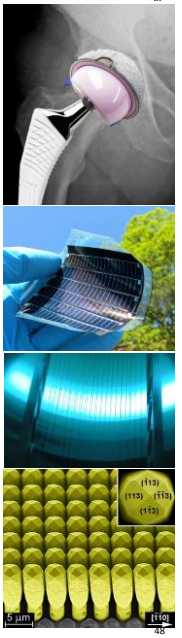


***G**razing **I**ncidence-SAXS*



Coating Competence Center

Current Situation of the Swiss Coating Scene



Challenges

- Novel coatings with improved properties
- Novel coating technologies
- Customized coatings
- Durability and reliability

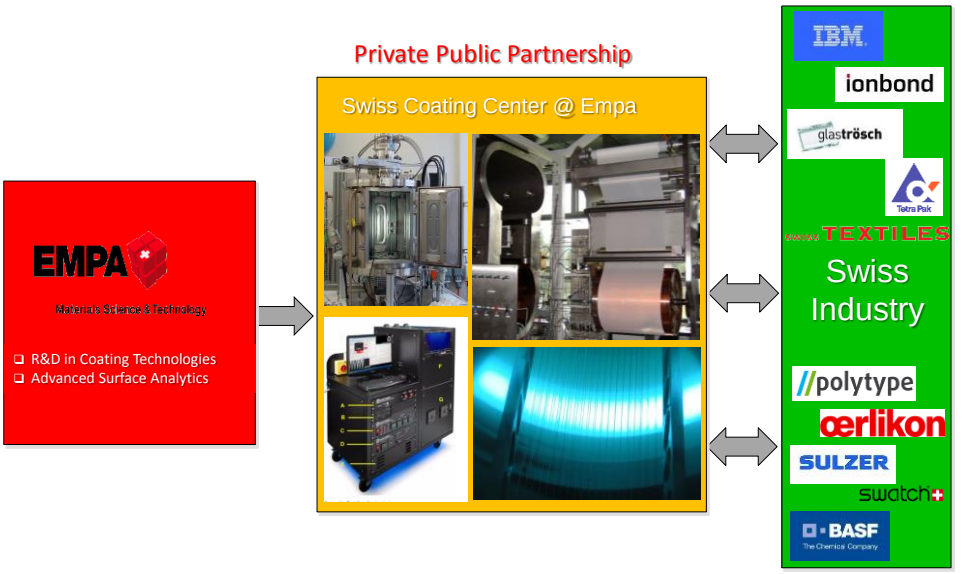
Requirements

- Scientific excellence in
  - Process monitoring and control
  - Process modeling
  - Thin film and interface characterization
  - Nanostructured Coatings
  - Computational Material Science

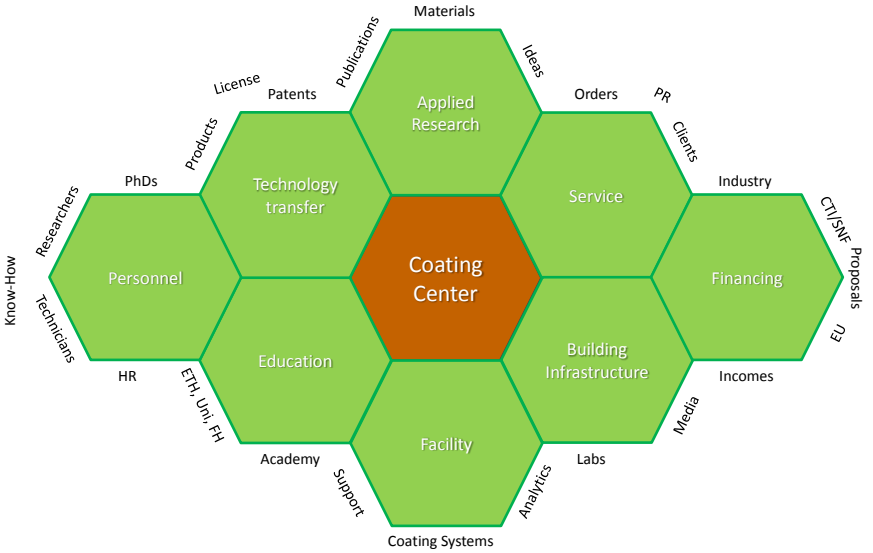
Aims:

- Improved Technology Transfer
  - Proof of Concepts
  - Process Development
- High educated experts

Coating Competence Center @ Empa



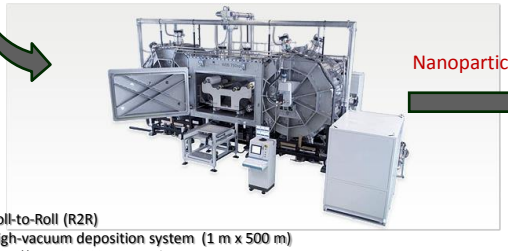
Coating Competence Center @ Empa



Inorganic Flexible Thin Film Solar Cells

Vision: From vacuum batch process to roll-to-roll printing technique!

$\Delta T_{substrate}$ = - 200°C



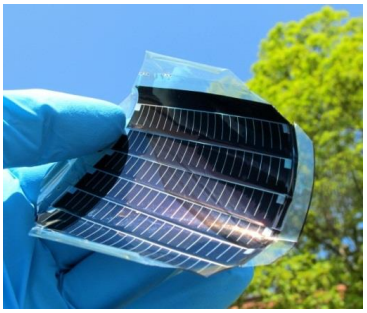
Nanoparticles

Roll-to-Roll (R2R)
High-vacuum deposition system (1 m x 500 m)
(http://www.leyboldoptics.com)

Roll-to-Roll (R2R) Printing System

Inorganic Flexible Thin Film Solar Cells

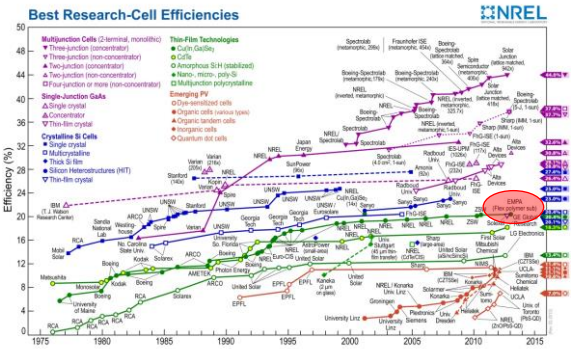
Cu(In,Ga)Se$_2$



Empa world records:

- CIGS on Polyimide: η = 20.38% (2012)
- CdTe on Kapton®: η = 13.80% (2011)

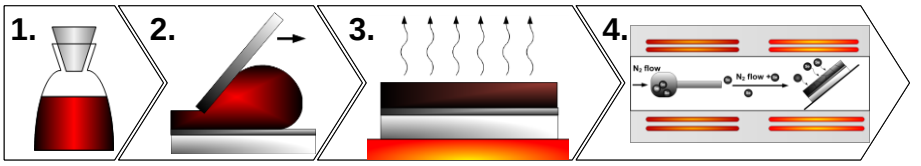
Adrian Chirilla et al., *Nature Materials* (online 18.9.2011)



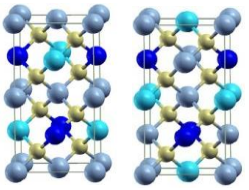
Inorganic Flexible Thin Film Solar Cells

Printing Technology

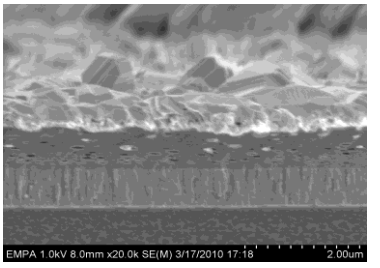
EMPA
Materials Science & Technology



Kesterites $Cu_2ZnSn(S,Se)_4$:



Efficiency: 7.5%



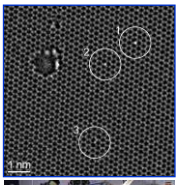
Coating Competence Center

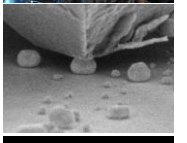
Strenght and Uniqueness of Empa

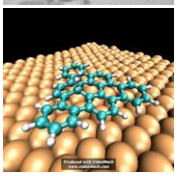
EMPA
Materials Science & Technology

Used inspired interdisciplinary approach combining high competences in:

- Materials science
- Solid State and Surface Physics
- Chemistry
- Corrosion Science
- Thin film and surface/interface characterization
- Micro- and Nanomechanics
- Computational modeling and simulation
- …







Coating Competence Center

First Collaboration: OC Oerlikon Balzers

INGENIA S3p™

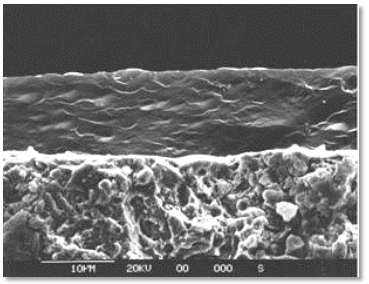
Vacuum Deposition System INGENIA S3p™

- Equipped with HIPIMS (High-power impulse magnetron sputtering)
  - Besides the gas composition and substrate temperature by the power electronic is used to control the deposition process
    - Duty cycle
    - Current pulse-height
    - Current pulse-time

Applications

- Automotive
  - Combustion engine
  - Gear
  - Injector
  - Decorative Coatings
- Energy Systems
  - Thermal barriers
  - Membranes
    - SOFC
    - Electrolysis
    - …
- Medical Implants

Diamond Like Carbon Coating (DLC)



Properties:

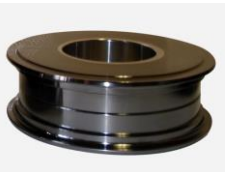
- Hardness: 1500 – 4000 HV
- Temperature Stability: < 350 °C
- Very low friction coefficient: m < 0.1
- High wear resistance: ≈ 10^{-7} mm^3/Nm
- Acid and base resistant
- Biocompatible

Industrial well established coating technology

Hard Disk

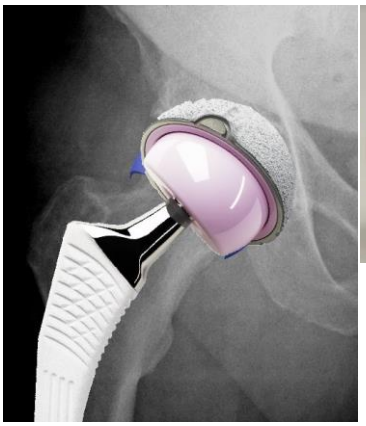
Diesel Injector

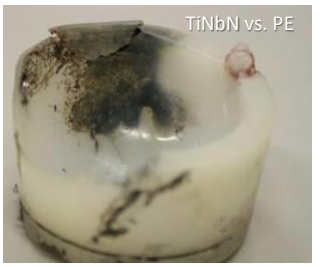
Watch Industry

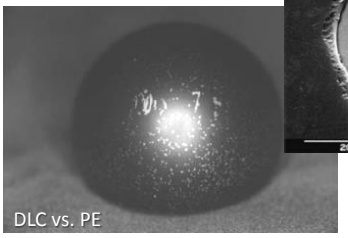


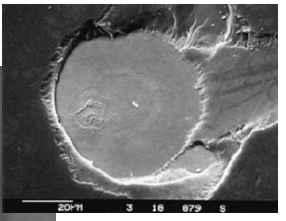
Automotive

DLC for Medical Implants

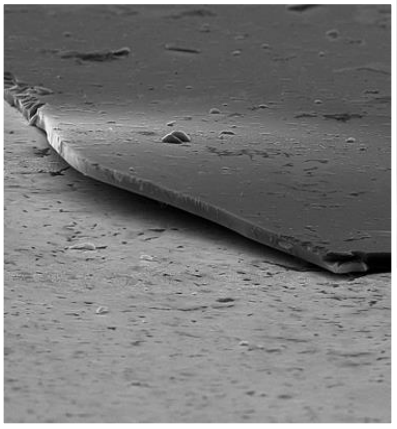


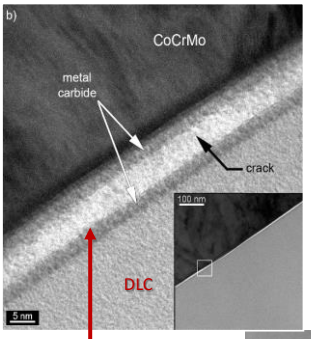




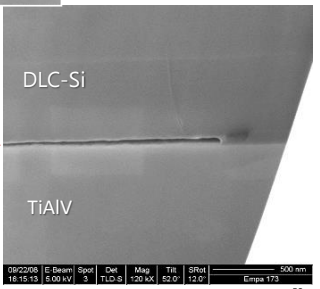


DLC for Medical Implants





Corrosion !!



Delamination of the DLC-Coating in
0.01M Phosphate-Buffered Saline (PBS)
PBS: KCl, NaCl, Na_2HPO_4, KH_2PO_4, H_2O

NEST: *Exploring the Future of Buildings*

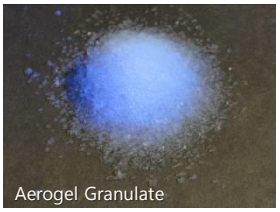
Large scale „plug-and-play“ Living Laboratory

2‘500 m² of innovation space

Public Private Partnership (Research – Business – Society)

Nanoparticles & Nanocomposites

Aerogel based Isolation Plaster



- Thermal conductivity < 27 mW/m·K
- Spray Coating: max. thickness 2 x 60 mm
- Low shrinkage (≤ 1‰)
- Moister diffusion resistance factor μ < 10
- Hydrophobic
- Pure mineral

➢ Market launch: March 2013

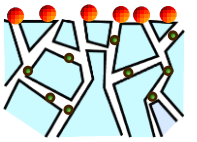
Nanoparticles & Nanocomposites

EMPA
Materials Science & Technology

Flame Synthesis
(TiO_2, SiO_2, Y_2O_3, …)
0.1 – 1 kg/day

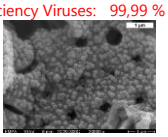
KATADYN
MAKING WATER DRINKING WATER

Bacteria and Viruses Water Filter



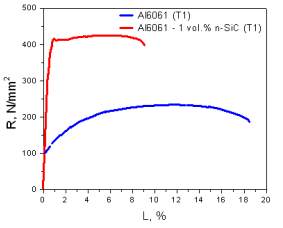
Bacteria
Viruses

Efficiency Bacteria: 99,9999 %
Efficiency Viruses: 99,99 %



Plasma Synthesis
(TiC, TiN_xC_y, Si, SiC, WC, …)
0.01 – 0.5 kg/day

ALCAN



….. from synthesis to applications!

Alex Dommann/ Empa

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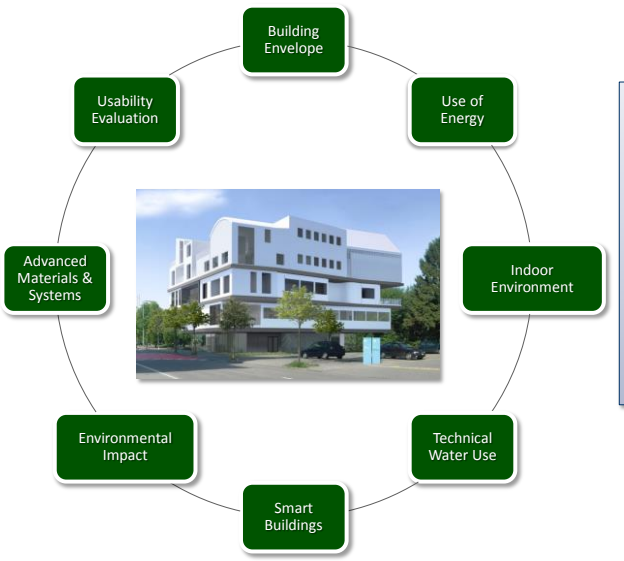
NEST: *A Holistic and Sustainable Approach*



Current topics of interests:

- Natural living
- City lifting
- Lightweight construction
- Office of the future
- Glass architecture
- Modular living
- Digital living

NEST: *A Holistic and Sustainable Approach*

Timeline

- Backbone: Ready Q1 2015
- First wave Research and Innovation Units
  - meet2create — University of Applied Science Lucerne (HSLU)
  - HiLo — ETH Zurich
  - City Lifting — EPF Lausanne
  - Natural Living — Empa

Partners:

Industry*	Academia	Foundations, Public Bodies
Siemens Building Technologies Zehnder Group Fatze Duravit Renggli Holzbau 3A Composites …	ETH Zurich EPF Lausanne EAWAG HSLU …	Canton Zurich Federal Office of Energy ETH Council Private Foundations ….

* LoI signed or in discussion

Collaborations

EMPA
Materials Science & Technology

ROLIC technologies
SOLARONIX "in sun we trust"
Flisom Flexible Solar Modules
CREATEC COMPETENCE IN MBE
CALORIFER
œrlikon
CREALAS Smart Micromachining
IBM
PHILIPS
ROHNER | CHEM
ILFORD
BASF The Chemical Company
NOVARTIS
IONTOF
ALCAN
Carbo Link
SCHOTT glass made of ideas
EVONIK INDUSTRIES
HEIQ Effects For Life
BÜHLER
KATADYN MAKING WATER DRINKING WATER
CTS The Composites Company
WESSLING Quality of Life
manz
glaströsch
BOBST
straumann
HEXIS
csm Instruments
ENGIMICS sa Engineered Ceramics
TESCAN PERFORMANCE IN NANOSPACE
Novelis
BEHR
Companies from the Watch Industry
FIXIT Schweiz. Suisse. Svizzera.
eschler
umicore
Cham Paper Group
nanoscan
TOFWERK Time-of-Flight Mass Spectrometry
COMETGROUP Technology with Passion