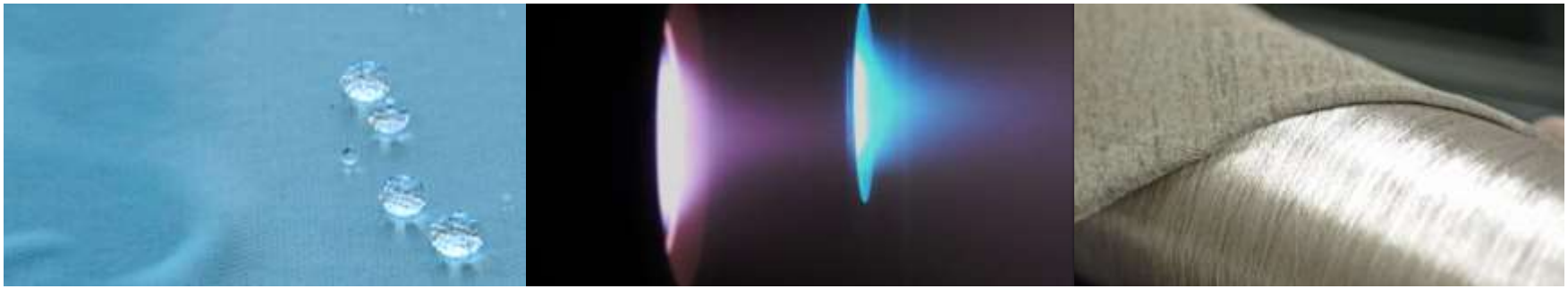
Plasmabeschichtungen auf Fasern für ‘Smart Textiles’



Dr. Dirk Hegemann

Empa, St.Gallen, Advanced Fibers, Plasma & Coating

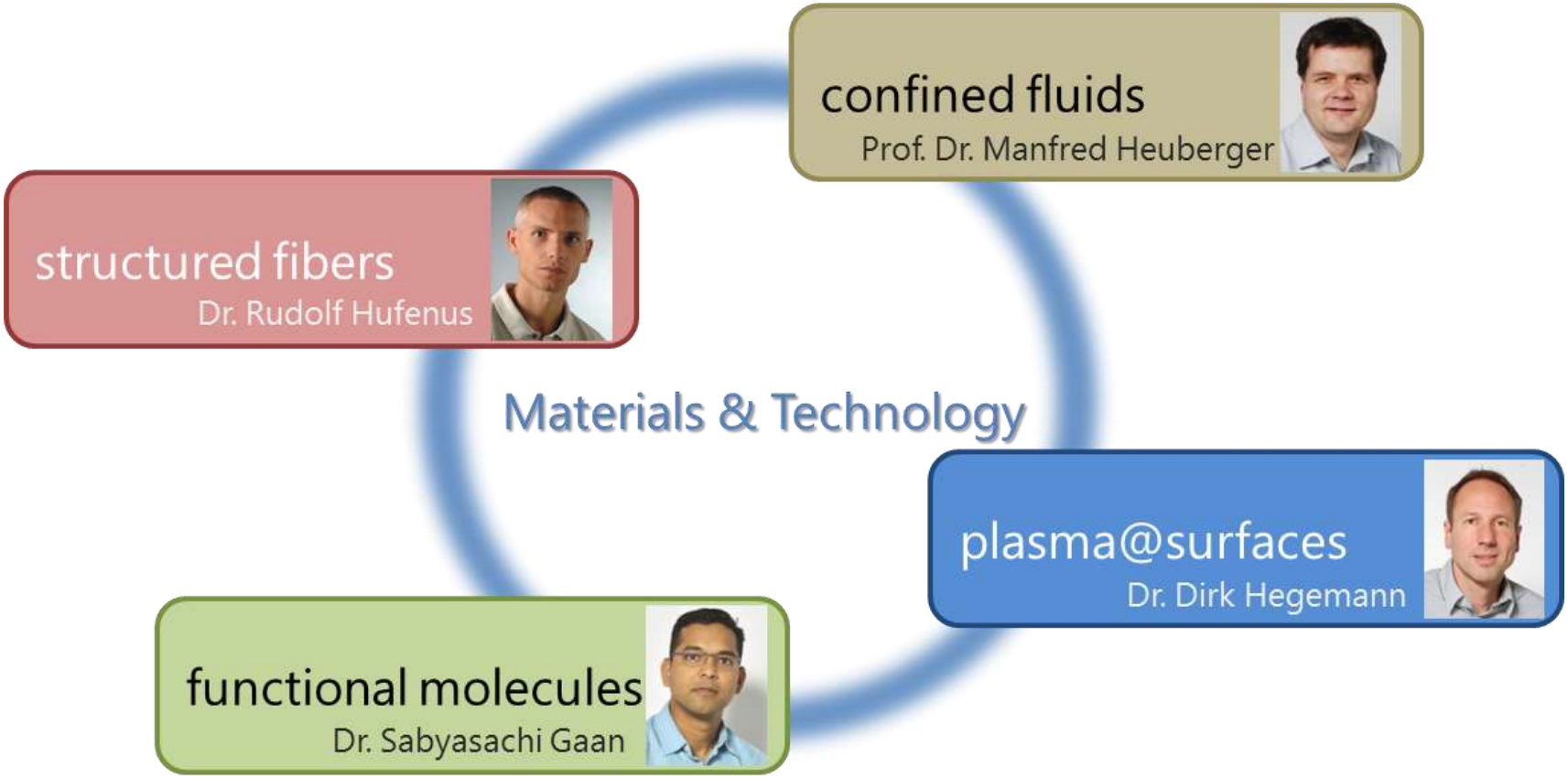
dirk.hegemann@empa.ch

Laboratory of Advanced Fibers

Empa
Materials Science and Technology

www.empa.ch/advancedfibers

Leading competences



Plasma & Coating

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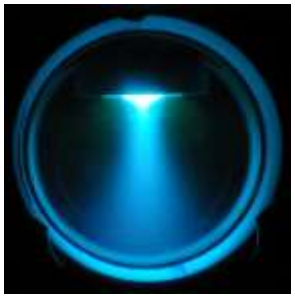
Plasma Polymerization

Co-Sputtering

Sputtering



AP vs. LP Plasma

→ **transfer to industry**
(economic, resource-saving processes)

Plasma & Coating

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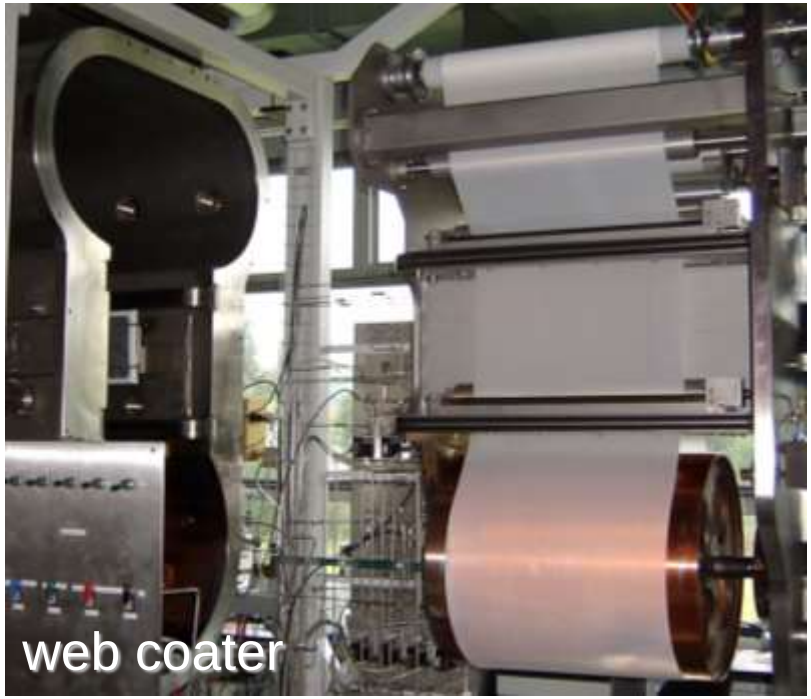
Unique plasma reactors for reel-to-reel treatment



width = 65 cm

- **Functional plasma polymer films**
- **Metallizations**
- **Combinations thereof**
  (codeposition, multilayers, gradients)

Continuous treatment of textiles, membranes, foils, ribbons, paper as much as fibers, yarns etc.

Plasma Polymerization

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Control of deposition conditions

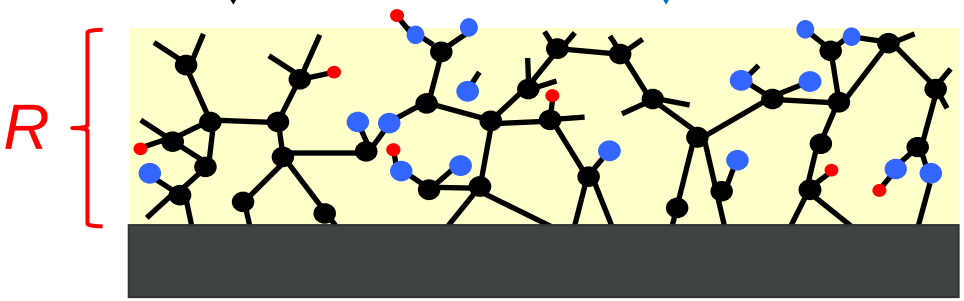
electrons n_e → monomer n_m ions $\oplus$ n_i

plasma chemistry

flux of film-forming species Γ_{dep}

plasma physics

energy flux $\Gamma_i \cdot E_i$



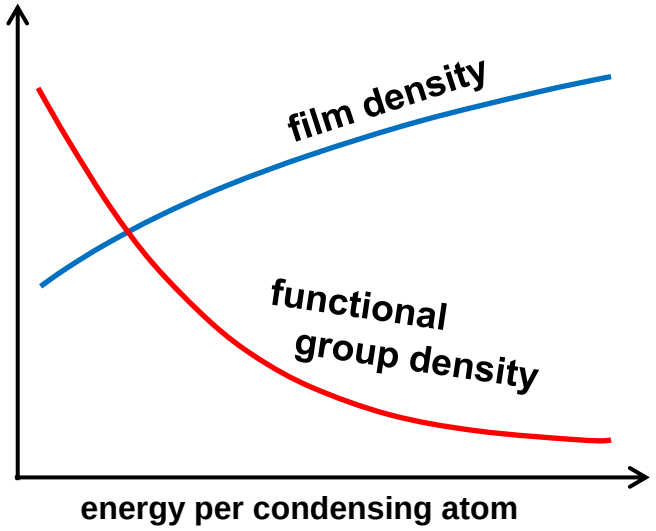
control of gas phase and surface processes during film growth

→ cross-linking vs. functionality

energy per condensing atom

$$\varepsilon_{surf} = E_i \frac{\Gamma_i}{s\Gamma_{dep}}$$

s: sticking probability



'trade-off'

Plasma Polymerization

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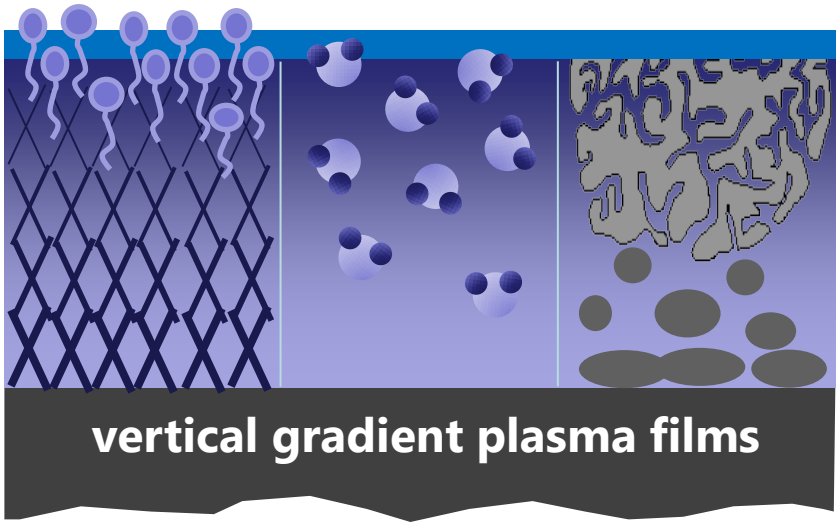
Control of deposition conditions – advanced

Interface (surface + sub-surface): interaction with environment

functionality, wettability, roughness, friction, passivation

surface
(~1-2 nm)

sub-surface
(~2-20 nm)



cross-linking/stability
hydration
porosity/loading
stiffness
adhesion

Future trends in plasma science: plasma + surface chemistry; plasma & bio: fluids
(Prof. R. Brinkmann, 'Future in Plasma Science', Greifswald, Germany, July 12-15, 2015.)

Tissue Engineering

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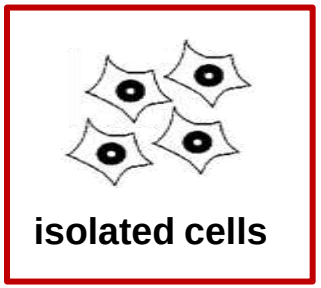
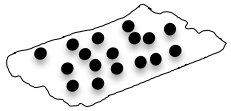
Matrix design for improved cell growth

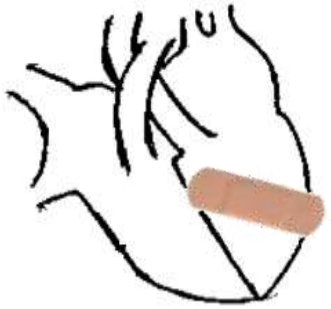

isolated cells

+


polymer matrix

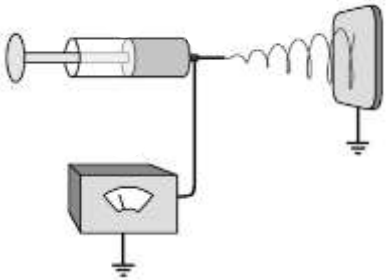
=

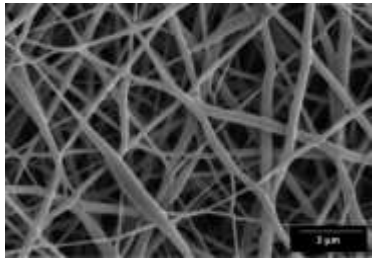

engineered tissue



implantation

Soft substrates (scaffolds) required


electrospinning

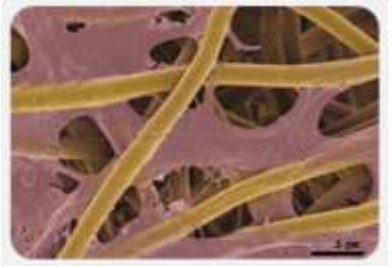

Poly(ε-caprolactone)

biodegradable

+

ultrathin functional plasma polymer (a-C:H:O)

=


heart muscle cells

G. Guex, D. Hegemann et al. *Acta Biomater.* 8 (2012) 1481.

Combination with Wet Chemistry

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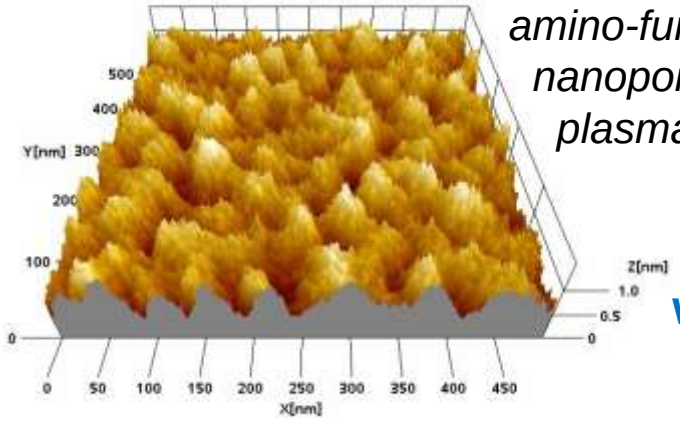
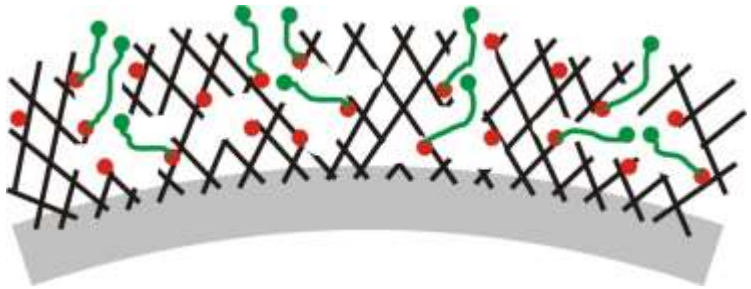
Attachment of chemical (or bio) molecules

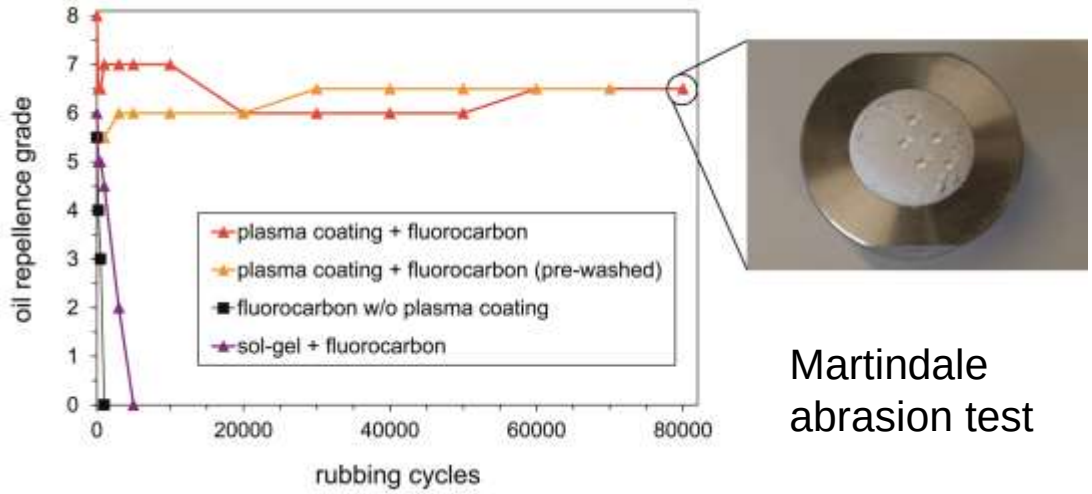


amino-functional nanoporous plasma polymer

wet chemistry



e.g. fluorocarbons
polyethylene glycols
antibodies
vitamines



Martindale abrasion test

- **increased abrasion resistance due to protection of attached molecules by nanoporous plasma polymer**

D. Hegemann *Thin Solid Films* 581 (2015) 2.

Adsorption / Desorption / Sensing

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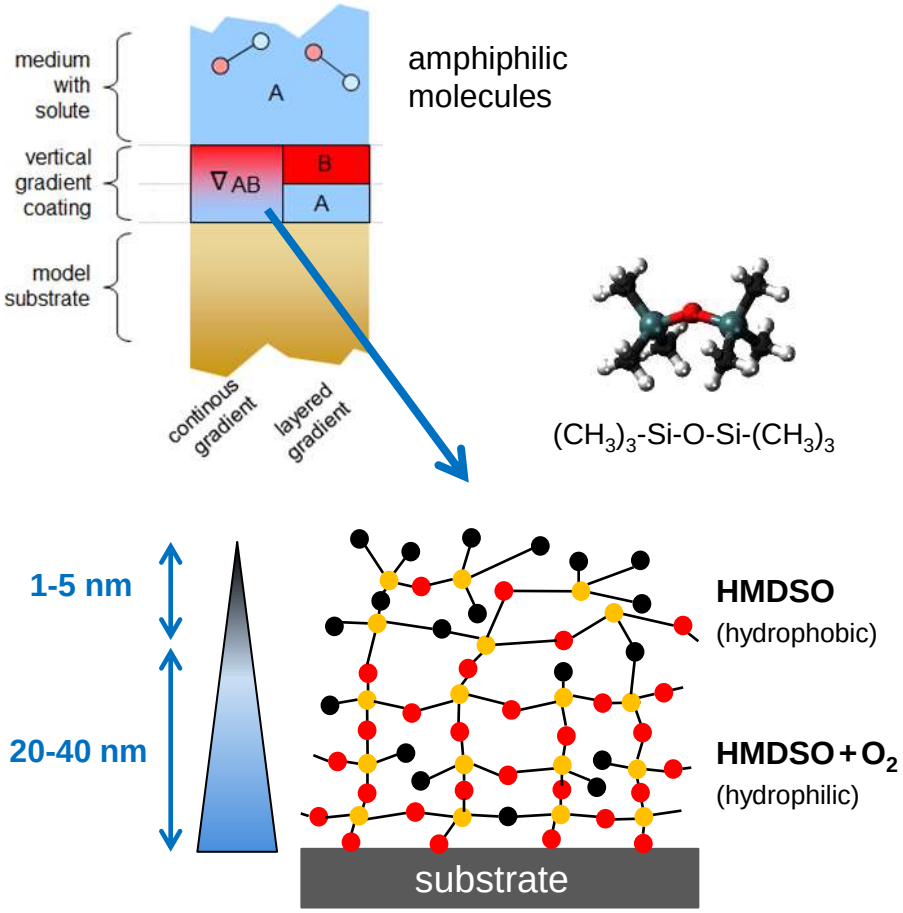
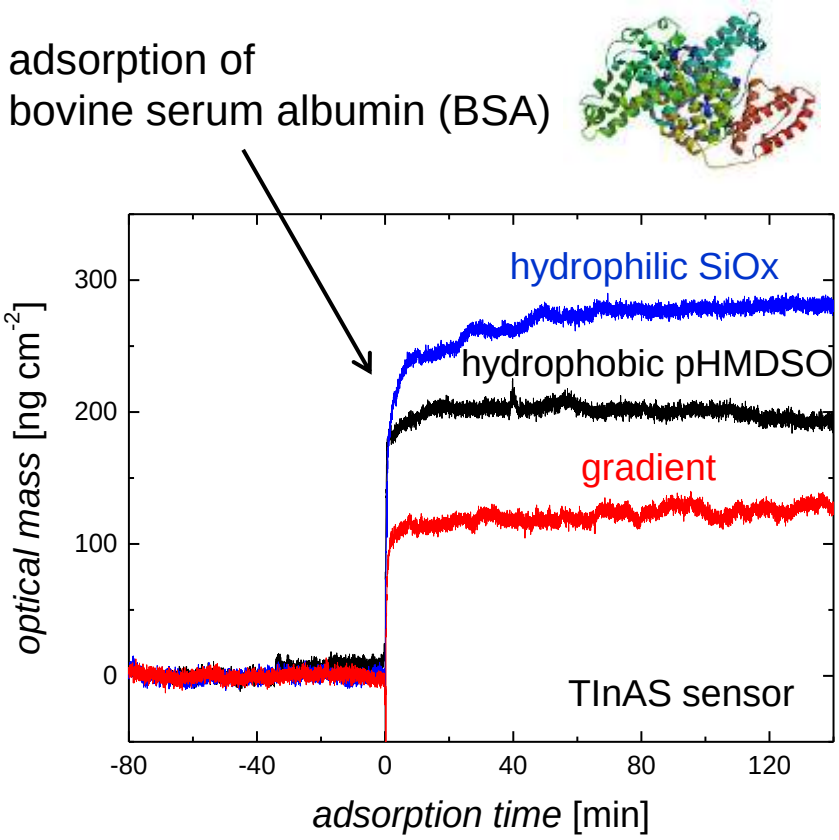
Plasma polymers with vertical chemical gradients





→ **reduced protein adsorption due to interaction with water molecules**

N.E. Blanchard, D. Hegemann et al. *Plasma Process. Polym.* 12 (2015) 32.

Reel-to-Reel Metallization

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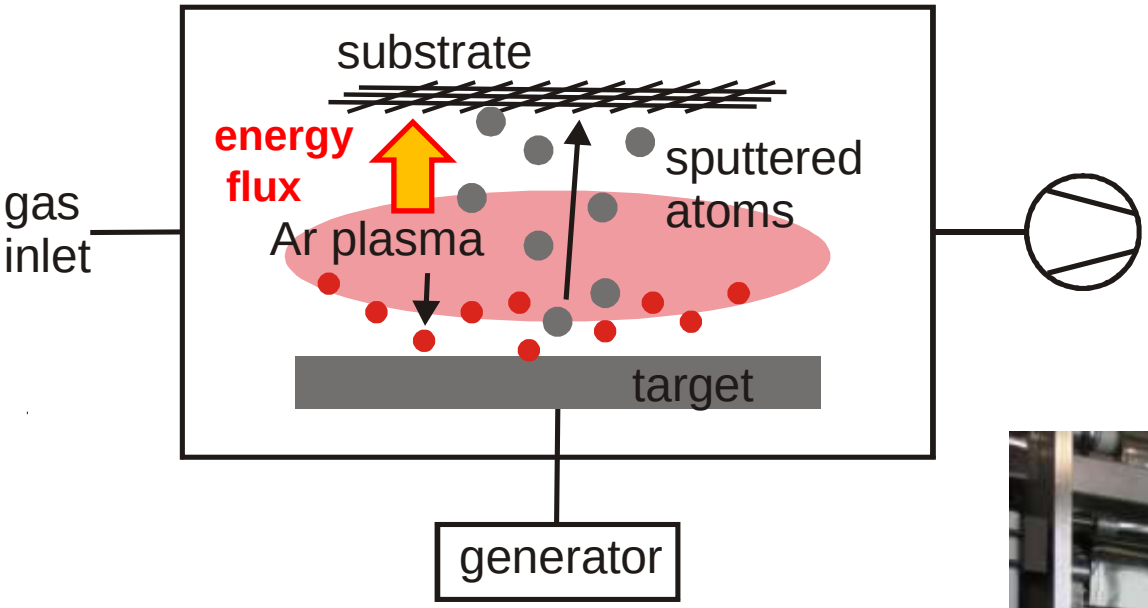
Physical Vapor Deposition (PVD) – Sputtering



pressure: ~1 Pa
@ target ~400 eV per atom
@ substrate >10 eV per atom

→ **dense morphology and good adhesion**

High-energetic Ar ions release atoms from the target (by collision cascades) yielding deposition on a substrate

metal coatings on foils and fibers

Smart Textiles

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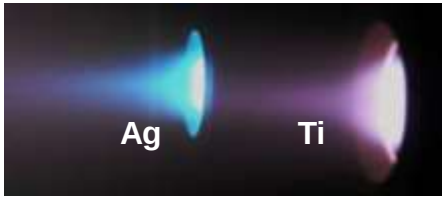
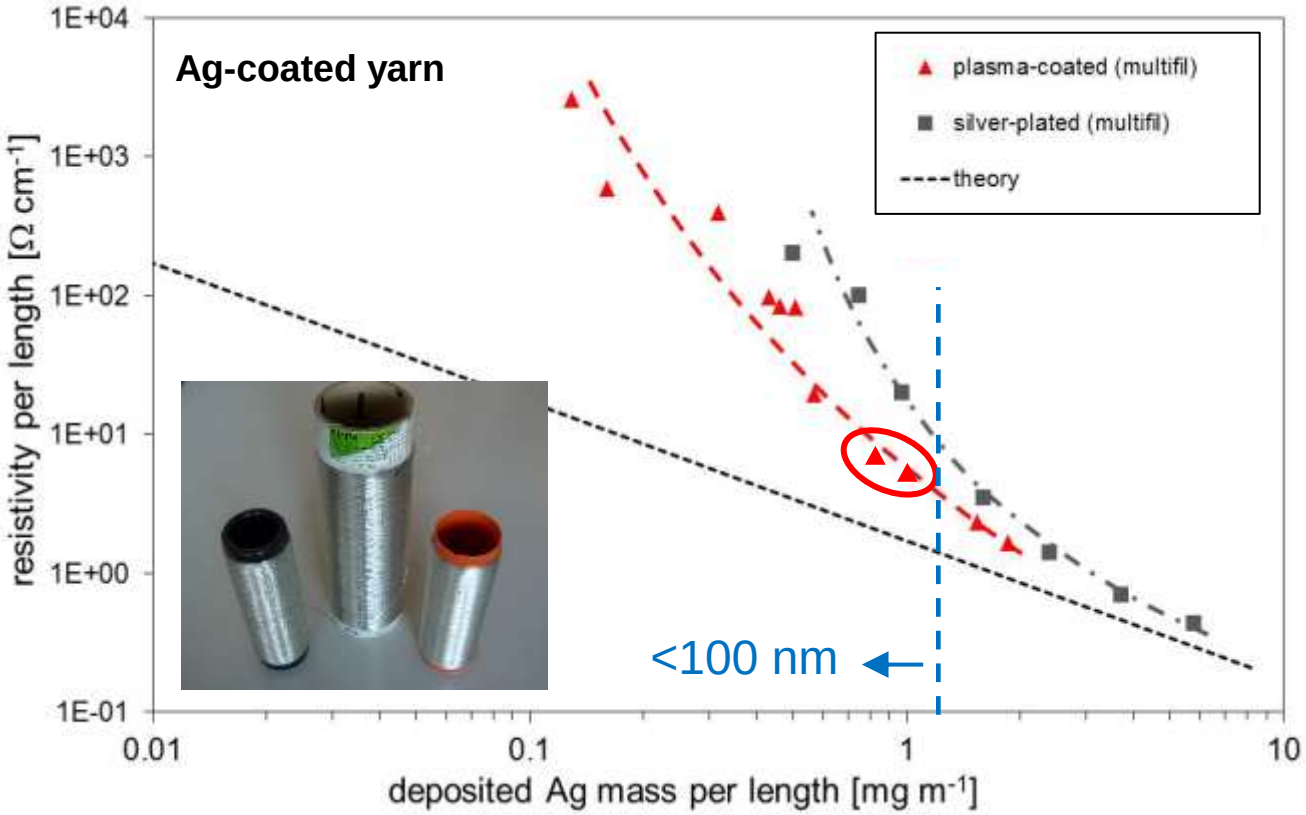
Materials Science and Technology

Electrically conductive fibers for textile processing

Fiber Coater (pilot scale)

Two layer deposition





→ original textile properties with good conductivity and high washing fastness

D. Hegemann, M. Amberg, M. Heuberger et al. *Mater. Technol.* 24 (2009) 41.

Fashion

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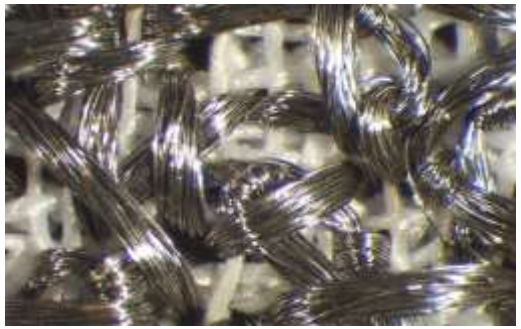
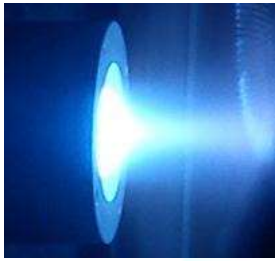
Metal coatings: Ag, Au, Pt, Ti, Cu, Al etc.





Serge Ferrari
TERSUISSE SA

JAKOB SCHLAEPFER

Bischoff
ST.GALLEN SCHWEIZ

HUBLOT

→ **full textile processability**

M. Amberg, D. Hegemann et al. *J. Adhesion Sci. Technol.* 24 (2010) 123.

Textile Electrodes

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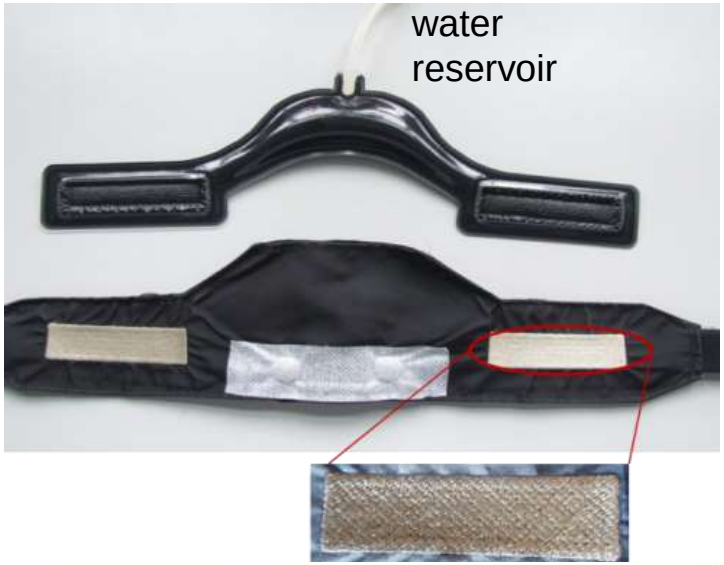
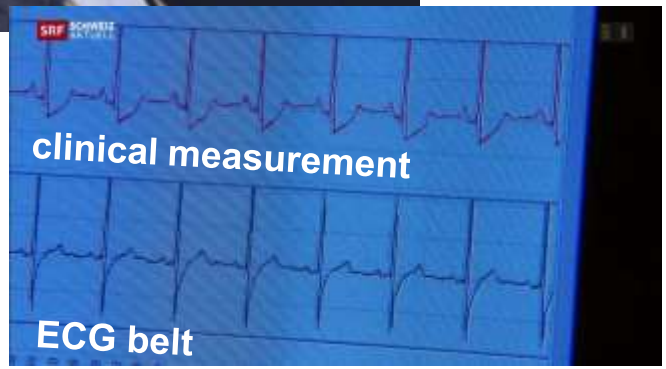
Ti-passivated Ag-coated fibers

Moistened textile electrodes for long-term ECG measurements



medical
device



→ stable, electrically conductive fibers

M. Amberg, D. Hegemann et al. *Nanomedicine: NMB* 11 (2015) 845.
M. Weder, D. Hegemann, M. Amberg et al. *Sensors* 15 (2015) 1750.

Textile Electrodes

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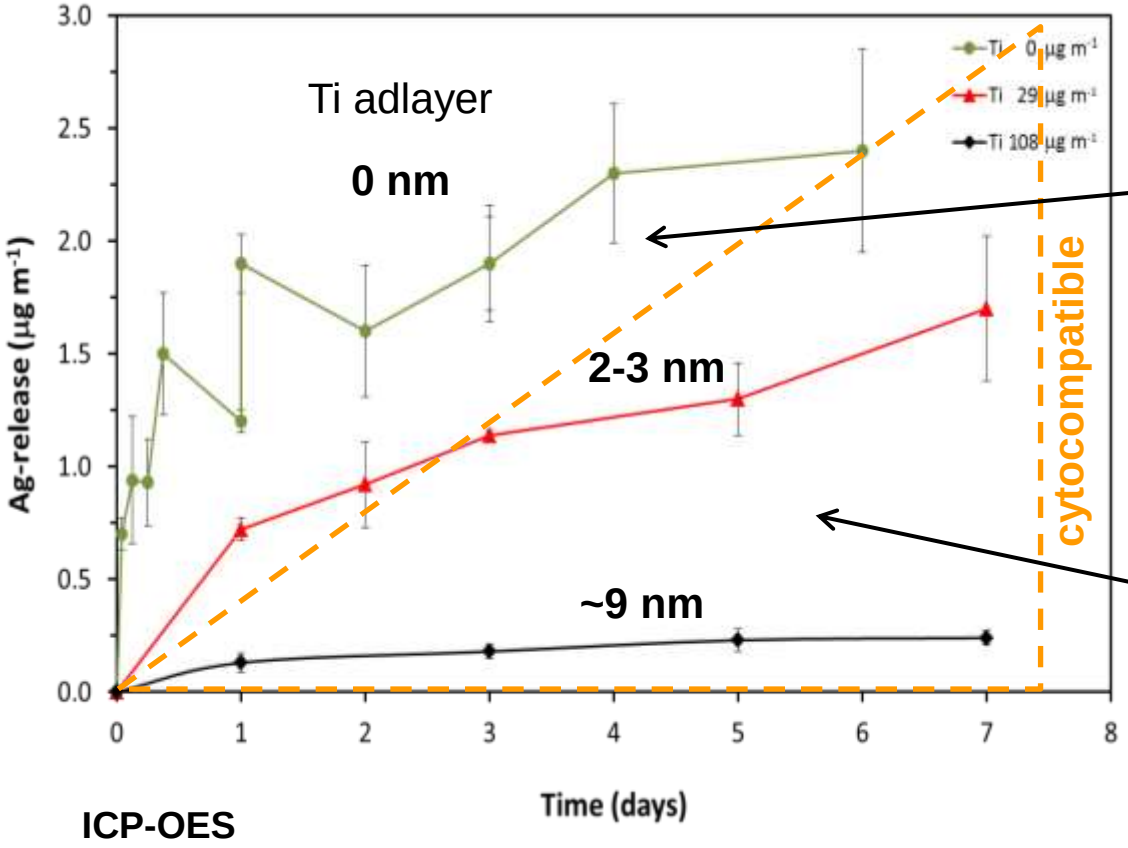
Materials Science and Technology

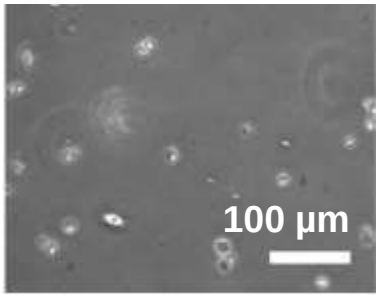
Ti-passivated Ag-coated fibers

Cytotoxicity of Ag-coated fibers

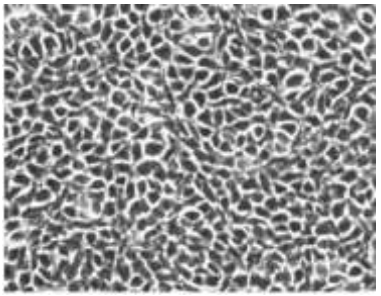


ICP-OES

potential issue:



cytotoxic



cytocompatible

M. Amberg, D. Hegemann et al. *Nanomedicine: NMB* 11 (2015) 845.

Drug Delivery

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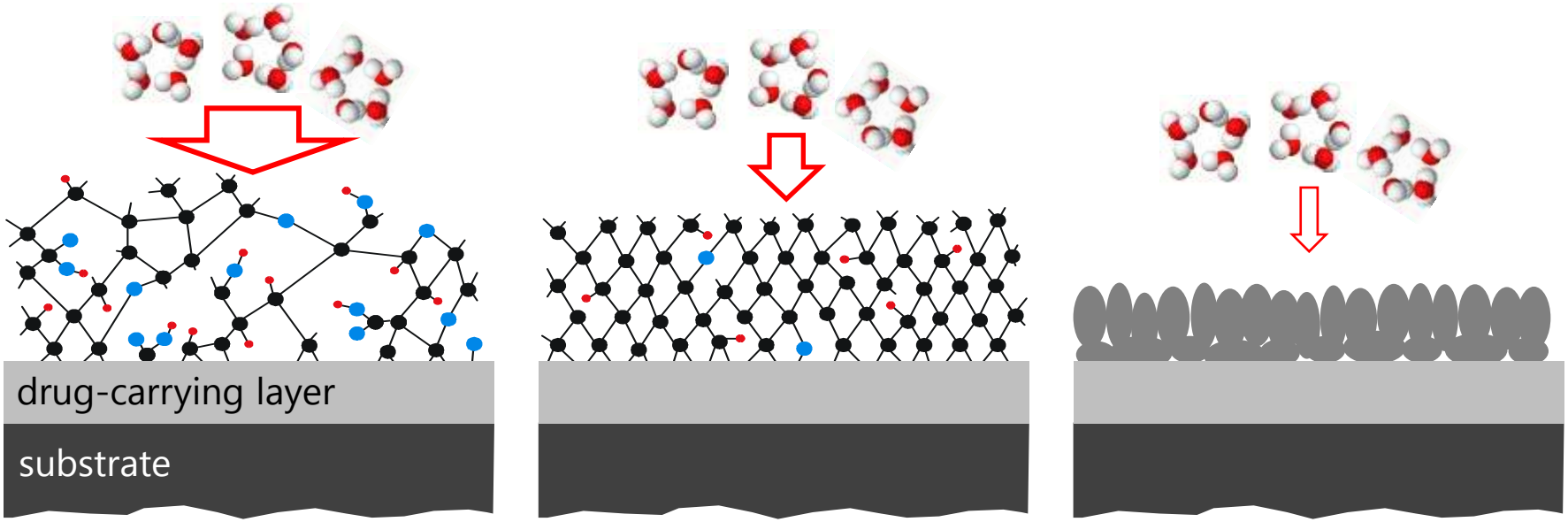
Defined release of agents (drugs)

Control of (water) diffusion through plasma coatings



hydrophilic plasma film

hydrophobic plasma film

metal adlayer

barrier effect

Drug Delivery

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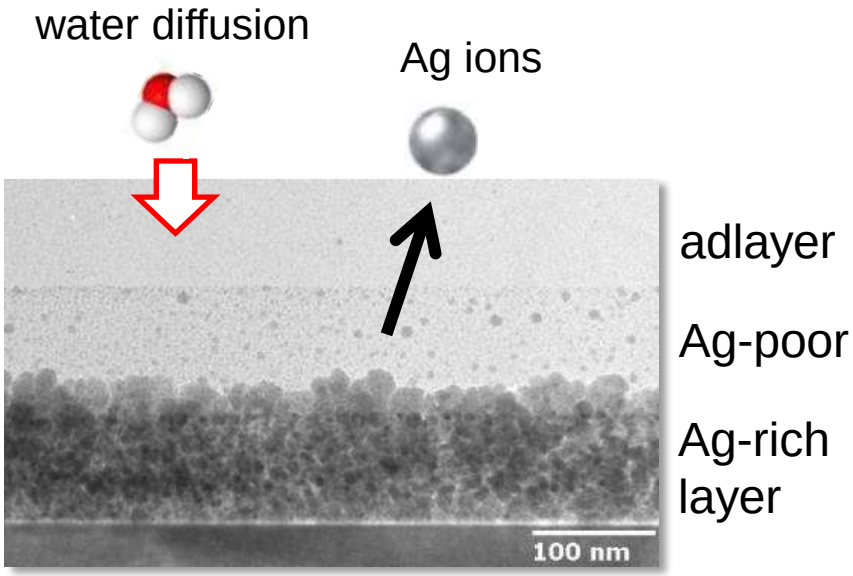
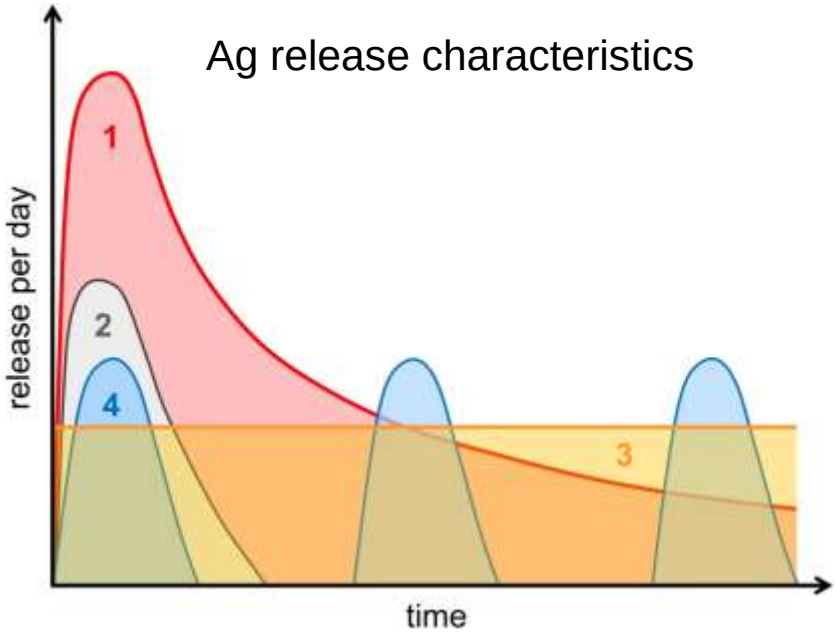
Controlled Ag ion release

$$4\,Ag_{(s)} + 4\,H_3O^+ + O_{2(aq)} \rightarrow 2\,Ag_2O_{(0.8\ V)} + 4\,H_3O^+$$
$$\rightarrow 4\,Ag^+_{(aq)} + 6\,H_2O$$



Ag-containing gradient film (with Ag reservoir)

E. Körner, D. Hegemann et al.
Plasma Chem. Plasma Process. 32 (2012) 619.



(1) initial burst release causing local cytotoxic effects
(2) adjusted Ag release for short-term antibacterial effects (Ag is depleted afterwards)
(3) steady state release using gradient layers
(4) repeated Ag ion release mediated by degradable layers in a multilayer set-up

Sensors on Fibers

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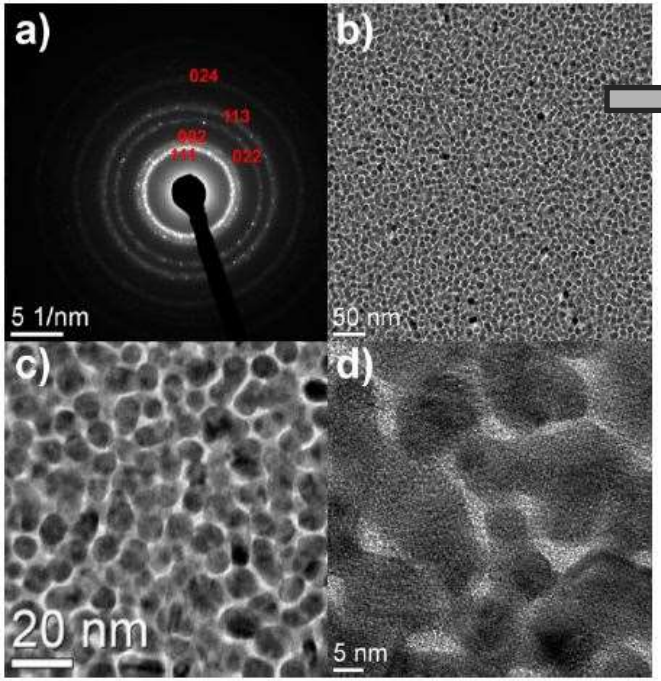
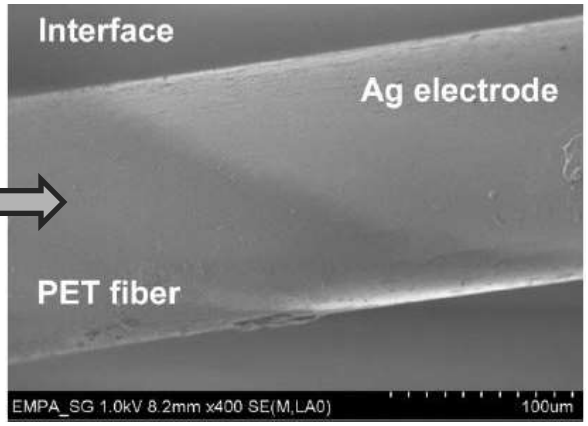
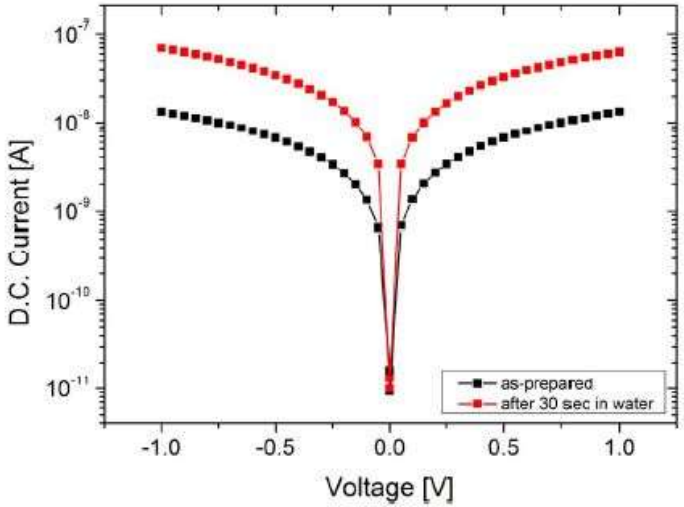
Ag nanocomposite plasma coatings at percolation threshold

Moisture sensor







→ **response at water penetration**

M. Drabik, M. Heuberger, D. Hegemann et al. *Nanomater. Nanotechnol.* 3 (2013) 1(13).

Zusammenfassung

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Plasmabeschichtung von Fasern für ‘Smart Textiles’

- **stabile elektrisch leitfähige Fasern (als Basistechnologie)**

→ **textile ‚Verdrahtung‘, Elektroden, Antennen, Sensoren**

gestickte LEDs; Quelle: Forster & Rohner

- **kontrolliertes Drug Delivery (durch Steuerung der Diffusion)**

→ **Wundauflagen, textile Implantate, chirurgische Fäden**

- **Bioresponse (Kontrolle von Proteinadsorption, Zellwachstum, Bakterien)**

→ **Tissue Engineering, Biosensoren**

→ **Fusion von Faser und Funktion**