Bio-inspired Surfaces for Solar Cells

Hendrik Hölscher
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

- Winglets
- Airfoils
- Airplane
- Future? Riblets inspired by shark scales
- Velcro in seat covers

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Color in Nature

Mating

Camouflage

Warning

Communication

Attraction of pollinators

Thermoregulation

Hendrik Hölscher | Smart Biomimetic Surfaces

Institute of Microstructure Technology
Adaptive Camouflage at its perfection: *Octopus vulgaris*
Who sees what?

Humans

Insects

Birds
WHAT HUMANS SEE

WHAT BIRDS SEE

might
Green Rose Chafer (*Cetonia aurata*)
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

Butterflies & Beetles
→ Structural colors
Siddique et al., Opt. Exp. 21, 14351 (2013)
→ Anti-reflection coatings
→ Absorbers for solar cells
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**

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**Figure 1.** Scanning electron microscope micrographs of the four types of trichomes found in *Salvinia* species: (A) Cucullata type (*S. cucullata*), (B) Oblongifolia type (*S. oblongifolia*), (C) Natans type (*S. minima*), and (D) Molesta type (*S. molesta*). Scale bar = 200 µm.

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Barthlott, Wiersch, Colic, Koch, Botany, 87, 830 (2009)
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

heating $T > T_g$

heating $T \geq T_g$

250 µm

50 µm

5 µm

Flat Polycarbonate

$\theta \approx 72^\circ$

Hairy Polycarbonate

$\theta \approx 172^\circ$

Nanofur – Highly Scalable Fabrication Process

Vüllers, Gomard, Preinfalk, Klampfatis, Worgull, Richards, Hölscher, Kavalenka, Small 12, 2016

sandblasting
steelpate

heated plate
polymer

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

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)
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**
- dry nanofur $> 87\%$
- wetted nanofur $> 85\%$

**Specular Transmission**
- dry nanofur $< 2.8\%$
- wetted nanofur $< 2.4\%$
Application on OLEDs

Application on yellow OLEDs

>10% intensity enhancement on OLEDs

Vüllers et al., Small 12, 2016
Application on Solar Cells

<table>
<thead>
<tr>
<th>Solar cell Configuration</th>
<th>External Quantum Efficiency</th>
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<tbody>
<tr>
<td>Bare SC</td>
<td>100%</td>
</tr>
<tr>
<td>SC with PC</td>
<td>103.4%</td>
</tr>
<tr>
<td>SC with Nanofur</td>
<td>105.8%</td>
</tr>
</tbody>
</table>

Short circuit current density

Vüllers et al., Small 12, 2016
Topography Transfer to FEP

Fluorinated Ethylene Propylene (FEP) Microcavityarray (MCA)

Vüllers et al., ACS Appl. Mater. Interfaces 10, 2018
Self-cleaning and Impact Stability

Smooth FEP

FEP MCA

Vüllers et al., ACS Appl. Mater. Interfaces 10, 2018
FEP MCA Application on Photovoltaics

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### Short circuit current

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<table>
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<tbody>
<tr>
<td>Bare PV module</td>
<td>100%</td>
</tr>
<tr>
<td>PV module with FEP</td>
<td>103.6%</td>
</tr>
<tr>
<td>PV module with FEP MCA</td>
<td>104.5%</td>
</tr>
</tbody>
</table>

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Vüllers et al., ACS Appl. Mater. Interfaces 10, 2018
Black Butterfly *Pachliopta aristolochiae*

Index matching experiment demonstrates that structure causes about 40% absorption

![Graph showing absorption vs. wavelength](image)

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

Simulation of Scale Structure

- 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

Absorber Fabricated by Polymer-Blend-Lithography

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