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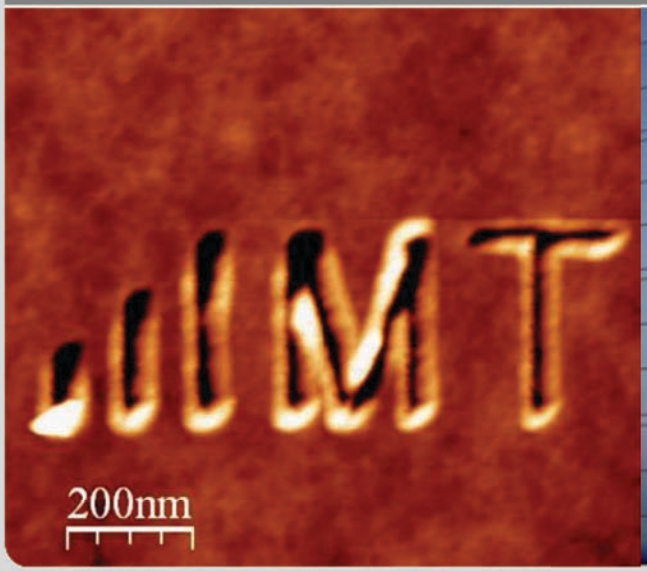
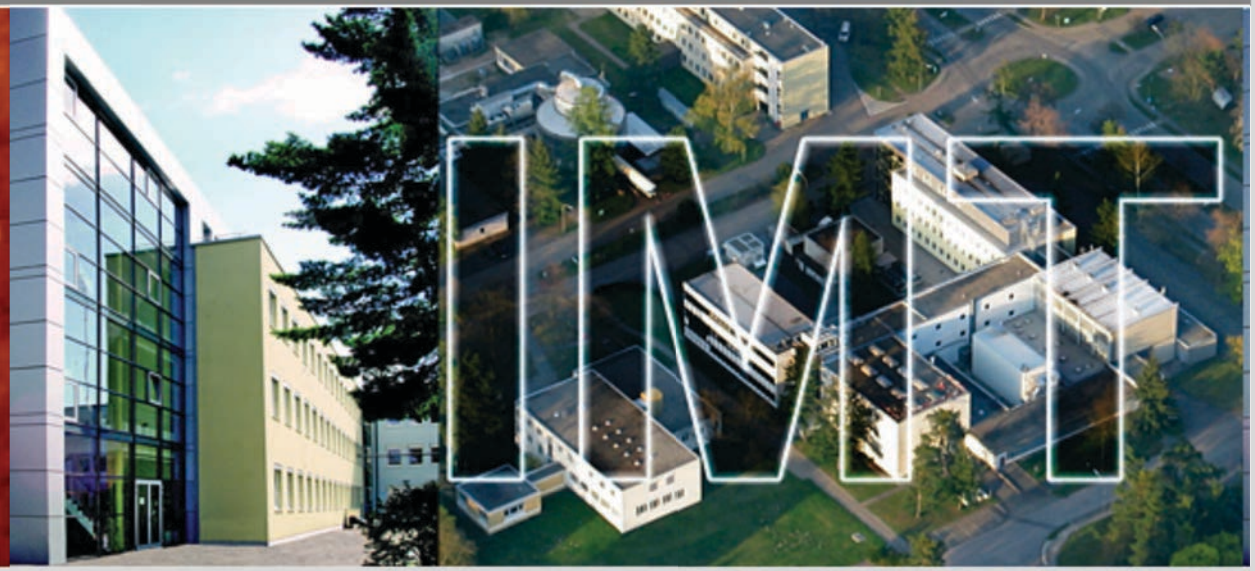
Bio-inspired Surfaces for Solar Cells

Hendrik Hölscher

INSTITUTE of MICROSTRUCTURE TECHNOLOGY (IMT)

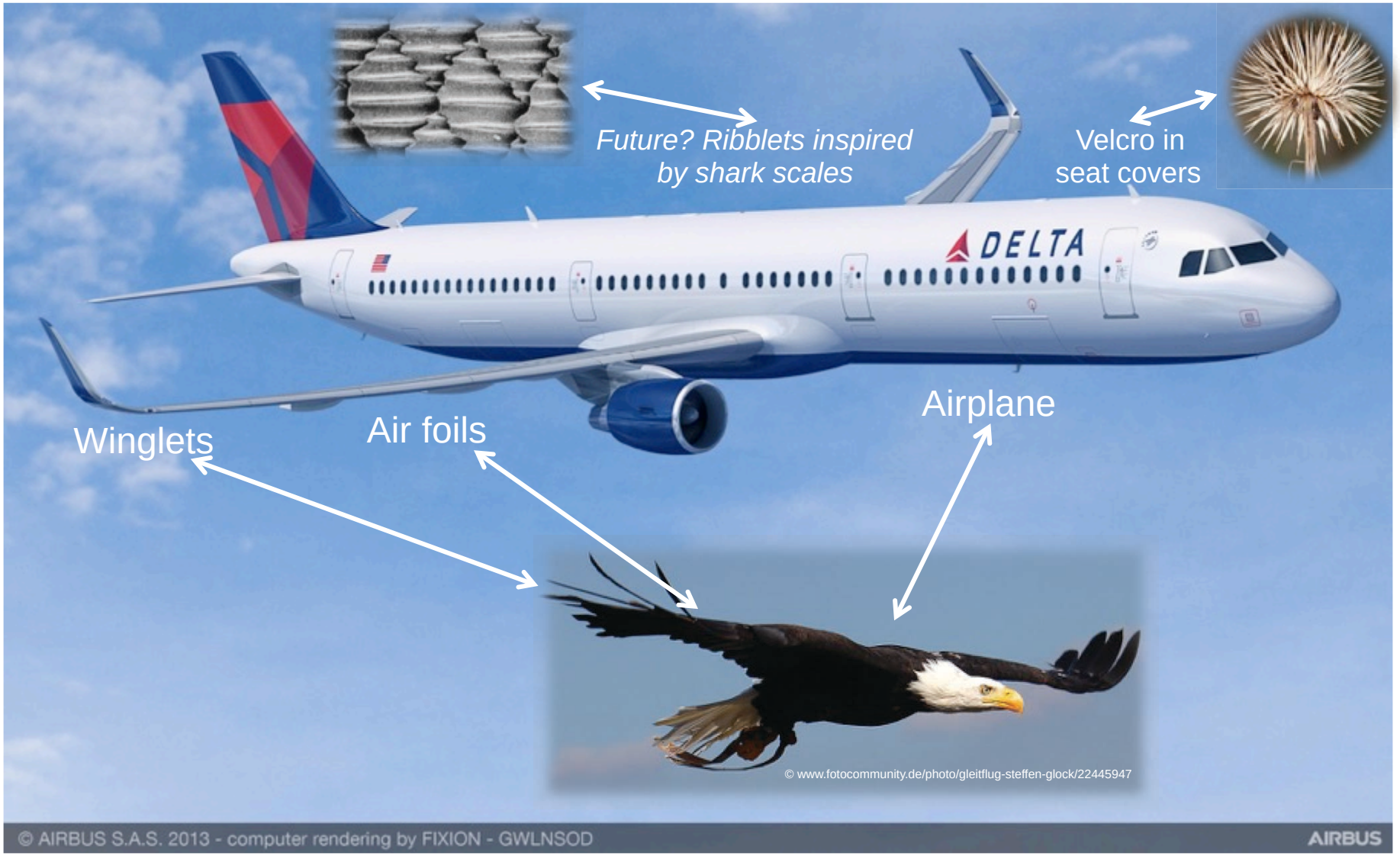




Biomimetics – Innovation Inspired by Nature

- Plants and animals are optimized for their habitat through evolution.
- In many cases these solutions can be transferred to technical applications.
- Biomimetic inspiration spans from shapes (e.g., air foils of planes) to materials (e.g., paper made from wood) and software algorithms (e.g., ant algorithm for travelling salesman problem)

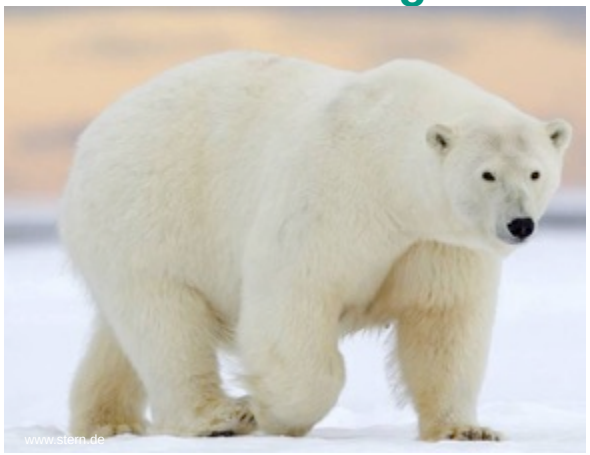
Biomimetic Inspired Airplains



Color in Nature

Mating

Camouflage



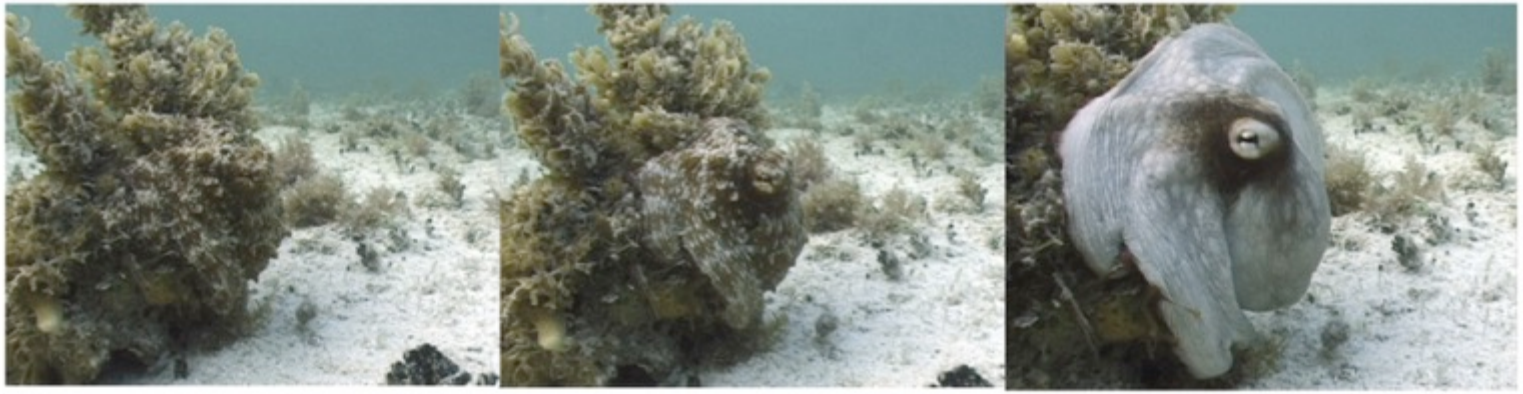
Warning

Communication

Attraction of pollinators

Thermoregulation

Adaptive Camouflage at its perfection: *Octupus vulgaris*



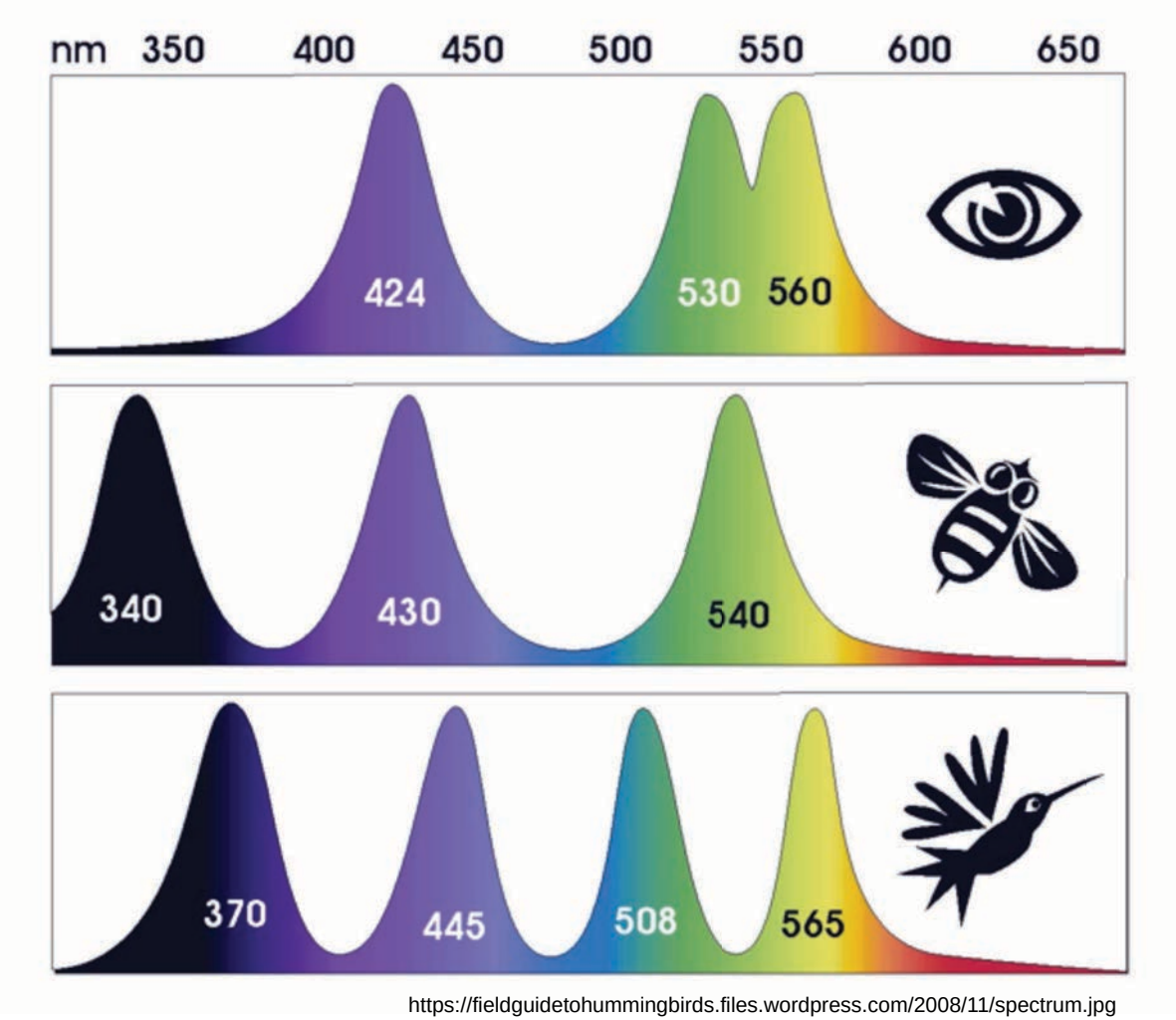
Second:frame 0:00 0:08 (270 msec) 2:02 (2,070 msec)

Current Biology

Current Biology

Hanlon, Current Biology **17**, R400 (2007)

Who sees what?



https://fieldguidetohummingbirds.files.wordpress.com/2008/11/spectrum.jpg

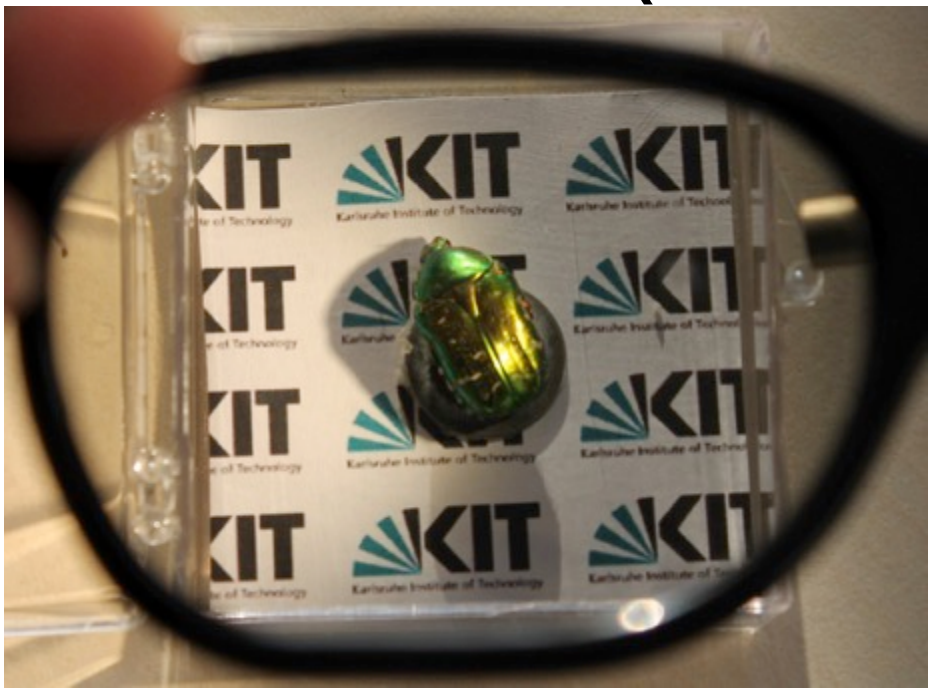
Humans

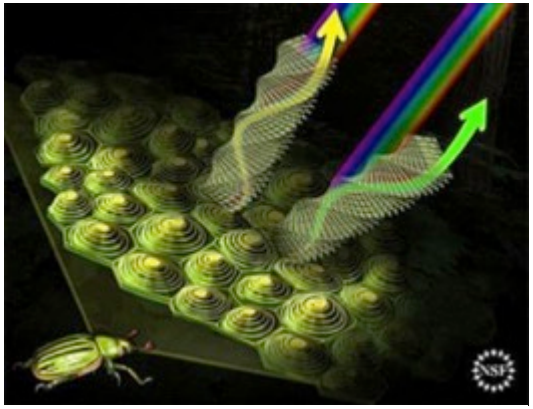
Insects

Birds

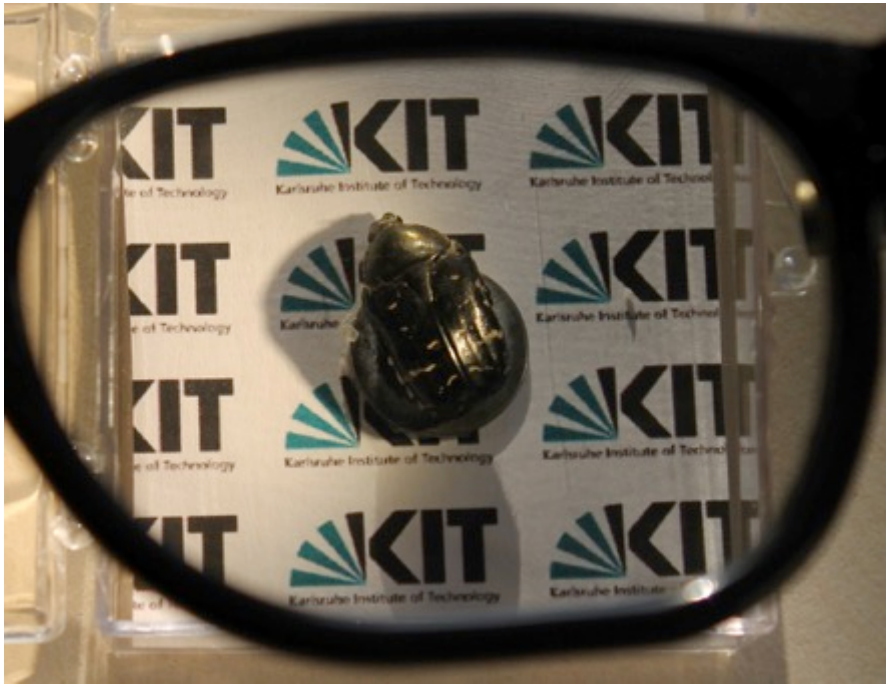
p2praveen.files.wordpress.com/2015/12/06_from_birds_point_of_view.png

Green Rose Chafer (*Cetonia aurata)*





edu.nano.ir



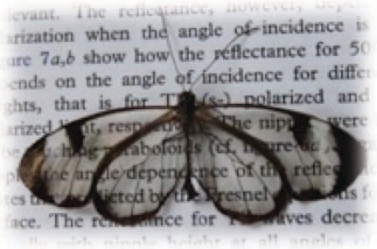
Nano- and Micro-structured Surfaces in Nature and their Biomimetic Applications

- Hierarchical hair in geckos' toes
  → **Self-cleaning adhesives**
  Röhrig *et al*., Small **8**, 3009 (2012)
  Mengüc *et al*., Interface **11**, 20131205 (2014)

- Hairy structures of water ferns and bugs
  → **Oil/water separation**
  Röhrig *et al*., Adv. Mater. Interfaces **1**, 1300083 (2014)
  Zeiger *et al*., Biomim. & Bioinsp. (2016)
  → Air retention for **drag reduction**
  Kavalenka *et al*., ACS Appl. Mater. Interfaces **7**, 10651 (2015)

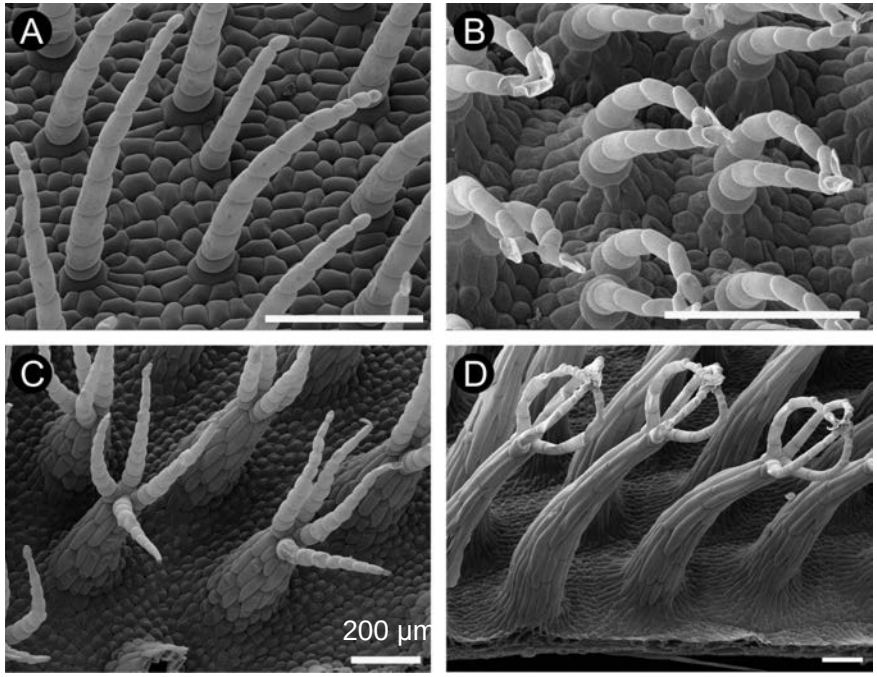

Ditsche-Kuru *et al*., Beilstein J. Nanotechnol. **2**, 137 (2011)

- Butterflies & Beetles
  → **Structural colors**
  Siddique *et al*., Opt. Exp. **21**, 14351 (2013)
  → **Anti-reflection coatings**
  Siddique *et al*. Nat. Comm. **6**, 6909 (2015)
  → **Absorbers for solar cells**
  Siddique *et al*., Sci. Adv. **3**, e1700232 (2017)



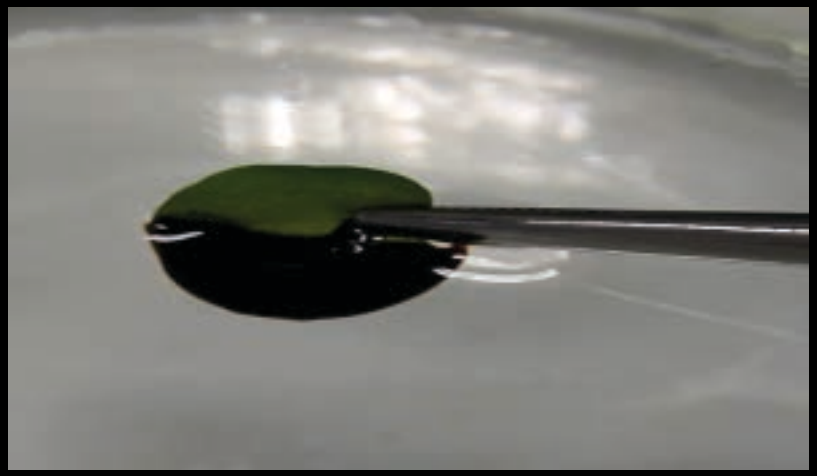
Floating water fern *Salvinia*

- Native to South America.
- Leaf covered by four different types of hairs (trichomes).
- Leaves are **superhydrophobic** and feature a **retaining air layer** and **high oil sorption**



Ribeiro, Rubio, Smith, *Sci. Technol. Bull* **8**, 483–489.(2003)
Barthlott et al., *Adv. Mat*.. 22, 2325 (2010)
Barthlott, Wiersch, Colic, Koch, Botany, 87, 830(20099
Mayser, Bohn, Reker, Barthlott, *Beilstein J. Nanotechnol.* **5**, 812 (2014)

Oil Spill Cleanup by Salvinia Leave

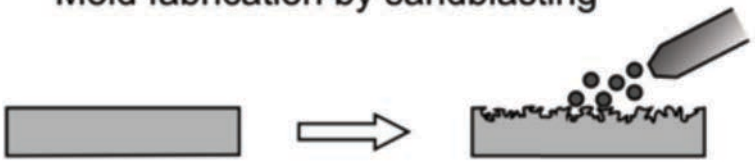


Video online at:
https://mediaservice.bibliothek.kit.edu/asset/player/DIVA-2016-603.html

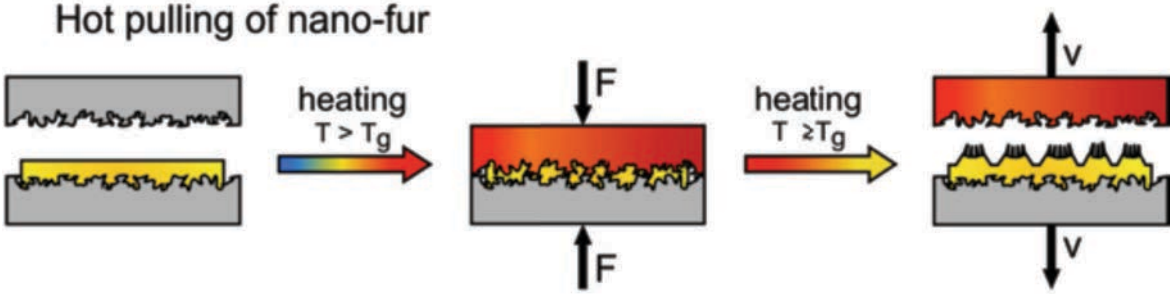
Zeiger, da Silva, Mail, Kavalenka, Barthlott, Hölscher, Bioinspir. Biomim. **11** 056003 (2016)

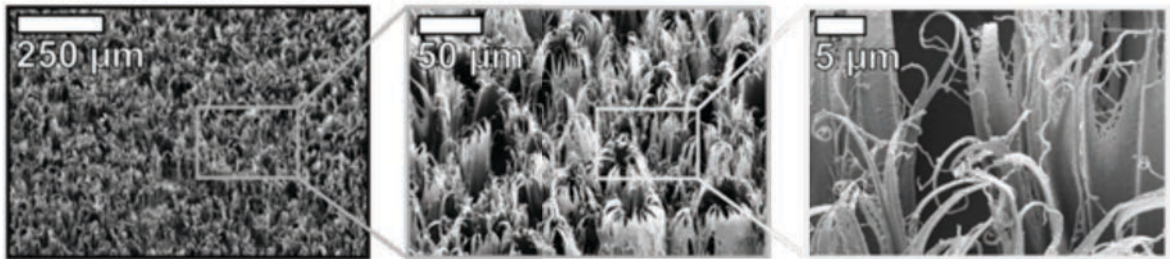
Fabrication of Nanofur by Hot Pulling

Mold fabrication by sandblasting

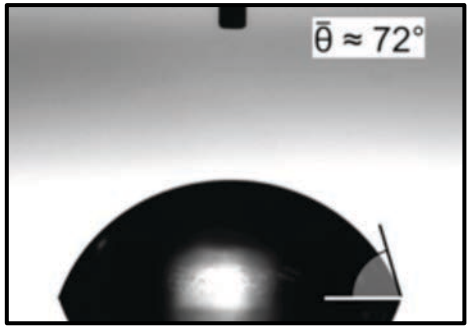


Hot pulling of nano-fur

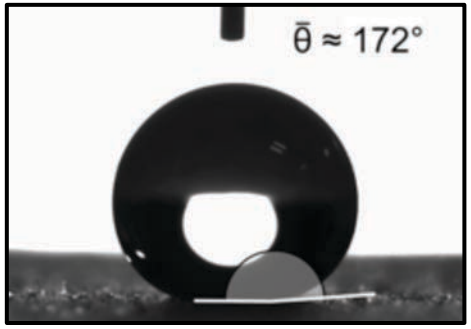




Flat Polycarbonate

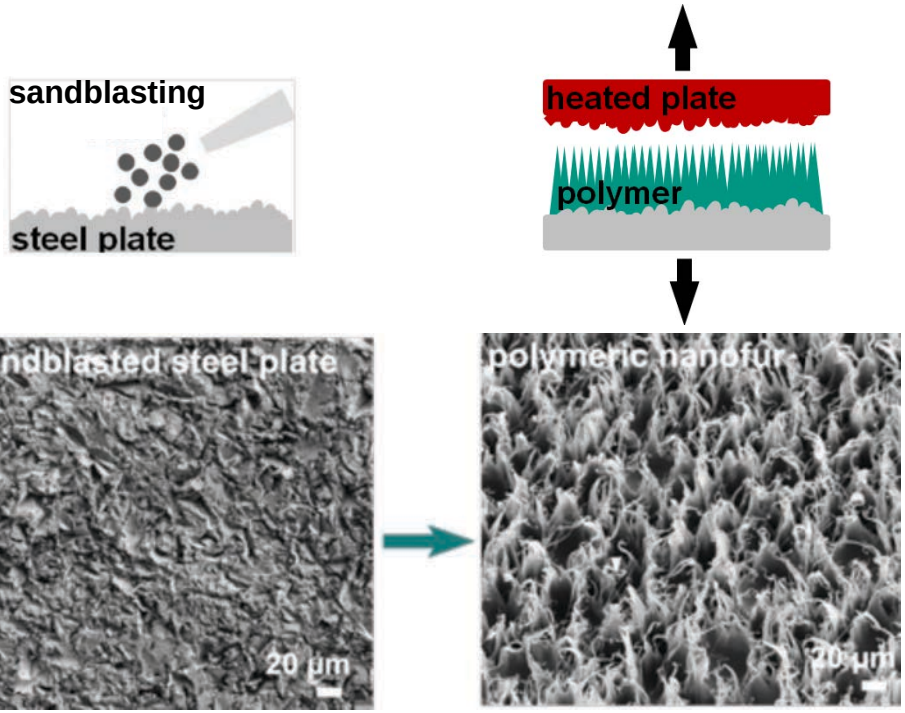


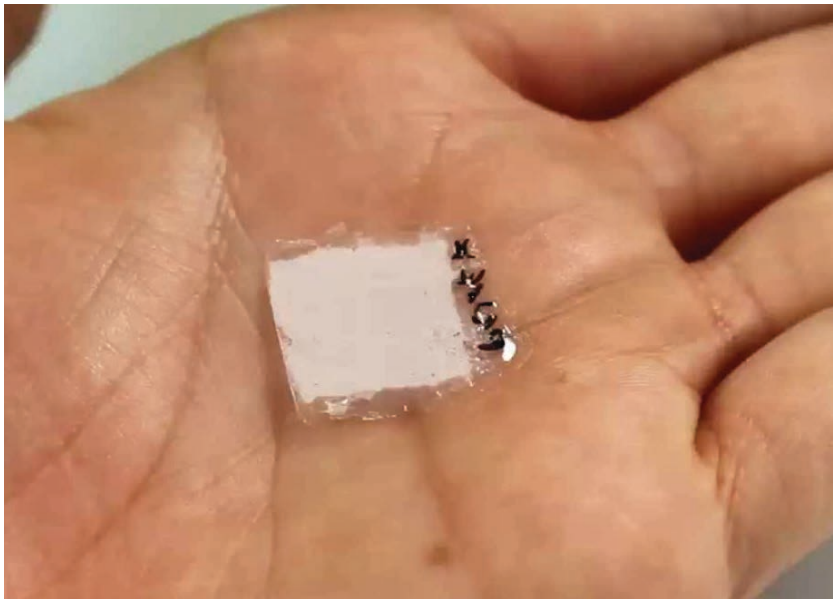
Hairy Polycarbonate

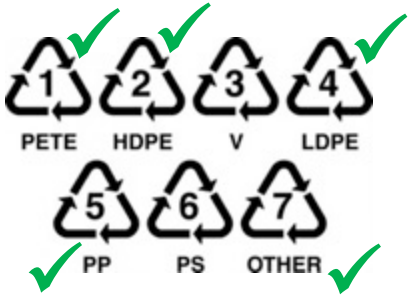


Röhrig, Mail, Schneider, Louvin, Hopf, Schimmel, Worgull, Hölscher, *Adv. Mater. Interface* **1**, 300083 (2014)
Röhrig, Schneider, Hopf, Worgull, Hölscher: *Patent pending* (2012)

Nanofur – Highly Scalable Fabrication Process







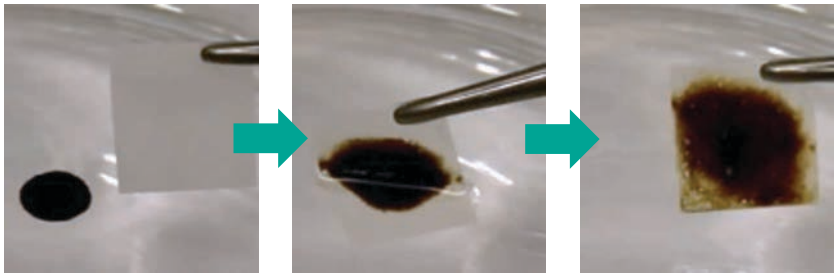
\+

PC
PLA (biodegradable)
Shape-memory
Wood-based (biodegradable)

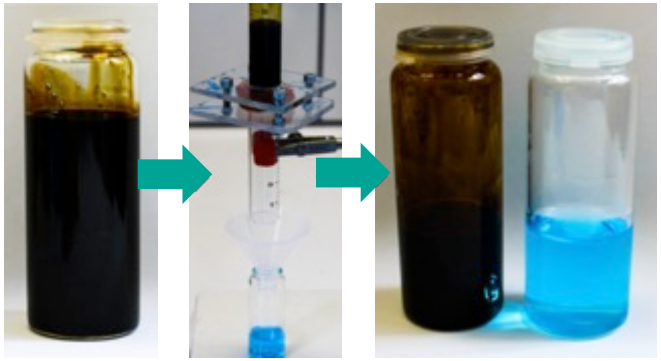
Kavalenka, Vüllers, Kumberg, Zeiger, Trouillet, Stein, Ava, Li, Worgull, Hölscher, *Sci Rep.* **7**, 2017
Vüllers, Gomard, Preinfalk, Klampfatis, Worgull, Richards, Hölscher, Kavalenka, *Small* **12**, 2016

Oil/Water Separation with Nanofur

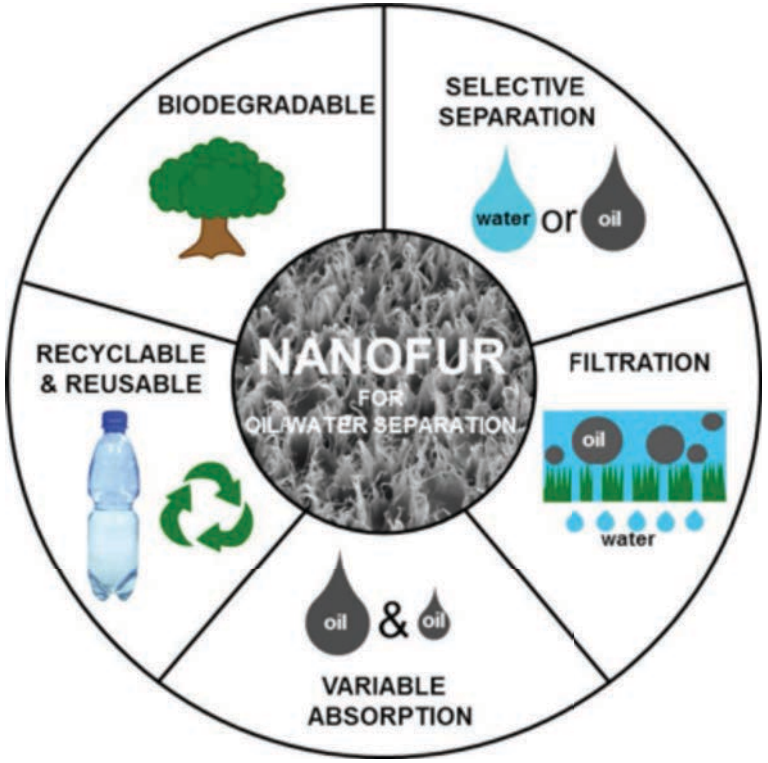
… through absorption



… through filtration

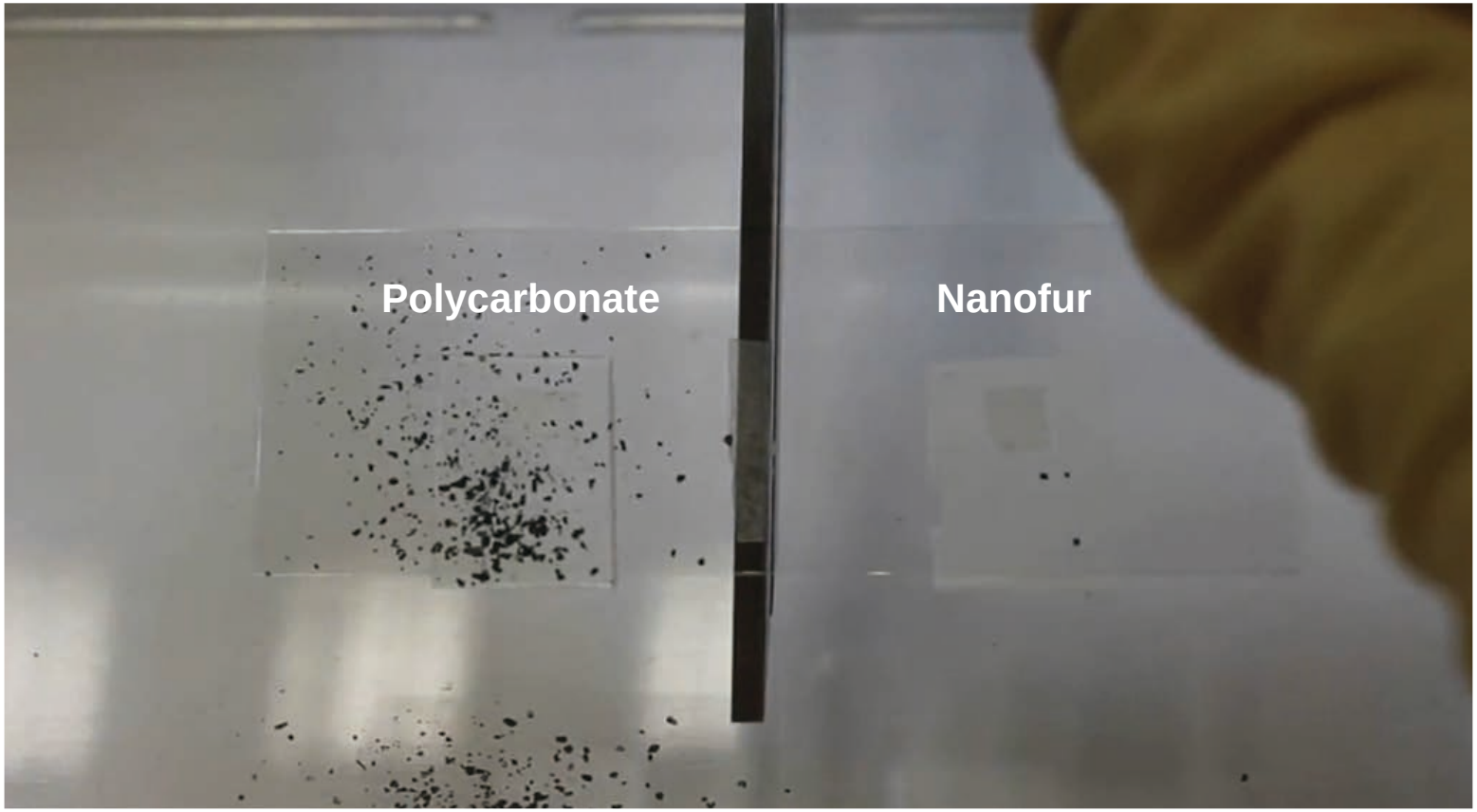


Multi-functionality



Kavalenka *et al*., RSC Adv. **4** (2014)
Zeiger *et al*., Bioinspir. Biomim. **11** (2016)
Kavalenka *et al*, Sci. Rep. **7** (2017)

Self-cleaning nanofur

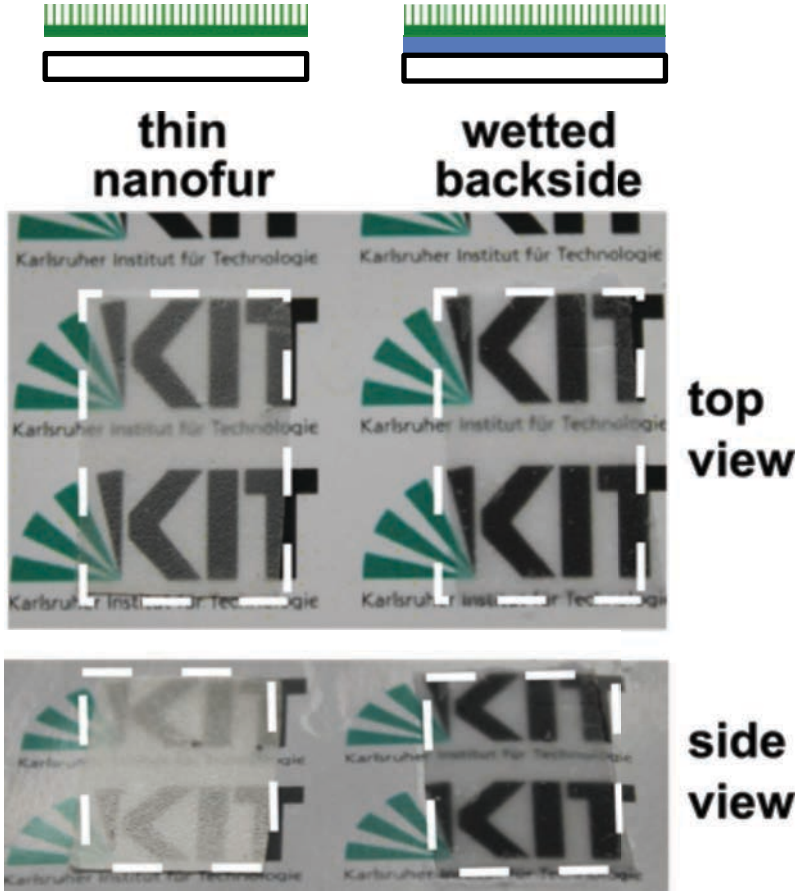


Contaminations tested:

Graphite, silver powder, paprika powder, clay, aluminum oxide F320, PMMA particles (20µm size)

Vüllers *et al*., Small **12**, 2016

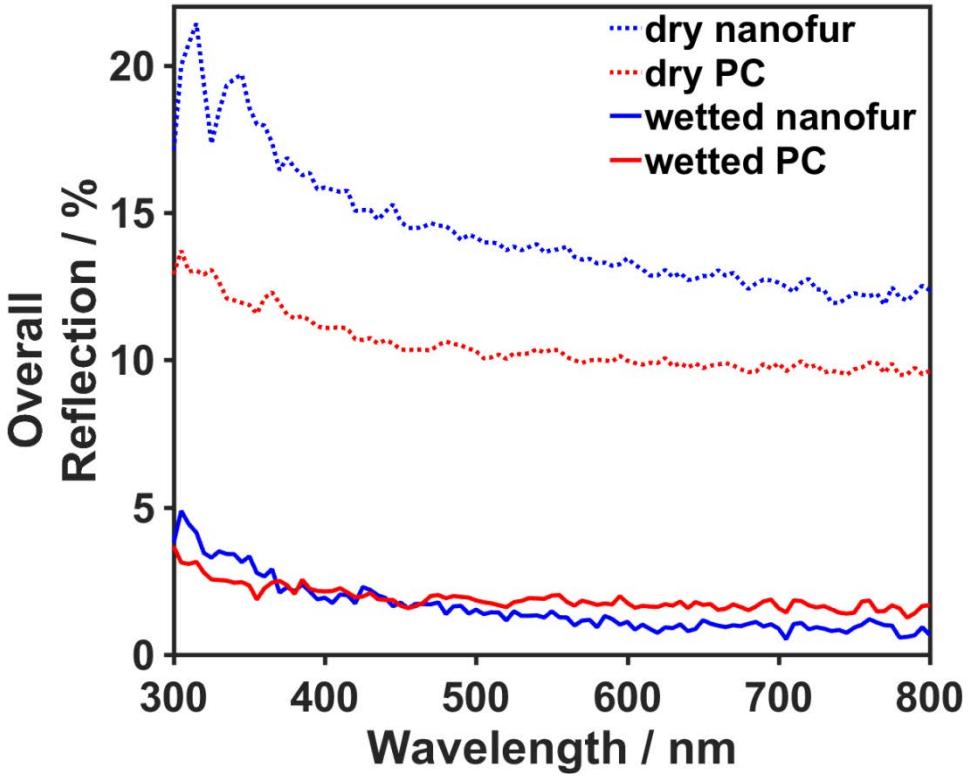
Transparent Nanofur Coating



Reflection values

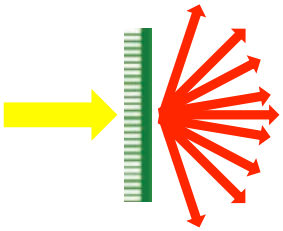
dry nanofur < 14%

wetted nanofur < 4%

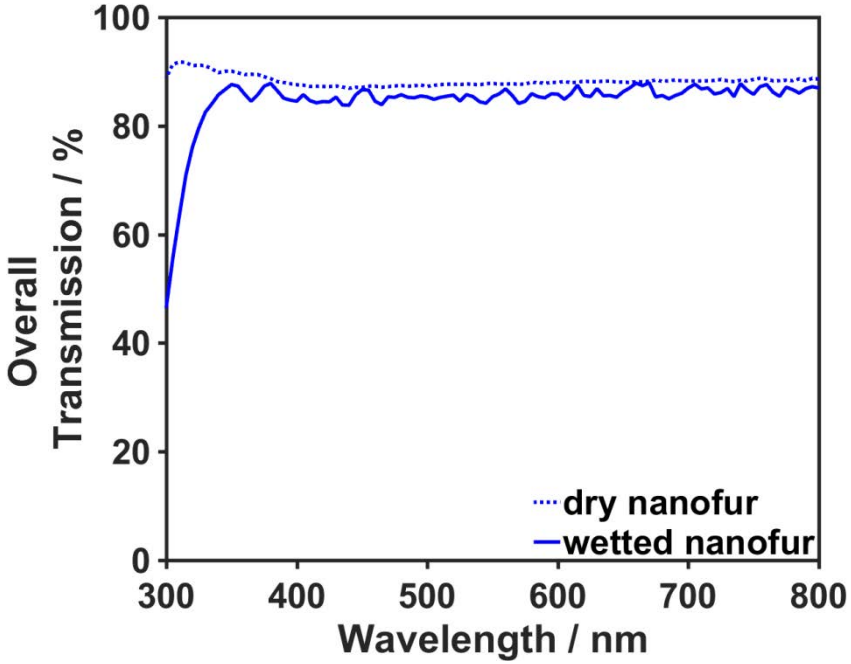


Vüllers *et al*., Small **12**, 2016

Translucent Self-Standing Film

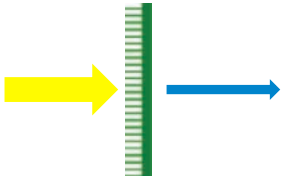


Overall Transmission

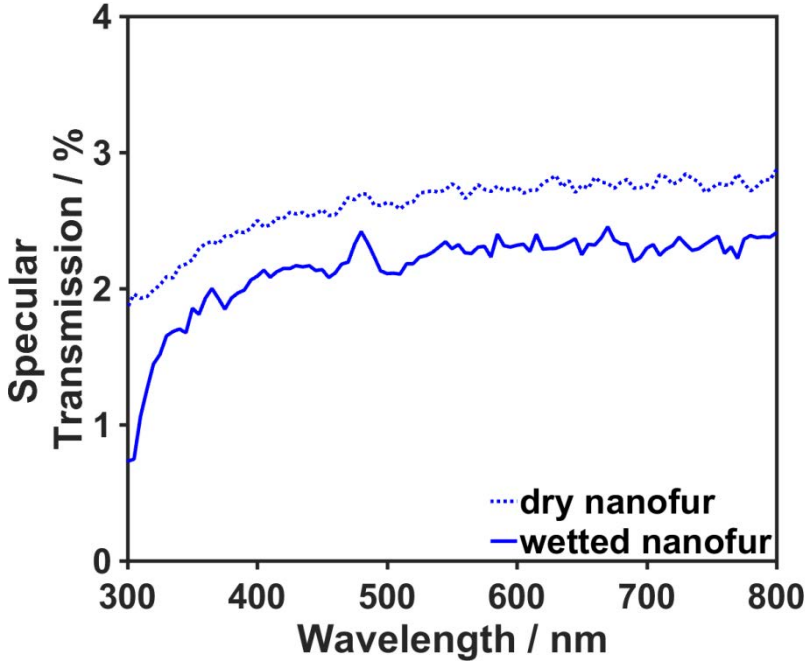


Overall Transmission

dry nanofur	> 87%
wetted nanofur	> 85%



Specular Transmission

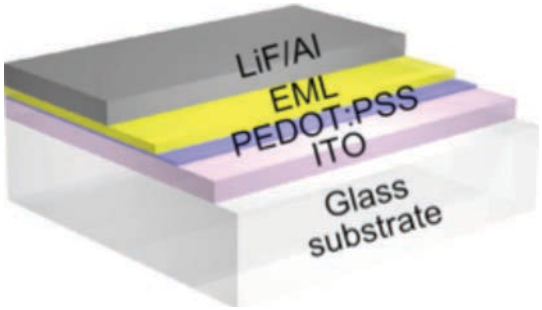


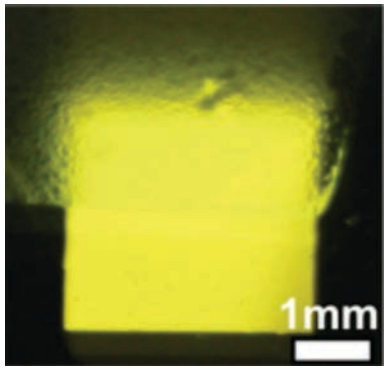
Specular Transmission

dry nanofur	< 2.8%
wetted nanofur	< 2.4%

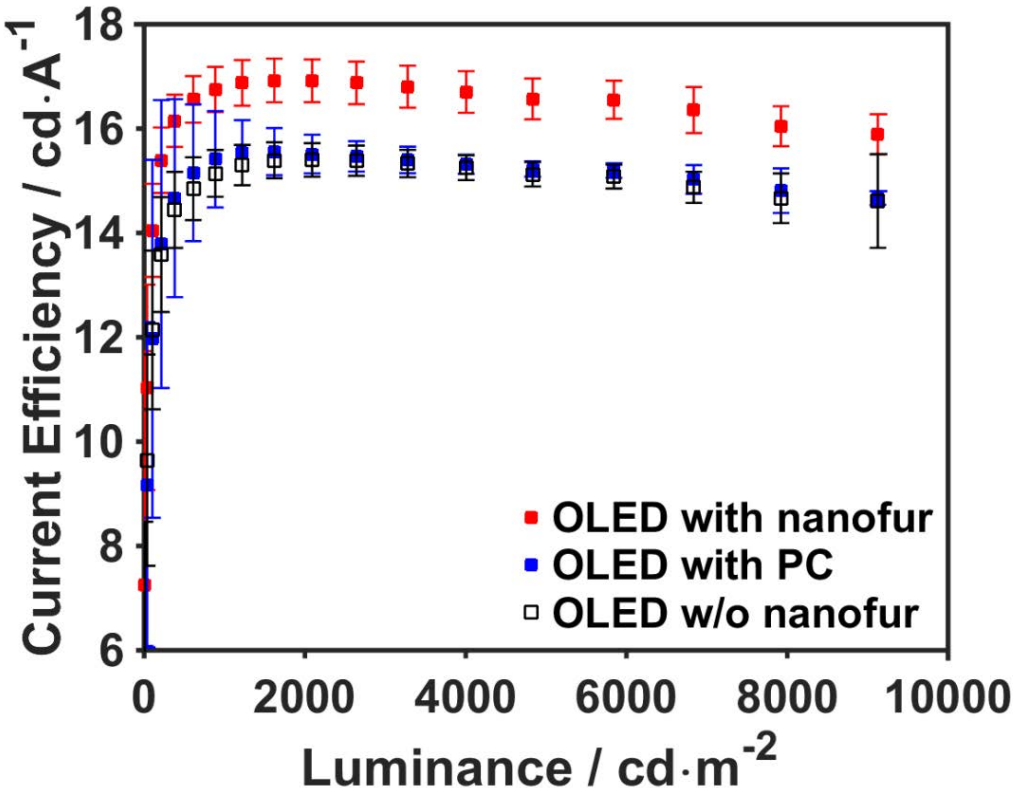
Application on OLEDs

Application on yellow OLEDs





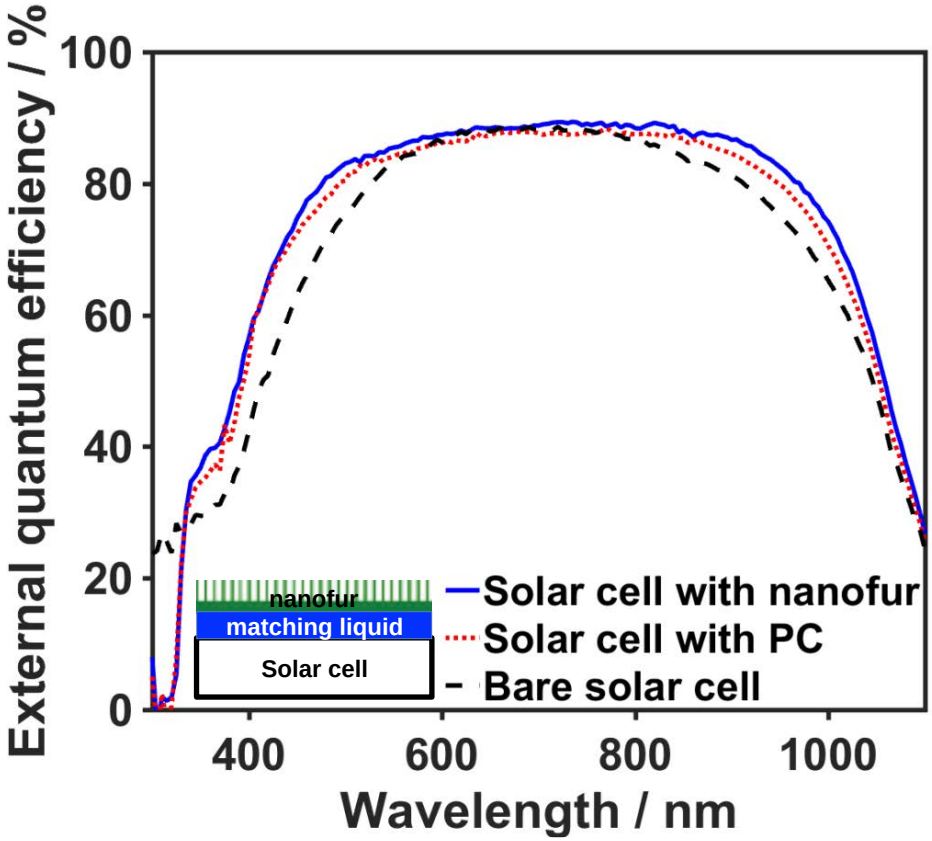
OLED current efficiency



>10% intensity enhancement on OLEDs

Vüllers *et al*., Small **12**, 2016

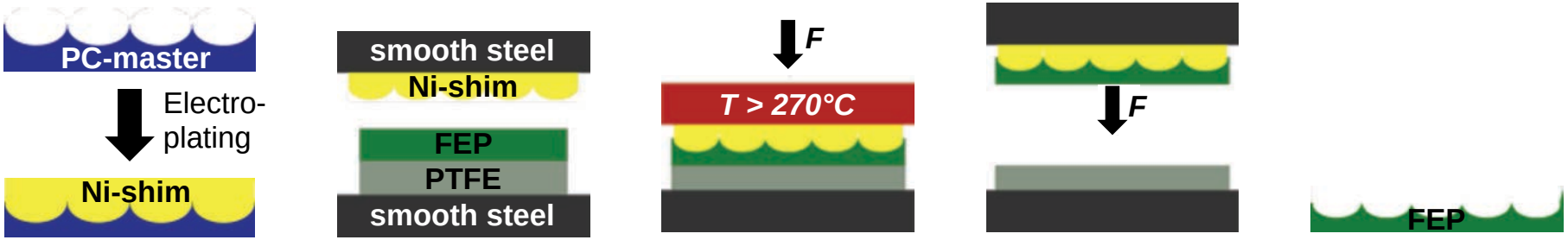
Application on Solar Cells



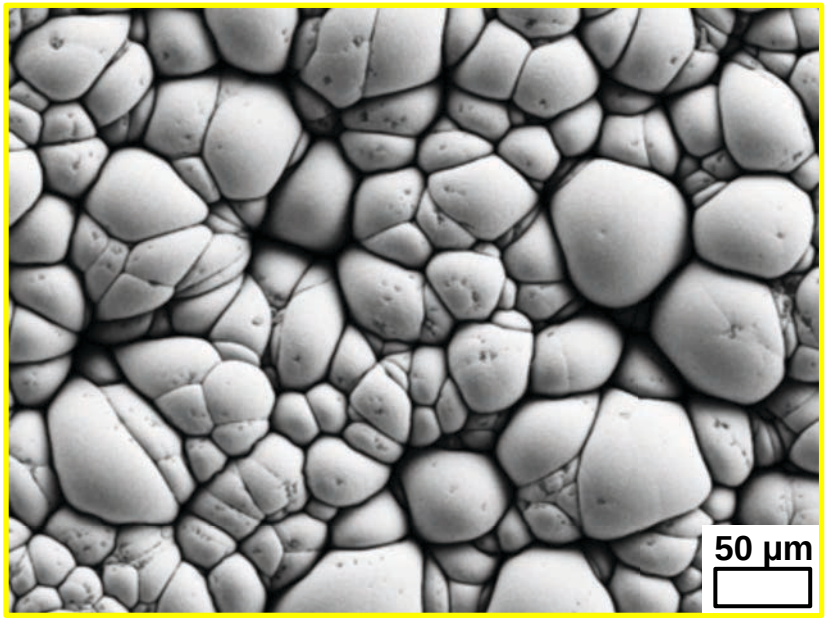
Short circuit current density		
Bare SC		100%
SC with PC		103.4%
SC with Nanofur		105.8%

Vüllers *et al*., Small **12**, 2016

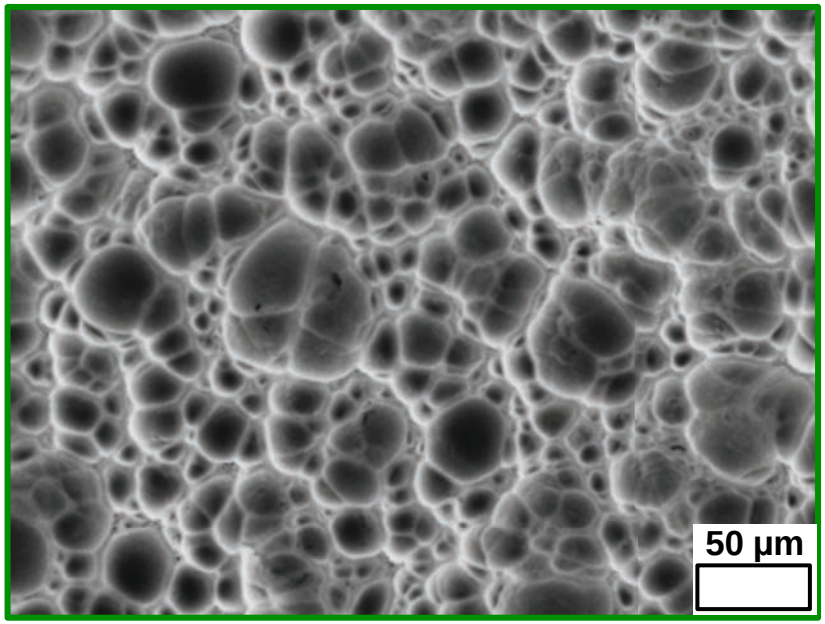
Topography Transfer to FEP



Ni-shim

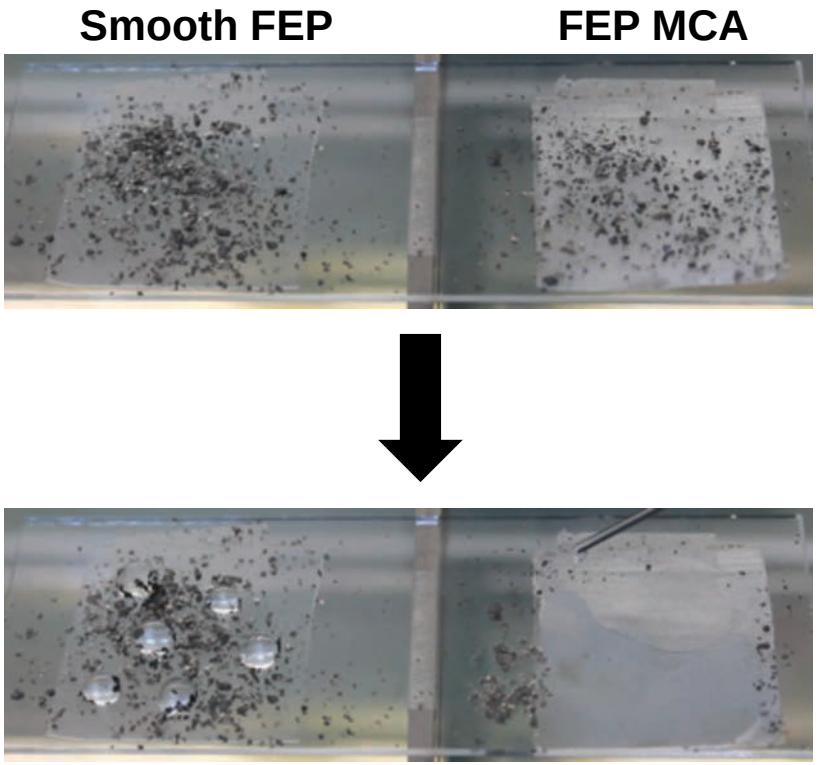


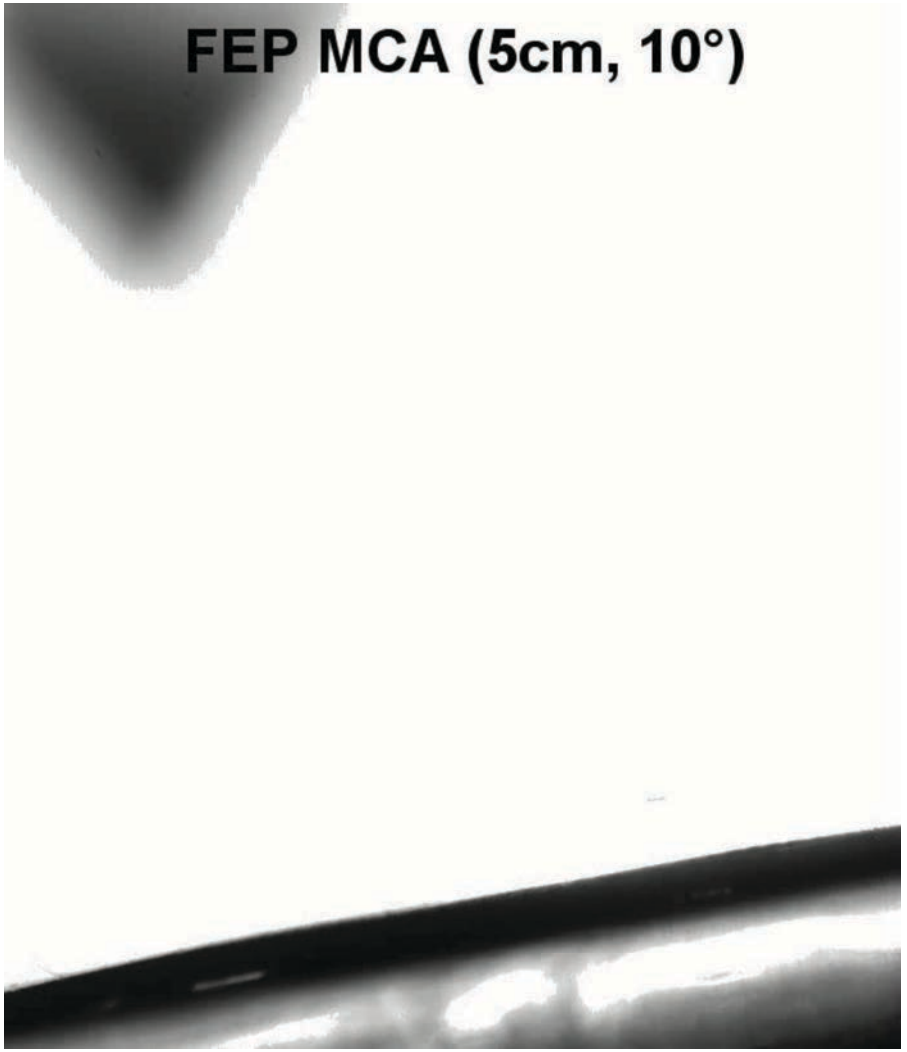
**Fluorinated Ethylene Propylene (FEP)
Microcavityarray (MCA)**



Vüllers *et al.*, ACS Appl. Mater. Interfaces **10,** 2018

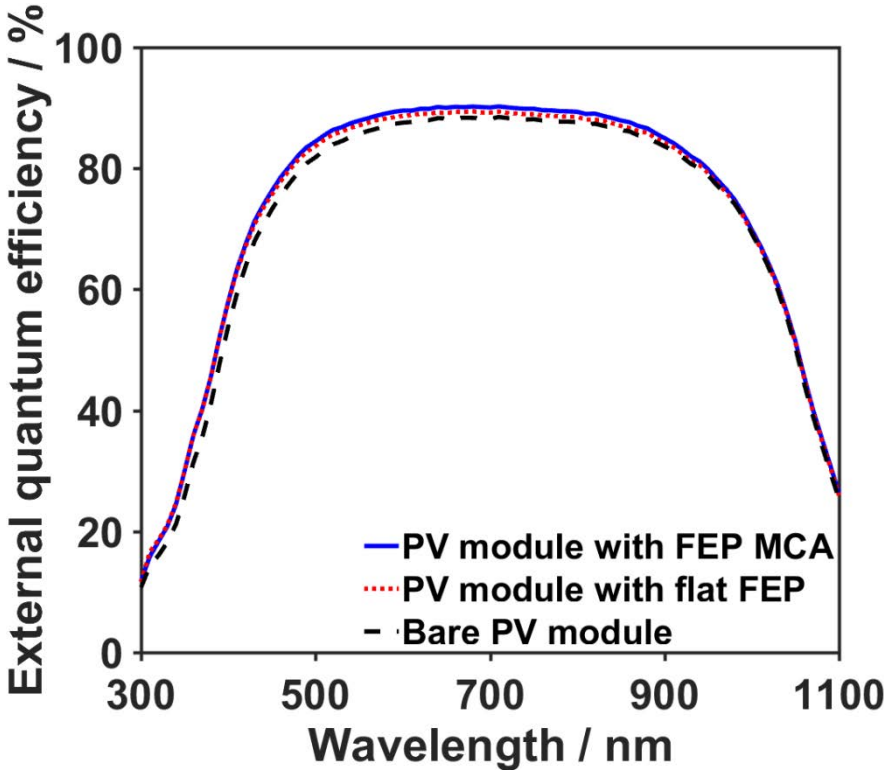
Self-cleaning and Impact Stability

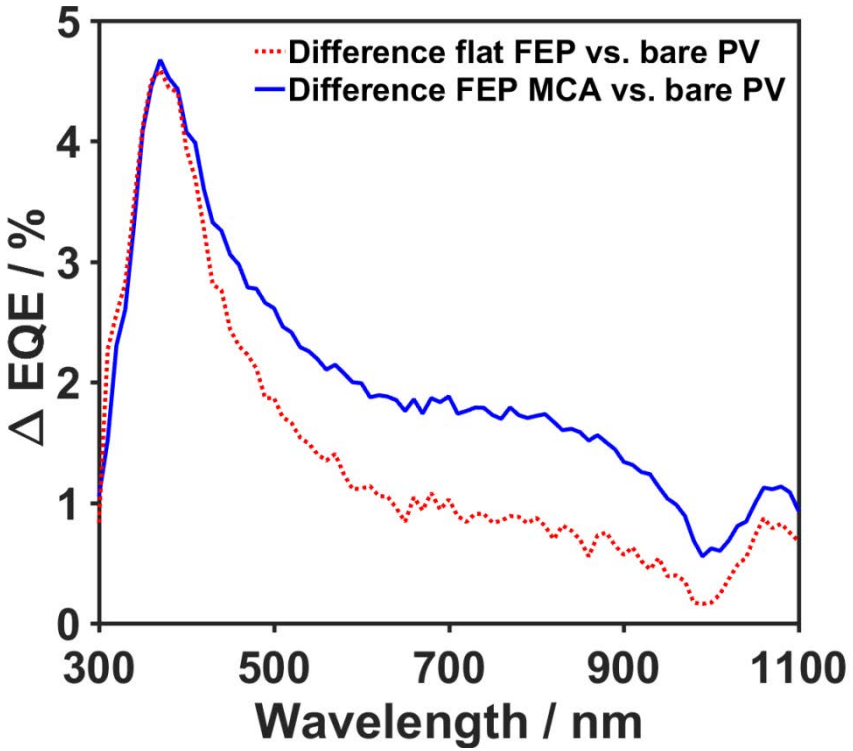




Vüllers *et al.*, ACS Appl. Mater. Interfaces **10,** 2018

FEP MCA Application on Photovoltaics

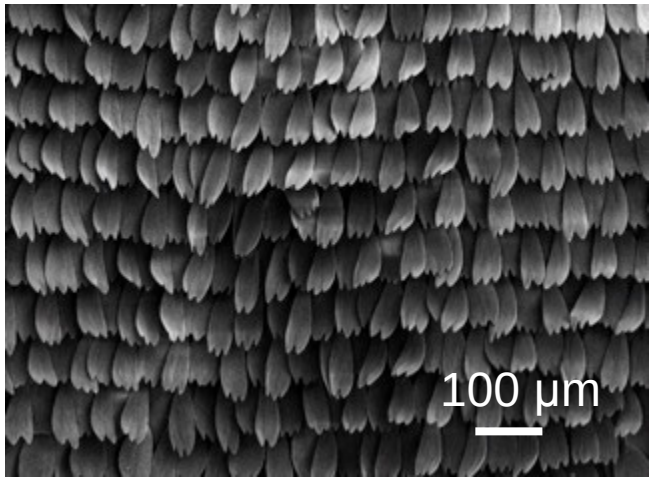




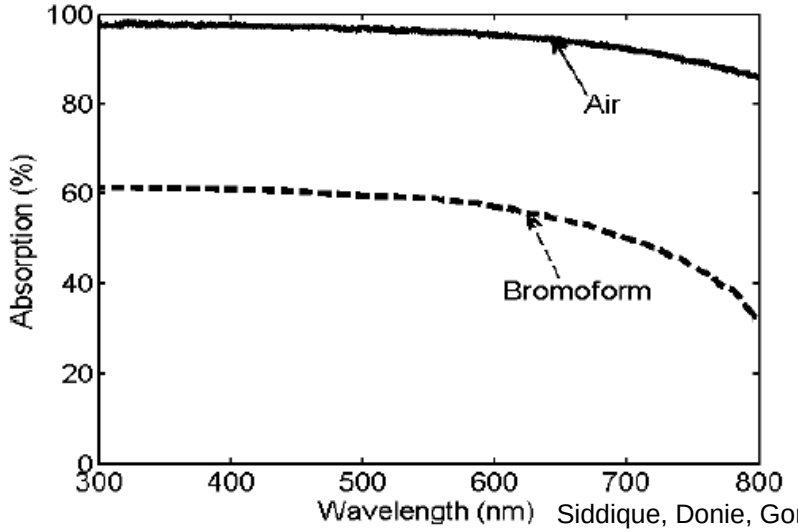
Short circuit current		
Bare PV module		100%
PV module with FEP		103.6%
PV module with FEP MCA		104.5%

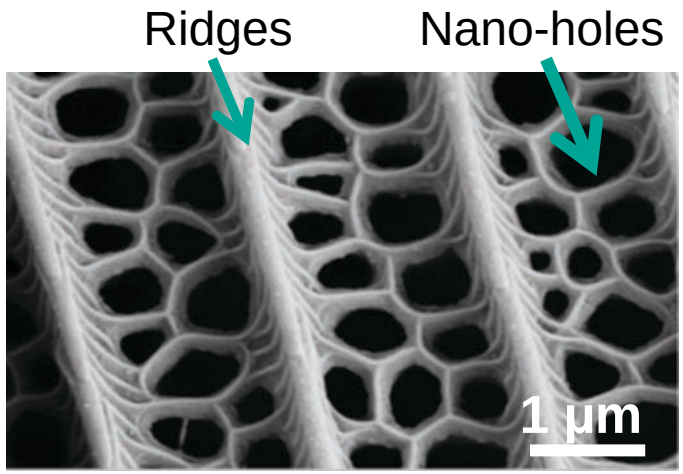
Vüllers *et al.*, ACS Appl. Mater. Interfaces **10,** 2018

Black Butterfly *Pachliopta aristolochiae*



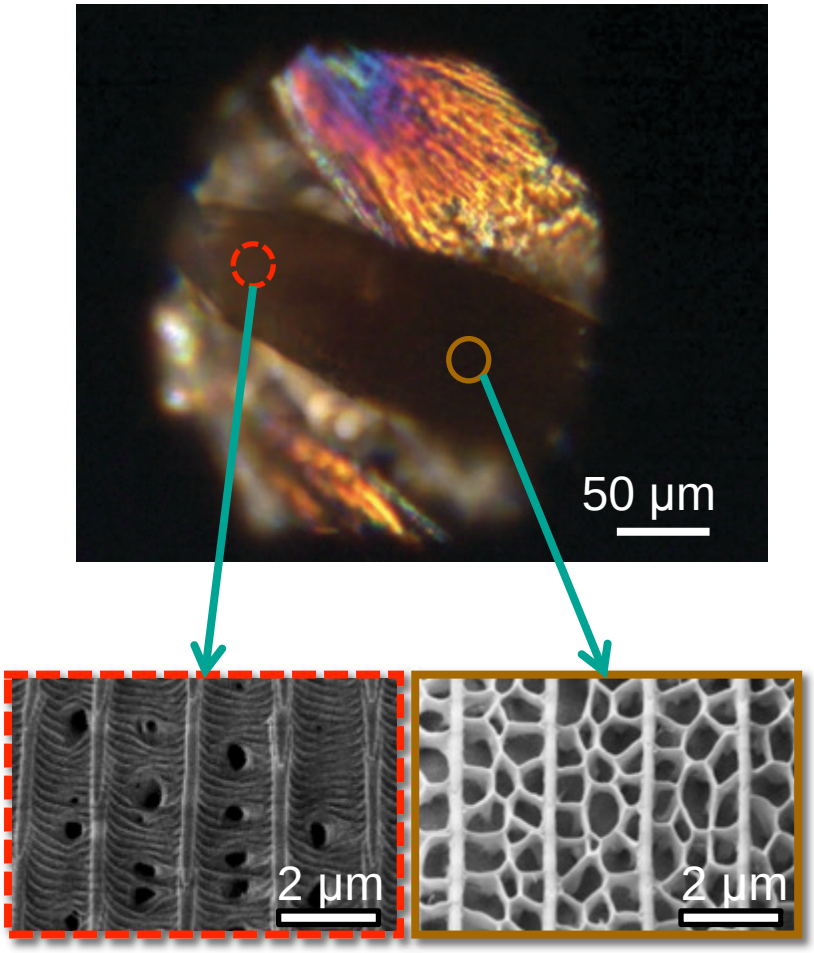
Index matching experiment demonstrates that structure causes about 40% absorption



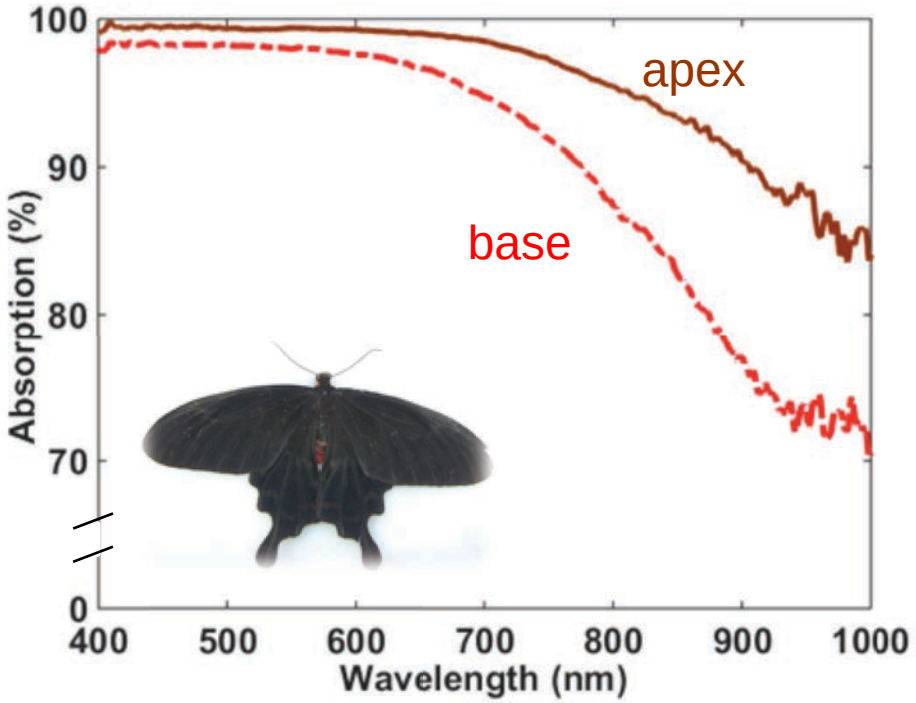


Siddique, Donie, Gomard, Yalamanchili, Merdzhanova, Lemmer, Hölscher, *Sci. Adv.* **3**, e1700232 (2017)

Structure of holes is not uniform

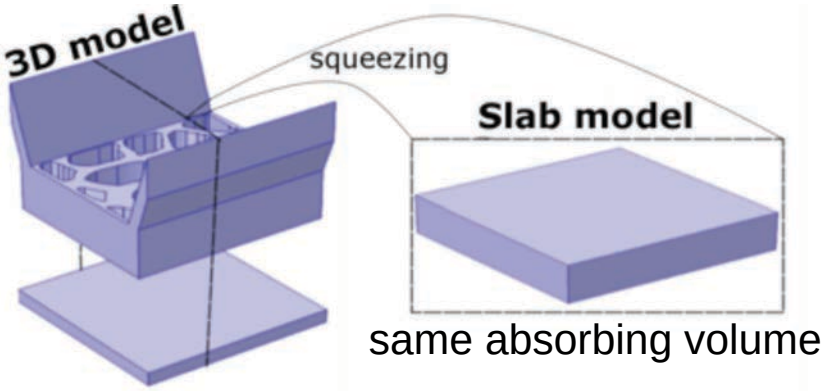


- nanohole diameters are 200 - 600 nm
- filling fraction (*ff*) decreases from base to apex
- absorption depends on filling fraction

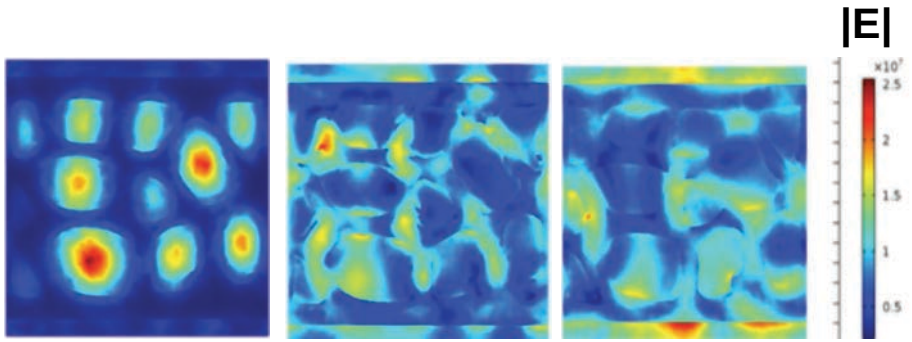


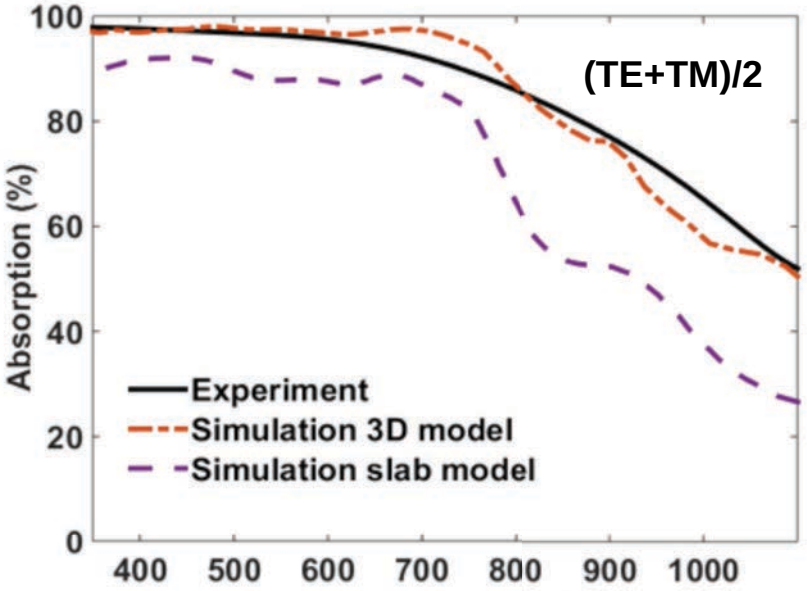
Siddique, Donie, Gomard, Yalamanchili, Merdzhanova, Lemmer, Hölscher, *Sci. Adv.* **3**, e1700232 (2017)

Simulation of Scale Structure



same absorbing volume

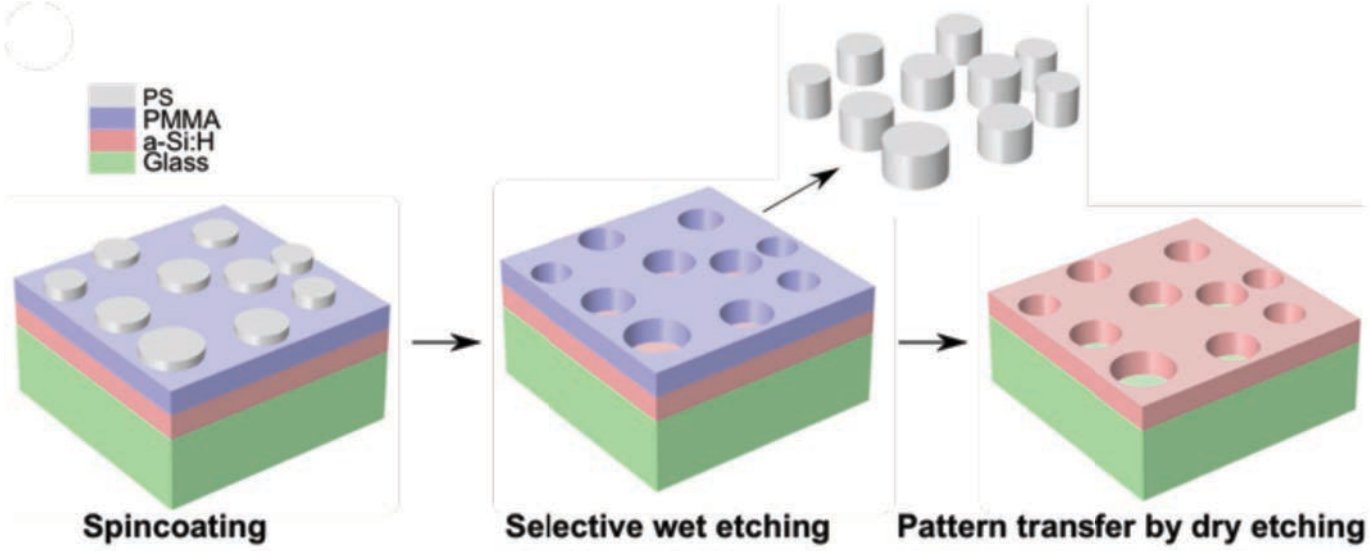


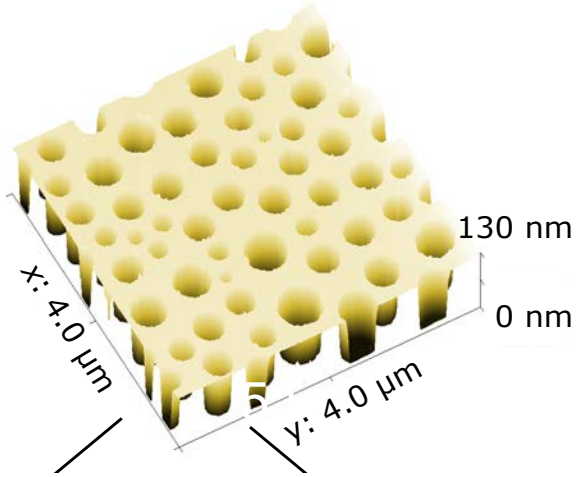


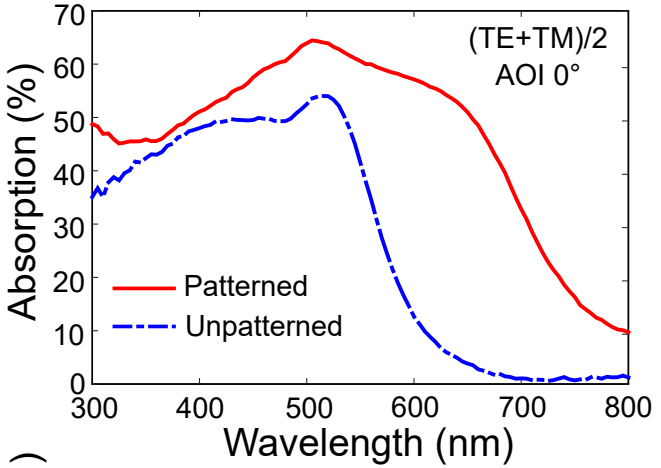
- Structure contributes
  - VIS: 15-20% increase of absorption
  - NIR: +20-35% increase of absorption
- UV-Blue: channeling of the light within the nanoholes
- Green-Red: scattering of light within the membranes
- NIR: significant effects at the ridges

Siddique, Donie, Gomard, Yalamanchili, Merdzhanova, Lemmer, Hölscher, *Sci. Adv.* **3**, e1700232 (2017)

Absorber Fabricated by Polymer-Blend-Lithography



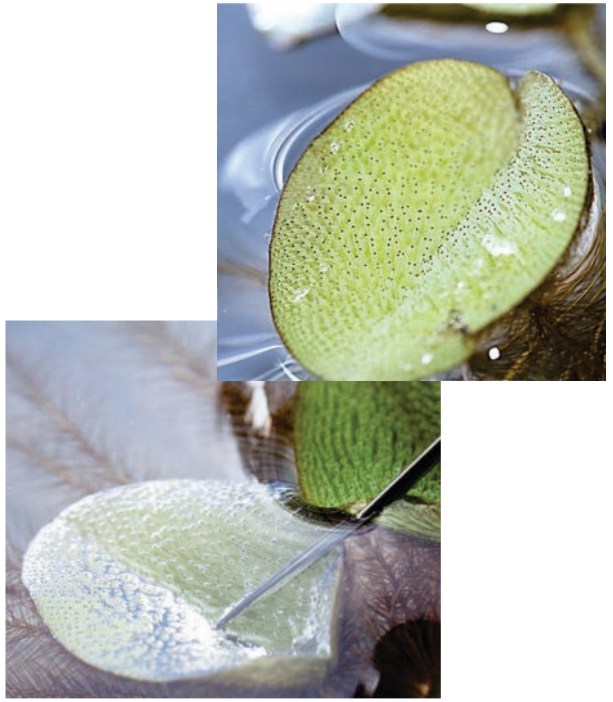




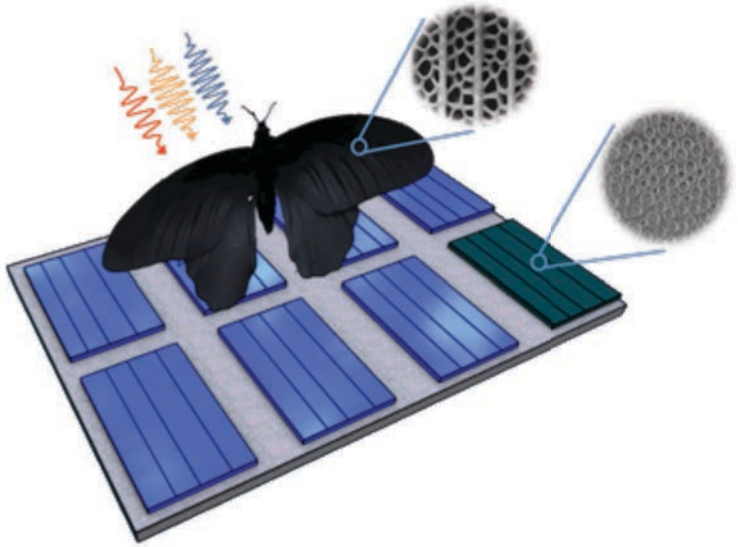
Siddique, Donie, Gomard, Yalamanchili, Merdzhanova, Lemmer, Hölscher, *Sci. Adv.* **3**, e1700232 (2017)

Summary

- Structure of *Salvinia* leaves
  - Oil/Water Separation
  - Coatings for self-cleaning, advanced solar cells



- Black Butterfly „Common Rose“
  - Absorbers for thin solar cells



Many Thanks to …

Hölscher group and friends in spring 2017