TECHNISCHE UNIVERSITÄT DRESDEN

iapp

Fakultät Mathematik und Naturwissenschaften Institut für Angewandte Photophysik http://www.iapp.de

Status and Potential of Organic Solar Cells

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IAPP, TU Dresden, Germany

DPG Frühjahrstagung 2011, Dresden

Acknowledgements

heliatek
Organic based Photovoltaics

M. Pfeiffer, C. Uhrich,
G. Schwartz, K. Walzer,
W. Gnehr, J. Förster,
O. Tsaryova, D. Hildebrandt,
S. Vetter, A. Weiß, ...

OSOL group at IAPP, Prof. K. Leo

Institut für Angewandte Photophysik (IAPP)

- University institute
- Founded 1908
- Until 1990 mainly work on photography

Present Topics:

- Organic thin films
  Semiconductor Properties/Devices
  Optical Properties
  Epitaxy
- Femtosecond spectroscopy
  on semiconductors (e.g., Bloch oscillations)
- Raster scanning microscopy
  STM/AFM, SNOM

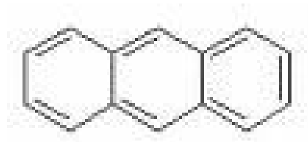
approx. 130 employees (9 funded by university)
(http://www.iapp.de)

Overview

- Working Principles of Organic Solar Cells
- Current Research Challenges
- Beyond 10% Efficiency

Comparison of typical Semiconductors

Property	Germanium	Anthracene
Atomic Weight	72.63	178.22
Melting Point (°C)	937	217
Density (g(cm³)	5.3	1.28
Density (molecules/cm³)	$4.42x10^{22}$	$0.42x10^{22}$
Crystal Strcture	Diamond	Monoclinic
Dielectric Constant	16	3.2
e-Mobility at 300K (cm²/Vs)	3800	1.06
h-Mobility at 300K (cm²/Vs)	1800	1.31
Concentration of intrinsic carriers (cm^{-3})	$5.2x10^{13}$	$\sim10^{-4}$
Vacuum Ionisation Energy (eV)	4.8	5.8



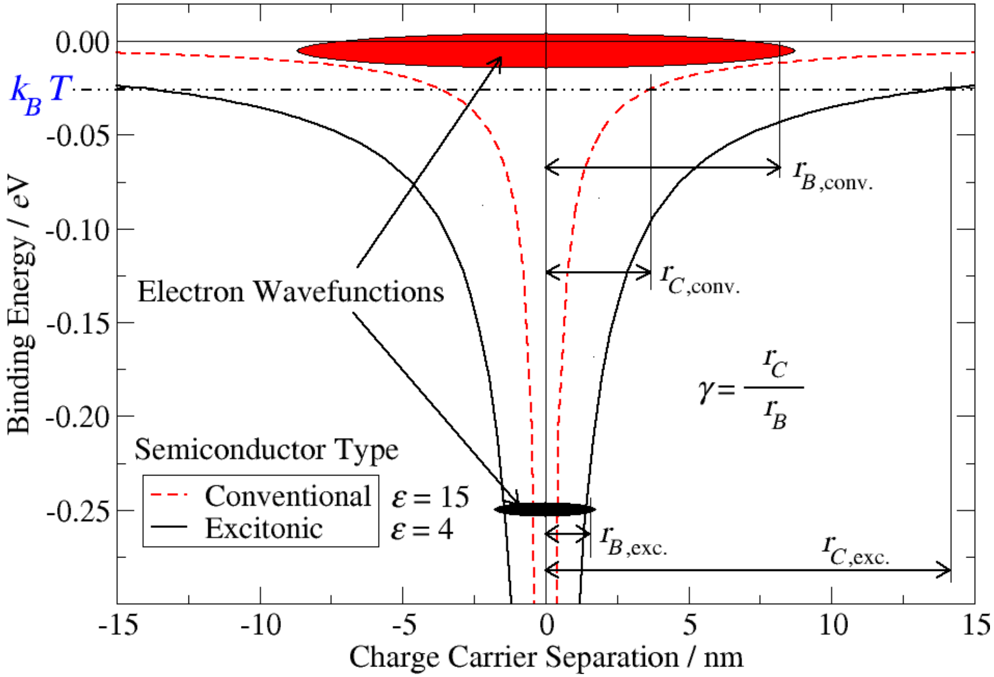
Anthacene data from W. Warta *et al.*, Phys. Rev. B 32, 1172 (1985)

What makes Organic Solar Cells special?

- Photon absorption does not directly generate free charge carriers, but excitons

- Diffusion length of excitons is much smaller than penetration depth of photons

➔ Excitonic Solar Cells

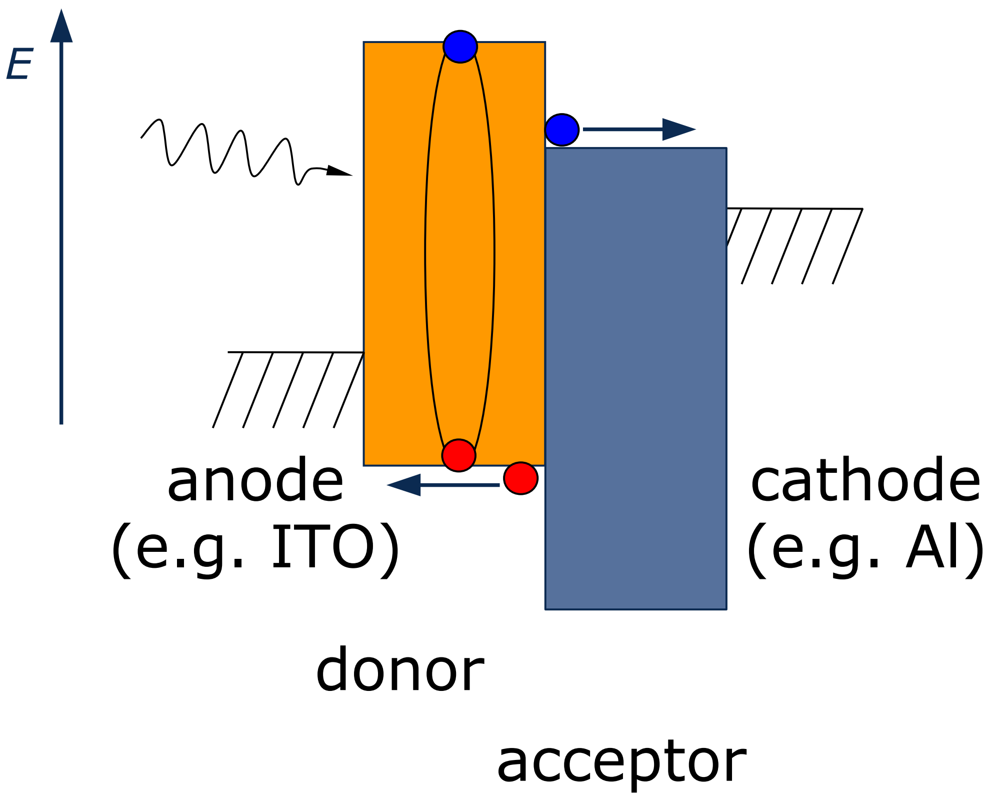


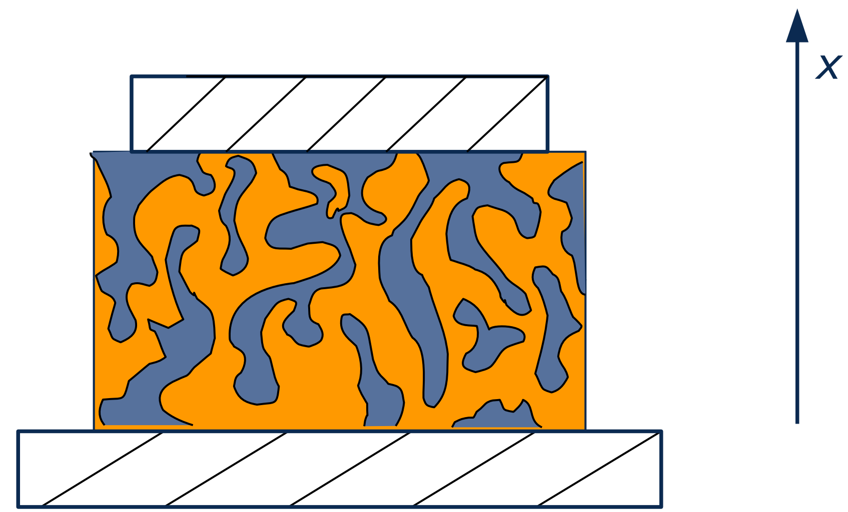
S. E. Gledhill *et al.*, J. Mat. Res. 20, 3167 (2005)

P. Würfel, CHIMIA 61, 770 (2007)

Brief History and Main Concepts

- First Breakthrough 1986: **D**onor-**A**cceptor Heterojunction
- Second Breakthrough early 1990s: Bulk Heterojunction Concept





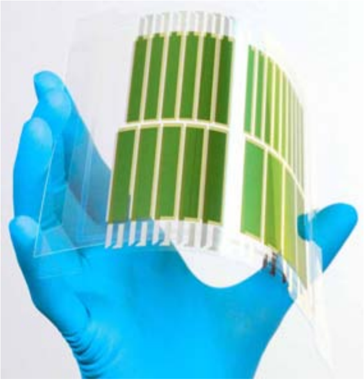
C. W. Tang, Appl. Phys. Lett. 48, 183 (1986)
M. Hiramoto *et al.*, Appl. Phys. Lett. 58, 1062 (1991)
J. J. Hall *et al*., Nature 376, 498 (1995)
G. Yu *et al*. Science 270, 1789 (1995)

Potential of Organic Photovoltaics

Light-weight, cheap, flexible, large area, long-living and efficient solar cells

Optional: colour-tunable and/or semitransparent






Reasons:

- Flexible plastic substrates and thin organic layers
  - → Little material and energy consumption
  - → Short energy payback time
- Compatible with cheap and large area production technologies
- Toolbox of organic chemistry
- Little restrictions on required materials

Images: Konarka, Neuber, Heliatek, IAPP

Classification of Organic Solar Cells

Solution-Processing

- Mainly polymers, but also small molecules and inorg. materials
- Layers made by e.g. printing
  - High production speeds possible
  - Room temperature process

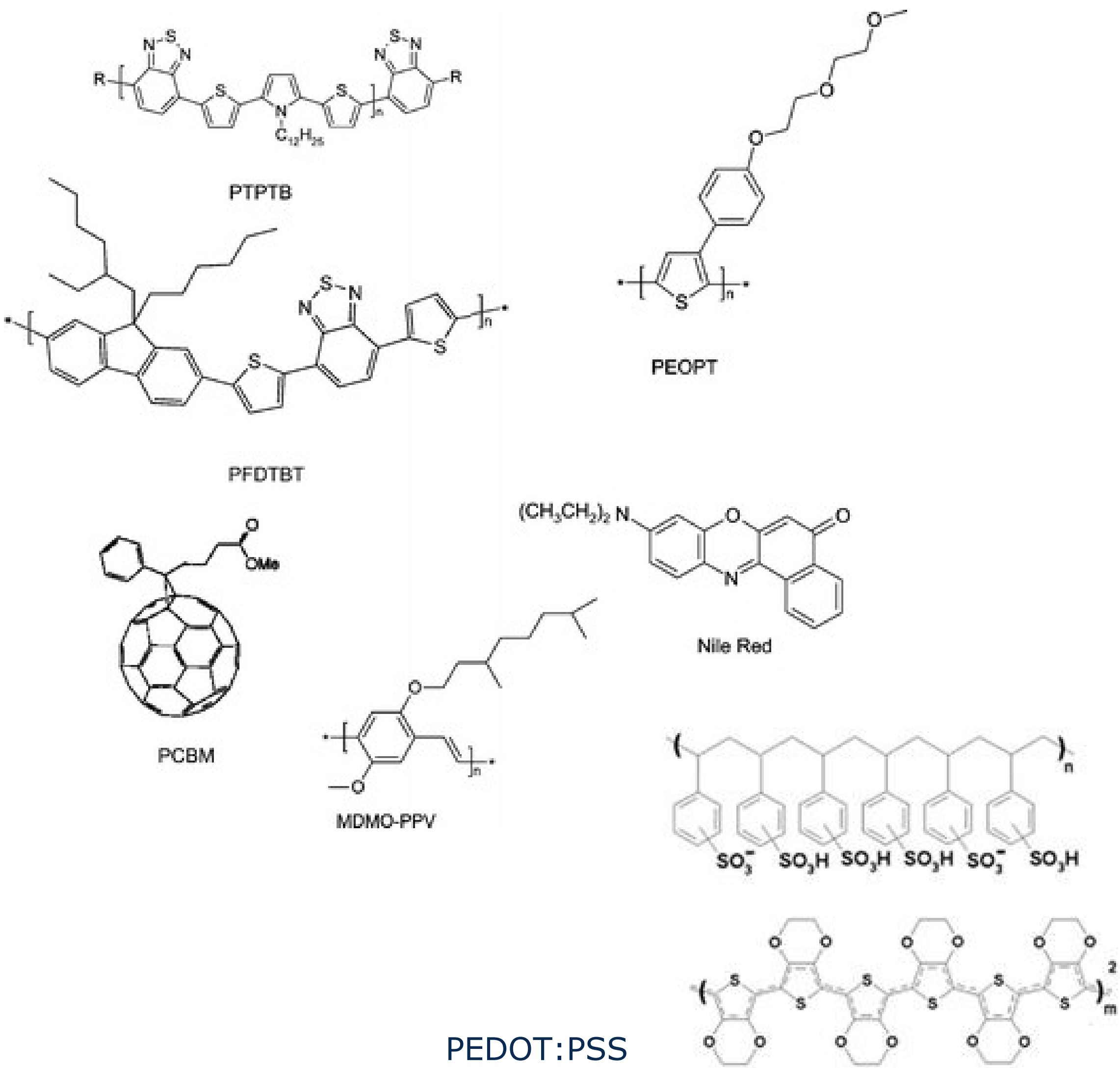
Vacuum-Sublimation

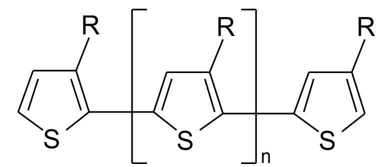
- Only small molecules possible
- Layers made by sublimation of material in vacuum
  - Easy access to multi-layer systems
  - High material purity

Dye Sensitized Solar Cells (DSSC) aka "Grätzel Cells"

- (nano-)porous TiO_2 layers coated with dye
- Layers made by (screen) printing

Typical Stack for solution-processed Organic Solar Cells





P3HT

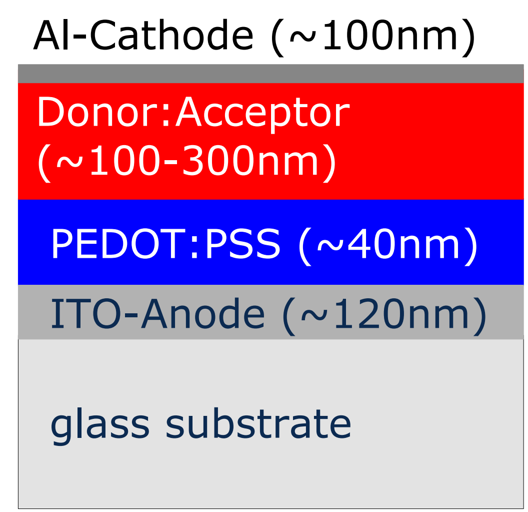
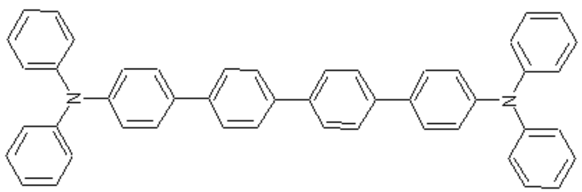
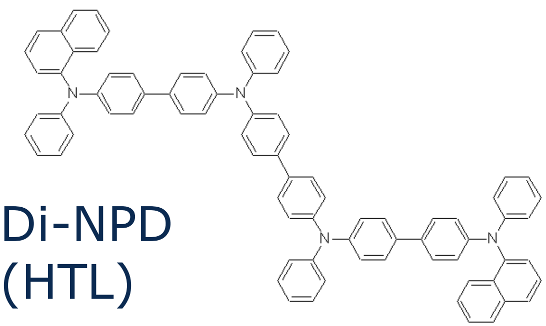


Image: Royal Society of Chemistry

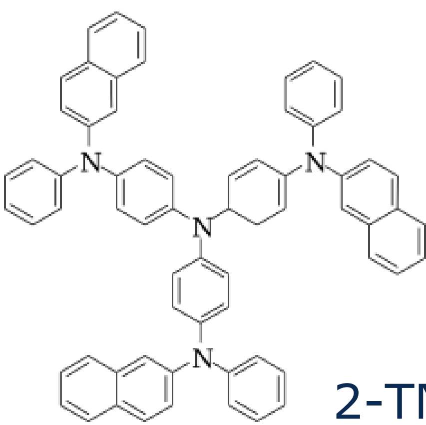
p-i-n Stack for vacuum-processed Organic Solar Cells



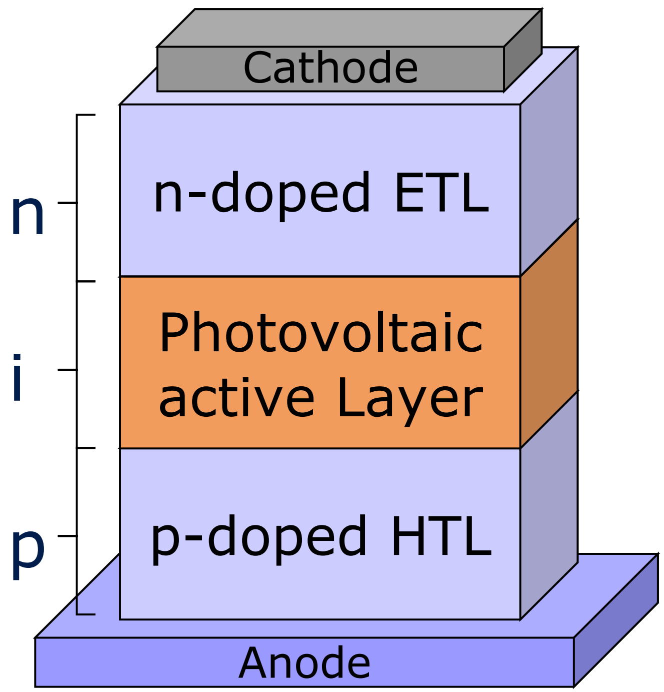
4P-TPD
(HTL)



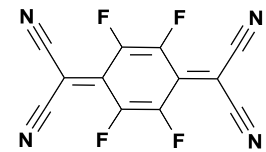
Di-NPD
(HTL)



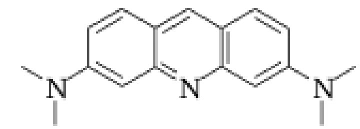
2-TNATA
(HTL)

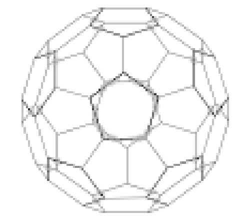


F4-TCNQ (p)

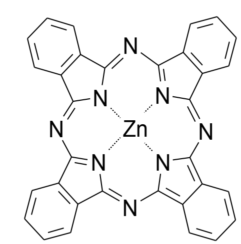


AOB (n)

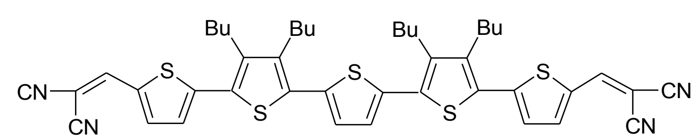




C60 (A/ETL)



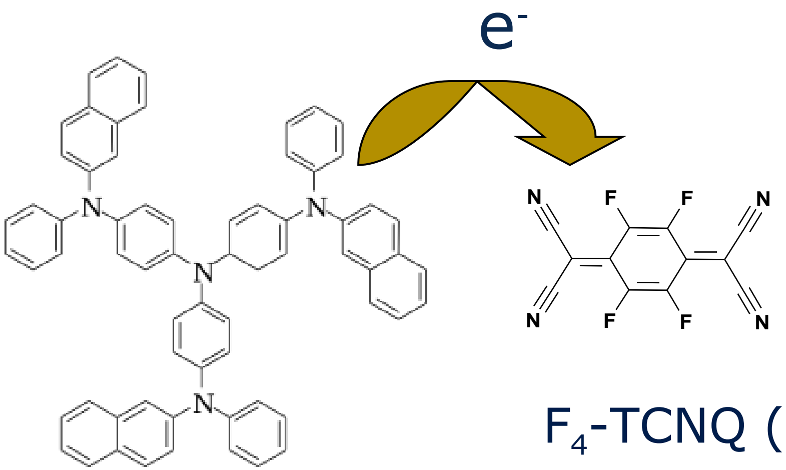
ZnPc (D)



DCV5T-Bu (D)

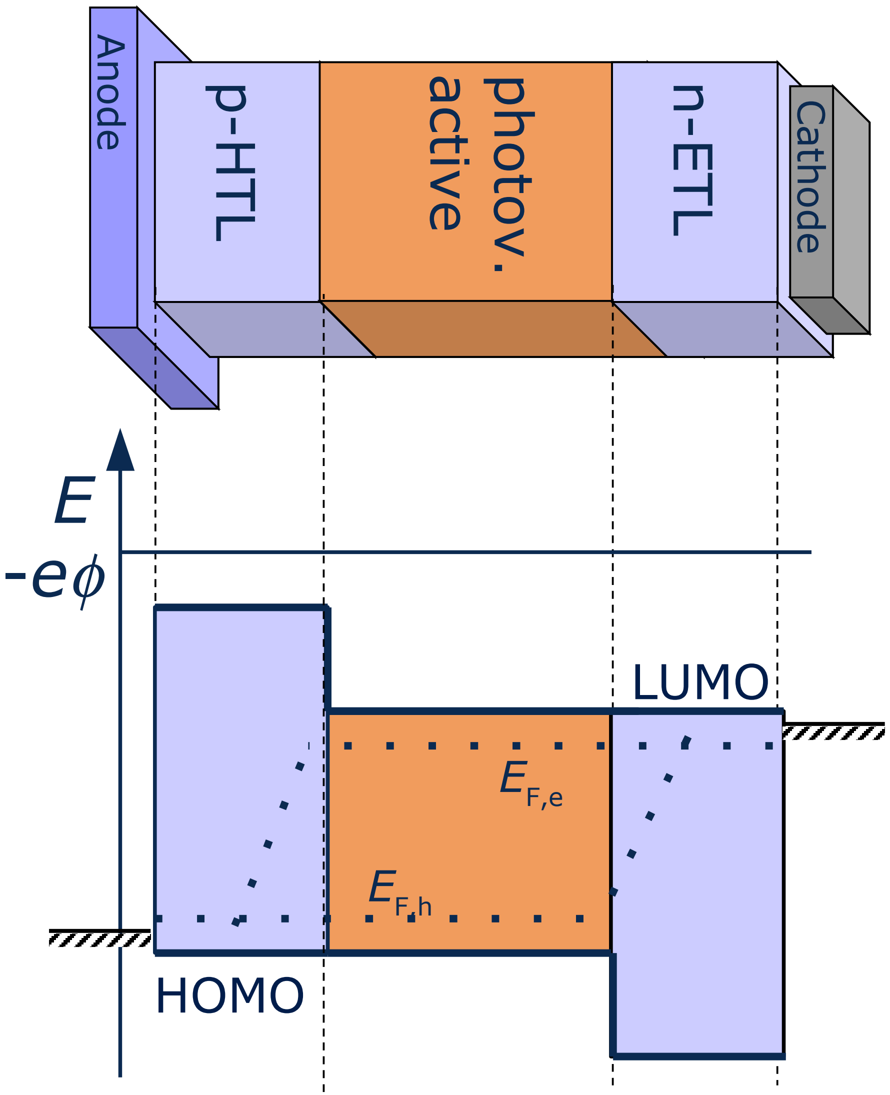
B. Maennig *et al.*, Appl. Phys. A 79, 1 (2004)
M. Riede *et al.*, Nanotechnology 19, 424001 (2008)

Advantages of molecular Doping



2-TNATA (HTL)

F_4-TCNQ (p)



- Active Fermi level control in HTL/ETL
- Quasi-Ohmic Contact to electrodes
- Conductivity increase by several orders of magnitude

→ Freedom of stack design

B. Maennig *et al.*, Appl. Phys. A 79, 1 (2004)
M. Riede *et al.*, Nanotechnology 19, 424001 (2008)

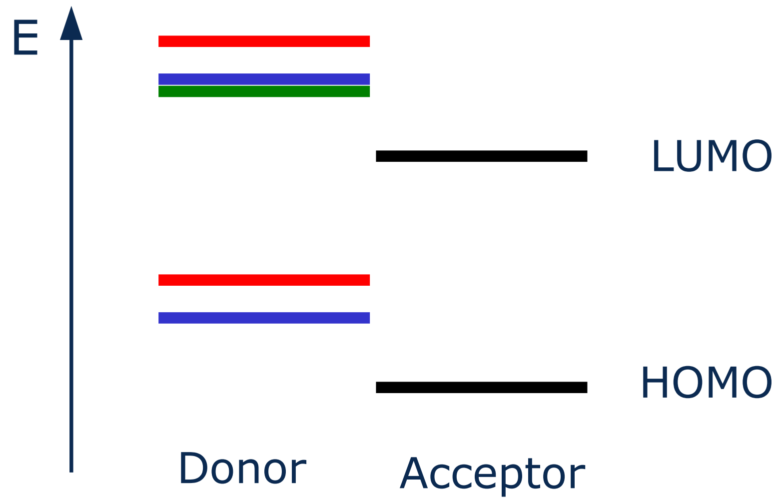
Overview

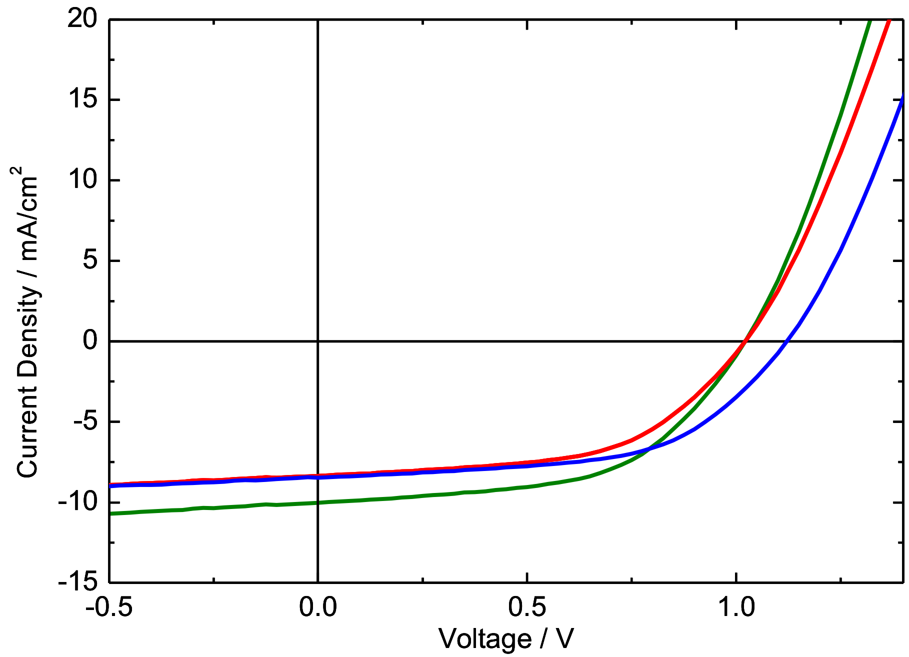
- Working Principles of Organic Solar Cells
- Current Research Challenges
- Beyond 10% Efficiency

Current Research Challenges

$$\eta = \frac{V_{oc} \cdot J_{sc} \cdot FF}{P_{ill}}$$

- Improving the device efficiency η
  - V_{oc} ← $HOMO_D$-$LUMO_A$ offset
  - J_{sc} ← Absorption gap
  - FF ← Barriers & transport





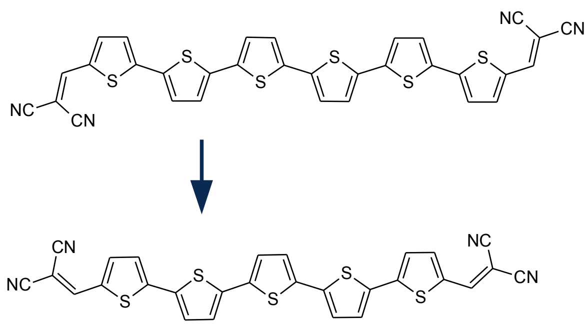
- Increasing device lifetime

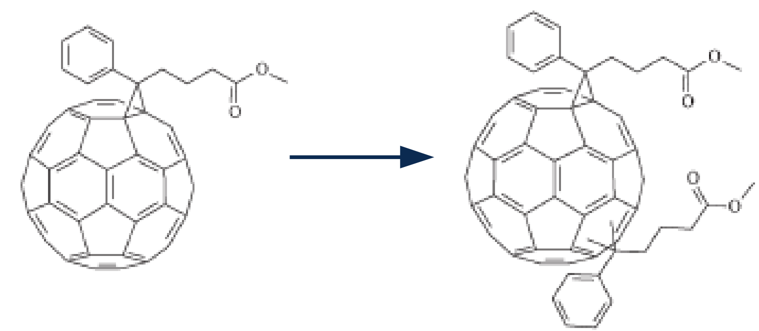
Tuning the Open Circuit Voltage V_{oc}: Examples

- Donor Side
- Acceptor Side

DCV6T

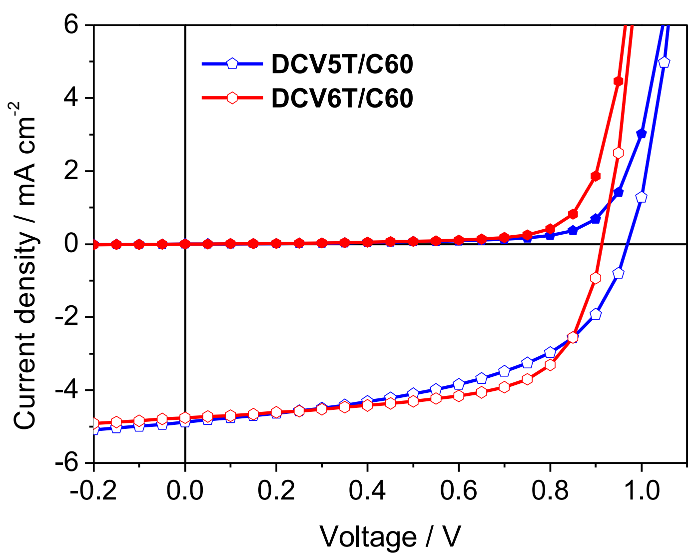
DCV5T

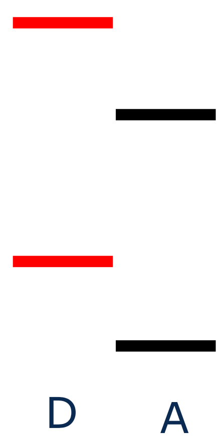


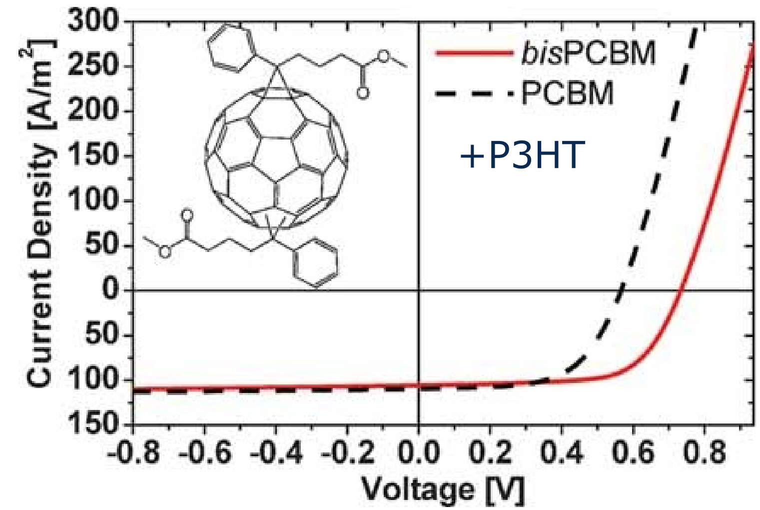


→ $\Delta HOMO_D \rightarrow \Delta V_{oc}$

→ $\Delta LUMO_A \rightarrow \Delta V_{oc}$



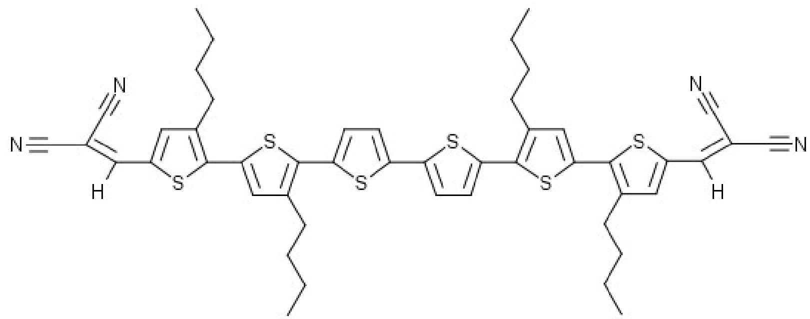


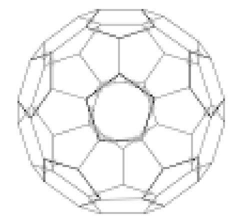


R. Fitzner *et al.*, Adv. Funct. Mat. 21, 897 (2011)
M. Lenes *et al.*, Adv. Mat. 20, 2116 (2008)

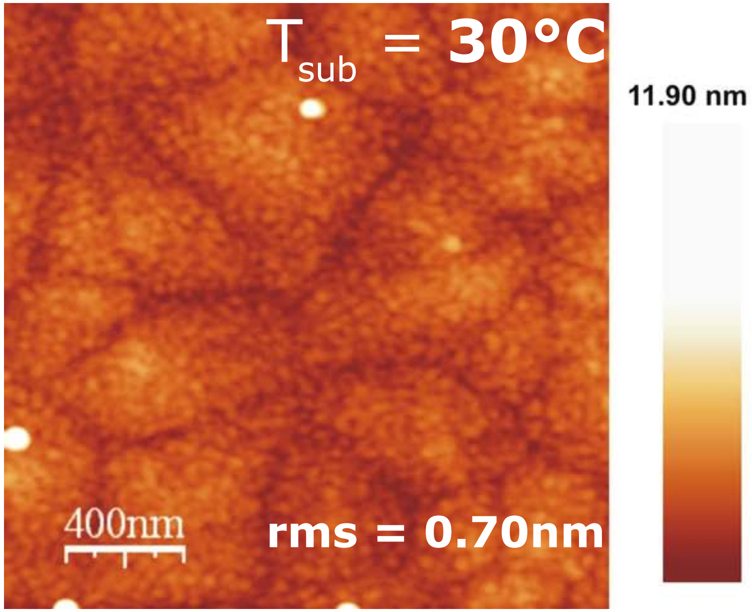
J_{sc} and FF: the Influence of Morphology

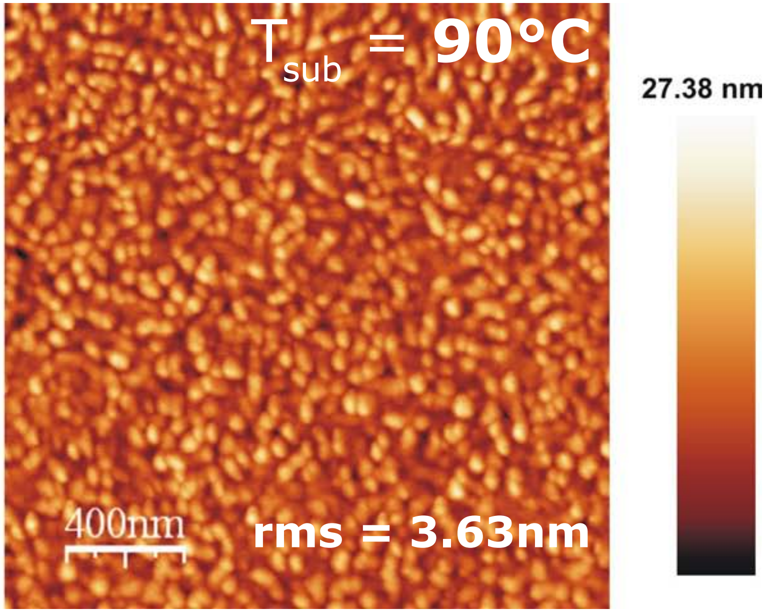
DCV6T-Bu4





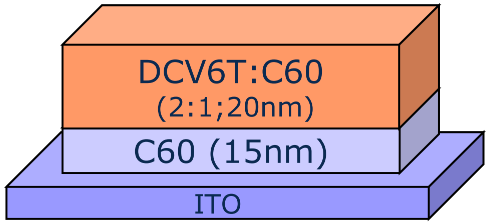
C60



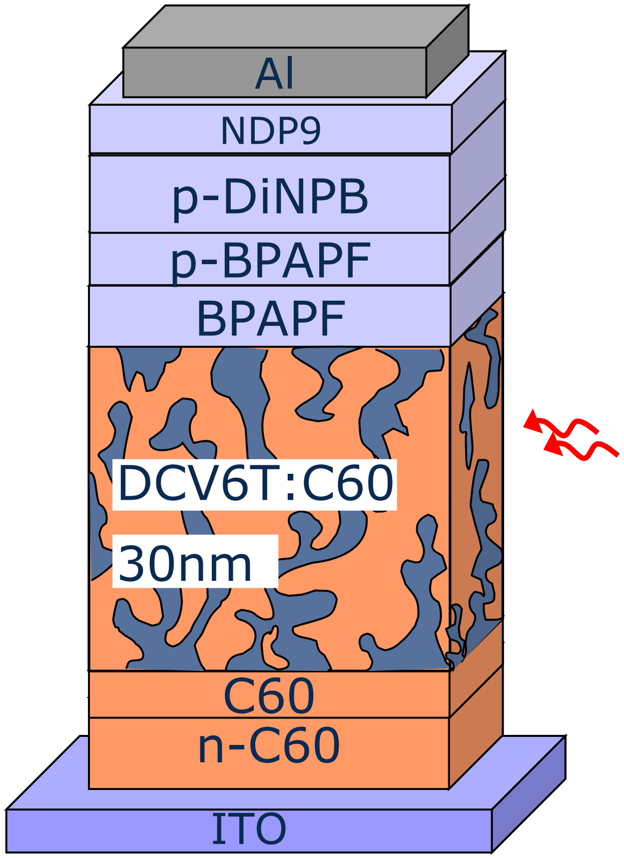


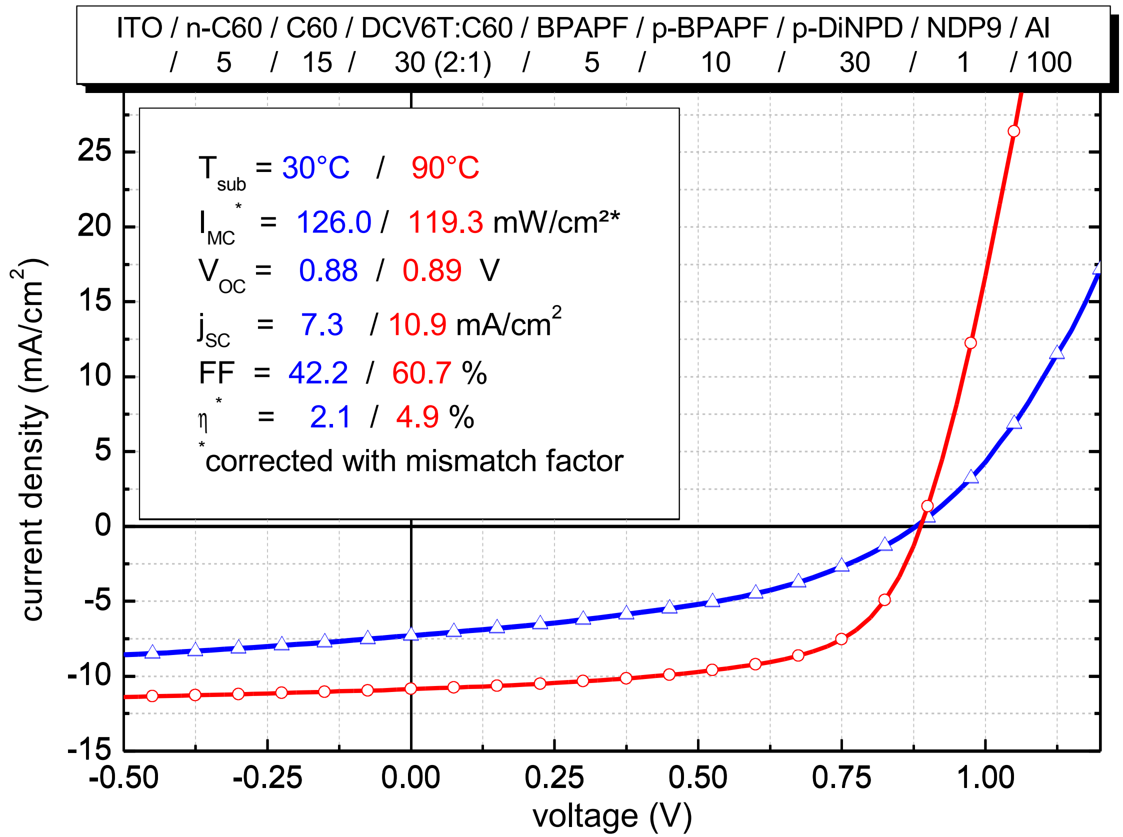
- Homogeneous mixture & smooth surface at RT
- Increased structure size, higher surface roughness

➔ Enhanced phase separation → better transport



J_{sc} and FF: the Influence of Morphology





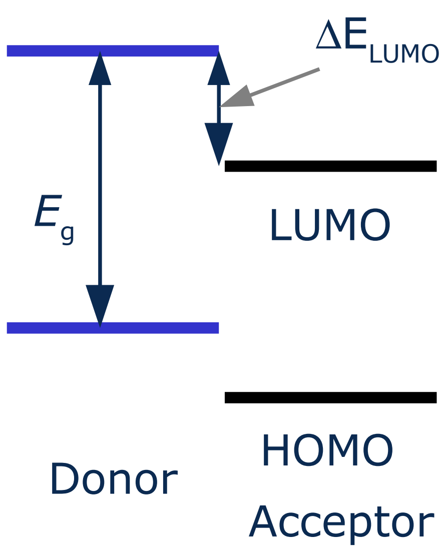
Sun simulator: Steuernagel (SoCo-1200MHG)

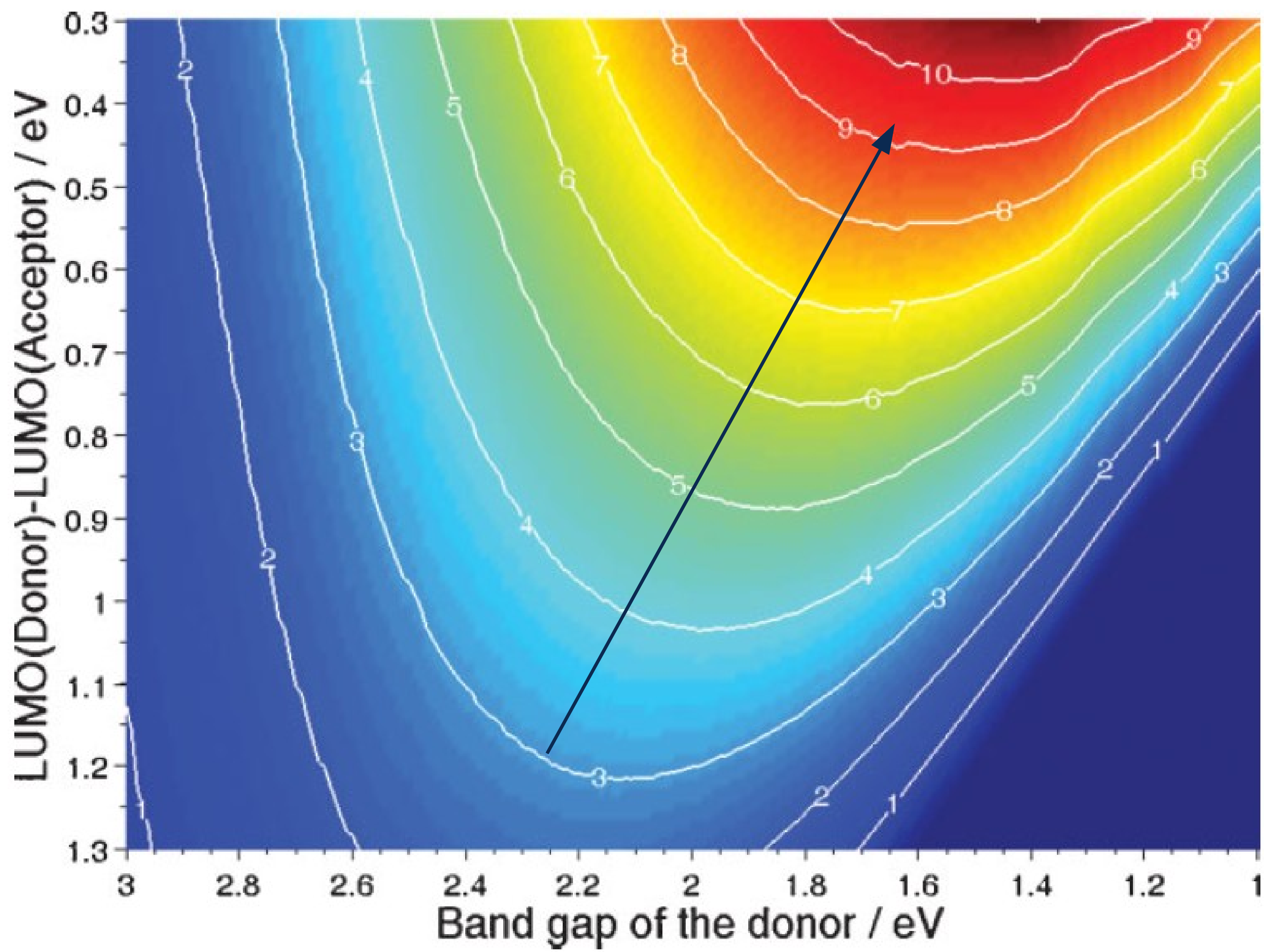
Measurement conditions: T~32°C, intensity calculated according to mismatch

Device area: 6.4mm²

D. Wynands *et al.*, Appl. Phys. Lett 97, 073503 (2010)

Efficiency Predictions for Single Heterojunction OPV





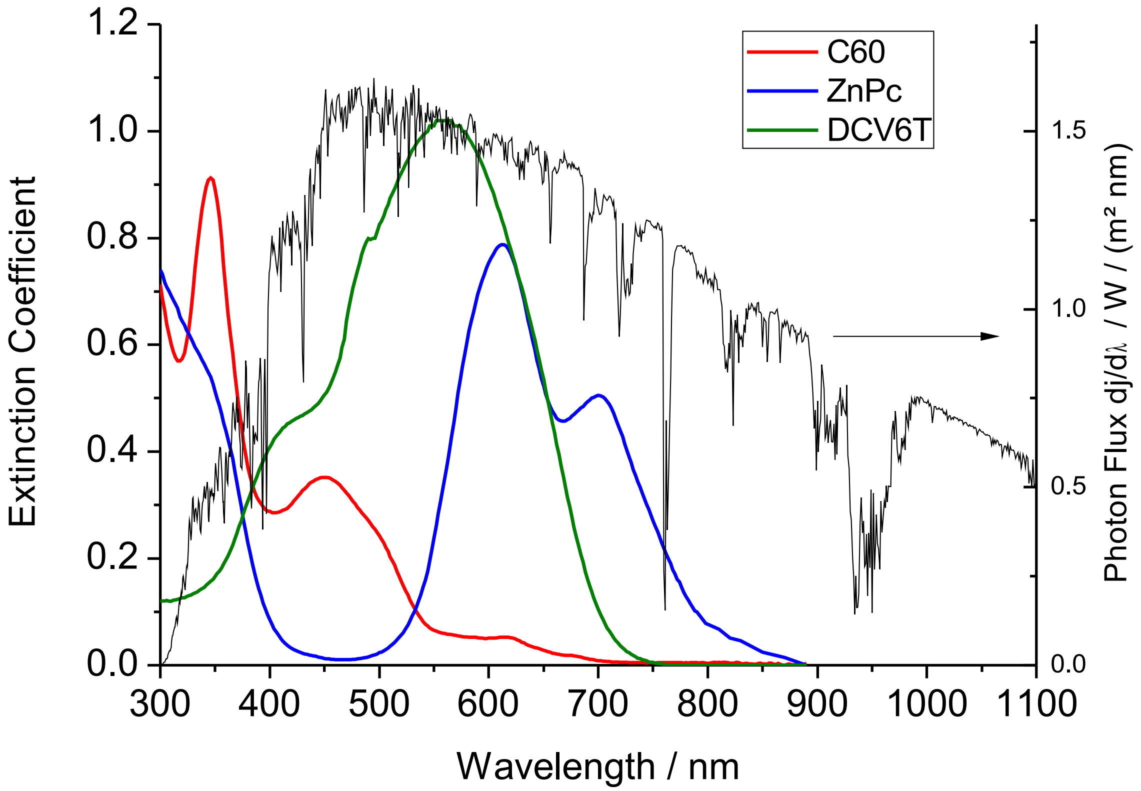
M. Scharber *et al.*, Adv. Mat. 18, 789 (2006)
G. Dennler *et al.*, Adv. Funct. Mat. 21, 1323 (2009)

Overview

- Working Principles of Organic Solar Cells
- Current Research Challenges
- Beyond 10% Efficiency

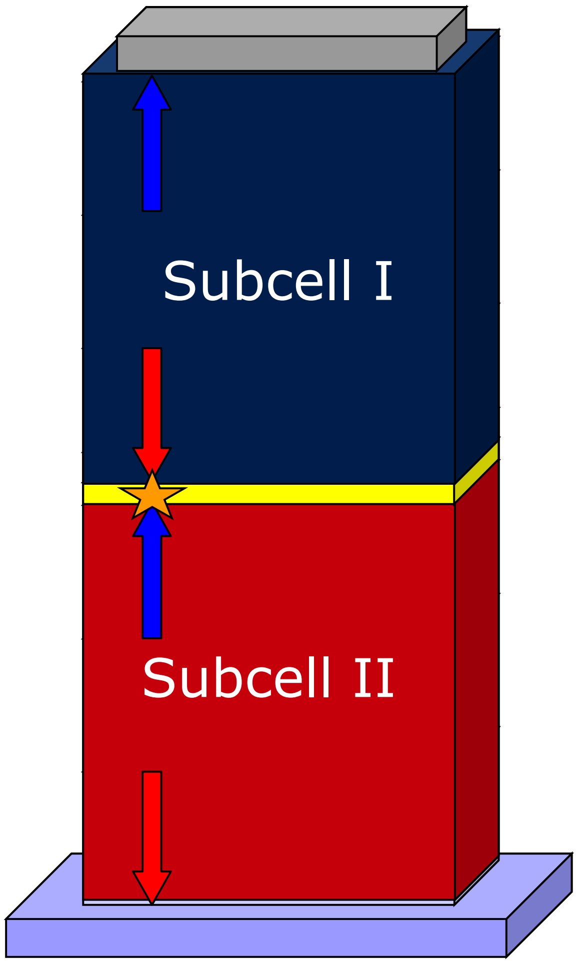
Beyond 10% Efficiency

- Much of the solar spectrum not used!
- Narrow absorption → absorption losses
- Wide absorption → thermalisation losses



From Single to Tandem Solar Cells

➔ Tandem Solar Cells



Goal:

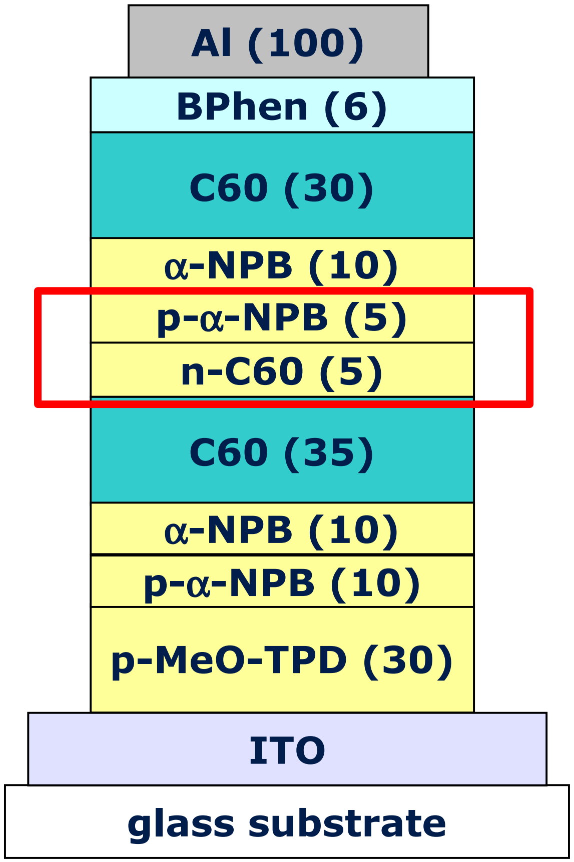
- to exceed the single heterojunction limit

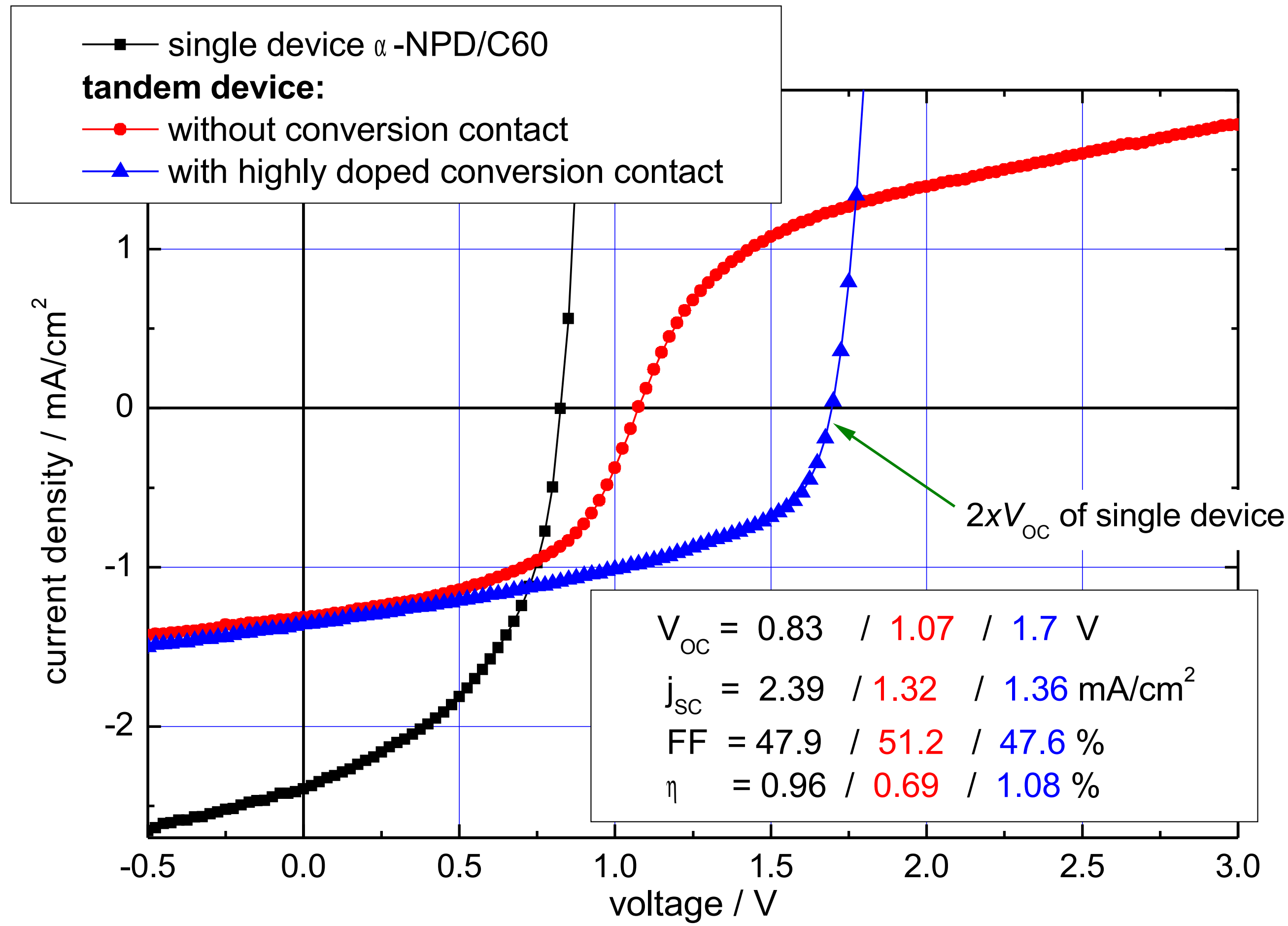
Requirements:

- Efficient recombination contact
- Current matching
- Complementary absorption

T. Ameri *et al.*, Energy Environ. Sci. 2, 347 (2009)
M. Riede *et al.*, Nanotech. 19, 424001 (2008)

Efficient Recombination Contact

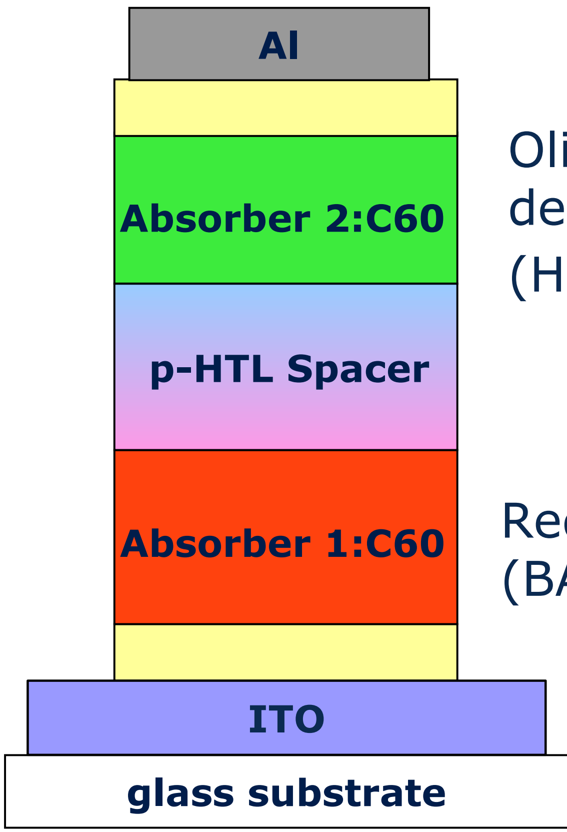




→ highly transparent recombination contact without loss of V_{oc}

R. Timmreck *et al.*, J. Appl. Phys. 108, 033108 (2010)

Current Matching and Complementary Absorbers

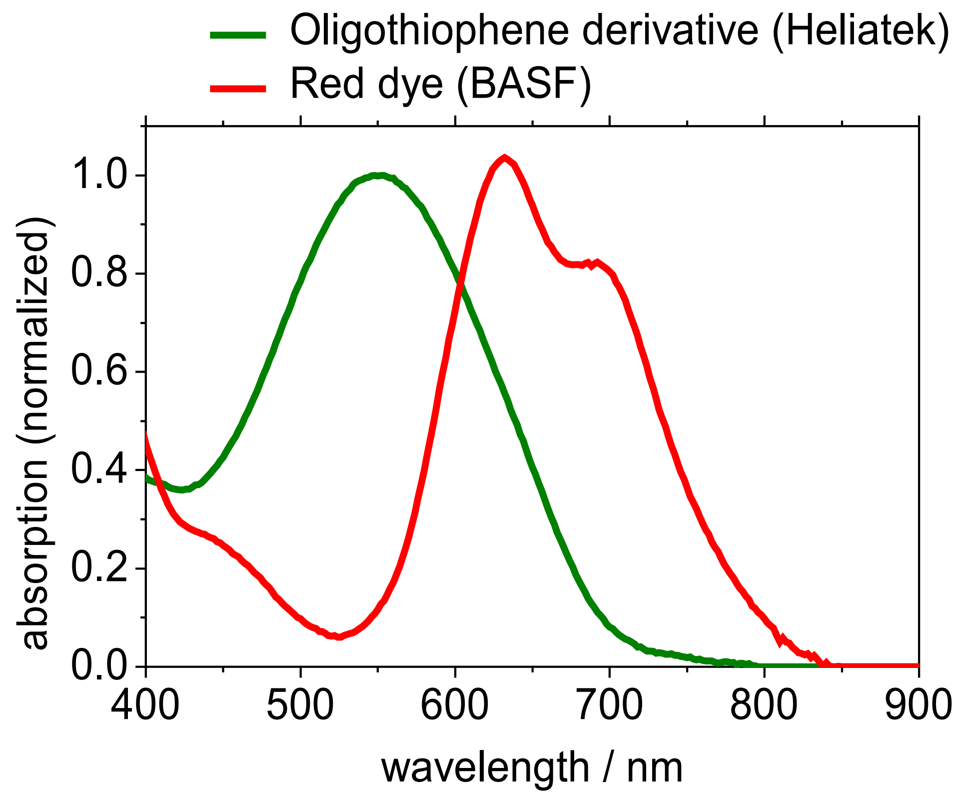


Oligothiophene derivative (Heliatek)

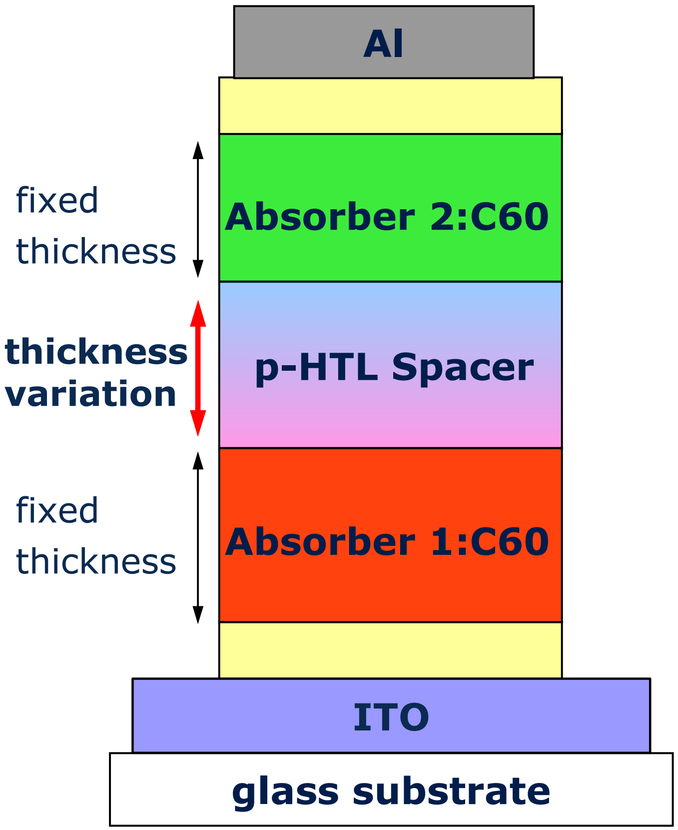
Red dye (BASF SE)

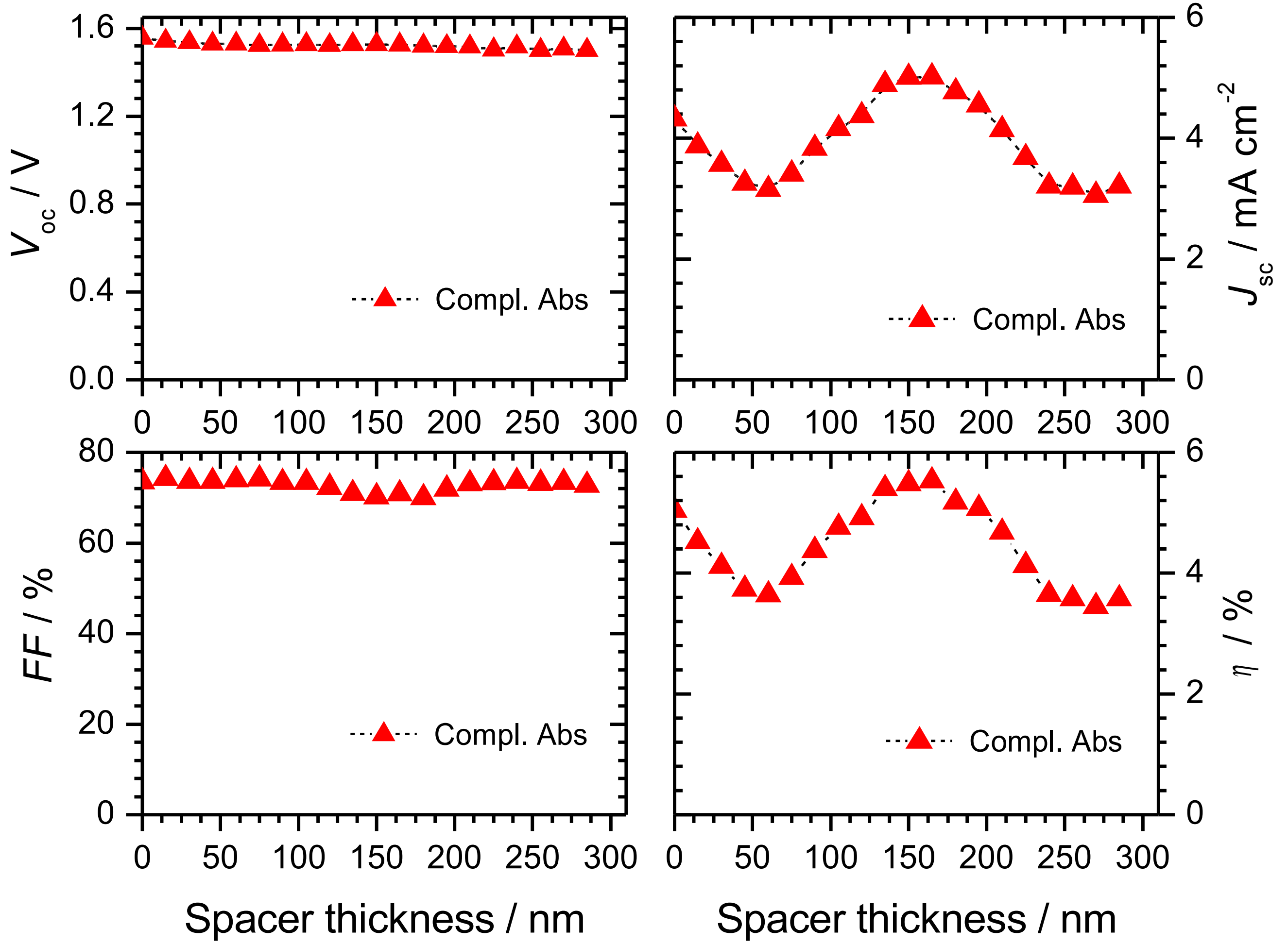
heliatek

Organic based Photovoltaics



Current Matching and Complementary Absorbers





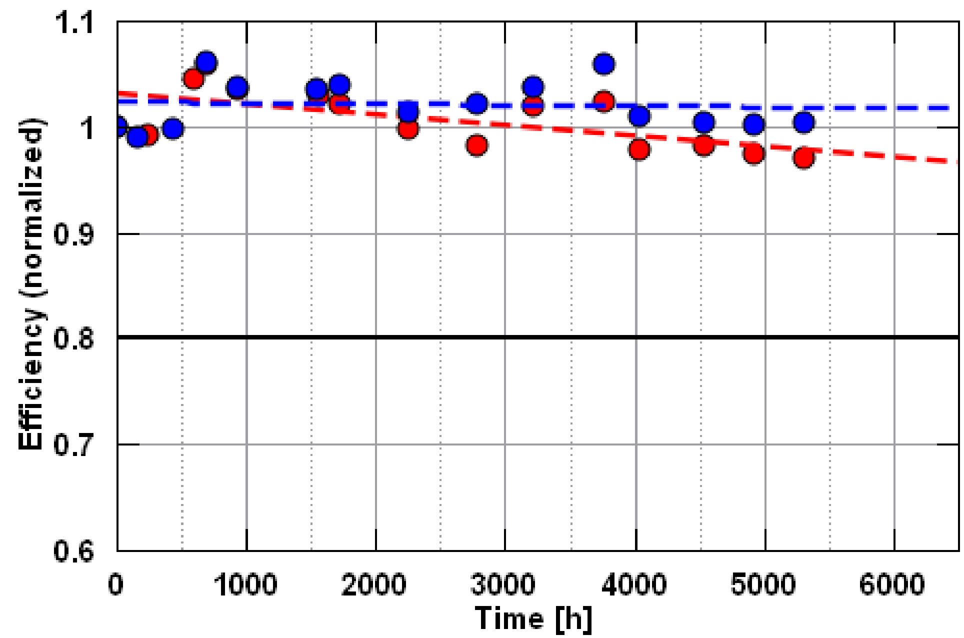
Measurement calibrated with aperture; area used for calculations: 7.1mm^2

Device Lifetime of a 6% Tandem Stack

heliatek
Organic based Photovoltaics

May 2009 State-of-the-art

- Tandem device
- Collaboration between Heliatek & IAPP
- Absorber materials from BASF and Heliatek, dopants from Novaled
- Glass-glass encapsulation
- Halogen light at about 1.5 suns



Stress Conditions	Device Temperature	Integrated Light Dosis	Corresponding Exposure Time in Middle Europe
●	50°C	8.1 MWh/m²	8 y
●	85°C	dark	

Data by Gregor Schwartz

OPV World Record > 1cm²

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Organic based Photovoltaics

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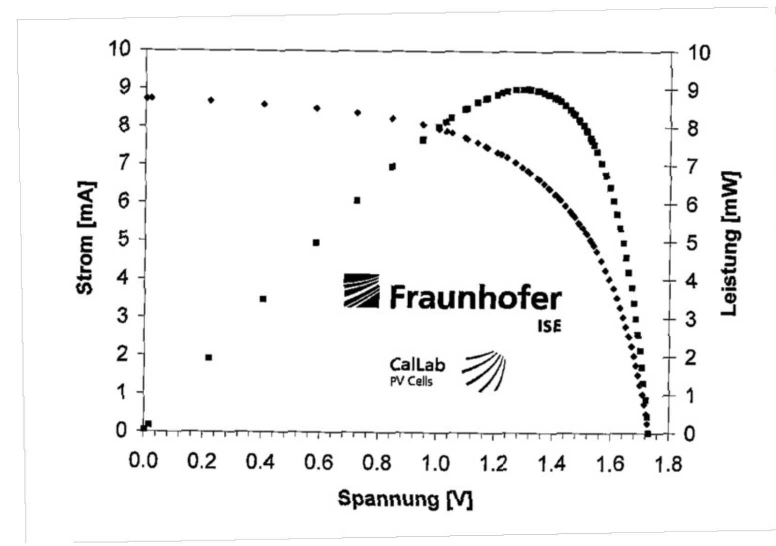
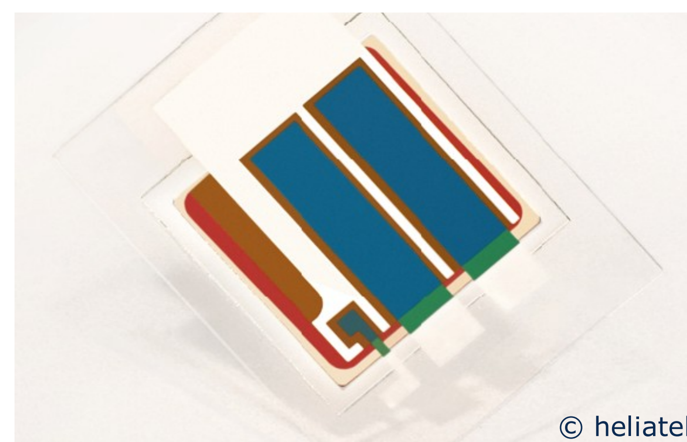


V_{OC}	=	(	1.7330	±	0.0087	) V
I_{SC}	=	(	8.73	±	0.22	) mA
FF	=	(	59.49	±	0.59	) %
η	=	(	8.28	±	0.25	) %

8.3 % on 1.1cm² certified by Fraunhofer ISE, Germany



Current World Record > 1cm²

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Organic based Photovoltaics

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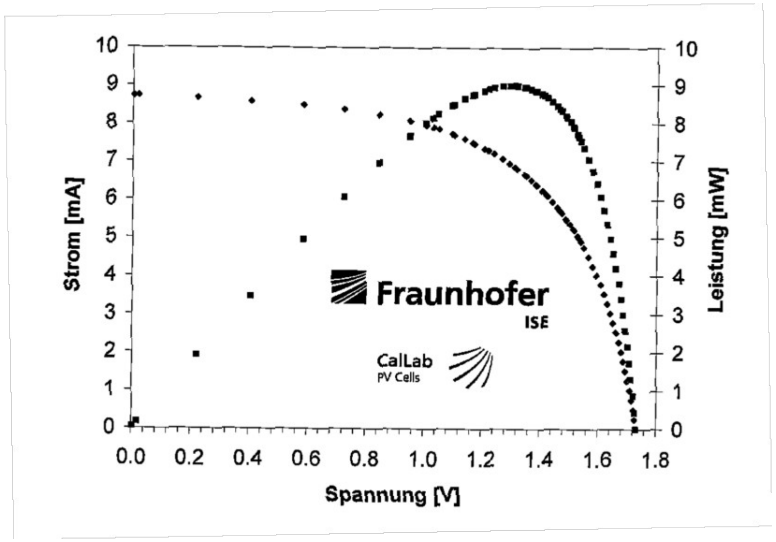
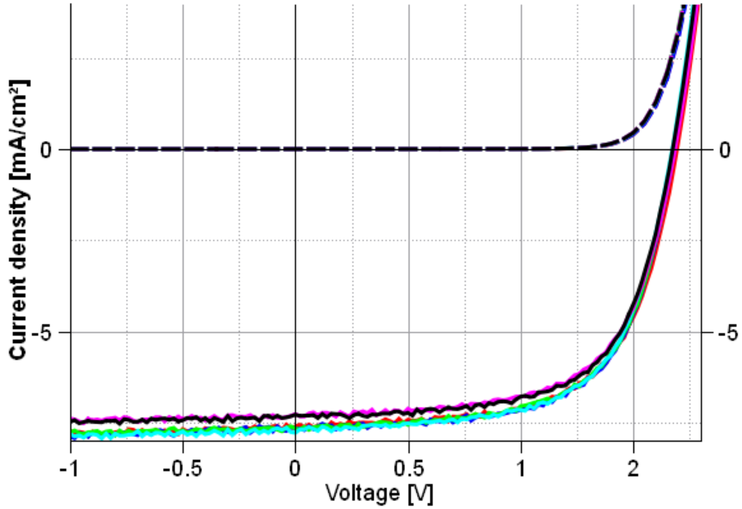
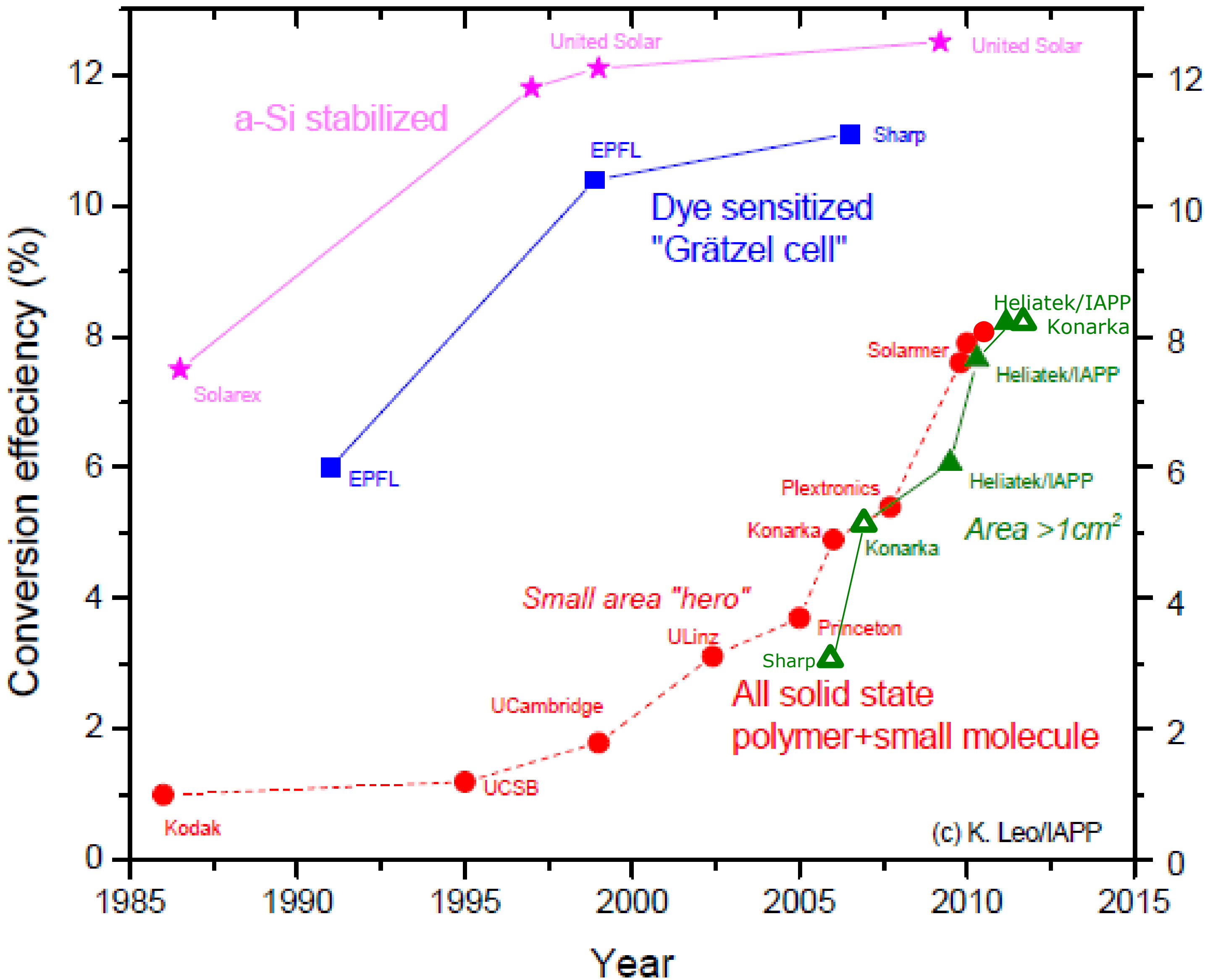
- Results are obtained within a co-operation between Heliatek and IAPP
- The device uses proprietary absorber materials developed and synthesised by Heliatek and C60
- It is based on Heliatek`s p-i-n tandem solar cell technology using p- and n-dopants provided by Novaled AG





Results are highly reproducible

Development of OPV Efficiencies in the Laboratory



Quo Vadis?

- Device lifetime sufficient for first applications
- Little material consumption ($<1 g/m^2$)
- In principle no material bottleneck for organic materials
- Large area fabrication possible

Images: Konarka, COMEDD, Heliatek

Organic Electronics Saxony

R&D

IHM, iapp, Fraunhofer IPMS, Fraunhofer ENAS, Organische Bauelemente, Fraunhofer FEP, AVT, pm TUC, COMEDD

oes Organic Electronics Saxony

Materials modeling → Organic technology → Tools → Products

Industry

novaled, simtec, CREAPHYS, SENSIENT, novaled, Sunic system, 3D MICROMAC, VON ARDENNE, CONTRONIX DER BLICK FÜRS GANZE, PLASTIC LOGIC, heliatek Organic based Photovoltaics, LEDON, WOLFRAM DESIGN

http://www.oes-net.de

Summary

- Many organic semiconductors available
- Little material and energy consumption during production
- High stability for small molecule 6% tandem devices
- Champion lab efficiencies above 8%
- OPV at the step towards products
- Next step: transfer to low cost, large area manufacturing...

Acknowledgements

OLED-Group, SPEX-Group, all technicians

heliatek
Organic based Photovoltaics

University of Ulm Department Organic Chemistry II

Prof. Peter Bäuerle
Dr. Egon Reinold
Roland Fitzner

novaled

BASF The Chemical Company

Fraunhofer IPMS

€:

Bundesministerium für Bildung und Forschung

Organische Bauelemente

INNOPROFILE

UNTERNEHMEN REGION
Die BMBF-Innovationsinitiative Neue Länder

OPEG

Europa fördert Sachsen.
EFRE
Europäischer Fonds für regionale Entwicklung

SAB
Sächsische AufbauBank

Deutsche Forschungsgemeinschaft DFG

Thank you for your attention!