Organic solar cells based on small molecules

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1. **Fundamentals**
   1. Excitonic processes
   2. Types of organic solar cells (OSC): polymer, small molecules

2. **Small molecule OSC**
   1. Processing
   2. p-i-n concept
   3. Materials

3. **Topics at IAPP and some results**
   1. High fill factors
   2. Semitransparent devices
   3. 6.07% certified efficiency

4. **Summary**
Inorganic devices:
- light absorption leads to Wannier Mott excitons
- binding energy $E_B < k_B T \approx 26$ meV
- instantaneous creation of free electrons and holes

Organic photovoltaics (OPV):
- light absorption results in strongly bound Frenkel excitons
- binding energy $E_B \approx 0.2 - 0.7$ eV
- suitable heterointerface necessary for charge carrier separation
- exciton diffusion length matters!

Advantages of OPV:
- Low weight
- Low material consumption
- Flexible
- Low price
Fundamentals: Excitonic processes

Generation of Frenkel exciton; Diffusion to heterojunction

Dissociation and charge transfer

Charge carrier transport to electrodes

Extraction
“Organic”: contains **carbon-based** absorber materials

**Polymer-based OSC**

**Small molecule-based OSC**

- Dry vacuum processes
- Thermal evaporation
- Easy in-line production

• Thermal vacuum evaporation
• Simultaneous evaporation of several materials (→ doping)

• Layers 1-100 nm thick; complete device < 300 nm thick (excl. substrate)
• Material consumption for 100 nm layer: 
  \[10^2 \times 10^2 \times 10^{-5} \text{ cm}^3 = 0.1 \text{ cm}^3\] 
  → Total material for device ≈ \(1 \text{ g/m}^2\)
• Aim: \(500 \text{ g/m}^2\) incl. substrate

→ low-cost, low-weight
→ Large commercial potential

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Jan Meiss
Slide 6
**Doping** of organic hosts by guest dopant materials (1-10 wt\%)

- Increases conductivity
- Ohmic contacts between layers
- Concept of semipermeable membranes
- Transparent transport layers (\(\rightarrow\) interference effects)

Small molecule OSC: Materials

Additional building blocks:
- capping layers for light incoupling,
- exciton blocking layers,
- bulk heterojunctions

→ Very high versatility
→ devices can be tailored
Main challenges:
- Excitonic processes
- Narrow absorption bands
- Morphology

15x15cm² OSC Module made in collaboration with Fraunhofer IPMS and Heliatek GmbH
Novel green donor materials tested at IAPP
With suitable dopants and p-i-n concept, fill factors > 76% possible
Extremely good transport properties

Building block for tandem devices?

\[ \text{Voltage (V)} \]

\[ 0.981 \text{ V} \]

\[ \text{Current Density (mA/cm²)} \]

\[ \begin{array}{c|c|c}
V_{OC} & 0.981 \text{ V} \\
FF & 76.2 \% \\
J_{SC} & 2.78 \text{ mA/cm}^2 \\
Eff. & 2.1 \% \\
\end{array} \]

J. Meiss et al., in preparation
Outstanding results: 
Semitransparent devices

- Huge market for building-integrated “power windows”
- Using advanced device concepts: 2% efficiency at 30-50% transmission;
close to 4% with tandem devices (< 20% transmission)

In cooperation with heliatek GmbH

J. Meiss, K. Leo, M. Riede, C. Uhrich, Stefan Sonntag,
W.-M. Gnehr, and M. Pfeiffer, Appl. Phys. Lett. 95(21),
213306 (2009)
Outstanding results: Certified world-record OPV efficiency

- Cooperation of heliatek, IAPP and BASF
- Dopants by Novaled
- 6.07% on large-area OSC (2 cm²), certified by ISE Freiburg:
  \[ V_{oc} = 1.59 \text{ V} \]
  \[ J_{sc} = 6.18 \text{ mA/cm}^2 \]
  \[ FF = 61.9 \% \]
  \[ \eta = 6.07 \% \]
- Notable exception for polymers: 7.9% on ≈ 4 mm² (Solarmer)

M. A. Green et al., Prog. Photovolt: Res. Appl. 18, 144 (2010).
• Small molecule-OSC
  – Vacuum processing
  – Low material consumption
  – Potentially very low costs

• Still basic research. Young field, not many small-molecule groups
• Highly interdisciplinary (materials science, chemistry)
• Promising efficiencies show potential; 10-15% possible

• Chance for cutting-edge technology in Germany
• Economic potential
• heliatek is planning pilot production facility in Dresden
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Thank you for your kind attention!
Solution Provider for Organic Electronics
in Dresden – the heart of the Organic Electronics Valley

www.oes-net.de
• Spin-off of IAPP
• Financing by BASF, Bosch, Wellington Partners, Technologiegründerfonds Sachsen
• CEO: Dr. Andreas Rückemann
• CTO: Dr. Martin Pfeiffer
• Recent financing round: 18 Mio. €
• Close cooperation with IAPP
• Plans to set up pilot processing line