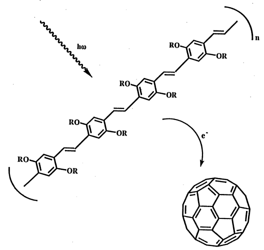
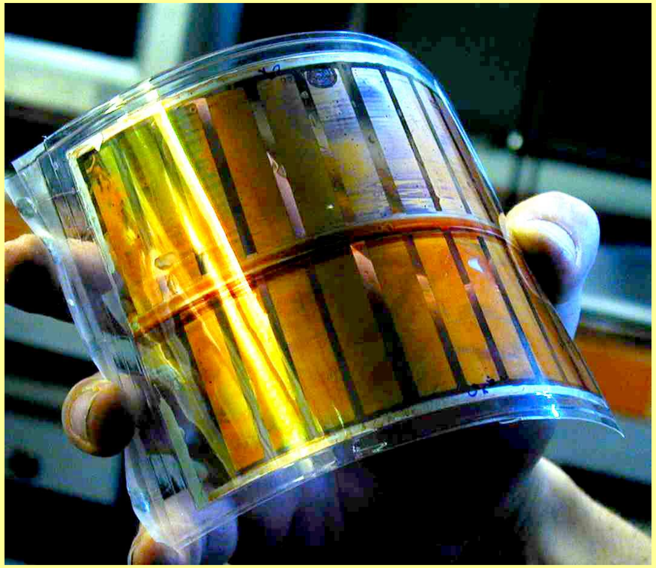
Introduction to



Conjugated Polymer Based Plastic Solar Cells



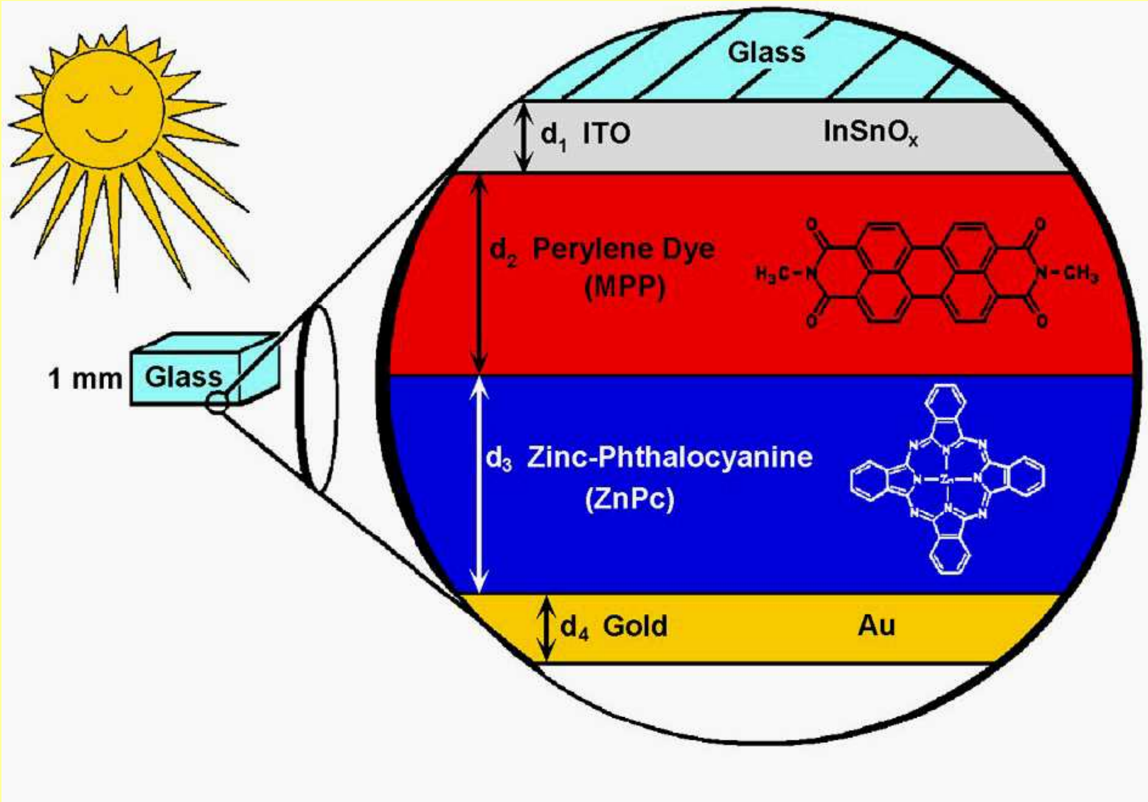
Niyazi Serdar SARICIFTCI
Linz Institute for Organic Solar Cells (LIOS),
Physical Chemistry, Johannes Kepler University Linz
Austria

Scope

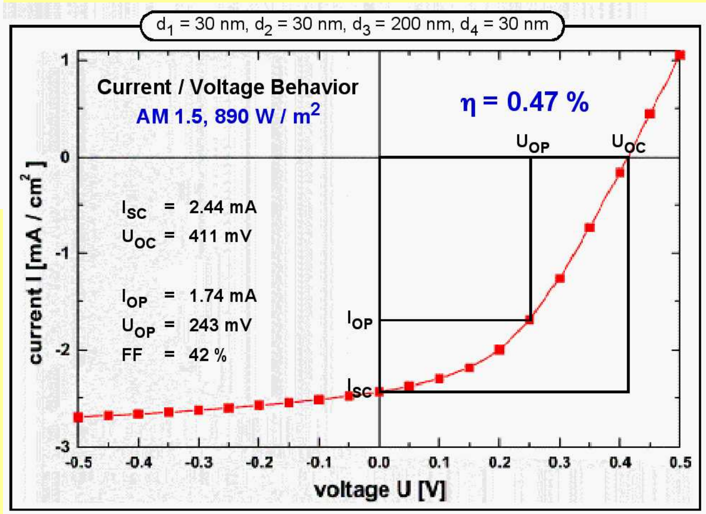
"The electronics of the 20th century is based on semiconductor physics. The electronics of the 21st century will be based on molecular chemistry/physics"

F. L. Carter

Small Molecular Organic Solar Cells



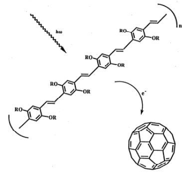
"Tang- Cell"

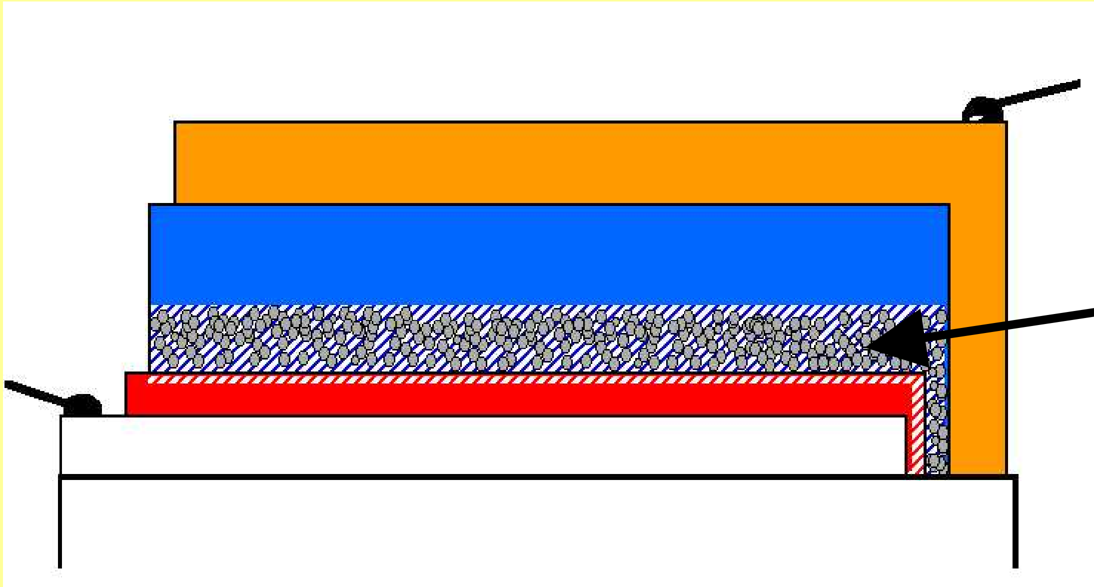


C. W. Tang

Appl.Phys. Lett. 48(86)183

Improving Molecular Cells



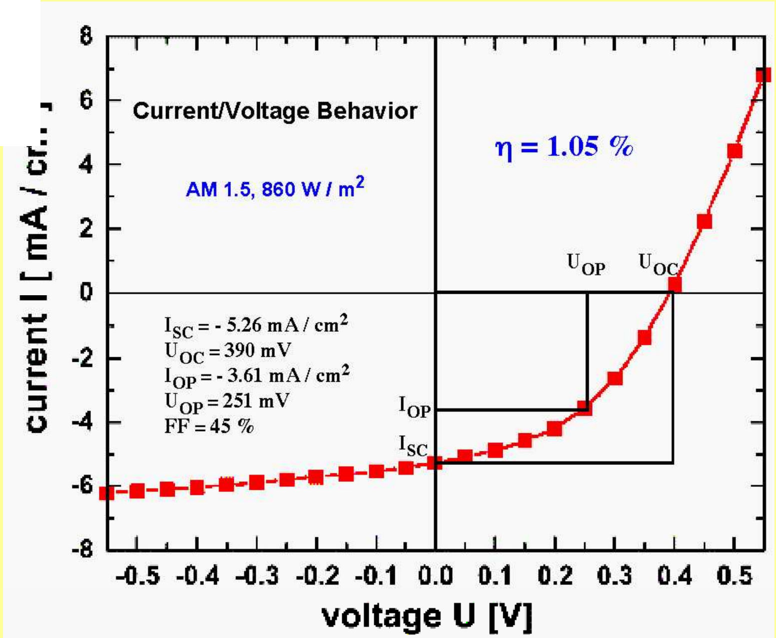


Mixed Interlayer
ZnPc mixed with C60

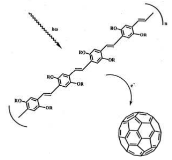
Dieter Meissner, Yasuhiko Shirota et al

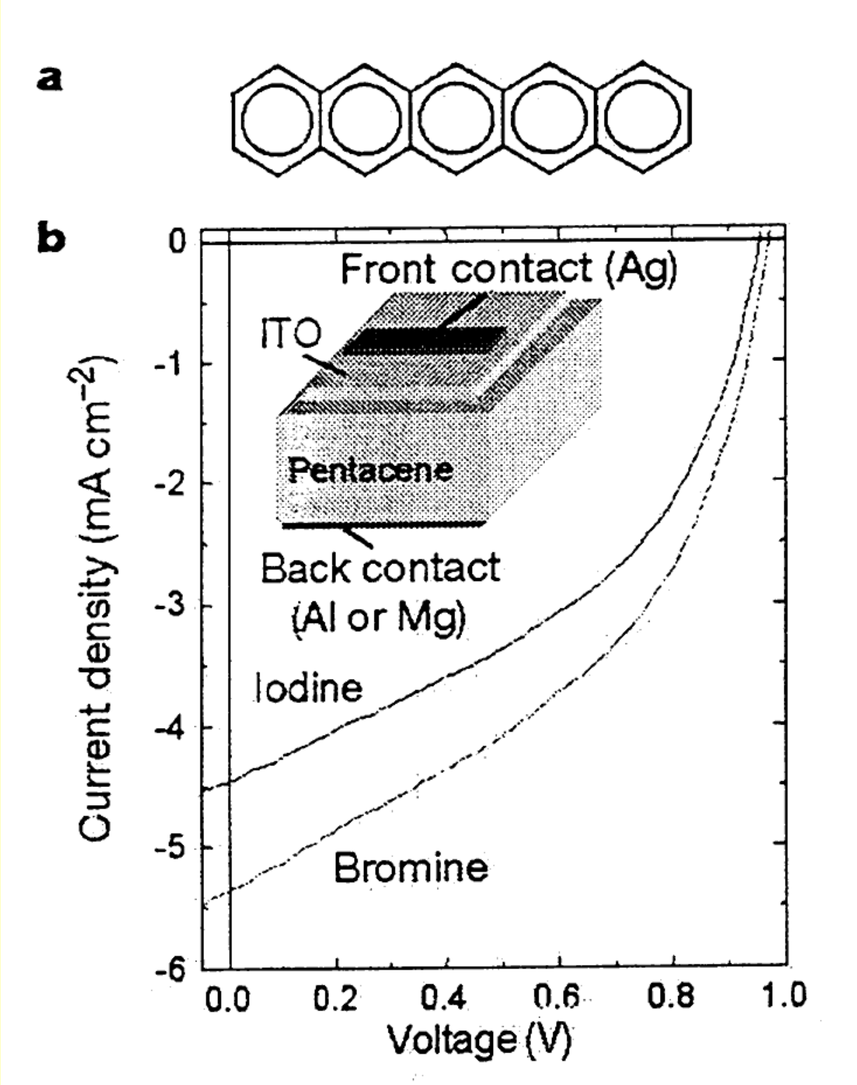
Solar Energy Materials and Solar Cells

***61** (2000) 1 and 87; ibid 63 (2000) 37.*



Organic Single Crystals





Single crystalline Pentacene, about 7 mm^2, halogen doped

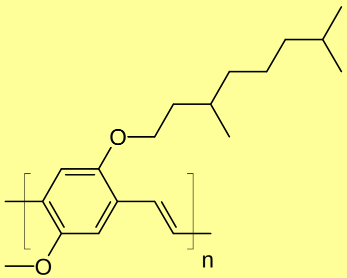
AM 1.5, 100 mW /cm^2, η= 1.9 - 2.4 %

J. H. Schön, Ch. Kloc, E. Bucher, B. Batlogg, *Nature* 403 (2000), 408

Photoinduced Charge Generation

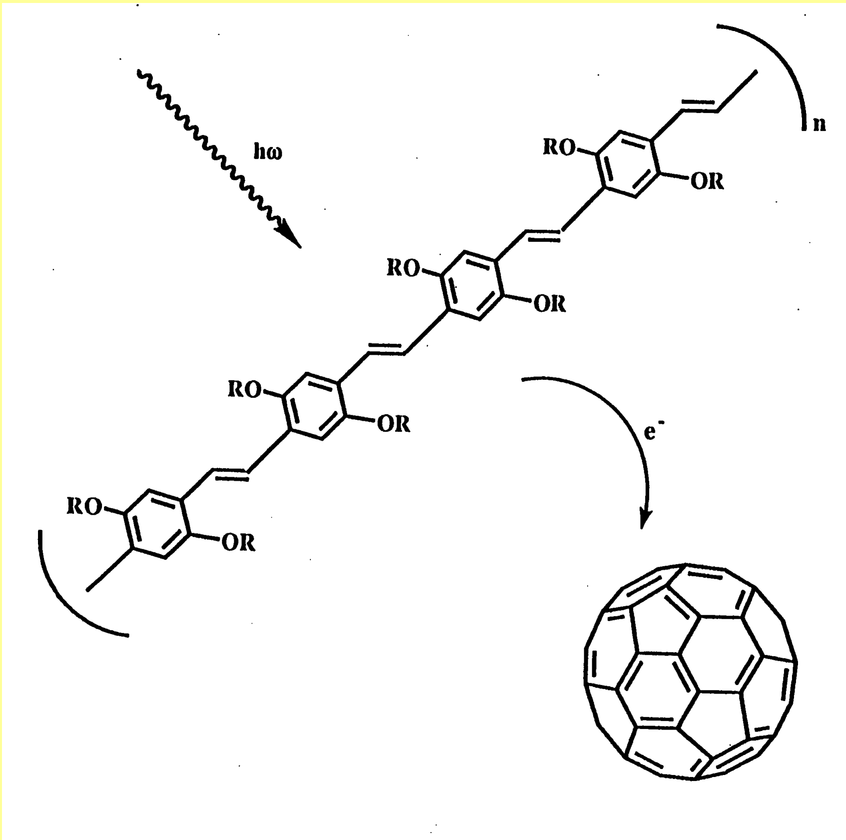
An ultrafast **e⁻ transfer** occurs between Conjugated Polymer / Fullerene composites upon illumination. The transition time is less than 40 fs. The Internal Quantum efficiency of charge generation is therefore ~100%.

DONOR

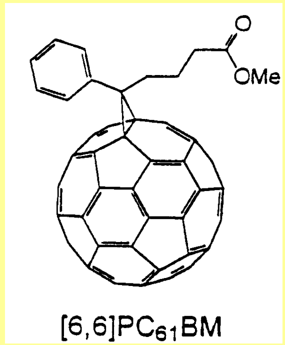


MDMO PPV

3,7 - dimethyloctyloxy methyloxy PPV



ACCEPTOR

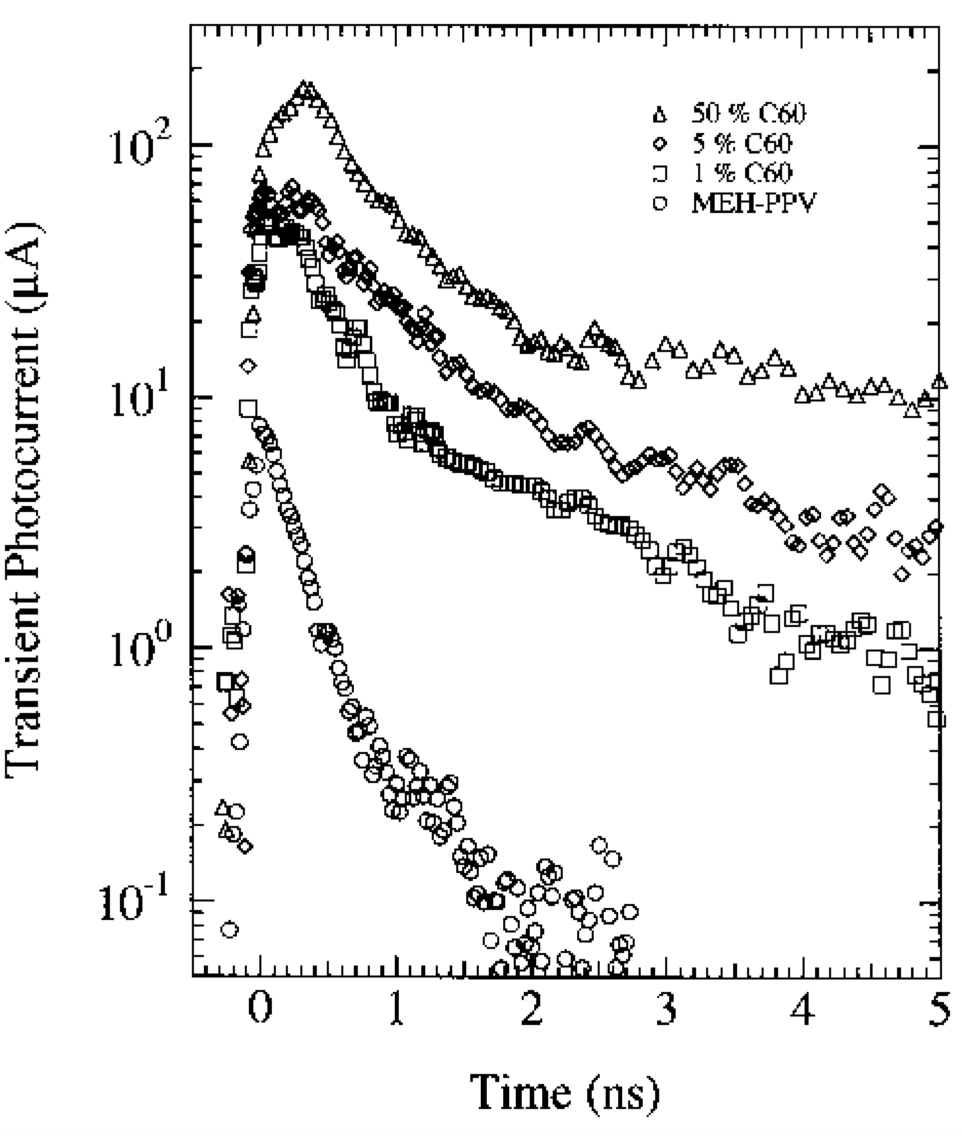


PCBM

1-(3-methoxycarbonyl) propyl-1-phenyl [6,6]C_{61}

N. S. Sariciftci *et al.*, *Science* **258**, 1474 (1992)

Transient Photoconductivity

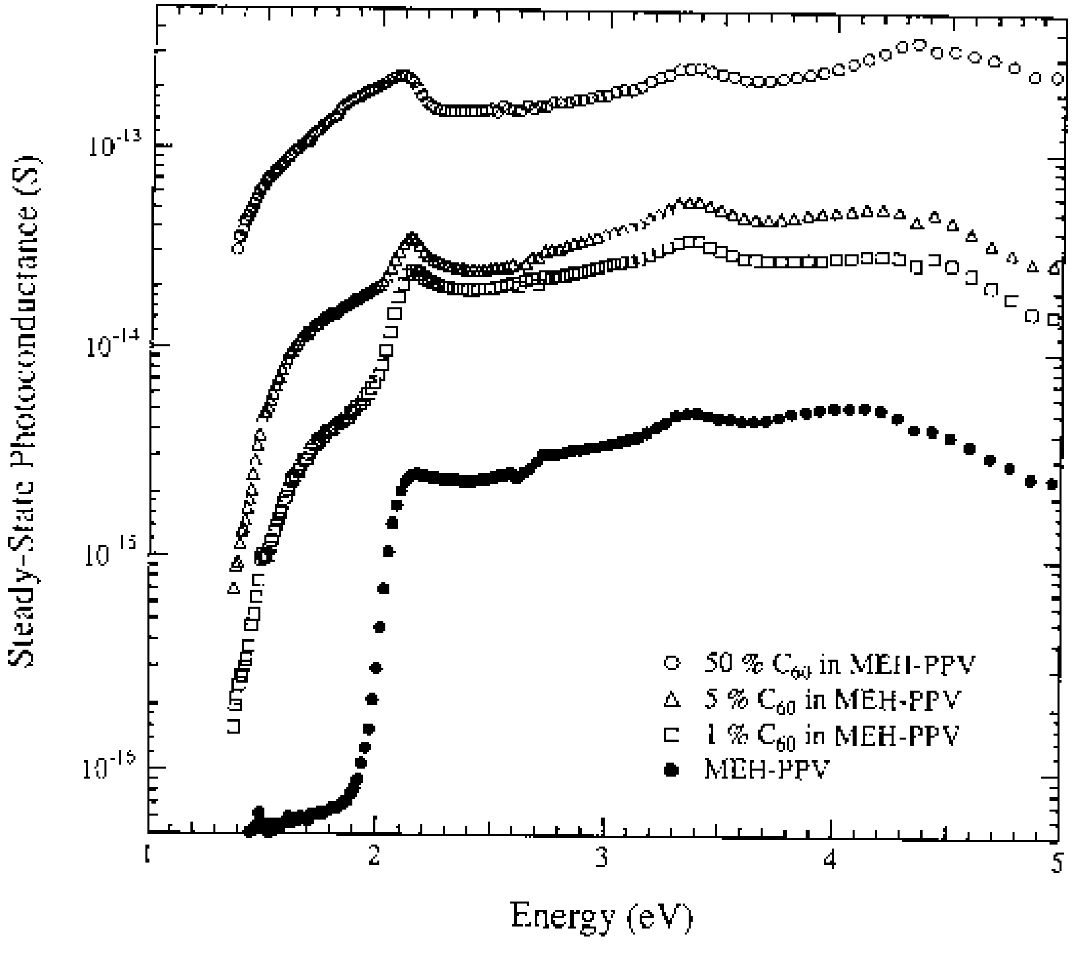


Peak Photocurrent as well as the lifetime of the charge carriers are enhanced upon increasing the C_{60} content in the composite.

Changhee Lee *et al.*,
Phys. Rev. **B 48**, 15425 (1993)

Enhanced Photoconductivity

Steady state photoconductivity of conjugated polymer is enhanced by several orders of magnitude upon adding C60. Changhee Lee *et al.*, *Phys. Rev*. **B 48**, 15425 (1993)

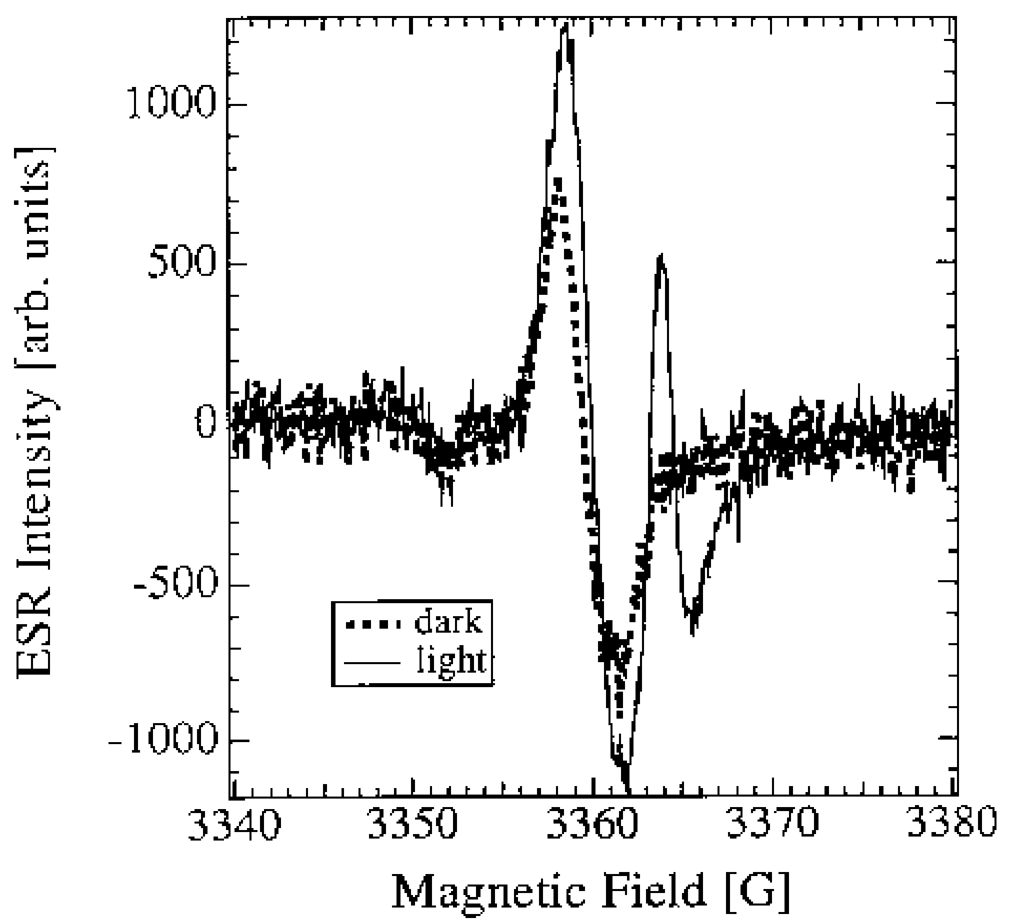


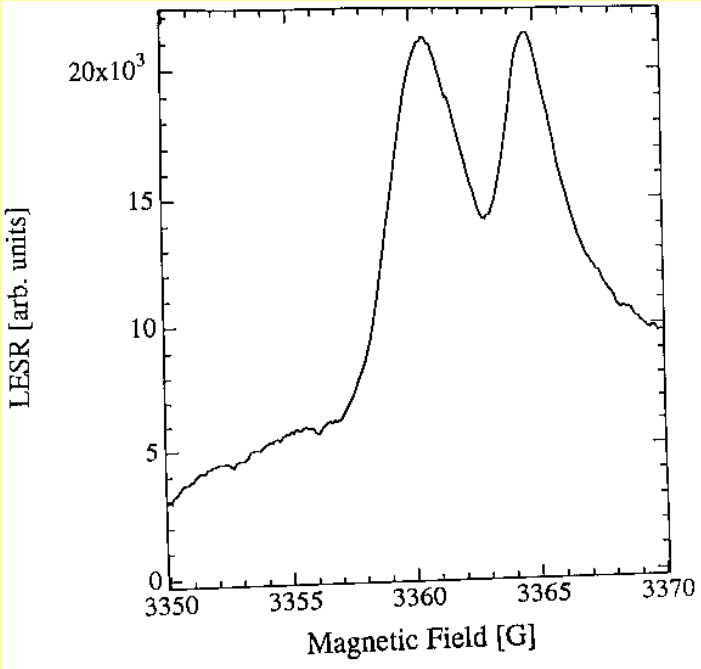
Light Induced Electron Spin Resonance

LESR of Poly(3-octylthiophene) + C60

(1:1 weight %), Ar+ Laser 488nm 100mW/cm2, 80 K

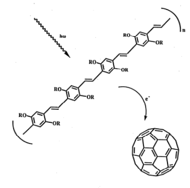
N. S. Sariciftci, *et al., Int. J. Mod. Phys.* **B8**, 237 (1994)

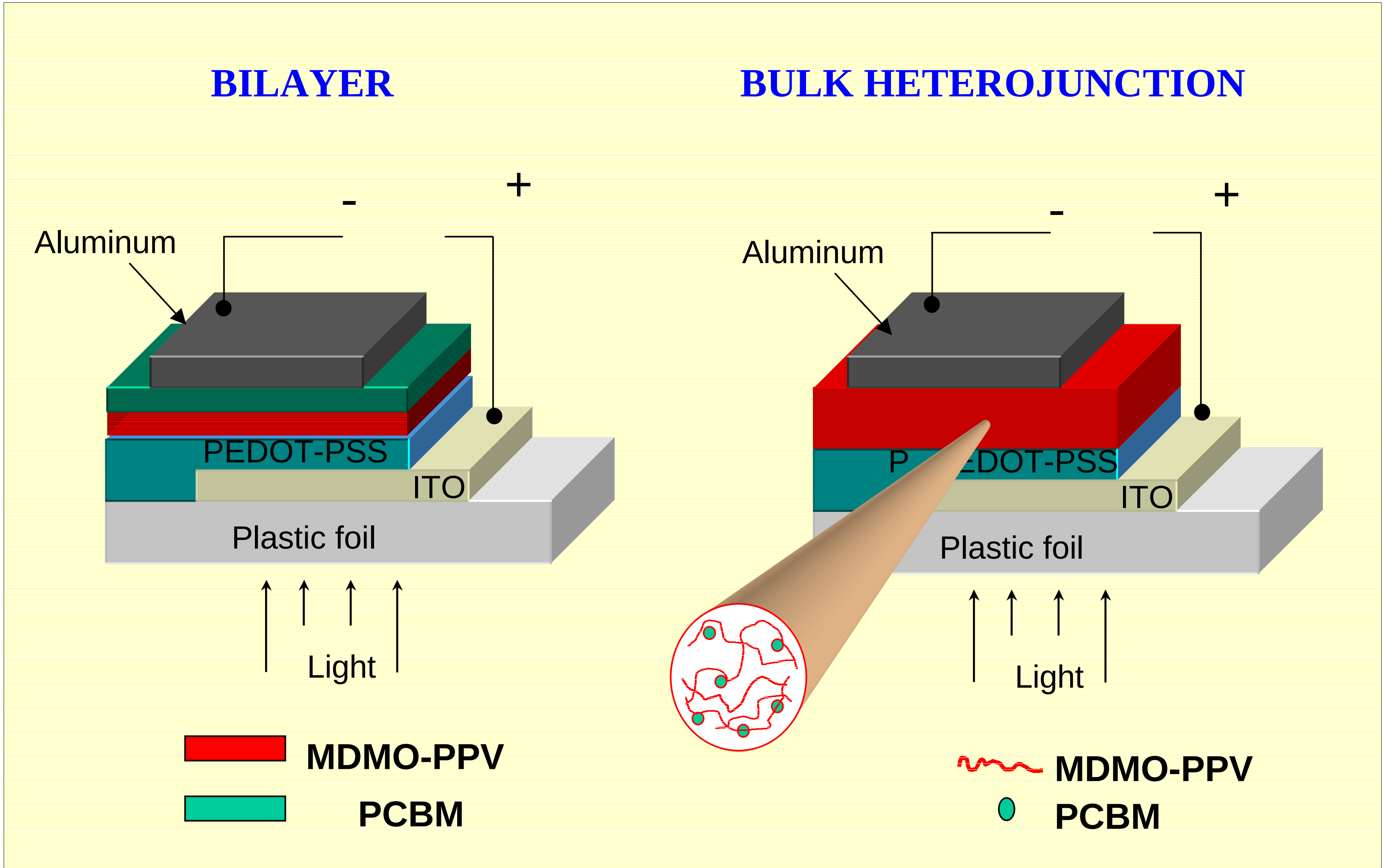




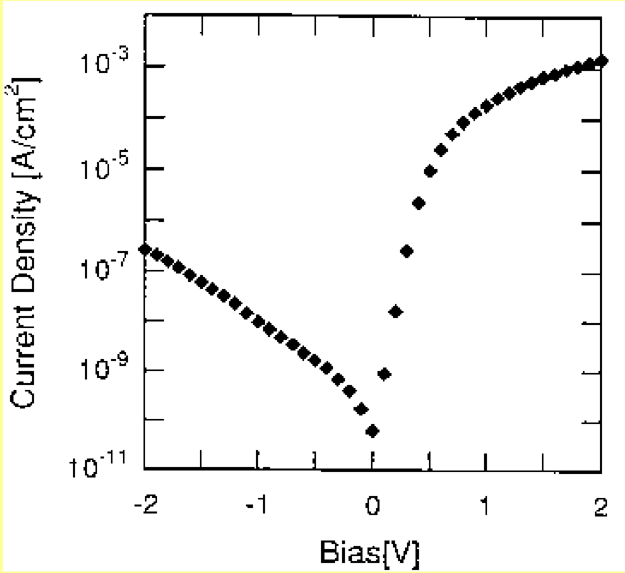
Integrated LESR Intensities

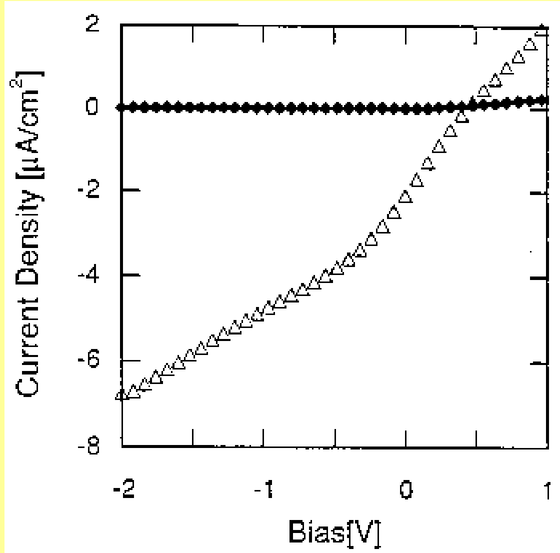
Device Geometries





Bilayer Heterojunction Devices

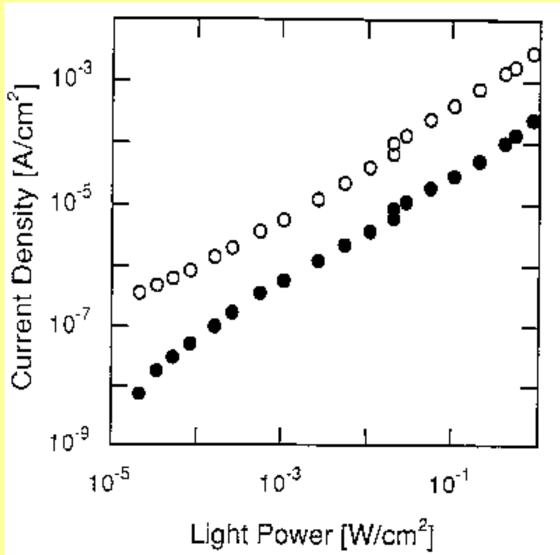




- Rectification ratio in the dark 10^4

- Short circuit current linear up to $1 W/cm^2$

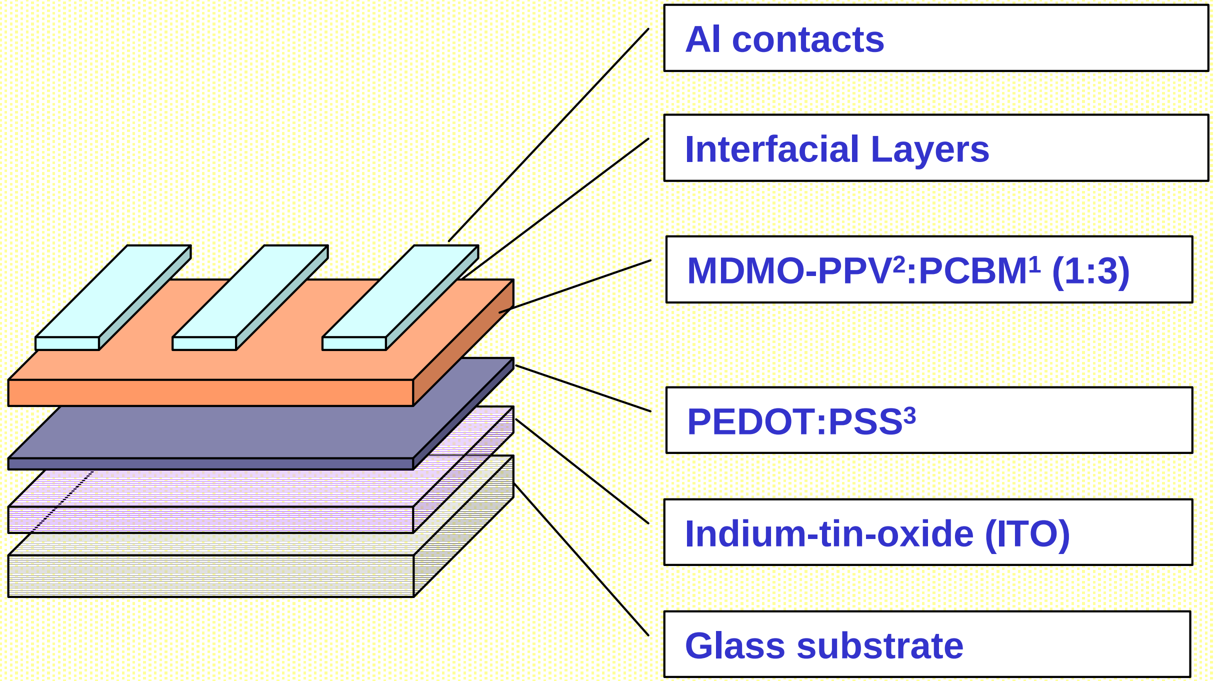
- Efficiency under monochromatic light $\approx 10^{-1}$ %



N. S. Sariciftci *et al.*, *Appl. Phys. Lett*. **62**, 585 (1993)

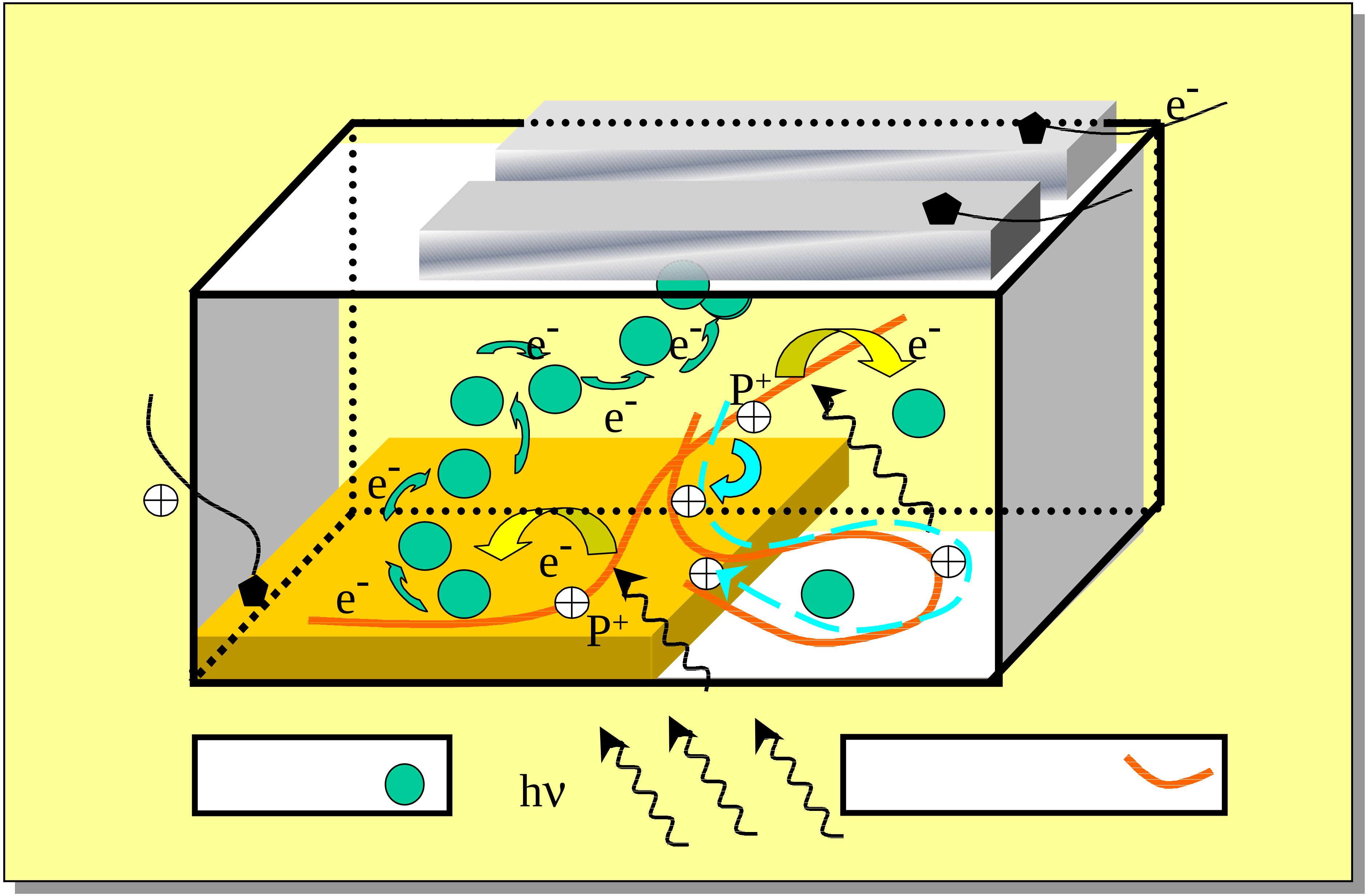
Plastic Solar Cell Device Geometry

Device structure



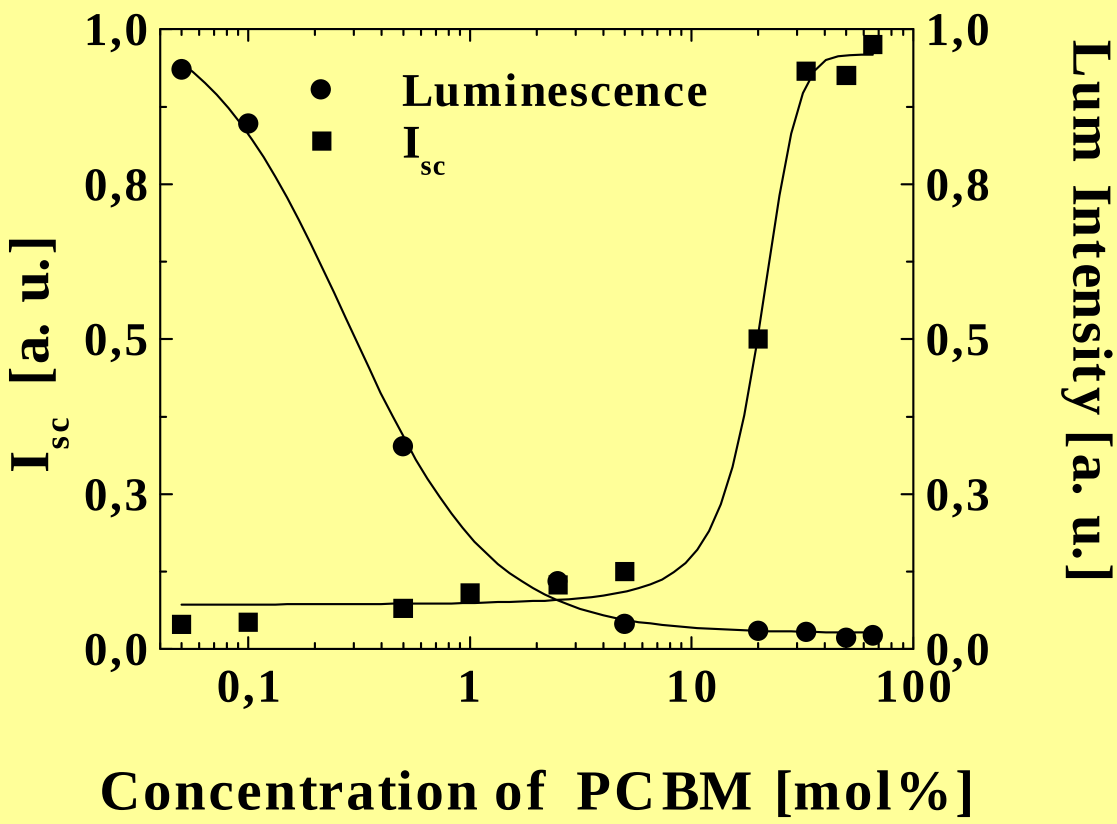
[1] [6,6] - **p**henyl-**C**$_{61}$-**b**utyl acid-**m**ethylester
[2] 3,7 - **d**imethyl-**o**ctoxy-**m**ethyloxy-**p**oly(**p**henylene-**v**inylene)
[3] **p**oly-**e**thylene-**d**i**o**xy**t**hiophene doped with polystyrene sulphonic acid

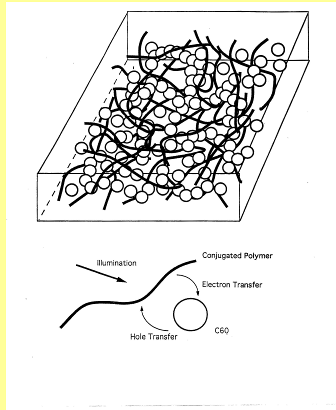
Bulk Heterojunctions

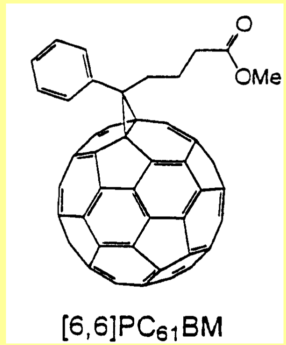


3-D Percolation

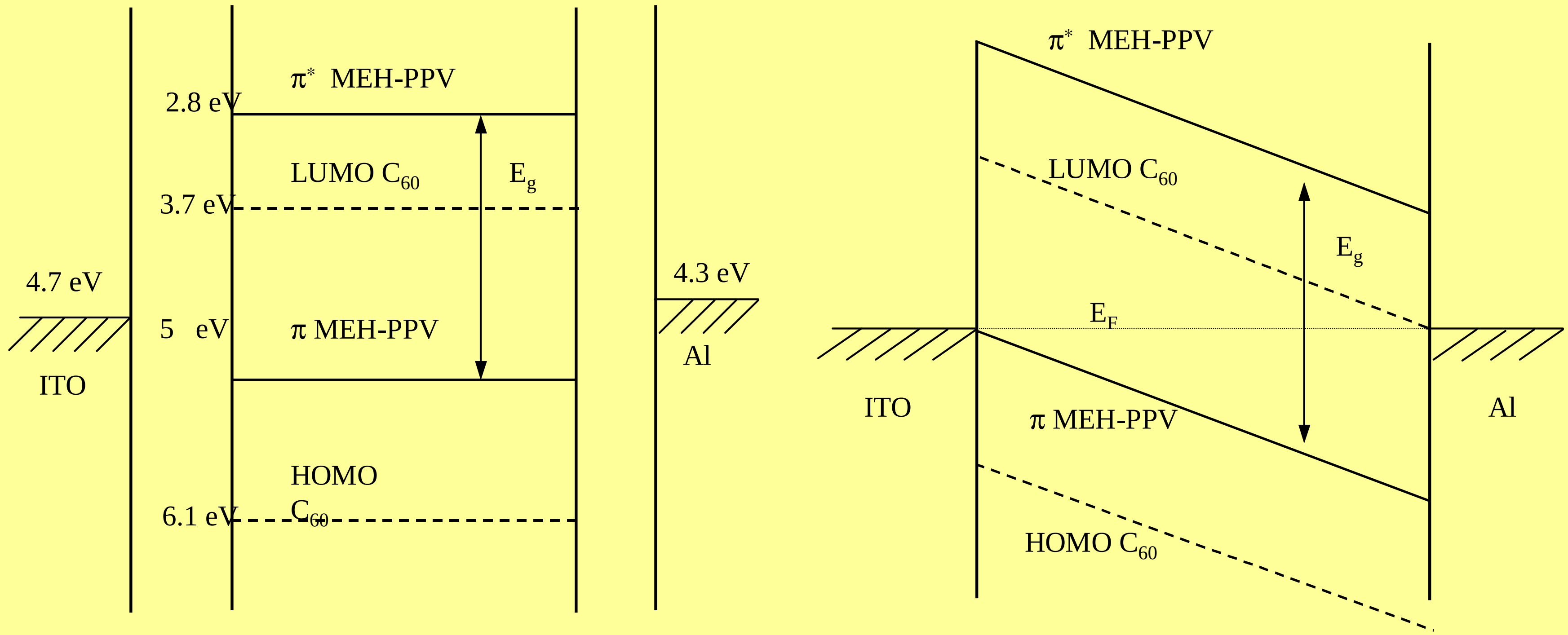
Strong luminescence quenching occurs at appr. 1 mol% of PCBM in alkoxy-PPV. Photocurrent onset at appr. 17 mol% PCBM, in accordance with percolation theory.



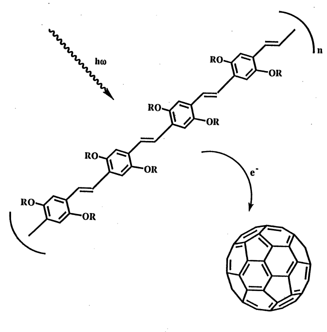


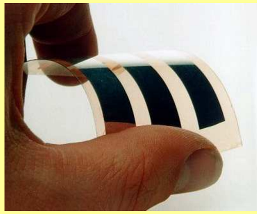


Schematic Band Diagram



Metal-Insulator-Metal (MIM) picture
implies the field of assymetric metal electrodes
(All interface effects neglected!)



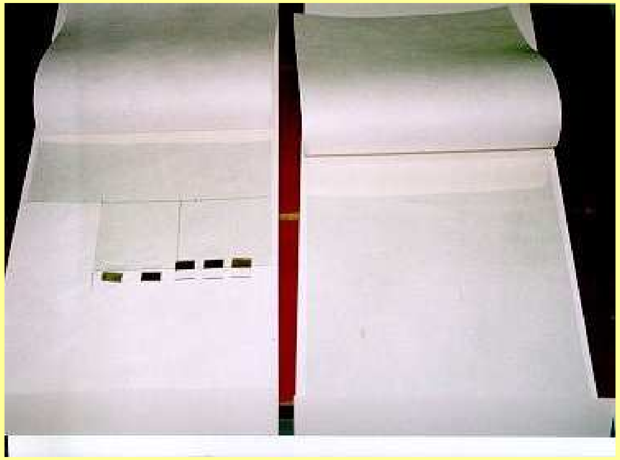


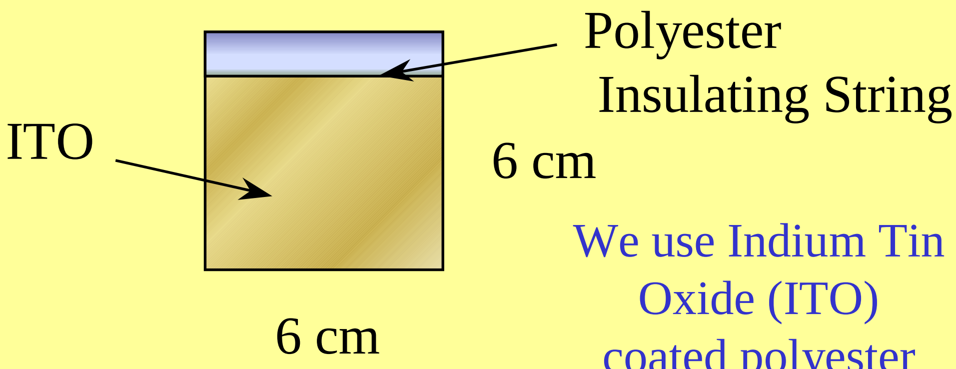
Plastic Solar Cells

Production Scheme

Plastic Solar Cells - SUBSTRATES

Substrates are available in any scale. They are flexible and transparent





We use Indium Tin Oxide (ITO) coated polyester foils or glasses.
R ~ 10-100 Ω/cm2

Substrates are cut in the desired size and cleaned in common organic solvents in a ultrasonic bath.

WHY Plastic Solar Cells - MATERIALS

The electroactive compounds can be already bought from companies. Prices are appr. 300 - 500 US$/gram for the polymers, fullerenes are appr. 20 - 50 US$/gram.

Polymers and Fullerenes are dissolved in common organic solvents. 1 gram yields appr.~ 200 ml solution

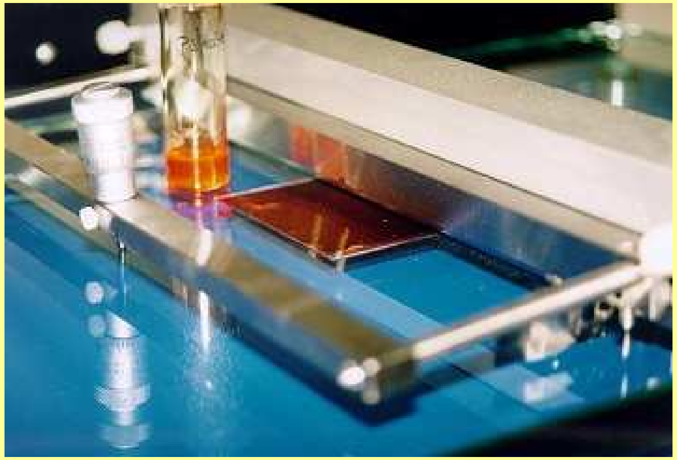
Different colors of the solutions correspond to different spectral sensitivities - Band Gap Tuning

Plastic Solar Cells - FILM PREPARATION

Spin Casting is a easy coating technique for small areas. Material loss is very high.

Doctor Blade Technique was developed for large area coating

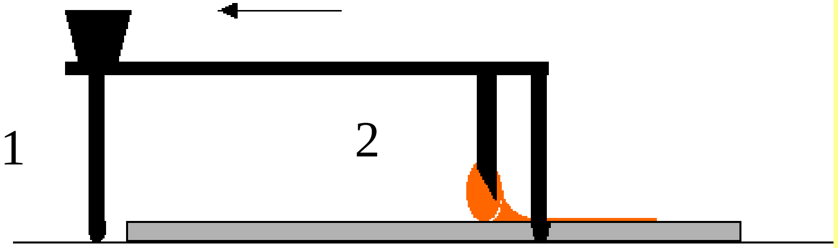
Doctor Blade Technique has no material loss



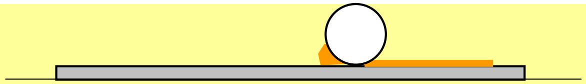
FILM THICKNESS IS ~ 100 nm

Production - Large Area

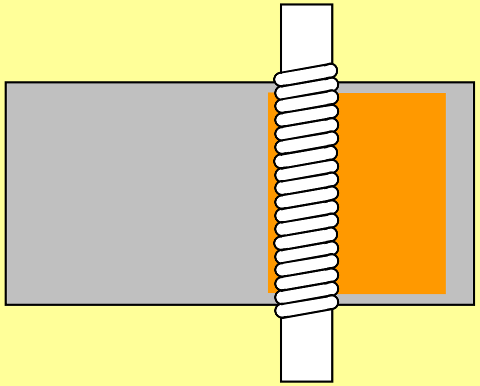
Large Area Thin Film Production using Doctor/Wire Blading



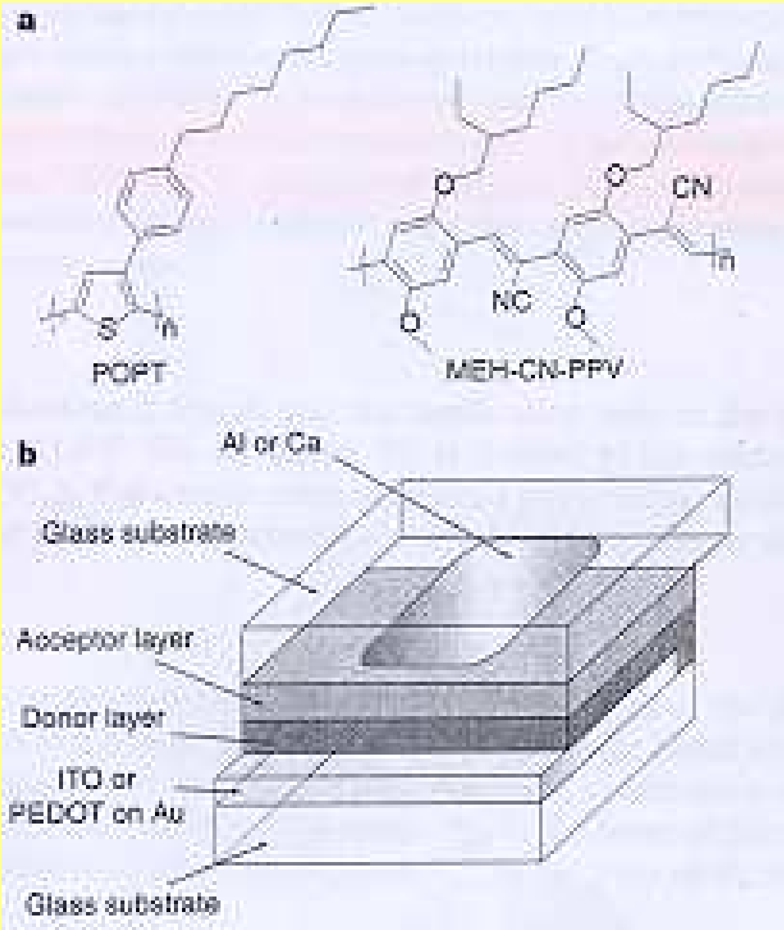
a)



b)



Laminated Polymeric Solar Cells



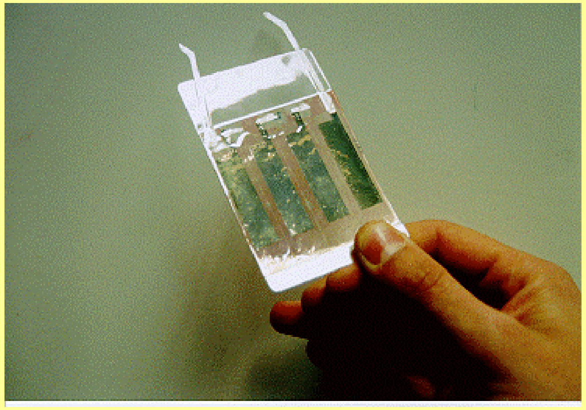
•Au/PEDOT/POPT:MEH-CN-PPV (19:1) laminated at 200 C onto the
•MEH-CN-PPV:POPT (19:1) /Ca

Power conversion efficiency around 4.8 % at 480nm irradiation.
Calculated AM1.5 efficiency around 1.9 %

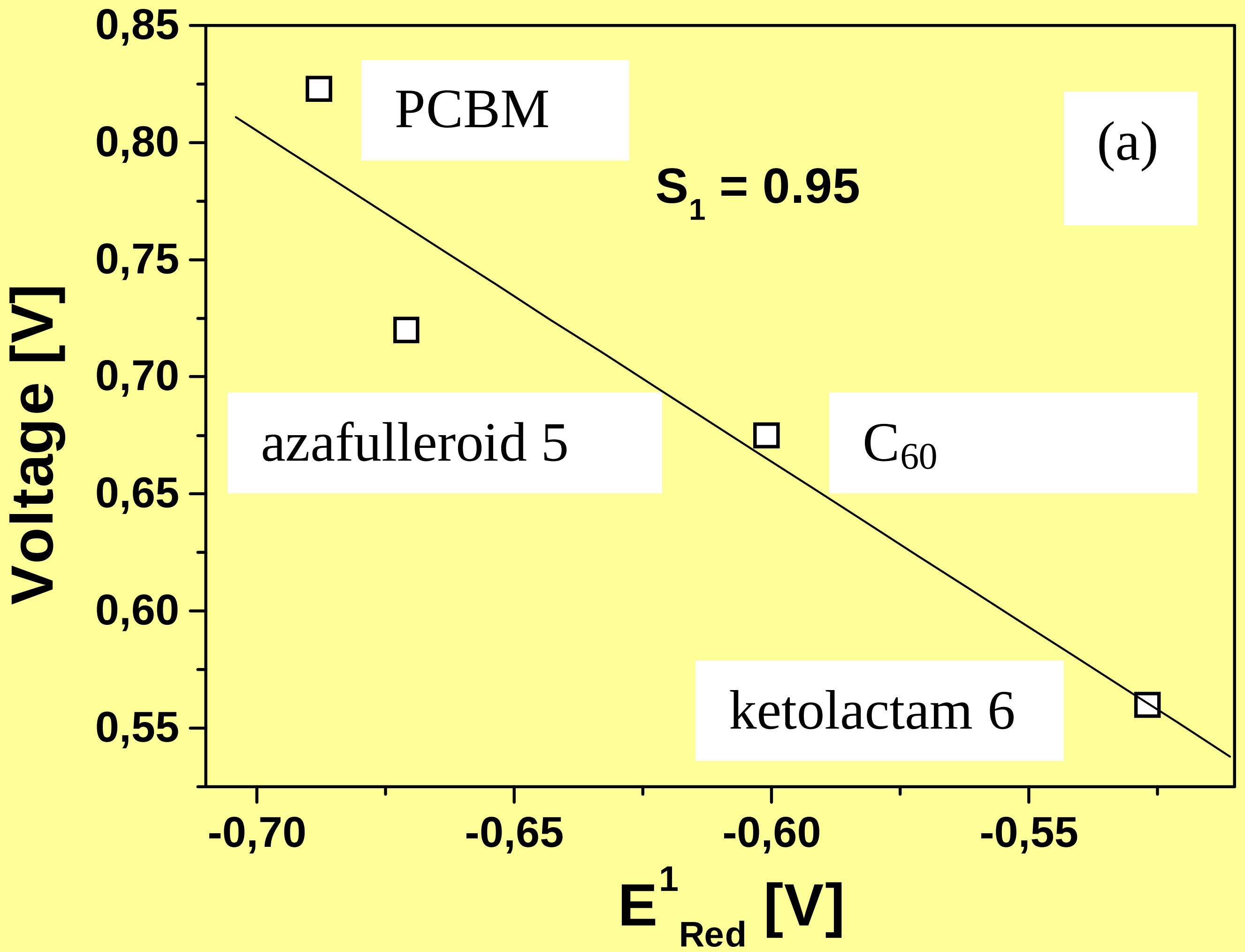
Large scale large area fabrication potential!

M. Granström, K. Petritsch, A. Arias, A. Lux, M. Andersson and R. H. Friend, *Nature* 395, 257 (1998).

WHY Plastic Solar Cells - SUMMARY

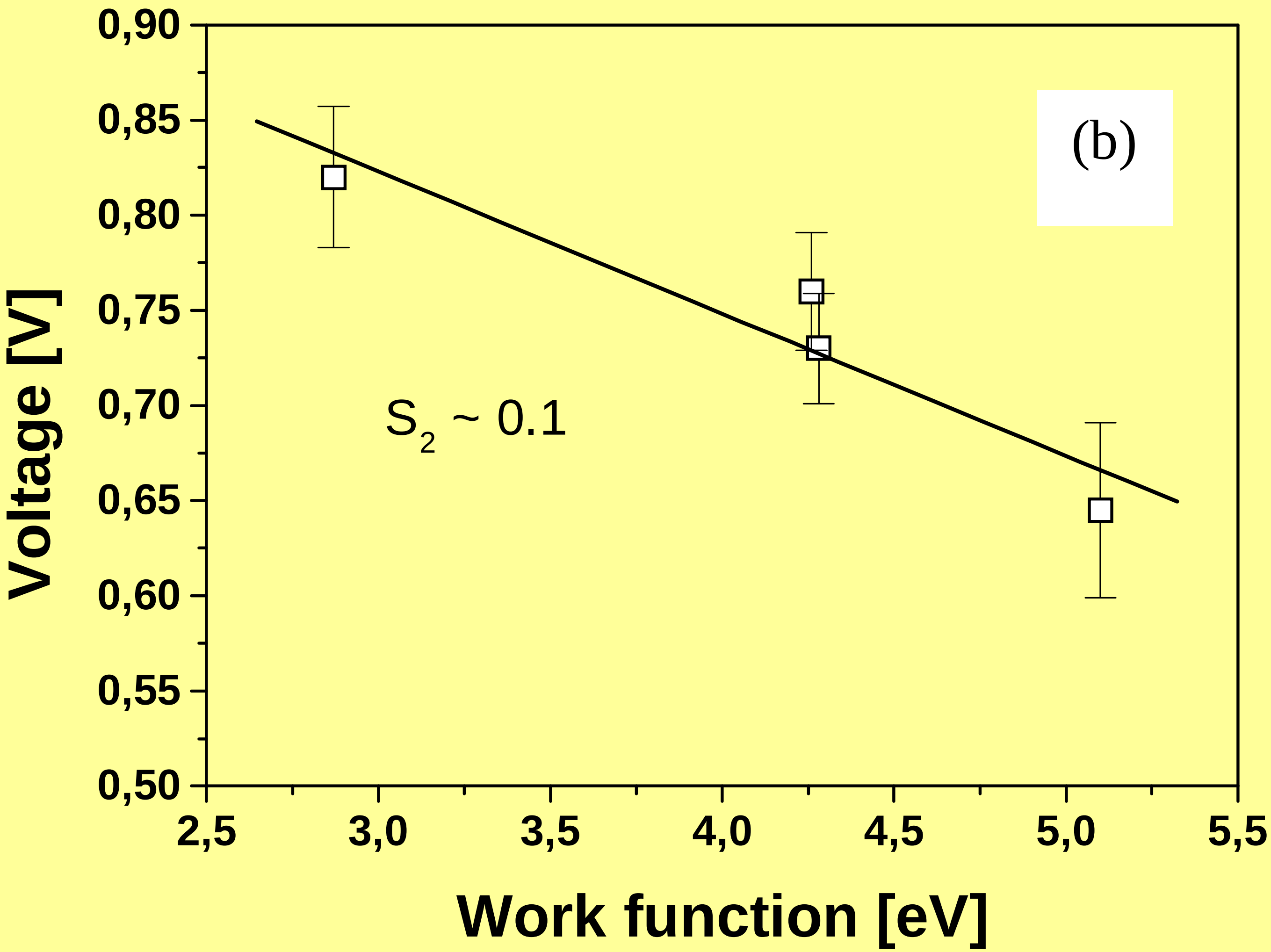


Voc vs LUMO of Acceptor



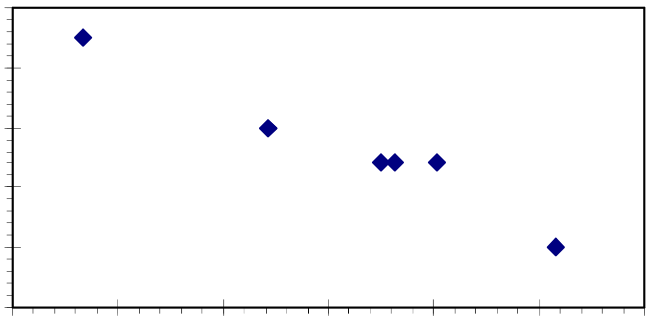
Brabec et al., Advanced Functional Materials (2001), ***11****, No.5, 374-380*

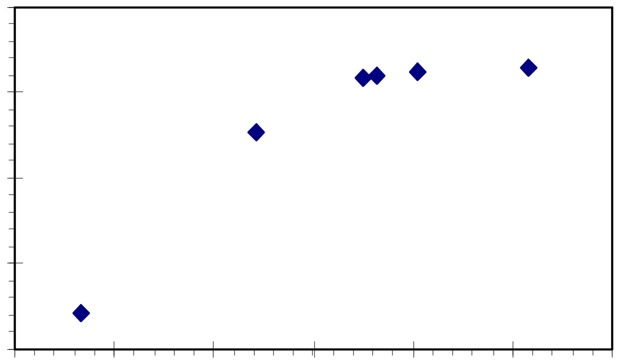
Voc vs Metal Work Function

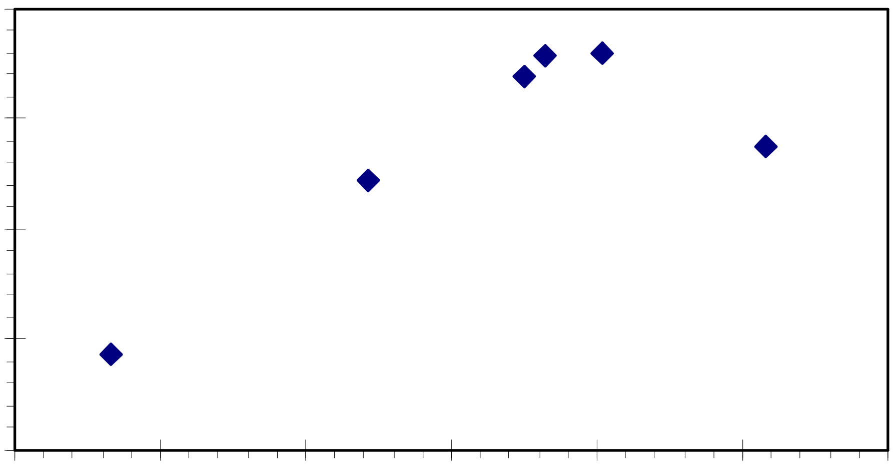


Brabec et al., Advanced Functional Materials (2001), ***11****, No.5, 374-380***.**

Anomalous Temperature Dependence



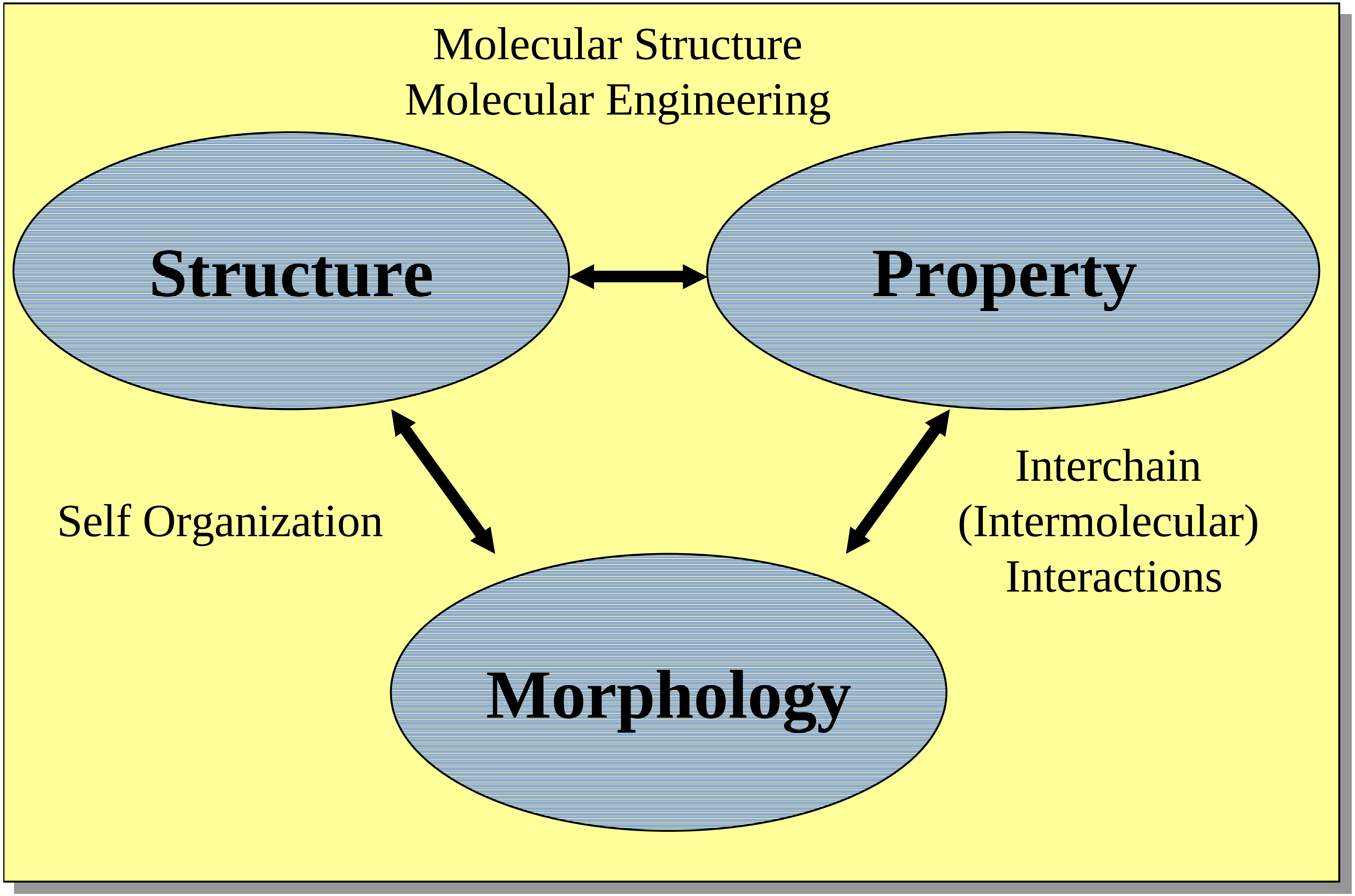




Eugene Katz,
David Faiman, et al
Journal of Applied Physics,
Vol 90, (2001), 5343-5350

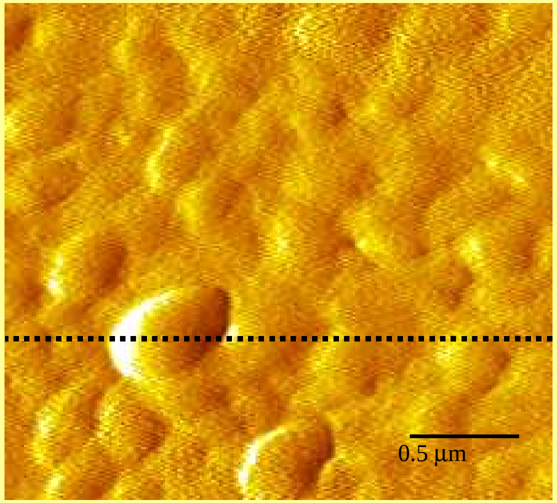
Outdoor Experiment in
Negev Desert Israel

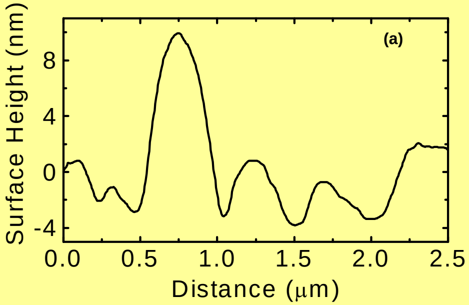
Property Optimization



Morphology Effects

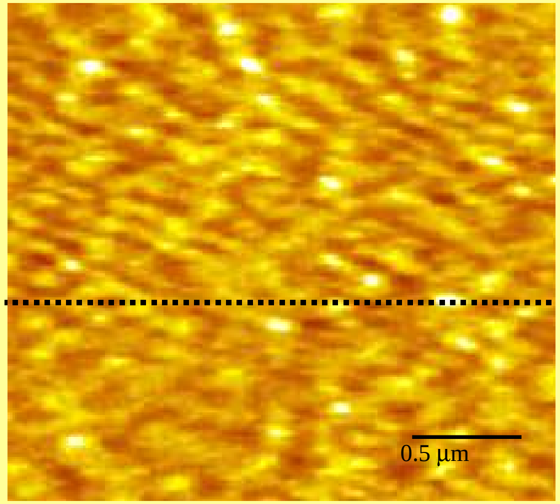
a

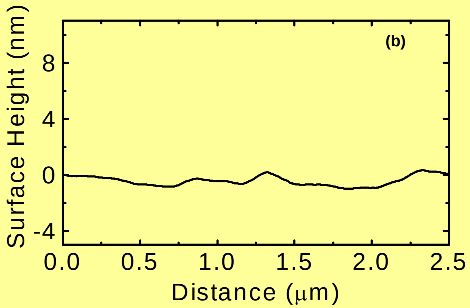




Toluene cast film

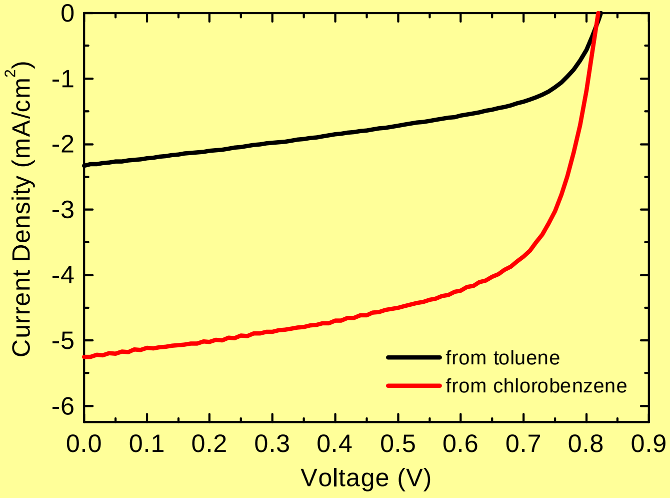
b

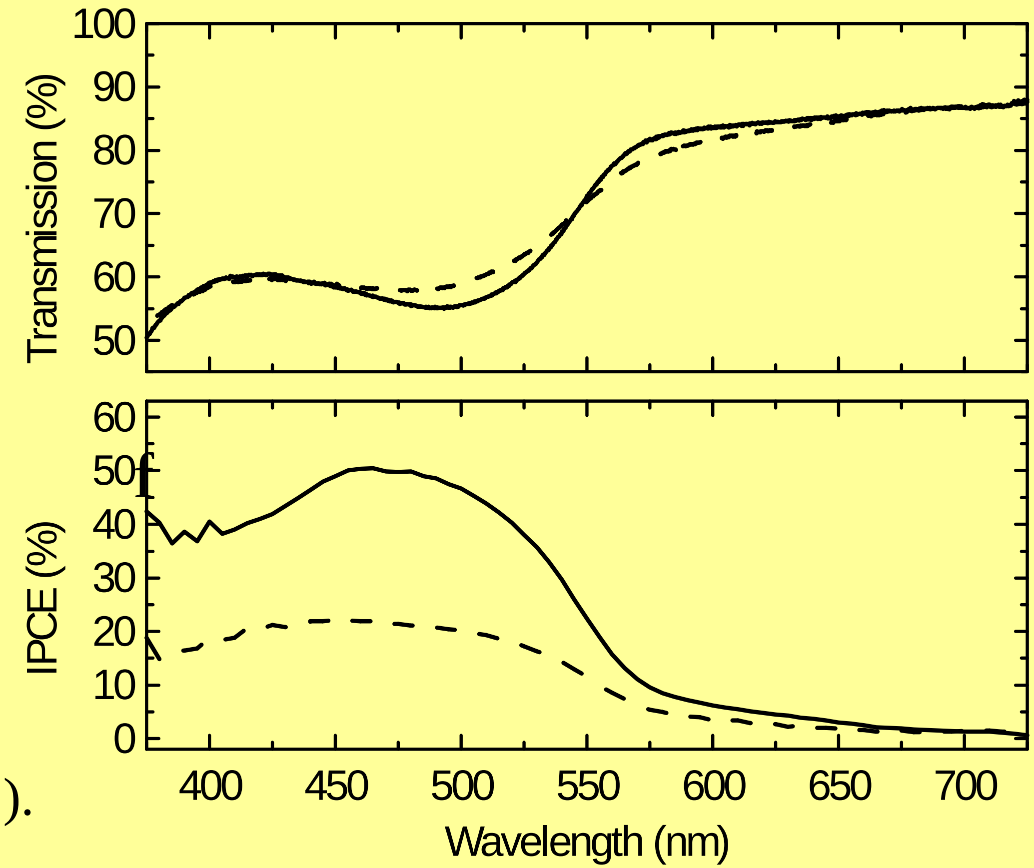




Cholorobenzene cast film

Morphology Effects

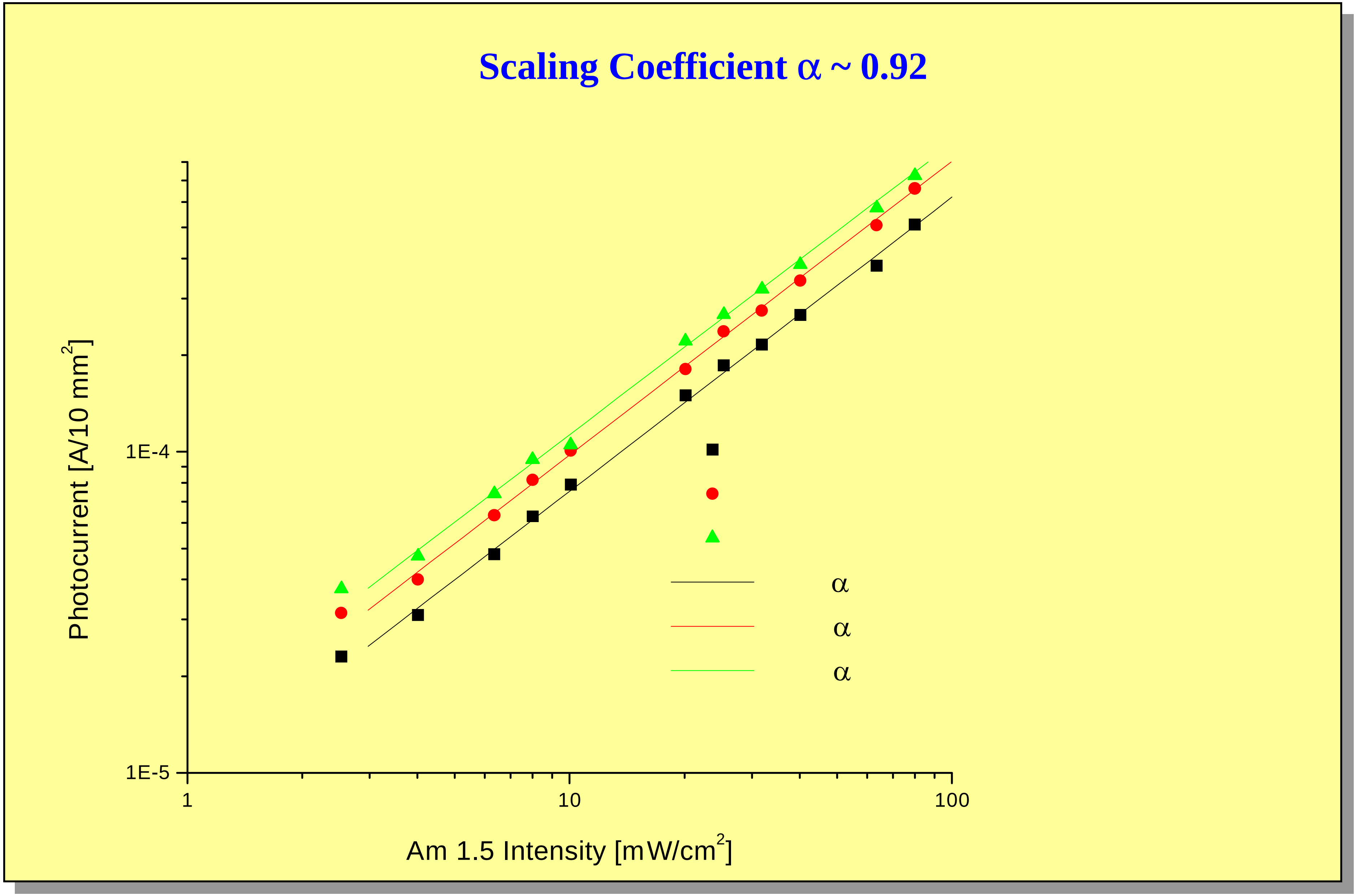




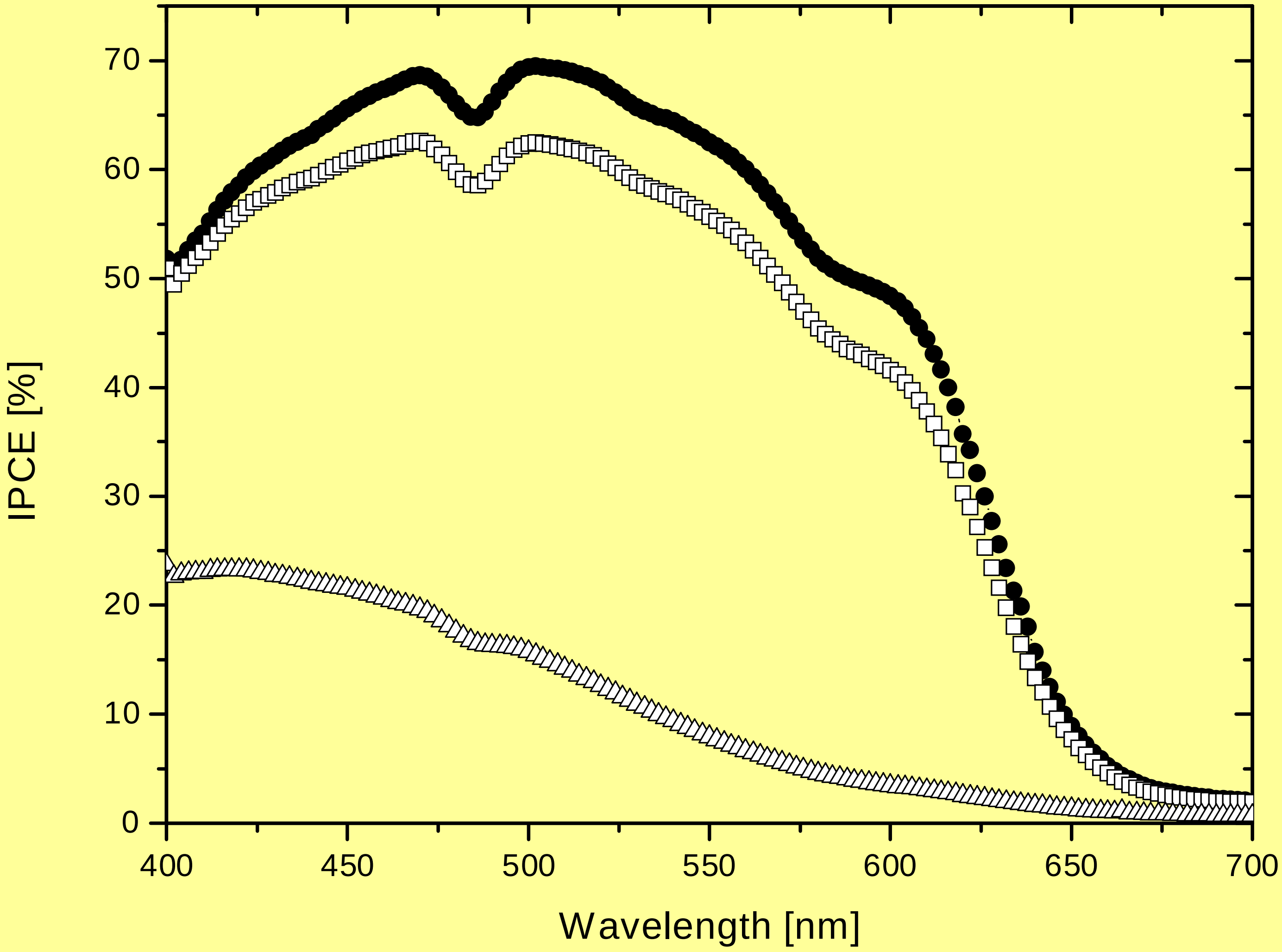
S. E. Shaheen, et al.
Appl Phys. Lett, **78**, 841 (2001).

The efficiency is strongly enhanced by
using cholorobenzene in MDMO-PPV/PCBM mixture

Intensity Dependence of Photocurrent



Post Production Treatment



Rittberger et al, 2002, Patent filed by QSEL

Optimization

Possible Improvements

$$\eta_{eff} = I_{sc} * V_{oc} * FF / I_{inc}$$

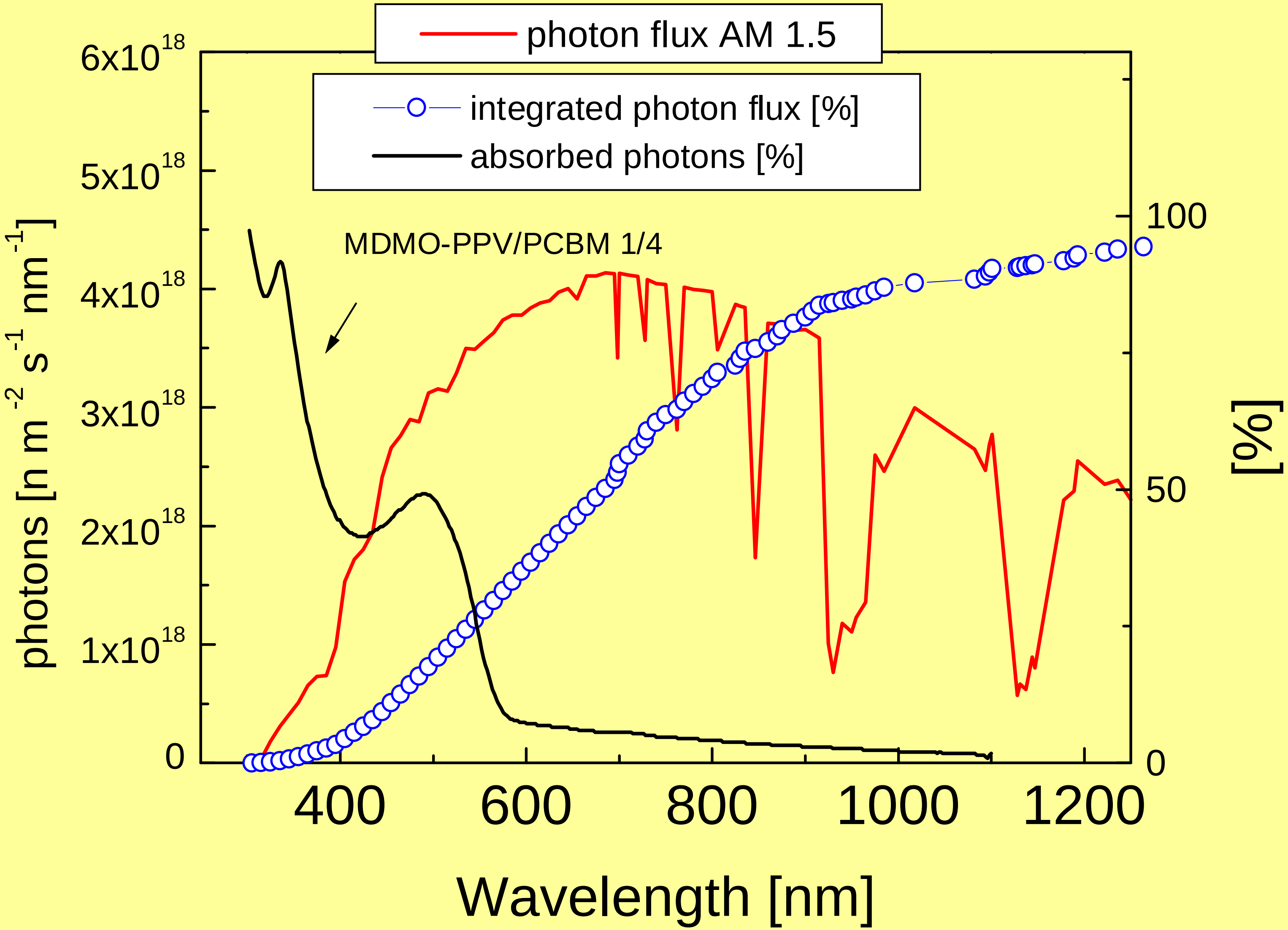
I_{sc} Tuning of the Transport Properties - Mobility
Optimization of Cell Geometry in Dependence of the Cell Thickness

V_{oc} Tuning of the Electronic Levels of the Donor Acceptor System
V_{oc} of ~2 V observed in polymeric Donor - Acceptor systems

FF Tuning of the Contacts and Morphology
Lowering of Serial Resistivities - Interpenetrating Network?

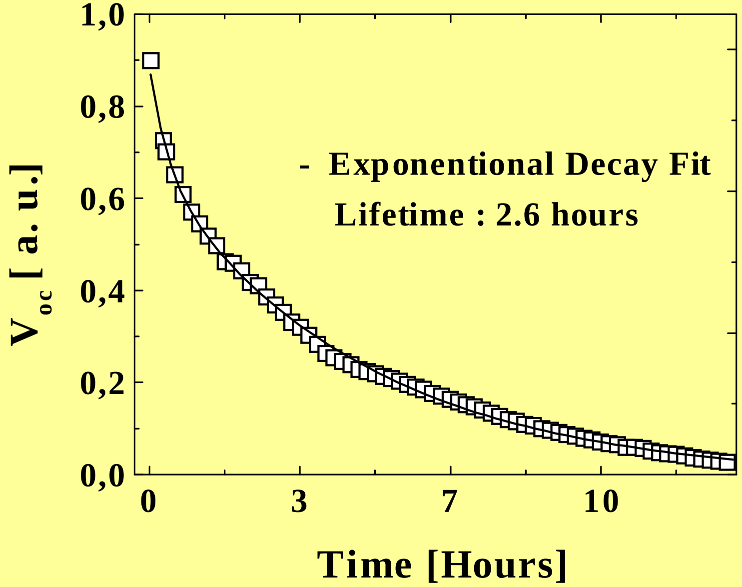
I_{inc} Tuning of the Spectral Absorbance
Sensitization to the Optical Bandgap

Spectral Mismatch to Solar Emission

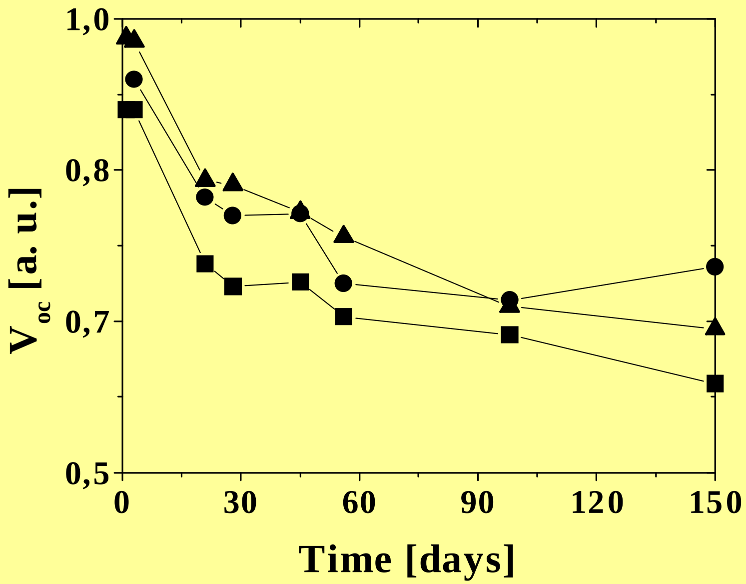


OUTLOOK - Stability

UNPROTECTED

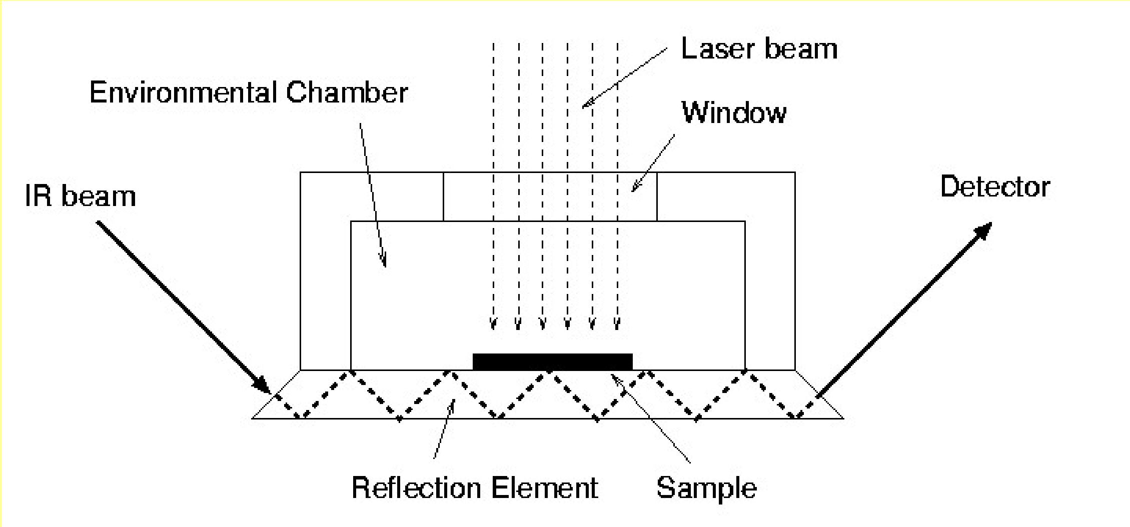


PROTECTED

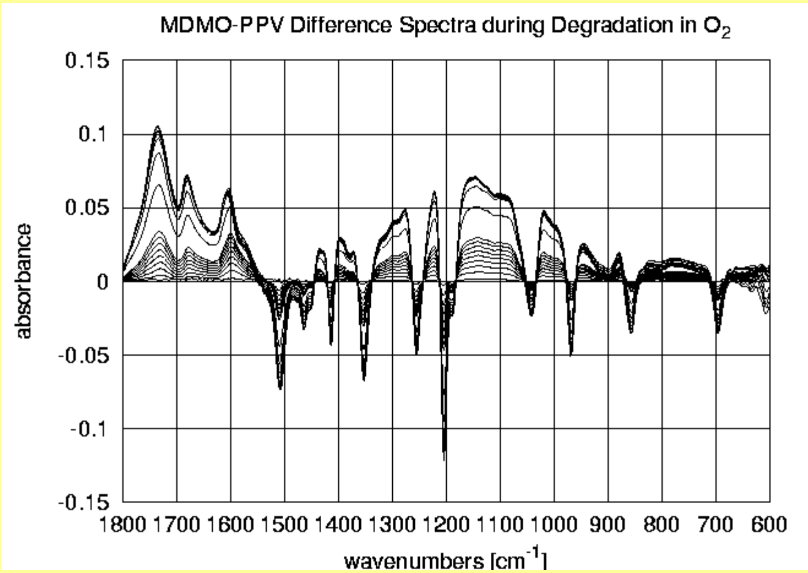


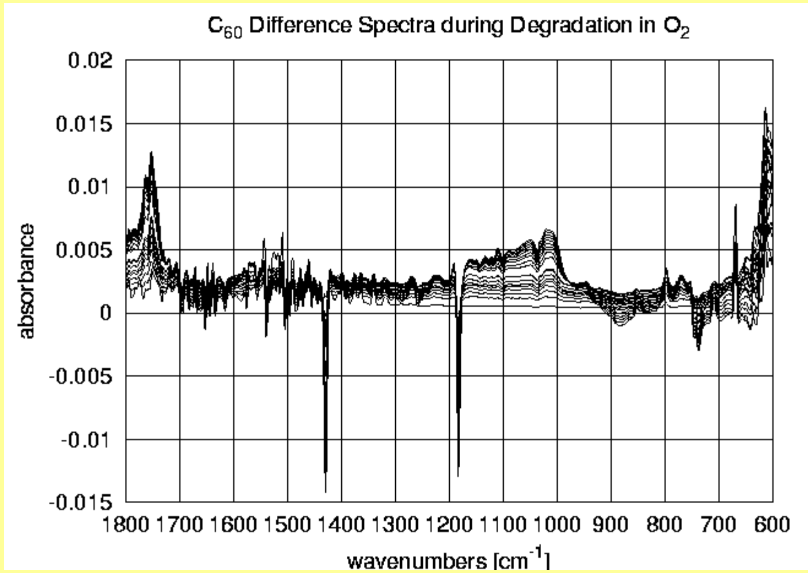
Stability

IN SITU FTIR



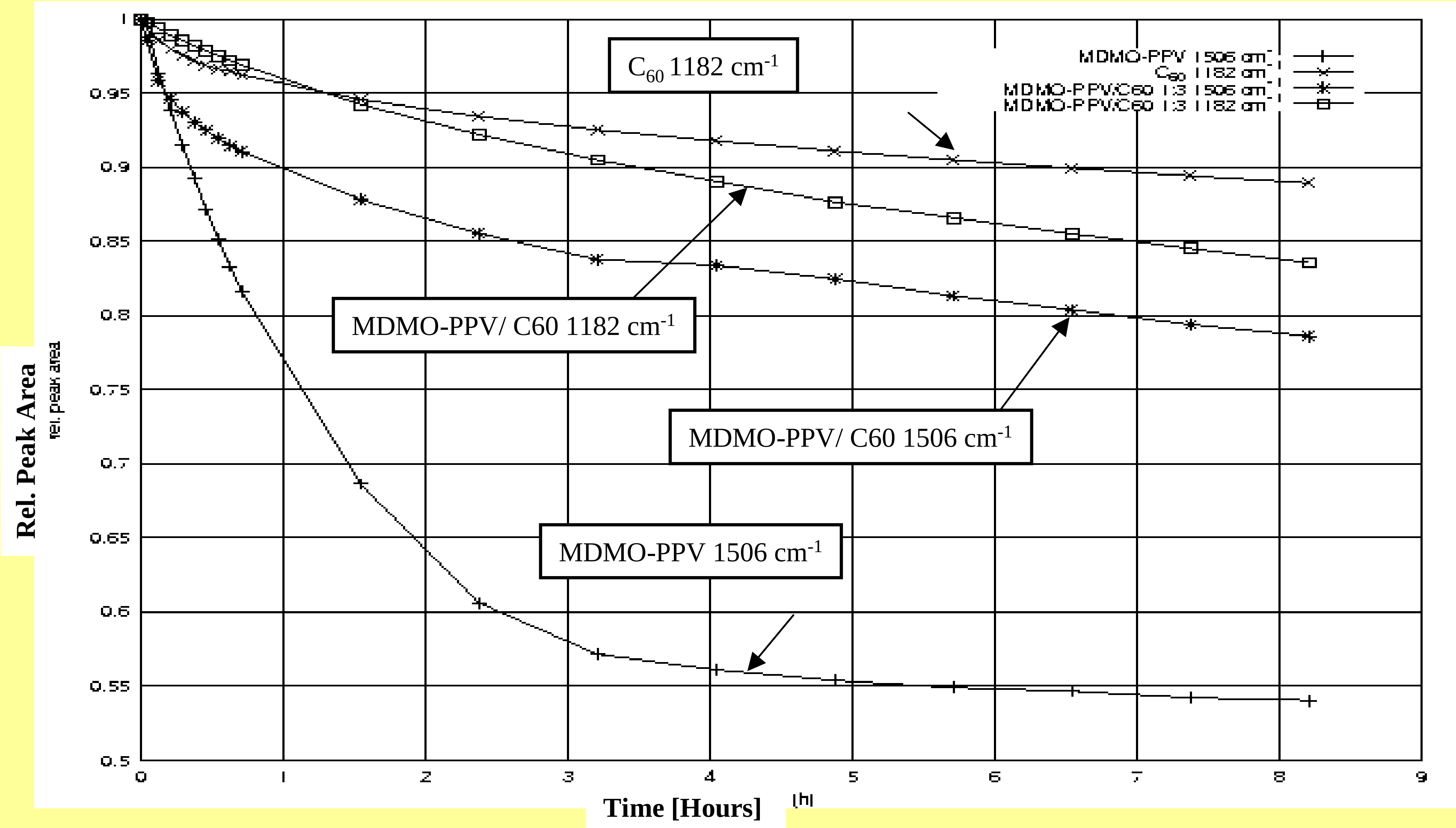
ENVIRON-MENTAL CELL





OUTLOOK - Stability

C_{60} slows down degradation of the Conj. Polymer



Linz Institute for Organic Solar Cells

Physics of Organic Semiconductors:

1.) Photoexcited spectroscopy
2.) Photoconductivity
3.) Thin film characterization
4.) Nanoscale engineering
5.) Nanoscale microscopy (AFM, STM...)
6.) In situ spectro-electrochemistry

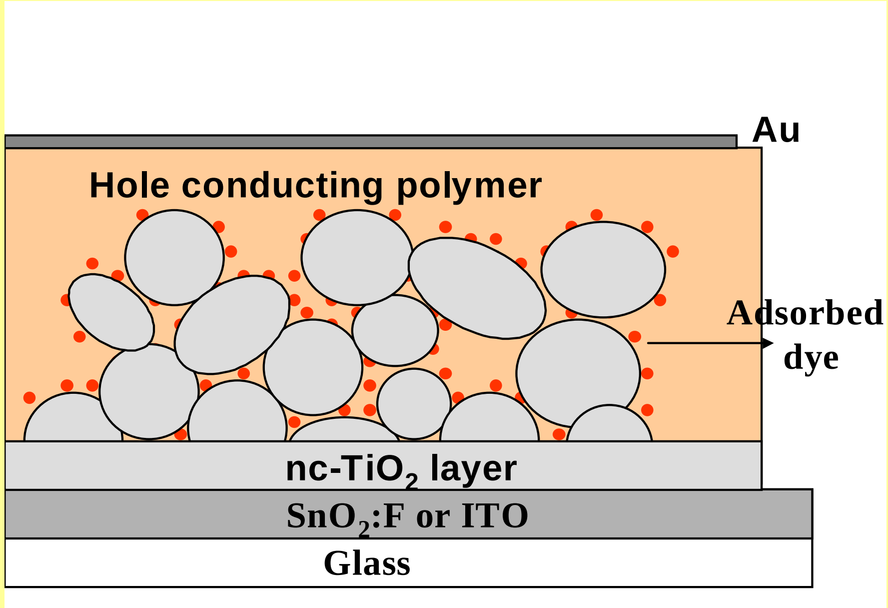
Plastic Solar Cells

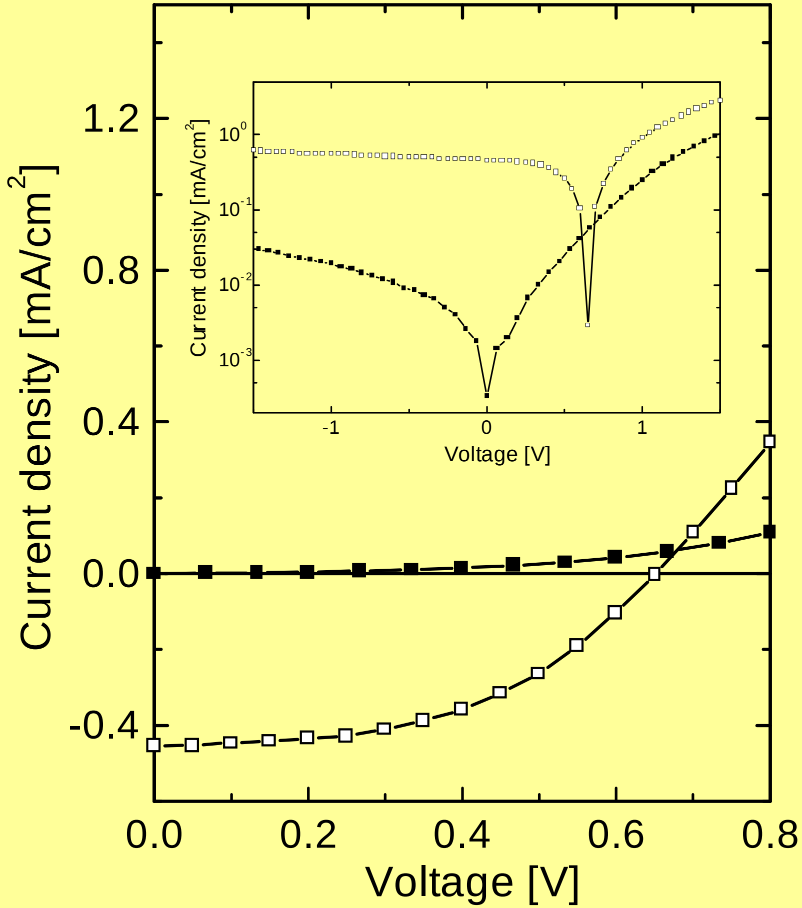
Molecular Solar Cells

Organic/Inorganic Hybrid Solar Cells

„Incubator“ for small high tech spin-off companies

NC-TiO2 with Polymeric Hole Conductor

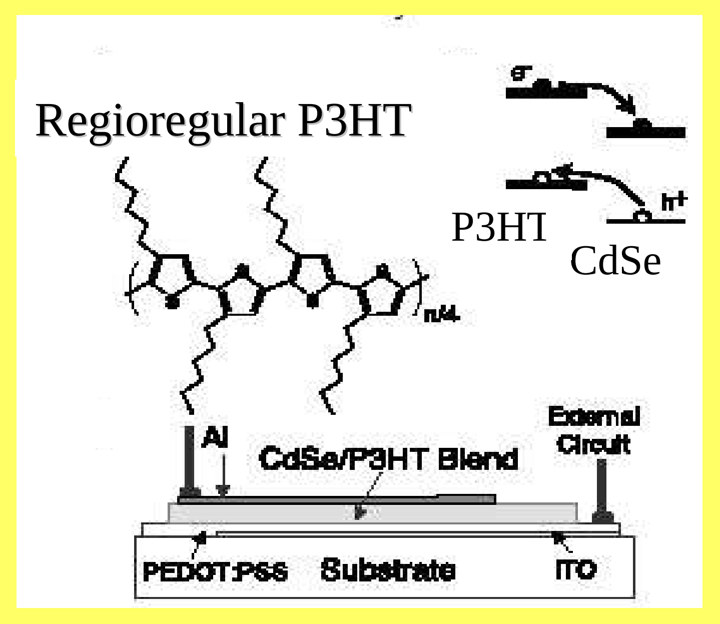


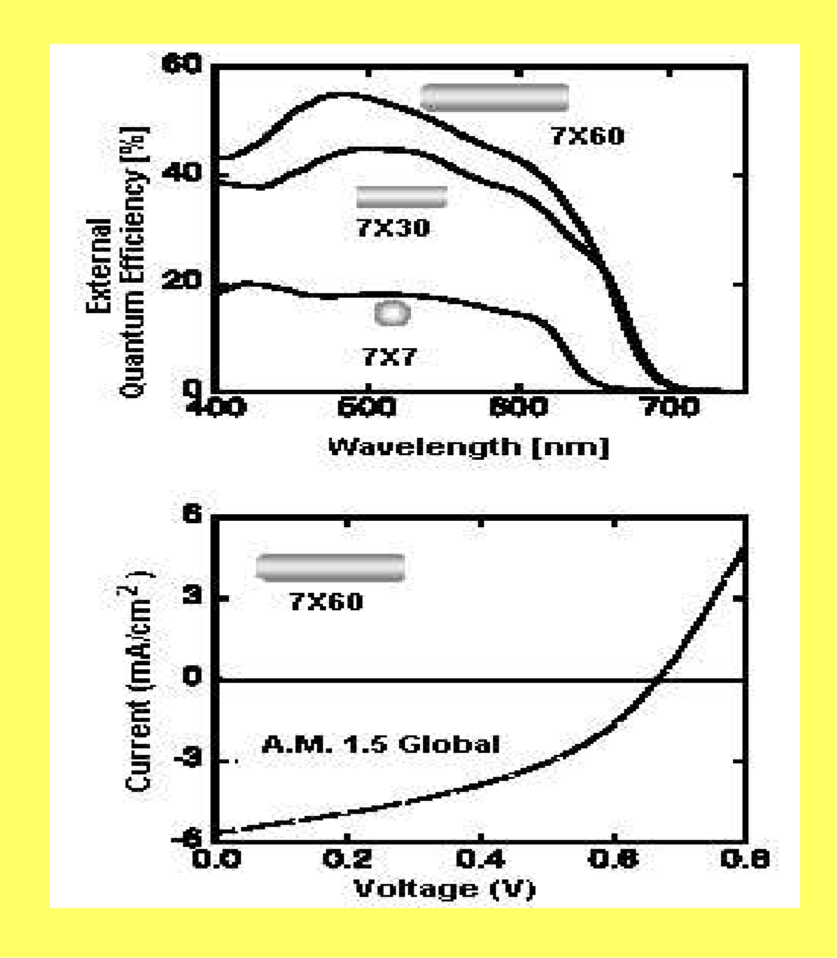


Organic/Inorganic Hybrid Solar Cells

Desta Gebeyehu, et al., Synthetic Metals, Vol. 125 (2002) 279-287

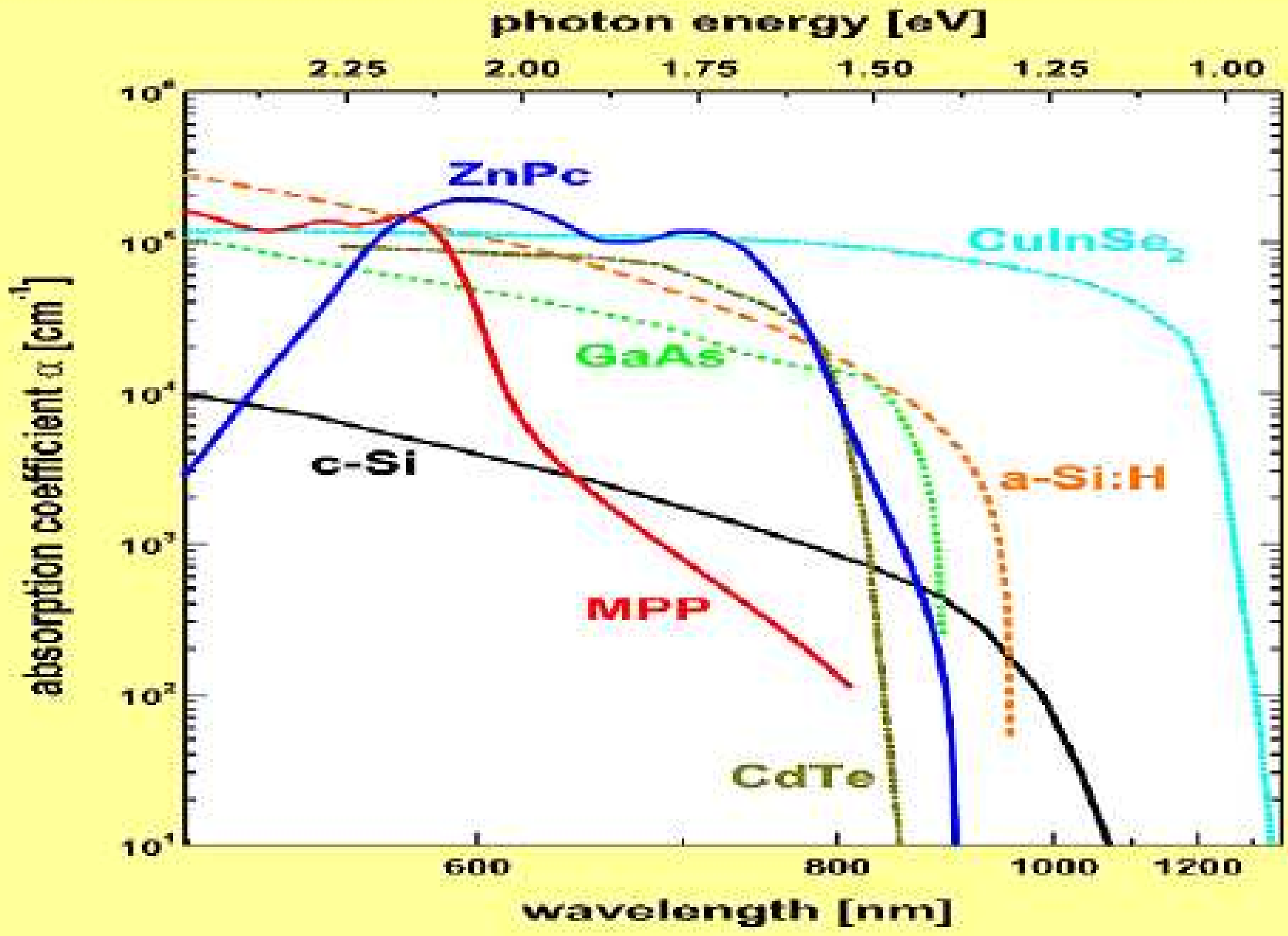
Hybrid Solar Cells



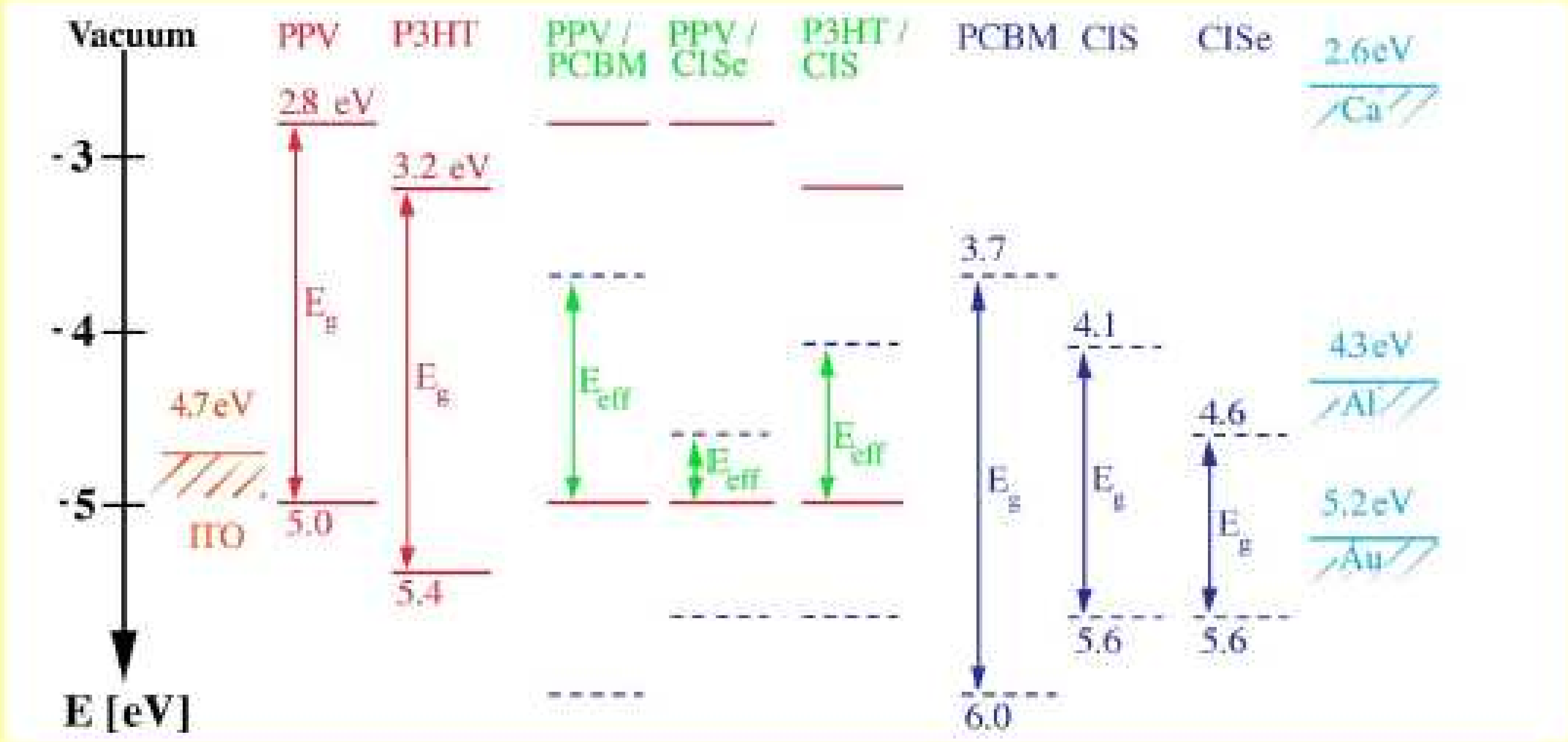


W.U. Huynh, J. Dittmer, A.P. Alivisatos
Science, 295 (2002) 2425

Absorption Coefficients

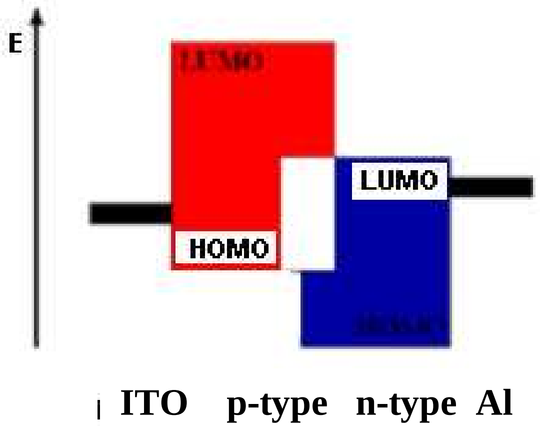


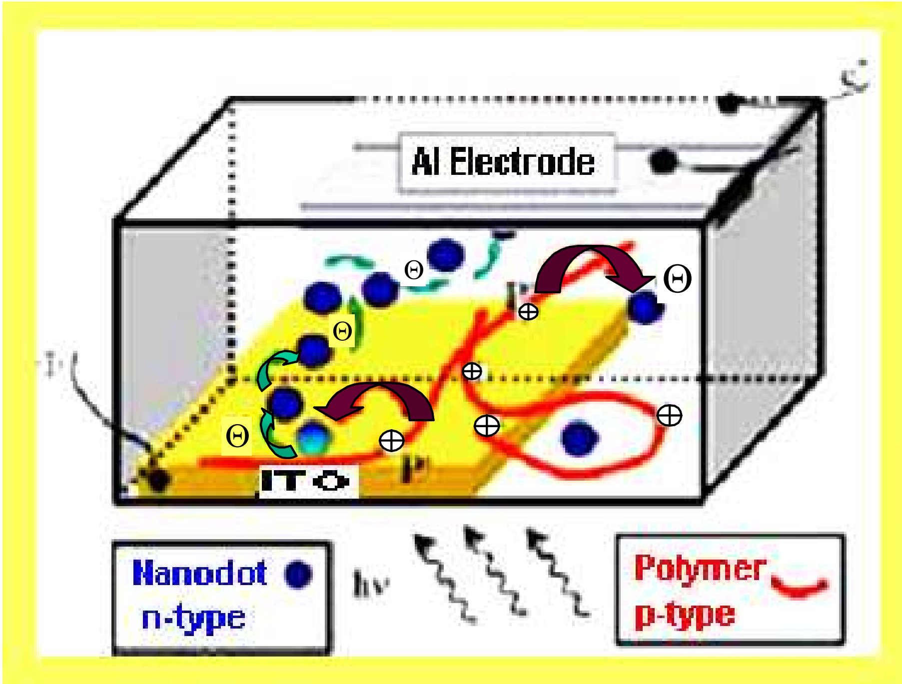
CIS Plastic Solar Cells



Band and Fermi level positions of the materials investigated.

Functioning Principle of Hybrid Solar Cells

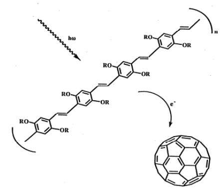




•

„Interpenetreting Network“

Synthese der CIS-Nanoteilchen



Elif Arici et al, 2002

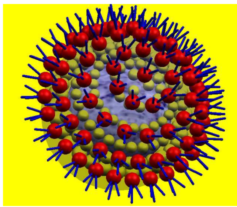
$InCl_3$ + TPP ⟶ $(In\text{-}TPP)^{+3}$ + $3Cl^-$

CuI + TPP ⟶ $(Cu\text{-}TPP)^{+1}$ + I^-

Bis(trimethylsilyl)-
sulfide

↓

$Cu_xIn_yS_z$-TPP + $(CH_3)_3SiCl$ + $(CH_3)_3SiI$



Organic Ligand
TPP (Triphenyl phosphit)
To prevent Aggregation

Nanodimension depends on:

- Temperature
- Rate of dropping
- Ligand/Reagenza-Ratio

Quantization

Elif Arici et al, 2002

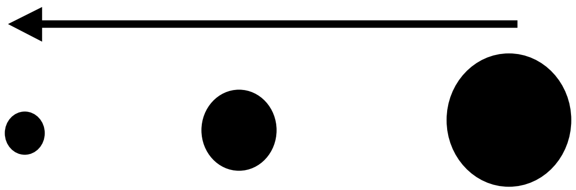
$$^{*}E_g = E_g(Bulk) + \left(\frac{h^2}{8R^2}\right)\left(\frac{1}{m_e} + \frac{1}{m_h}\right) - \frac{1.8e^2}{4\pi\varepsilon_0\varepsilon R}$$

Particle-in-the-box-Term   Coulomb-Term

$$R_{CIS} < R_{WM}$$

Wannier Mott Exciton Radius

$$R_{wm} = (\varepsilon_{oo}/\mu).\ \alpha_B$$
$$= 8.1\ \text{nm}$$



2.3 eV **1.5 eV**

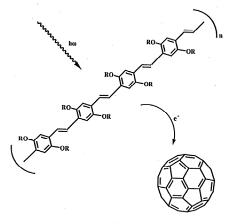
ε_{∞} = *Dielectric const.*

μ = *Reduced Mass*

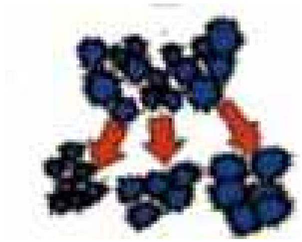
α_B = *Bohr Radius of H-Atom*

**L.E. Brus, J. Chem. Phys. 80, 4403 (1984)*

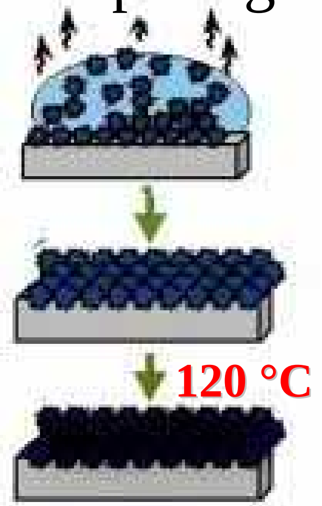
Nanocrystalline CIS



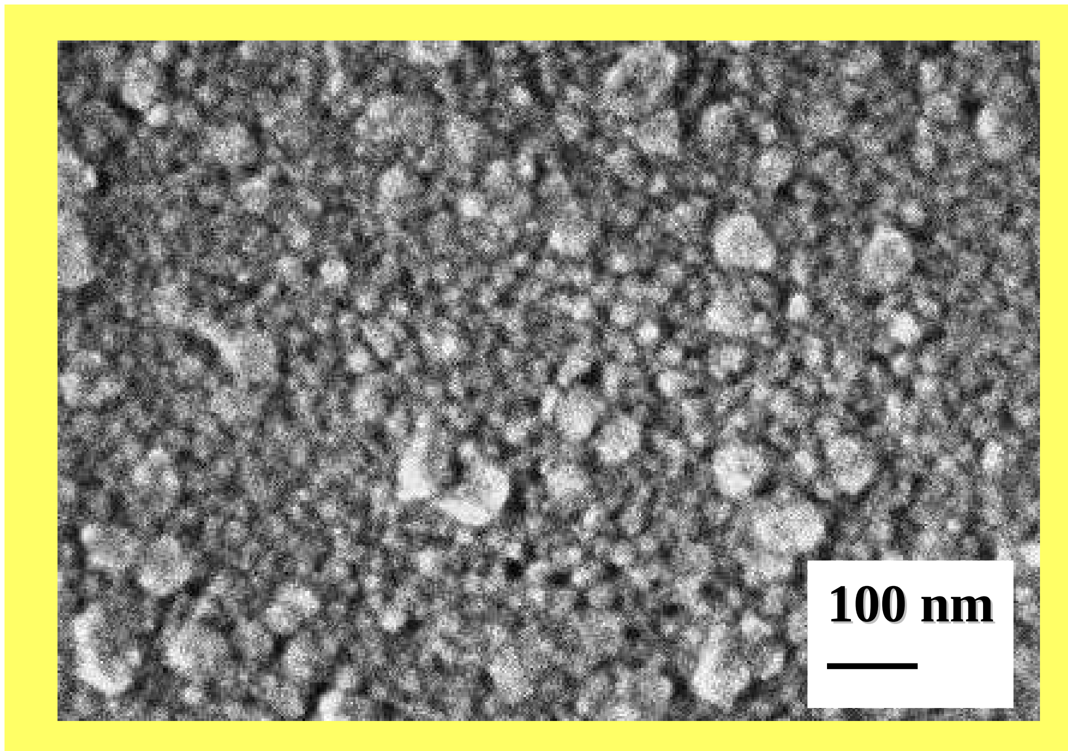
- Centrifuge



- Spincoating/
  Tempering



Scanning Electron Microscopy



CIS/TPP: Percolation

Interdisciplinary R & D