TECHNISCHE UNIVERSITÄT DRESDEN

iapp

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

Efficient Organic Solar Cells based on Small Molecules

C. Körner, R. Fitzner, C. Elschner, F. Holzmüller, P. Bäuerle, K. Leo and M. Riede

DPG AKE Meeting 2013
AKE 7.2

05.03.2013

Organic Solar Cells

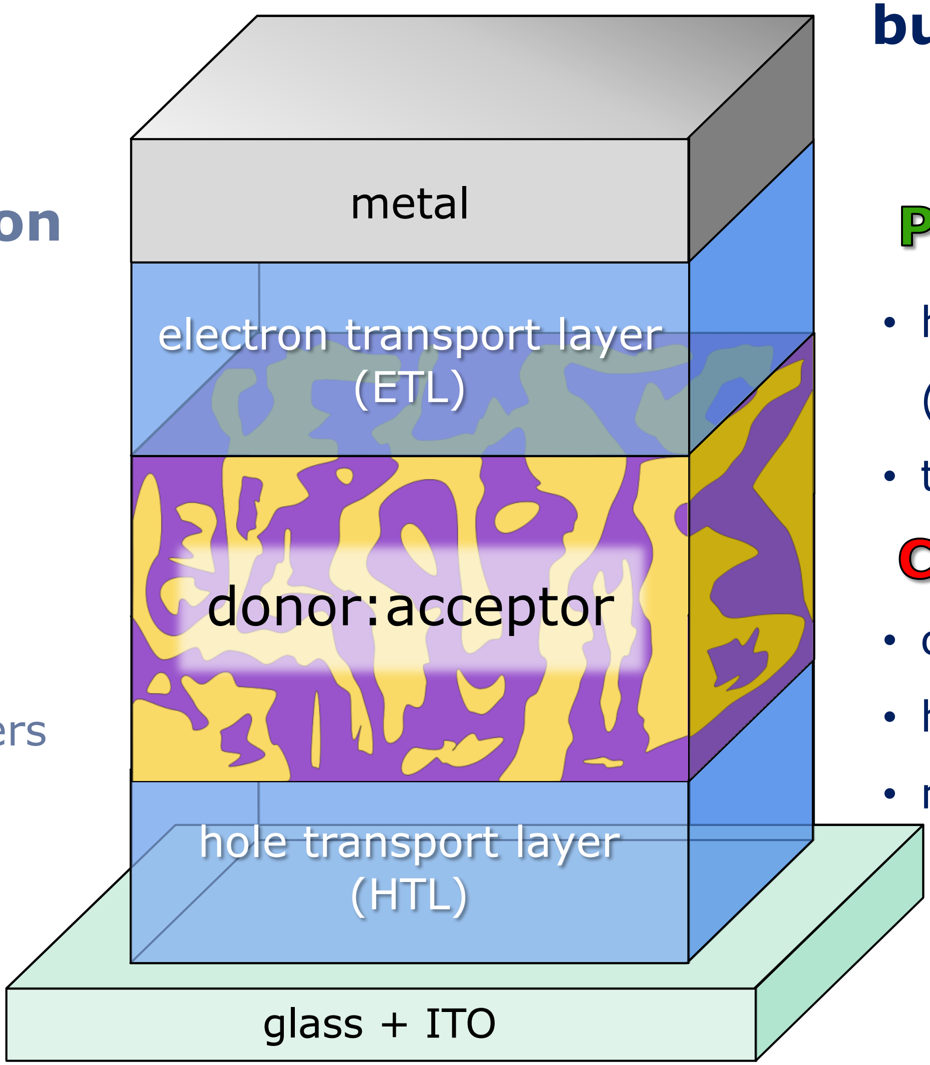
flat heterojunction (FHJ)

Pro's

- charge transport
- easy to process

Con's

- limited to thin layers (little absorption, low currents)



bulk heterojunction (BHJ)

Pro's

- high currents (small D/A distances)
- thicker layers possible

Con's

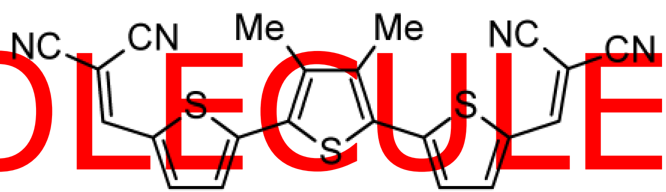
- charge transport disturbed
- higher recombination
- multi-parameter optimization

Reasons/Ways for Improvement towards Higher Efficiency

material purity?

processing issues?

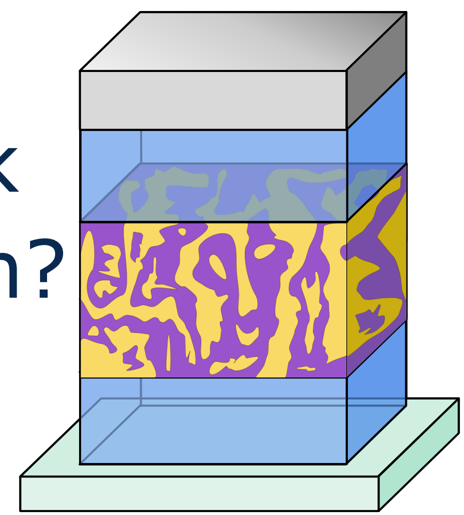
!!MOLECULES!!



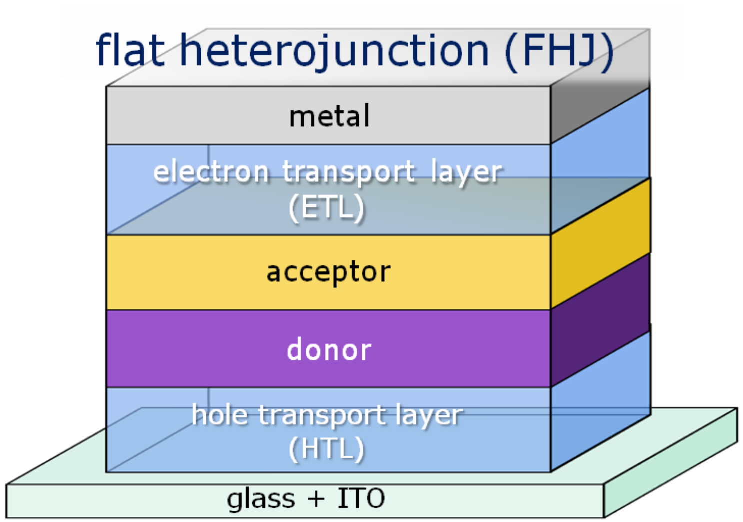
module integration?

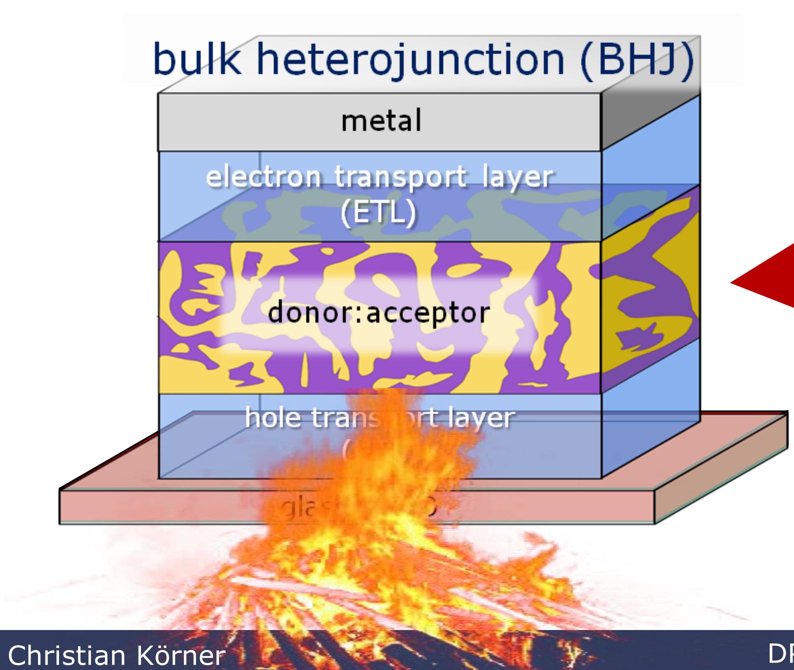
contacts materials?

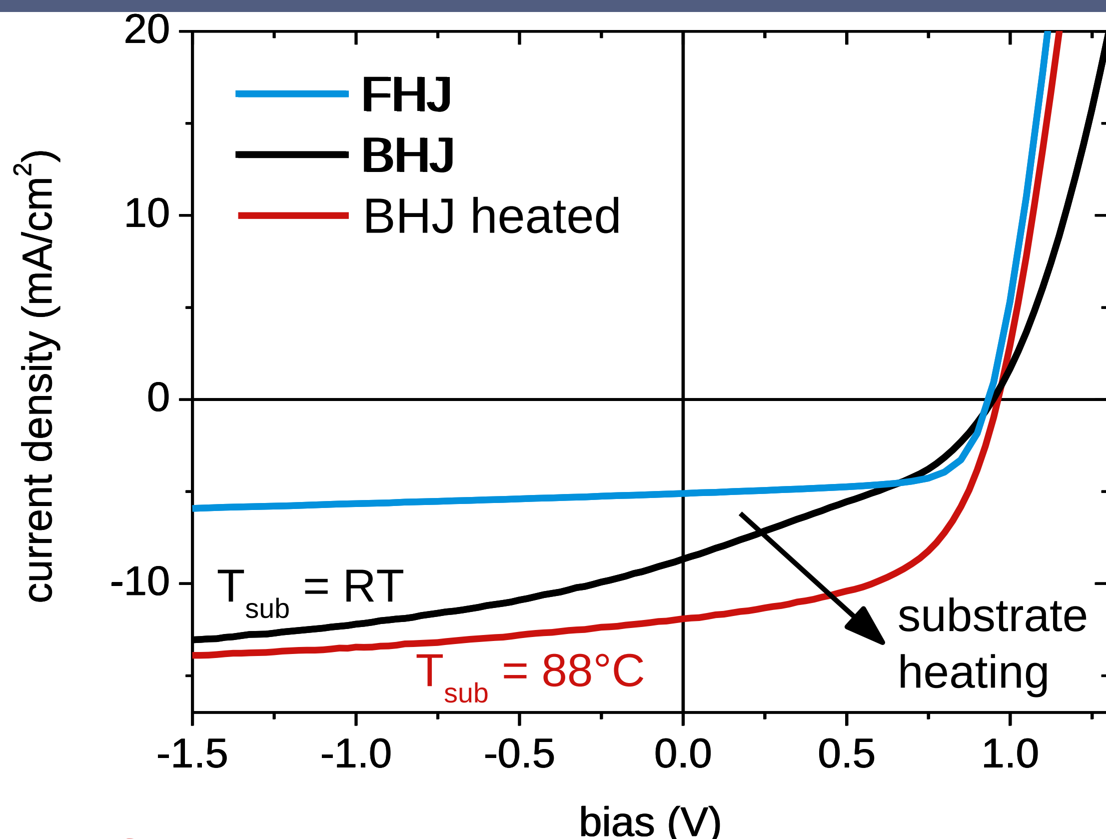
stack design?



Processing: Substrate Heating







Influence morphology

increase FF in BHJ solar cells

↓

charge transport ⇄ (nano-)crystallinity
phase separation

Molecules: Variability!

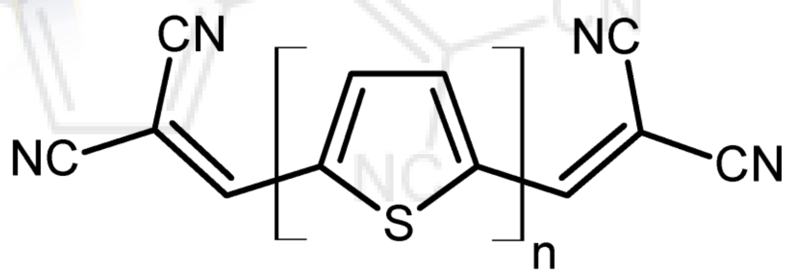
ulm university universität uulm

The DCVnT Material System

2006

- K. Schulze
- C. Uhrich
- R. Schüppel
- D. Wynands
- M. Levichkova
- H. Ziehlke
- C. Körner
- C. Elschner

2013



TECHNISCHE UNIVERSITÄT DRESDEN

The DCVnT-Zoo

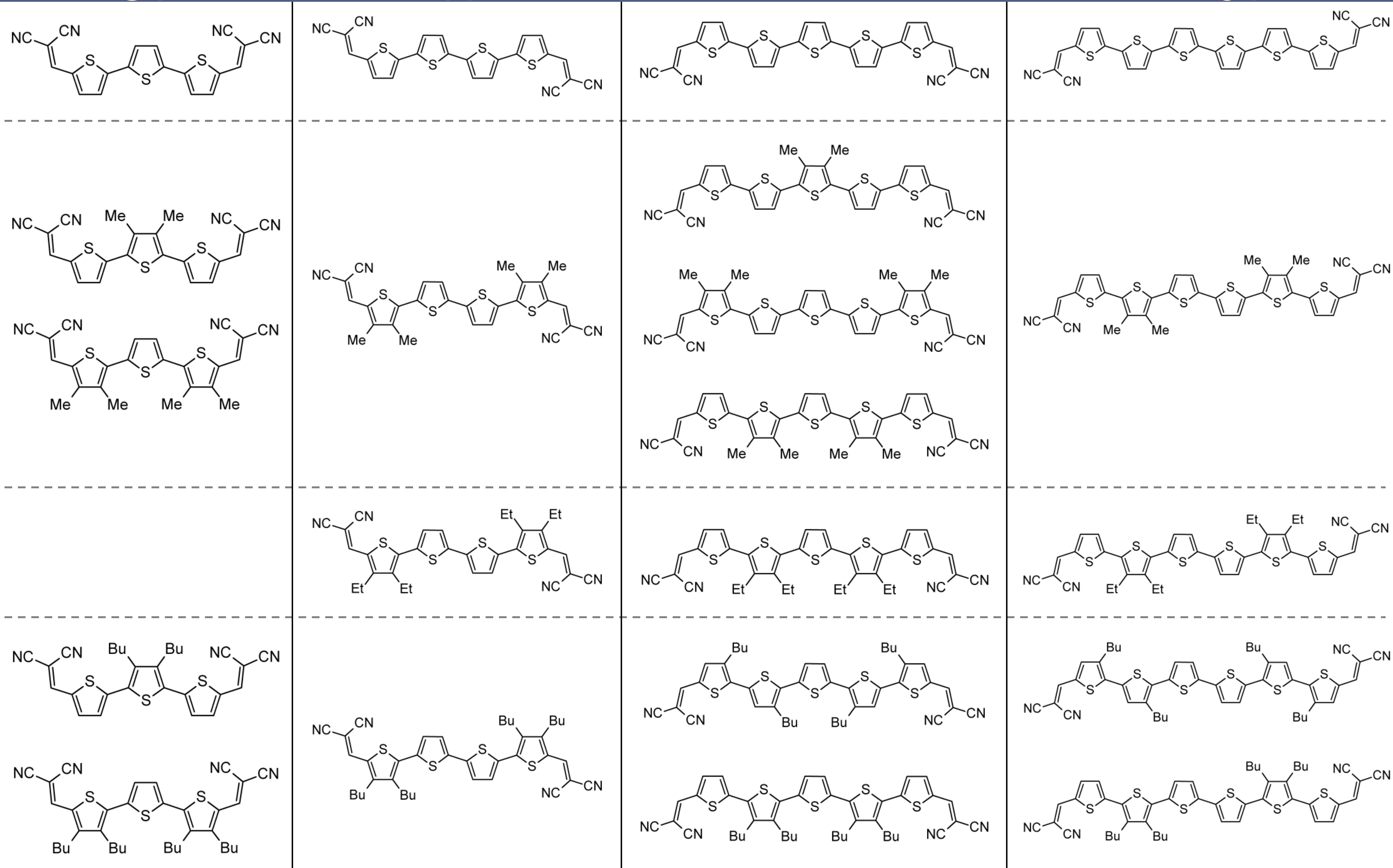
iapp

3T | 4T | 5T | 6T

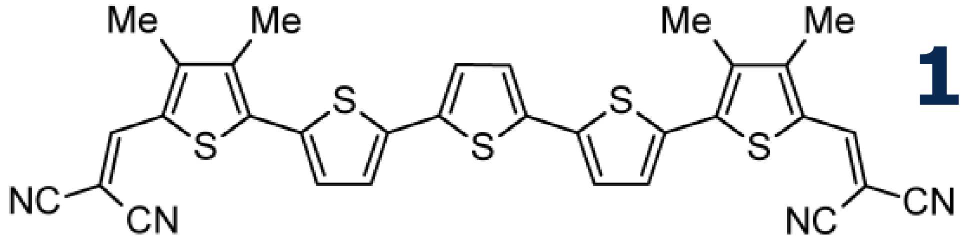
Me

Et

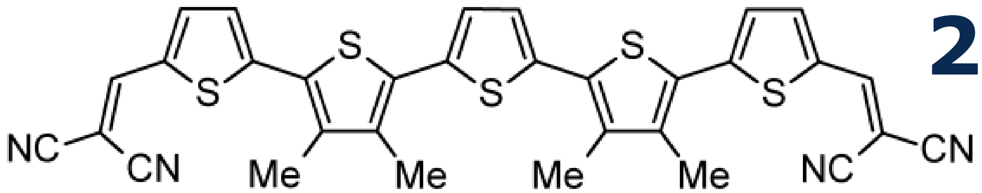
Bu



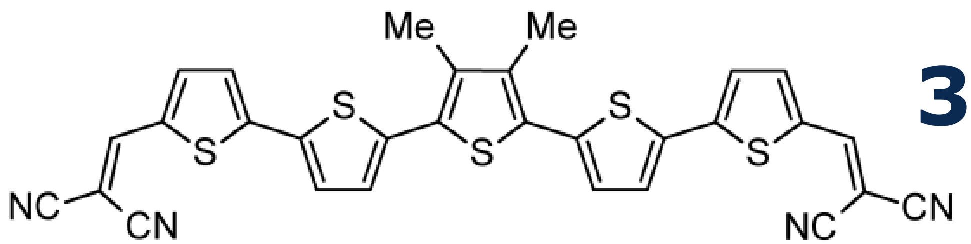
The DCVnT-Zoo



15



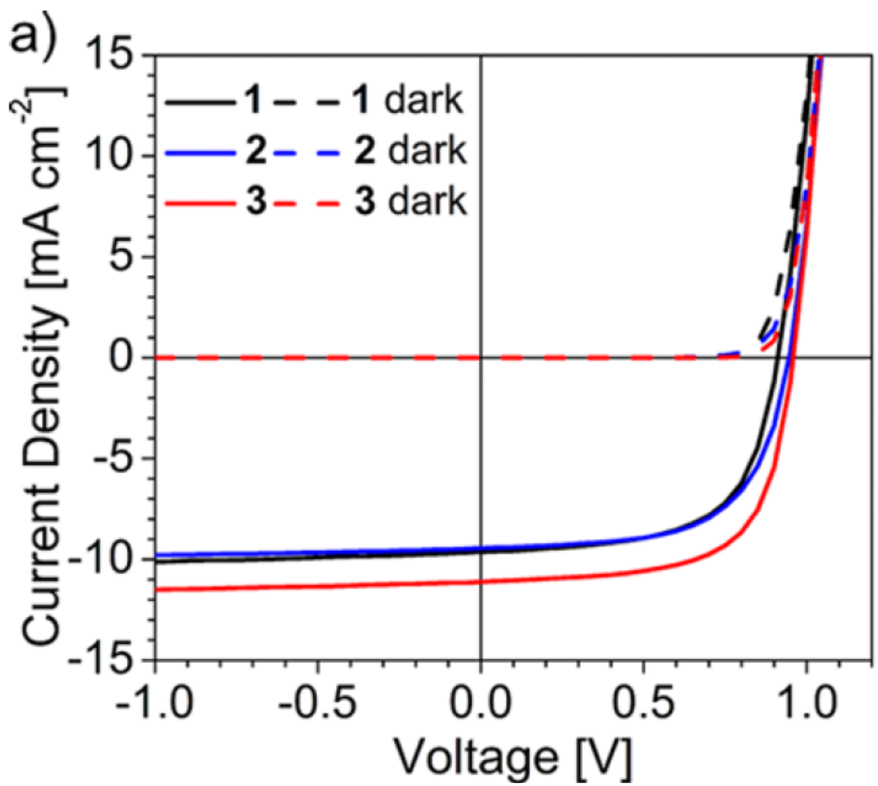
24



33

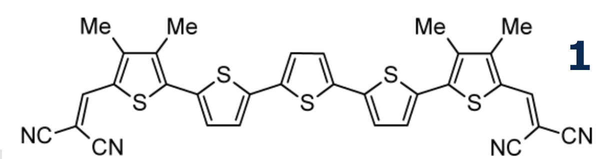
Similar properties – different performance

The Starting Point

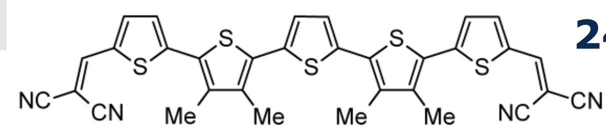


- outstanding performance for compound 33
- high efficiency of 6.1% reached already for non-optimized standard device

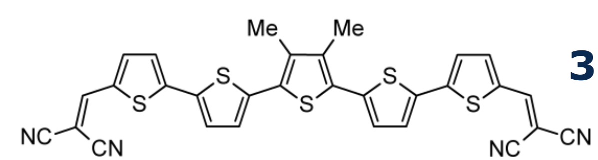
oligomer (stack)	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)
15 **1** (A)	0.91	9.6	63	4.8
24 **2** (A)	0.95	9.4	62	4.8
33 **3** (A)	0.96	11.1	66	6.1



15



24

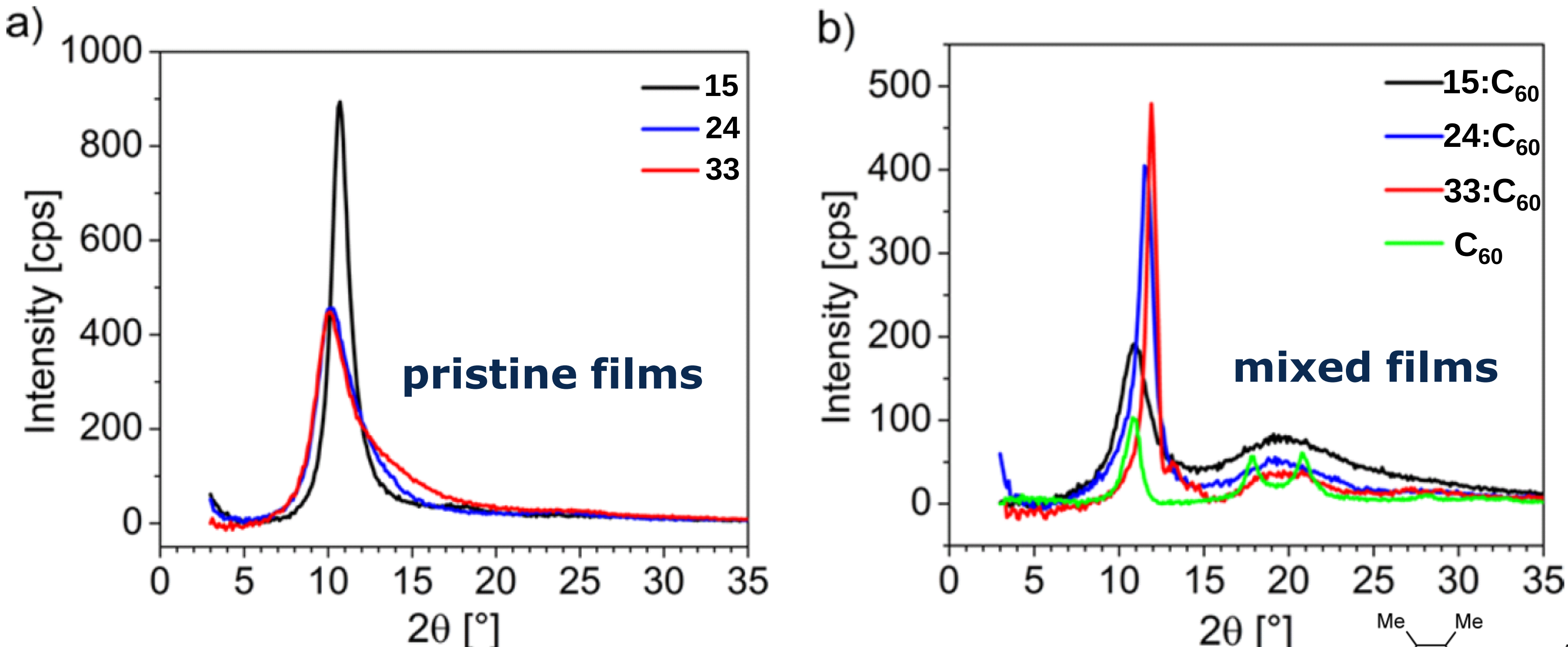


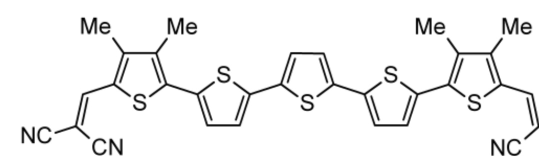
33

T_{sub} = 90°C

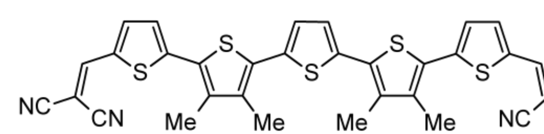
Fitzner, Elschner et al., J. Am. Chem. Soc. 2012, 134, 11064

Thin Film Morphology via GIXRD

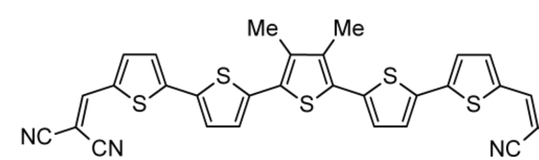




15



24



33

pristine films:
highest crystallinity for comp. 15
mixed films:
highest crystallinity for comp. 33

→ ongoing investigations!

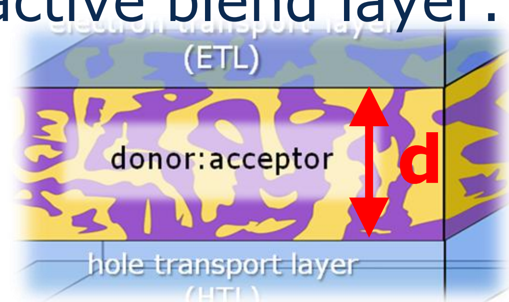
Fitzner, Elschner et al., J. Am. Chem. Soc. 2012, 134, 11064

Roadmap for High Efficiency

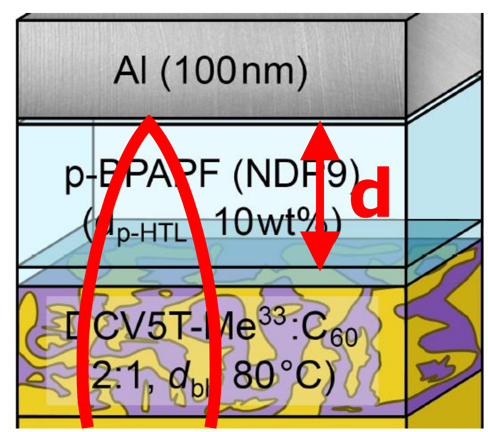
- optimize mixing ratio DCV5T/C60: **2:1**

- optimal substrate temperature: $\mathbf{T_{sub}=80°C}$

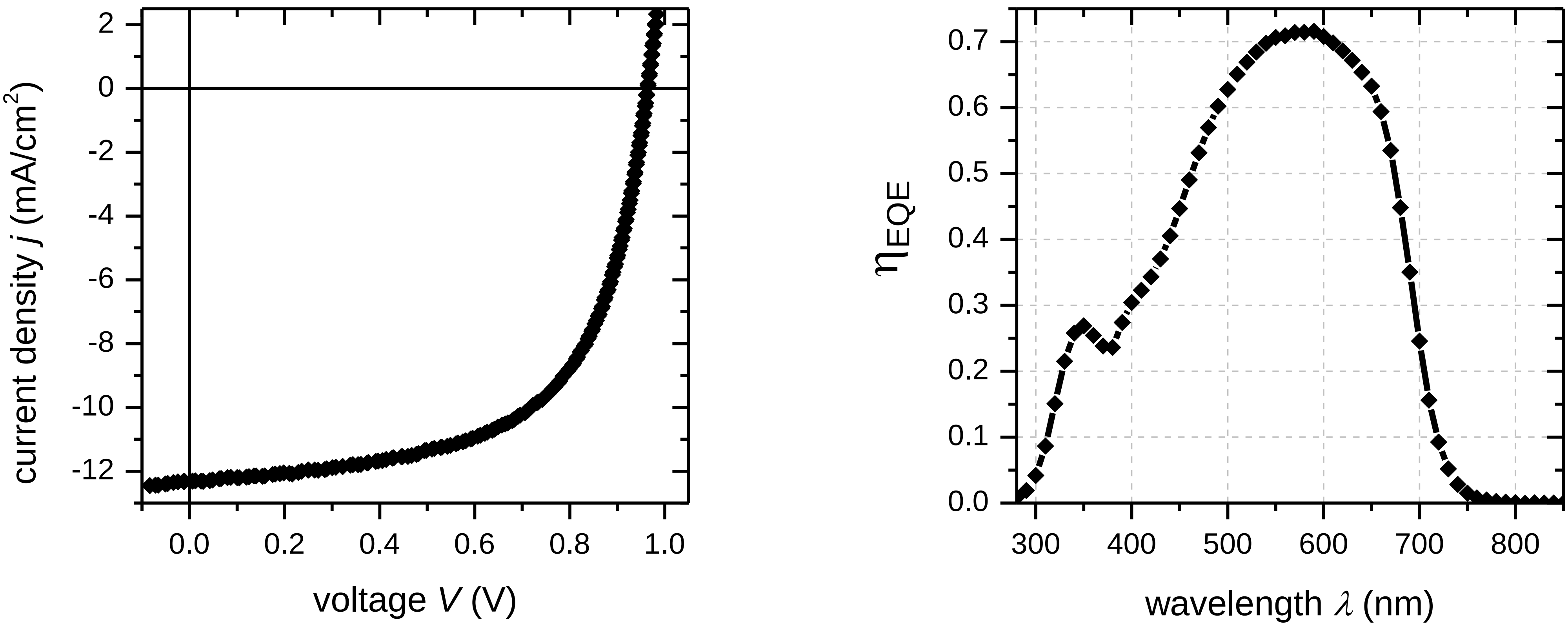
- optimize thickness of the active blend layer: **35-40nm**



- optimize thickness of window layer: **35-40nm**

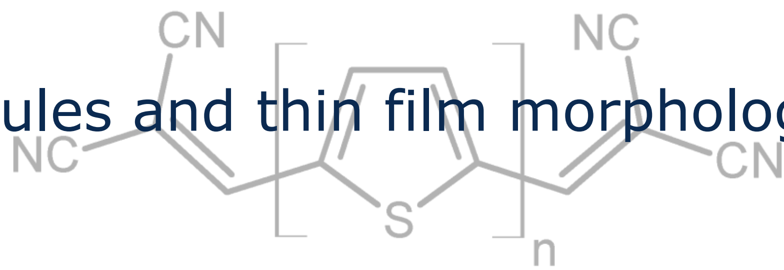


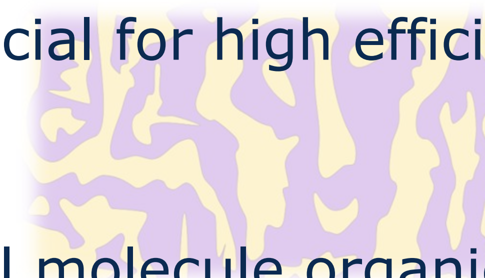
7.2% reached!



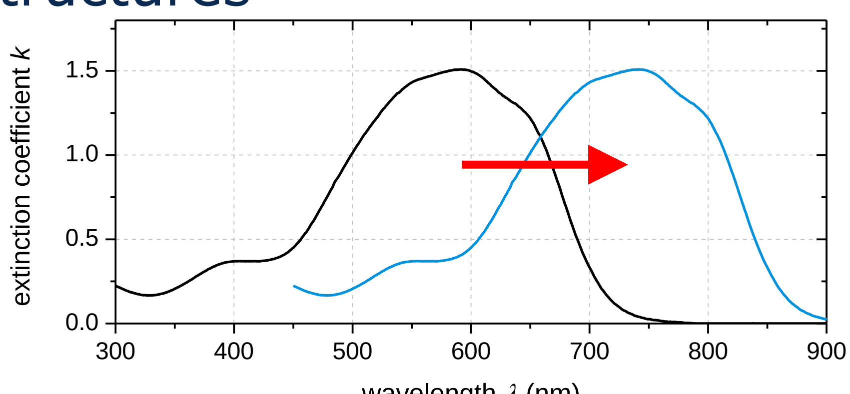
certified efficiency at Fraunhofer ISE: **η = 7.2%**

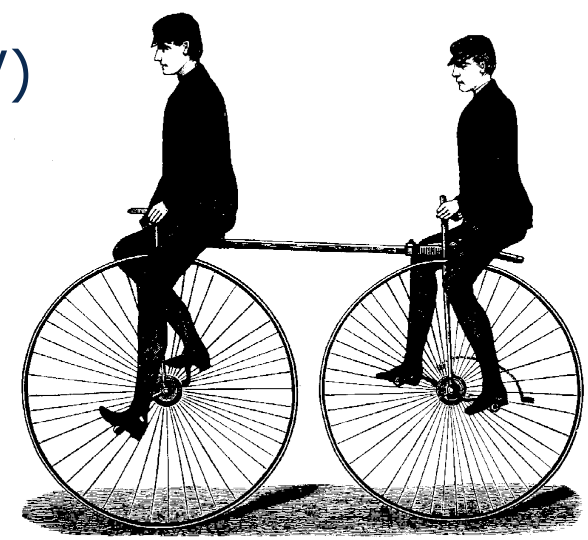
Summary





- molecules and thin film morphology are crucial for high efficiency
- record efficiency of 7.2% achieved for small molecule organic solar cells
- Further optimization by
  - increased absorption
  - red-shifted absorption (optical gap at 1.4eV)
  - tandem structures
  - …





TECHNISCHE UNIVERSITÄT DRESDEN

Acknowlegdments

iapp

OSOL-group at IAPP

ulm university universität ulm

Deutsche Forschungsgemeinschaft DFG

Thank You For Your Attention

Appendix

Introduction

Organic Solar Cell properties

- leight-weight
- flexible
- cheap
- colorful
- transparent
- superior temperature, angle and low-light performance

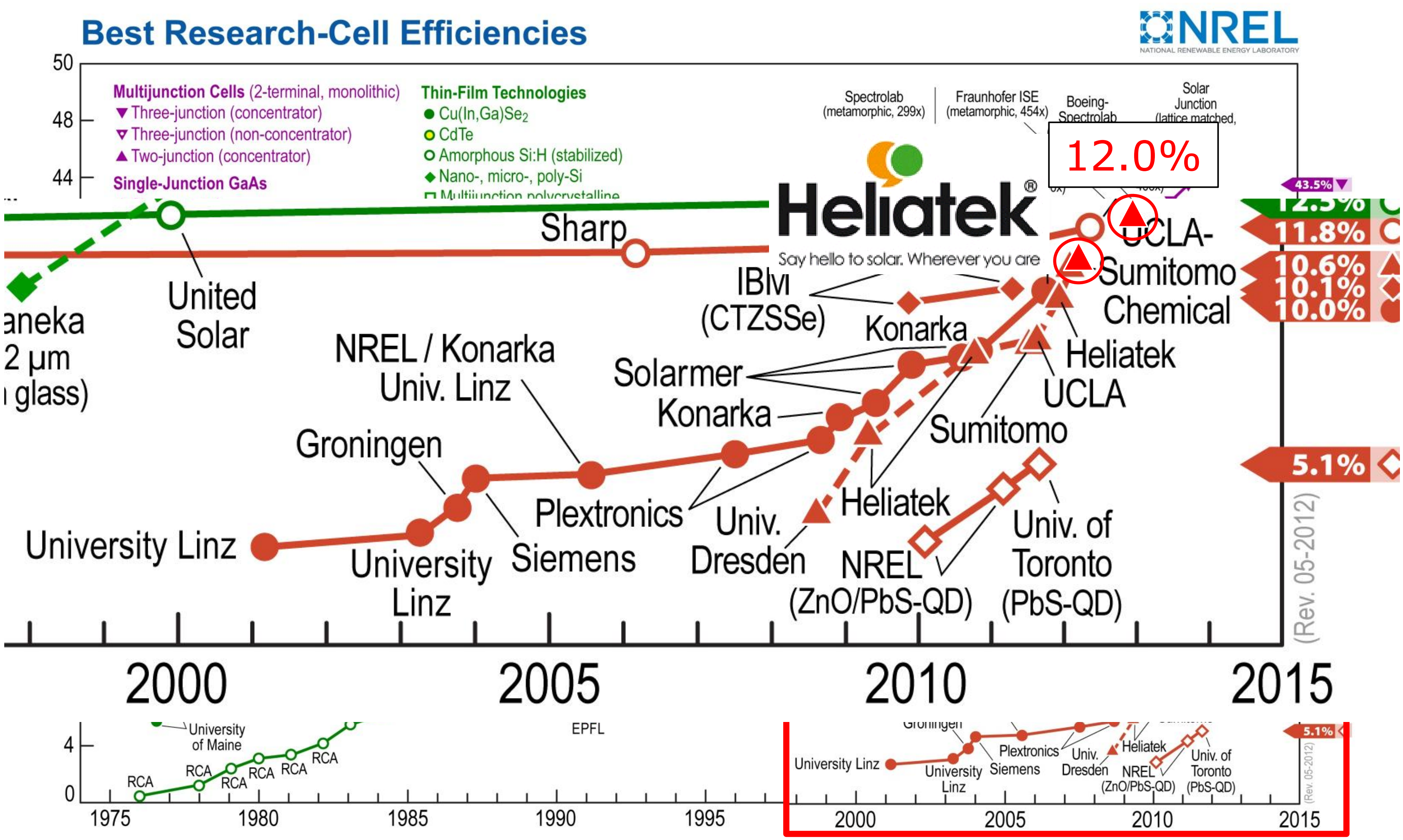
http://www.fotoskizzen.de/deutschland/fotografie/frankfurt-glasfassade.jpg

possible applications

- building integration
- facades
- mobile applications
- …

pictures taken from Heliatek

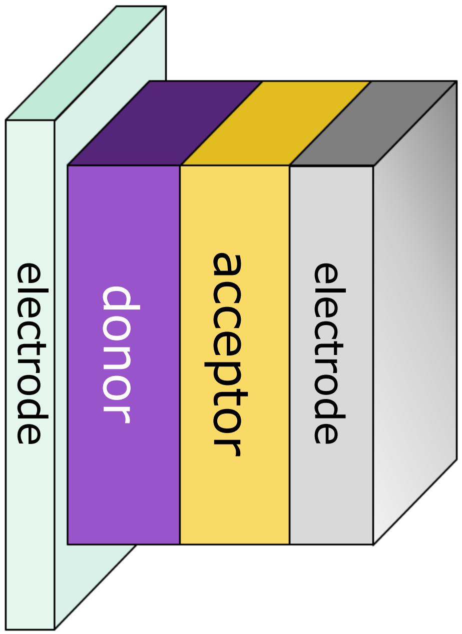
Solar Cell Efficiency Development

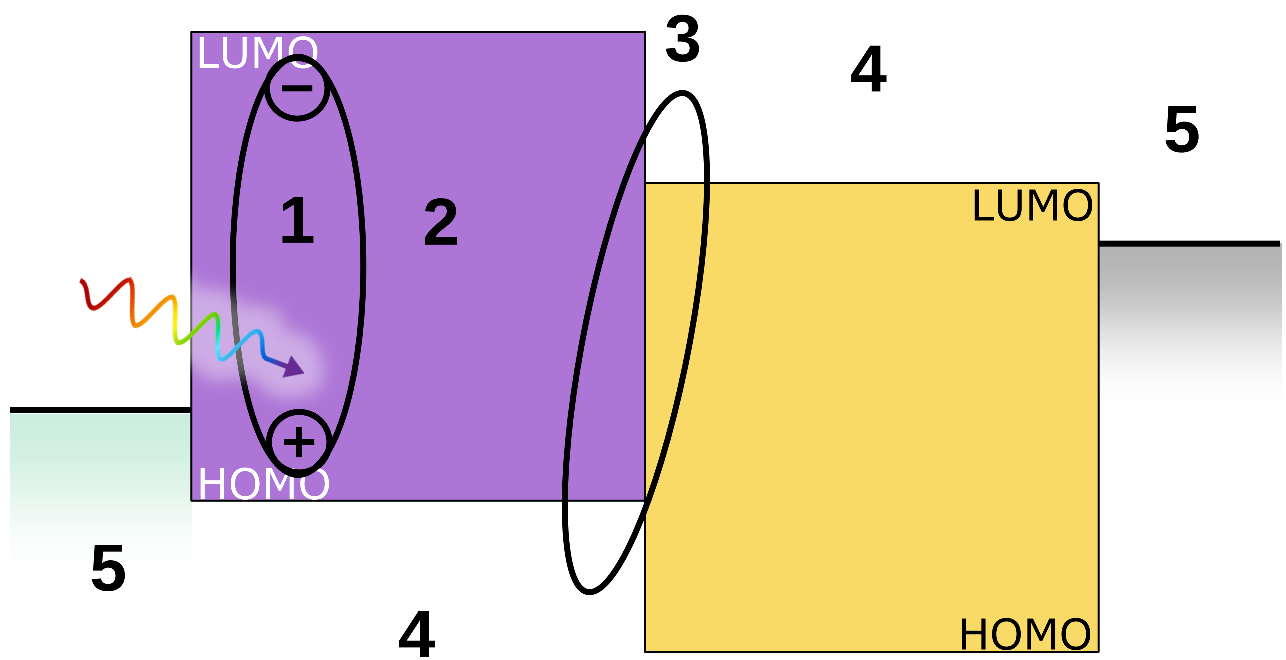


Sources: NREL (www.nrel.gov/ncpv/images/efficiency_chart.jpg); heliatek press releases

Charge Carrier Generation Scheme

C. Tang, APL 48, 183 (1986)





1 photon absorption (exciton generation)

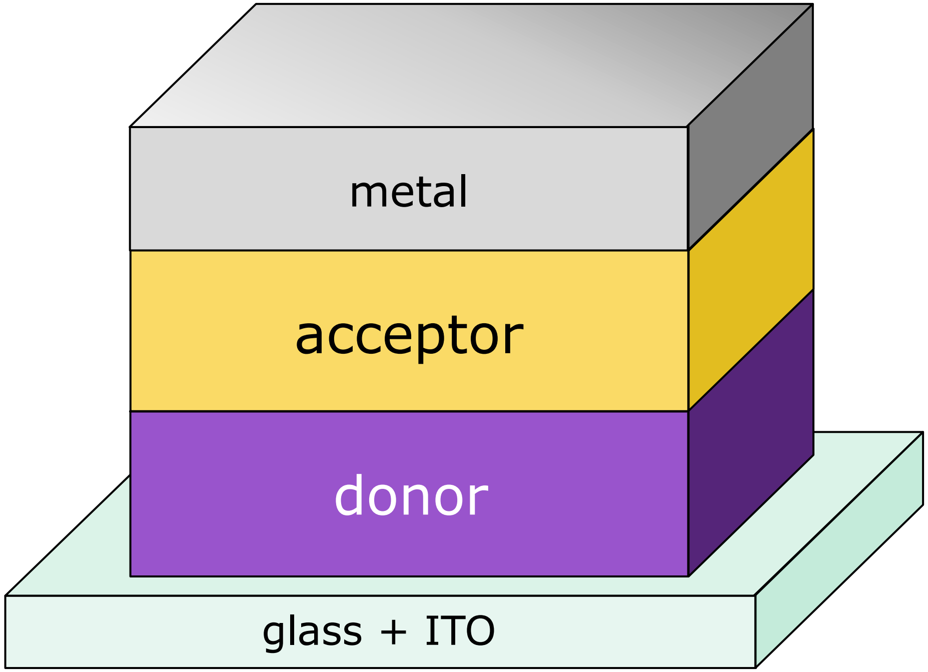
2 exciton diffusion

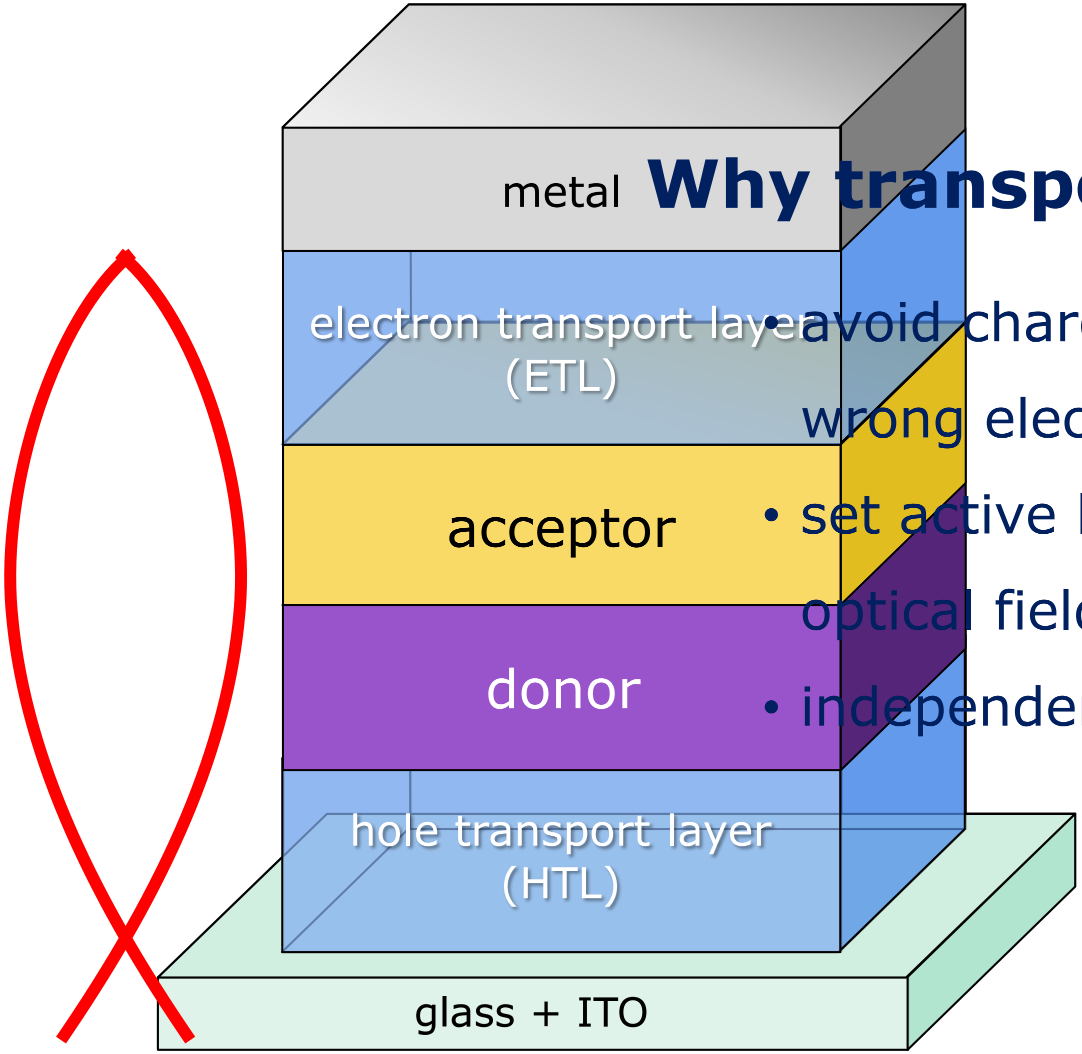
3 charge transfer

4 charge transport

5 charge collection

Organic Solar Cells



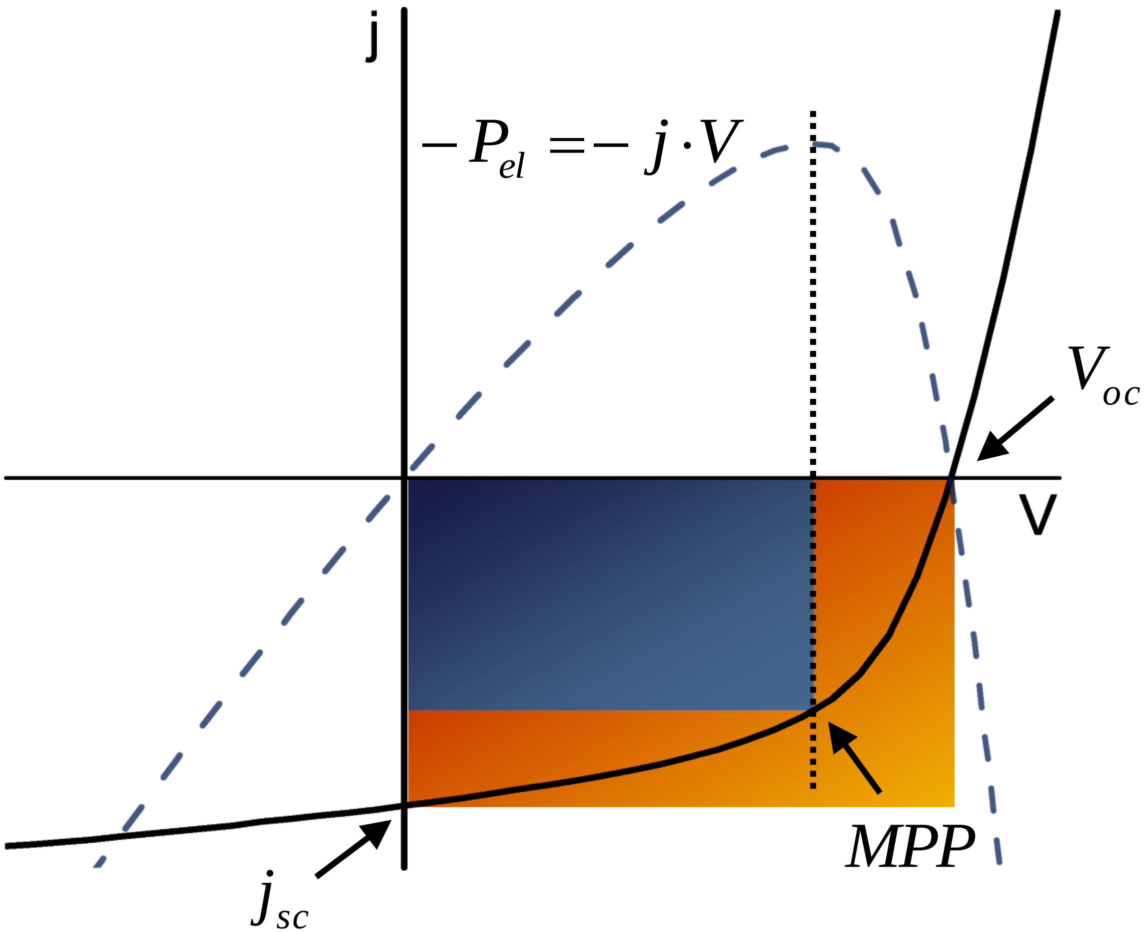


Why transport layers?

- avoid charge transport to wrong electrode
- set active layer to maximum of optical field (window layers)
- independent of contact material

Solar Cell Characterization

jV-characteristics



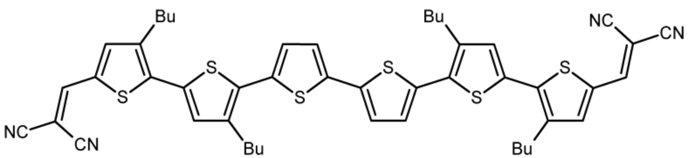
$$PCE = \frac{P_{out}}{P_{in}} = \frac{j_{MPP} V_{MPP}}{P_{in}}$$

$FF =$  < 1

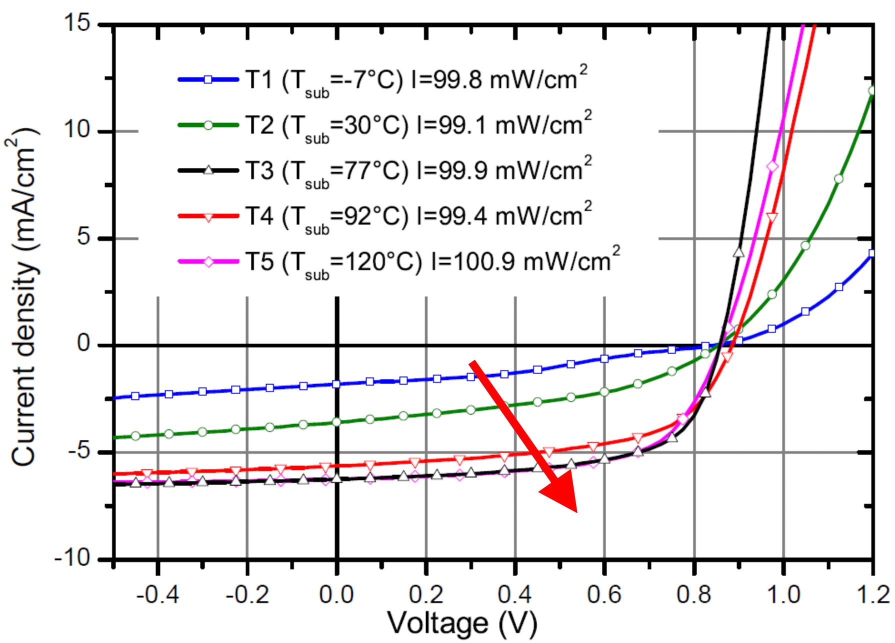
$$PCE = \frac{j_{sc} V_{oc} FF}{P_{in}}$$

Substrate Heating Review

David Wynands:

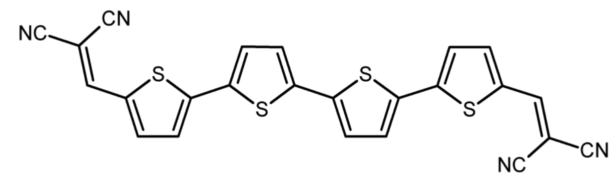


DCV6T-Bu(1,2,5,6)

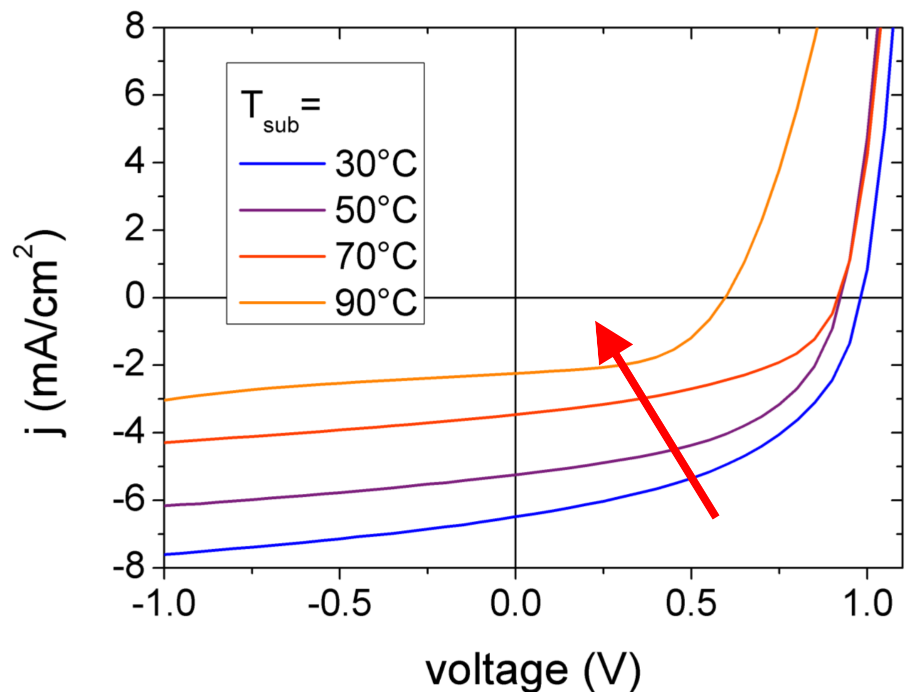


Substrate heating

Christian Körner/Franz Selzer:

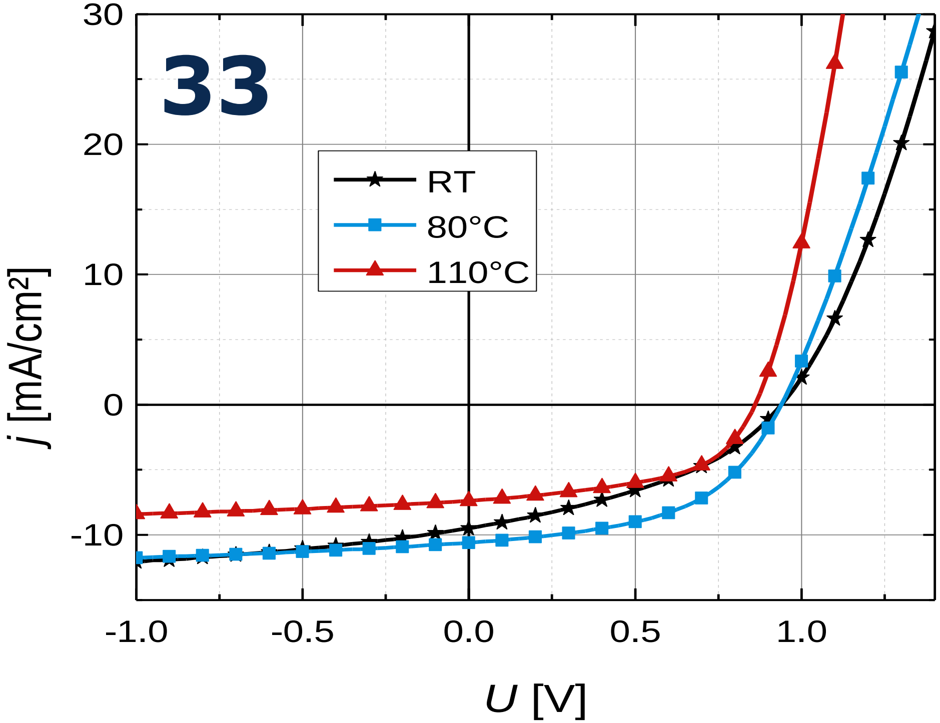


DCV4T

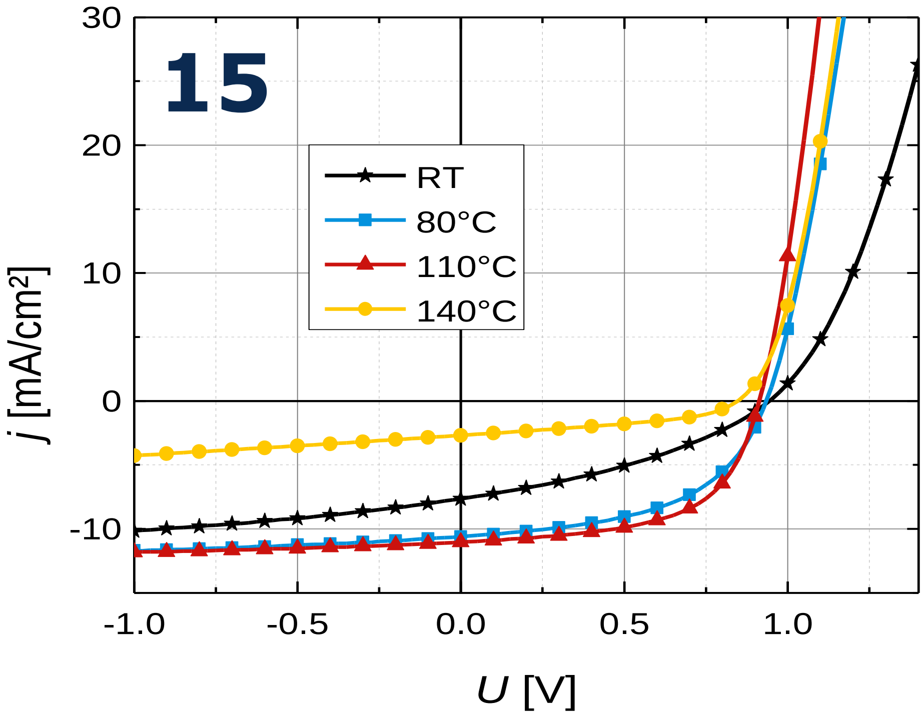


Substrate heating

Variation of Substrate Temperature

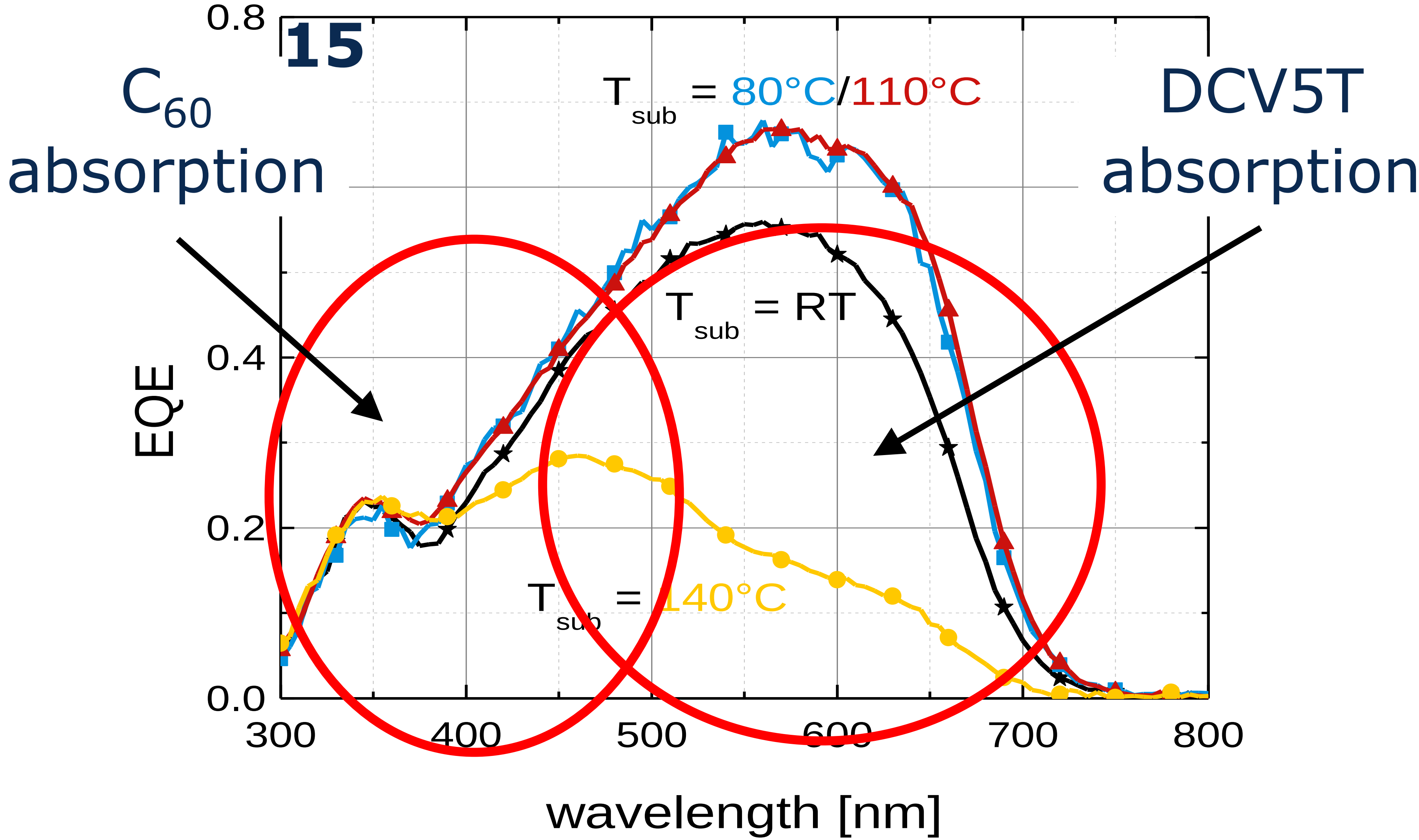


- improvement up to T_{sub}=80°C
- above a critical temperature, j_{sc} and V_{oc} are decreased



- critical temperature higher for compound 15

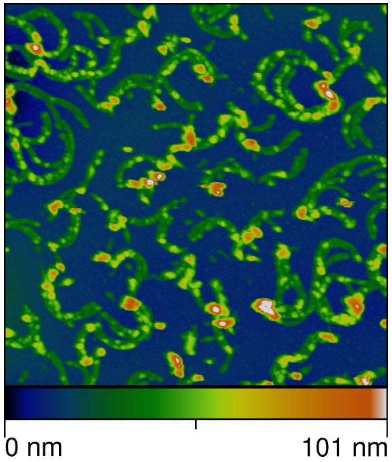
Morphological Changes upon Substrate Heating



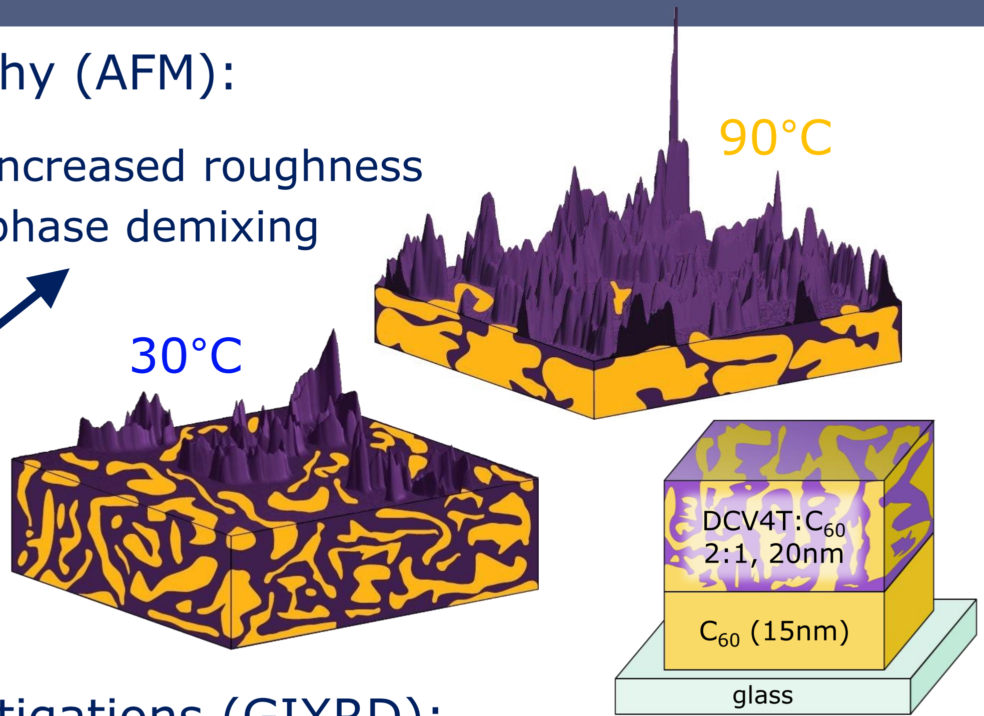
→ Koerner et al., …DCV4T…, Organic Electronics 13, … … (2012)

Substrate Heating
Detailed Investigations

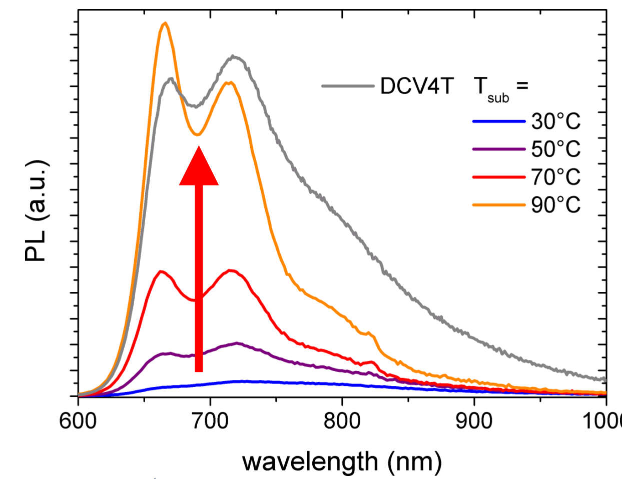
surface topography (AFM):



increased roughness
phase demixing



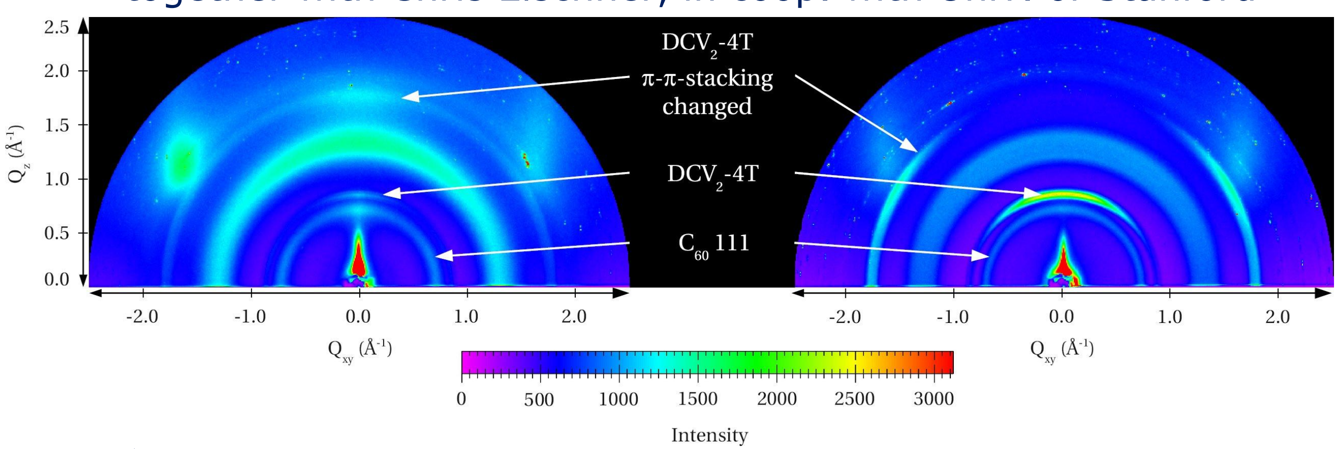
PL quenching decrease:



→ excitons are lost

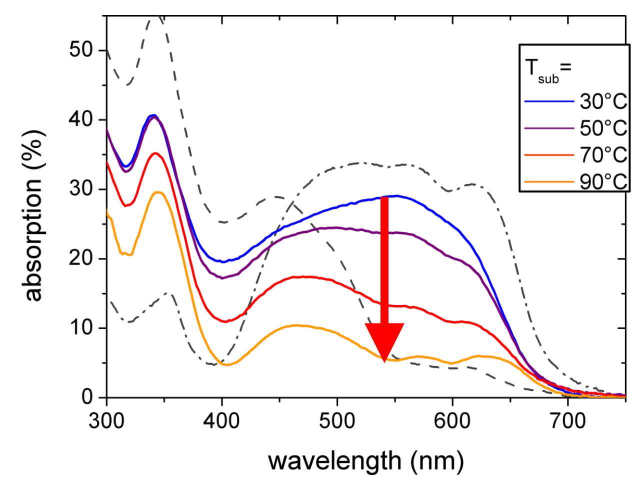
structure investigations (GIXRD):

together with Chris Elschner, in coop. with Univ. of Stanford



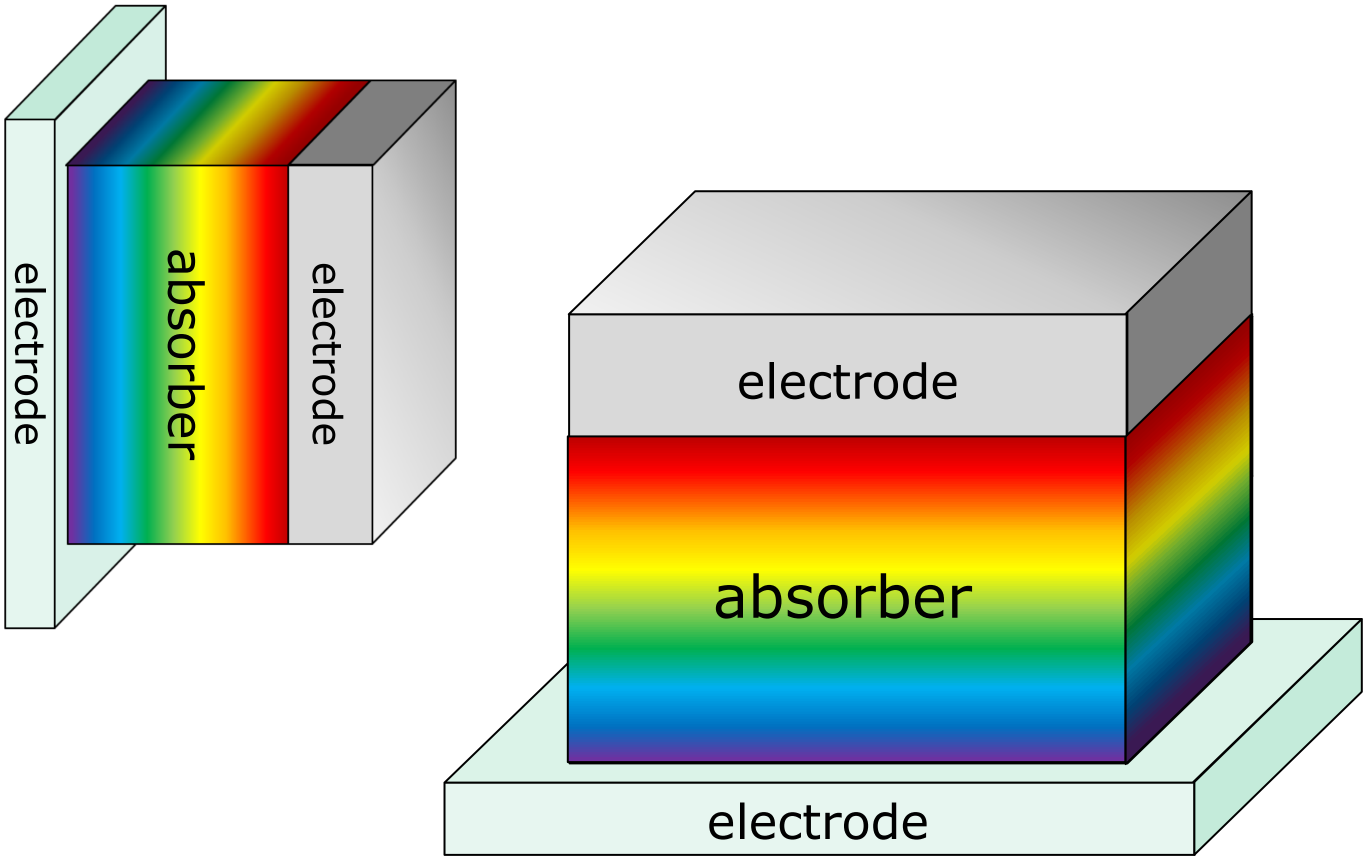
→ π-stacking / molecular orientation changed

absorption decrease:

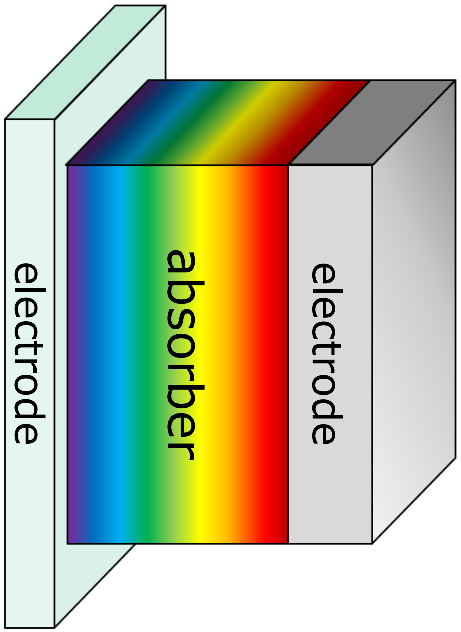


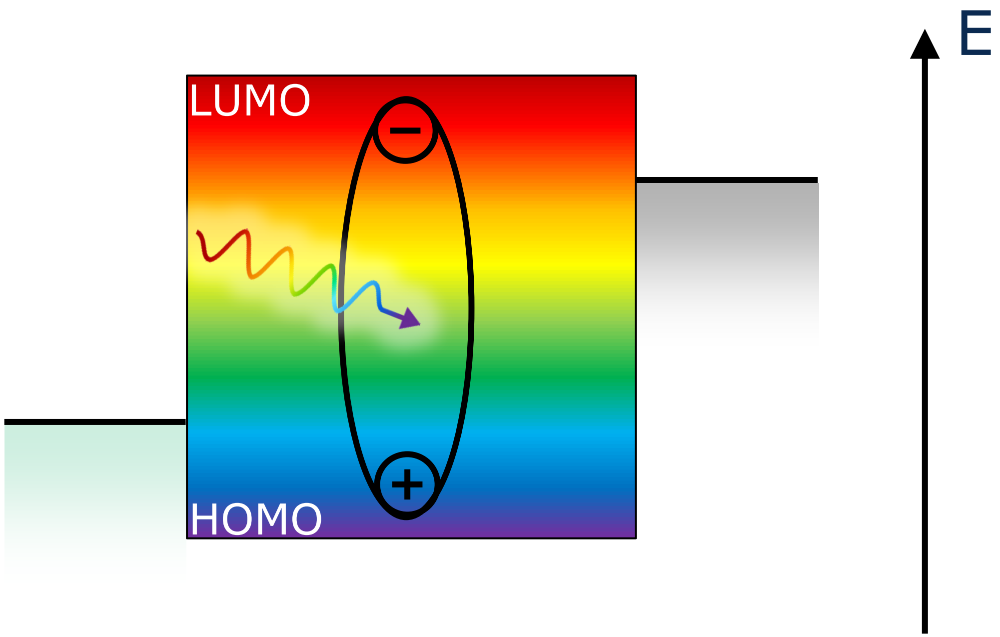
→ decrease in j_{SC}

Organic Solar Cells



Organic Solar Cells





very strong exciton binding energy

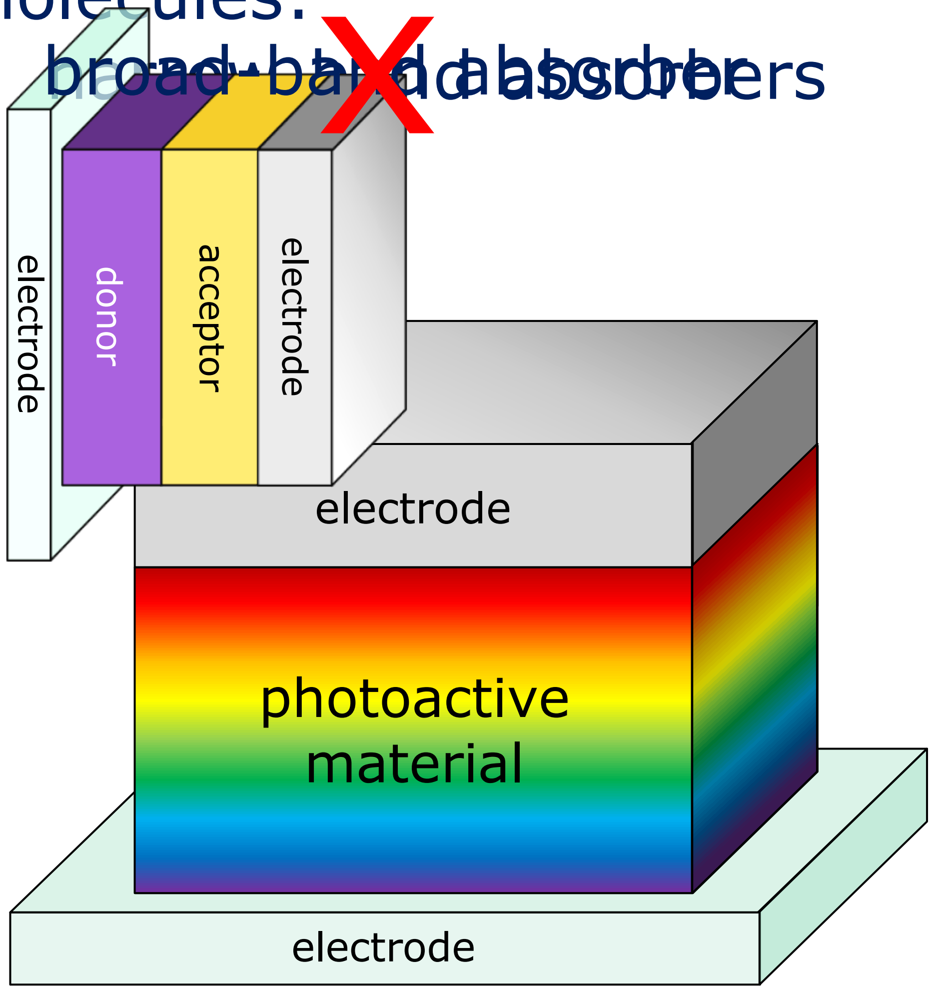
→ **negligible photocurrent!**

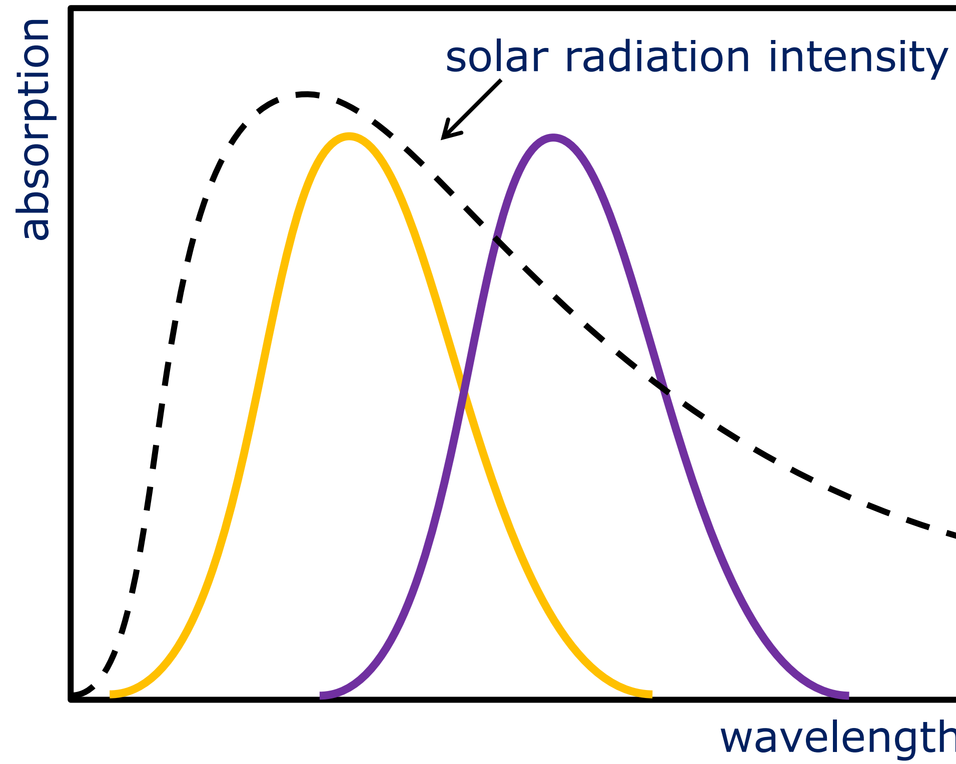
Organic Solar Cells

molecules:

broad-band absorber

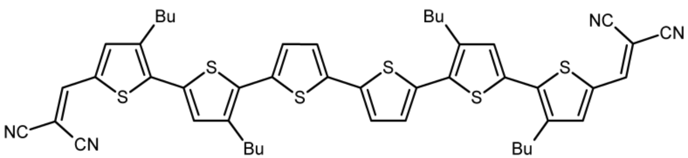
narrow-band absorbers





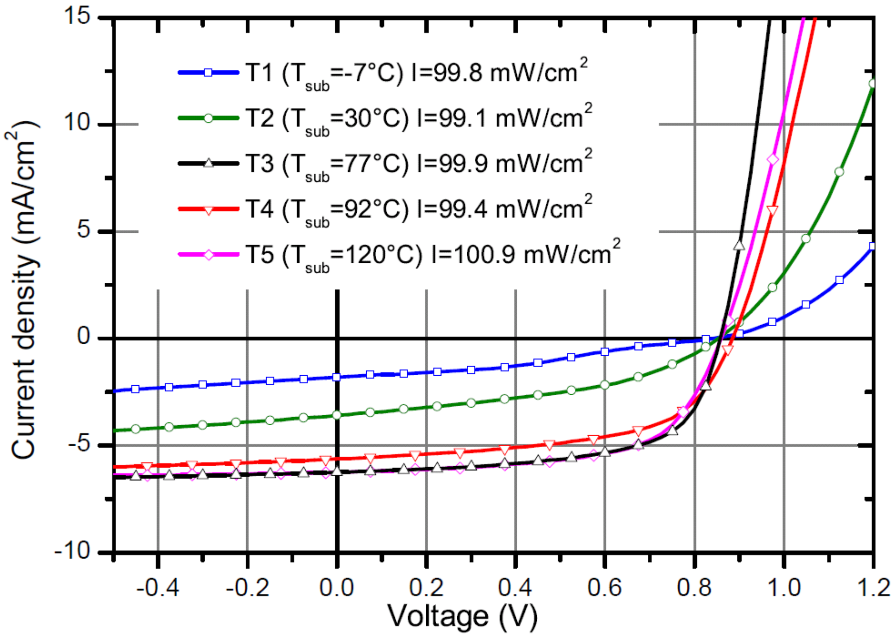
Substrate Heating Review

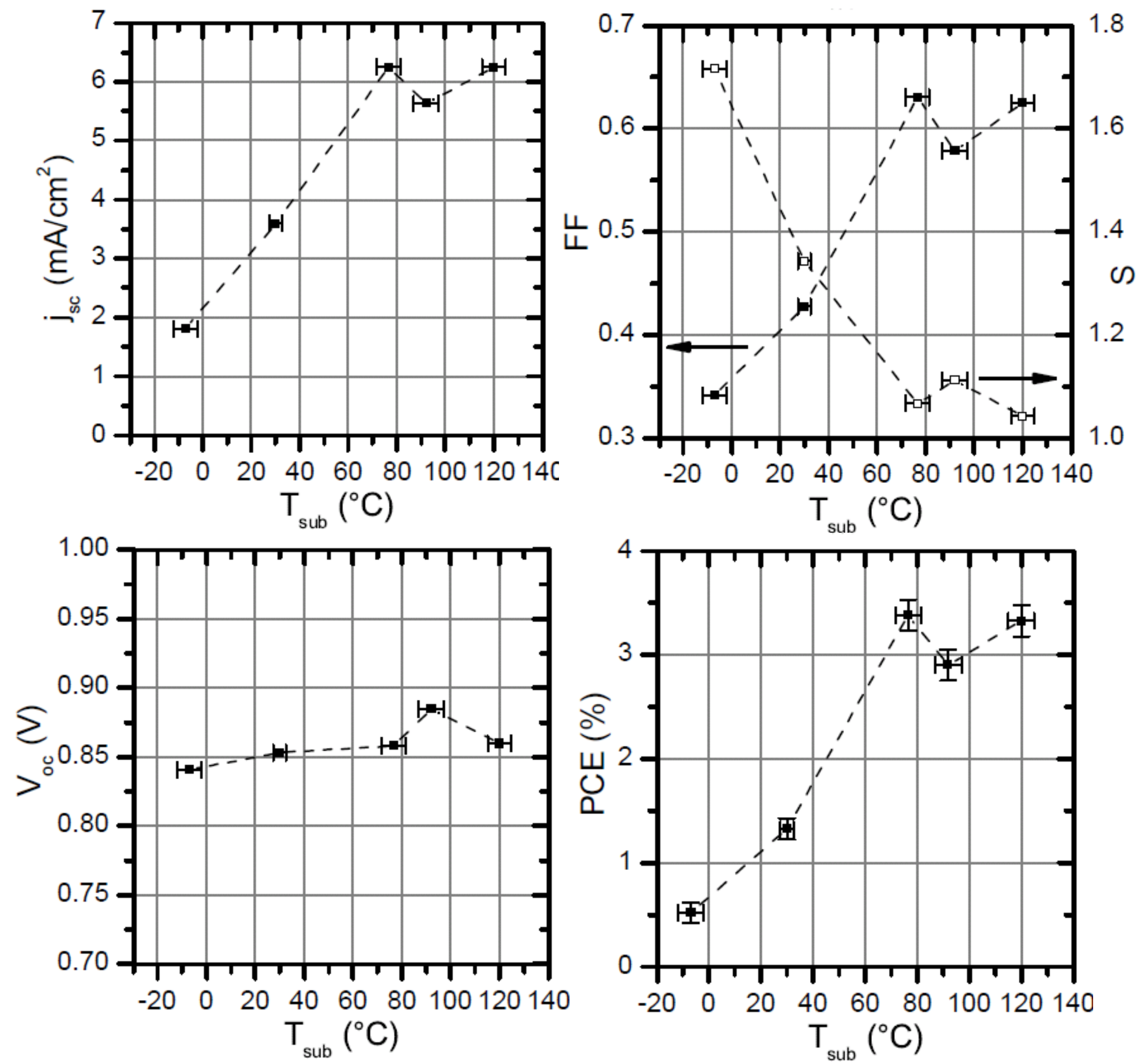
David Wynands:



DCV6T-Bu(1,2,5,6)

Similar results for DCV6T-Et(2,2,5,5)

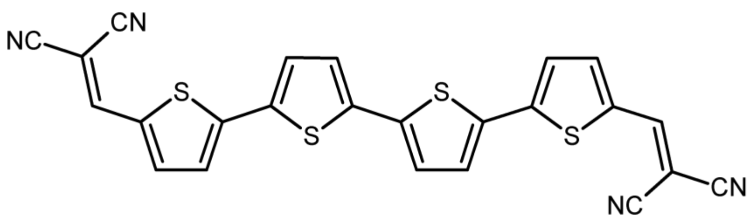


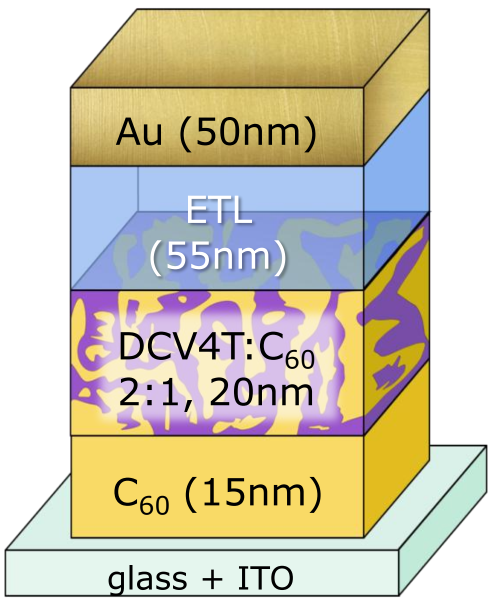


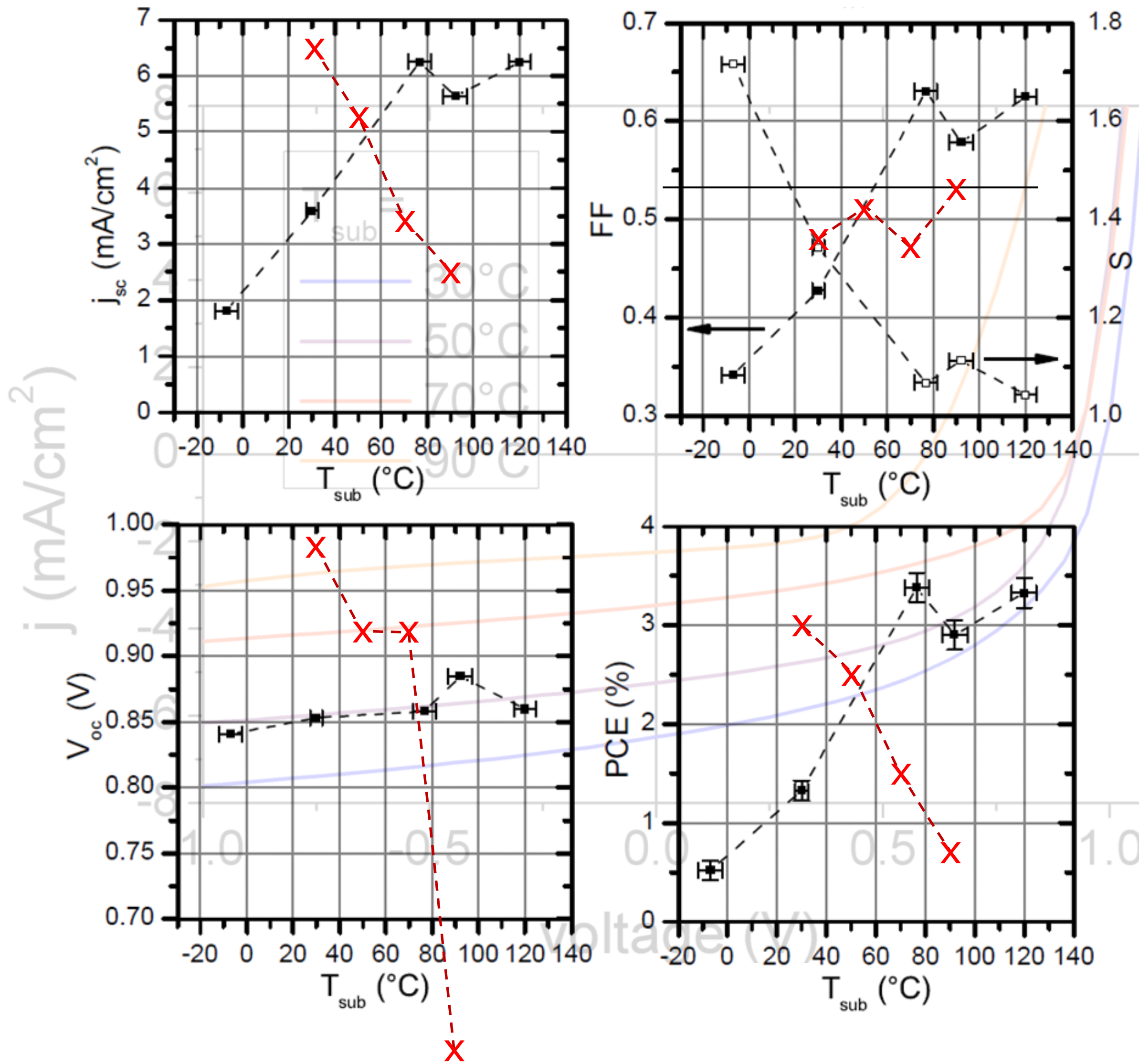
Substrate heating Like

Substrate Heating
Solar Cell Characteristics

DCV4T

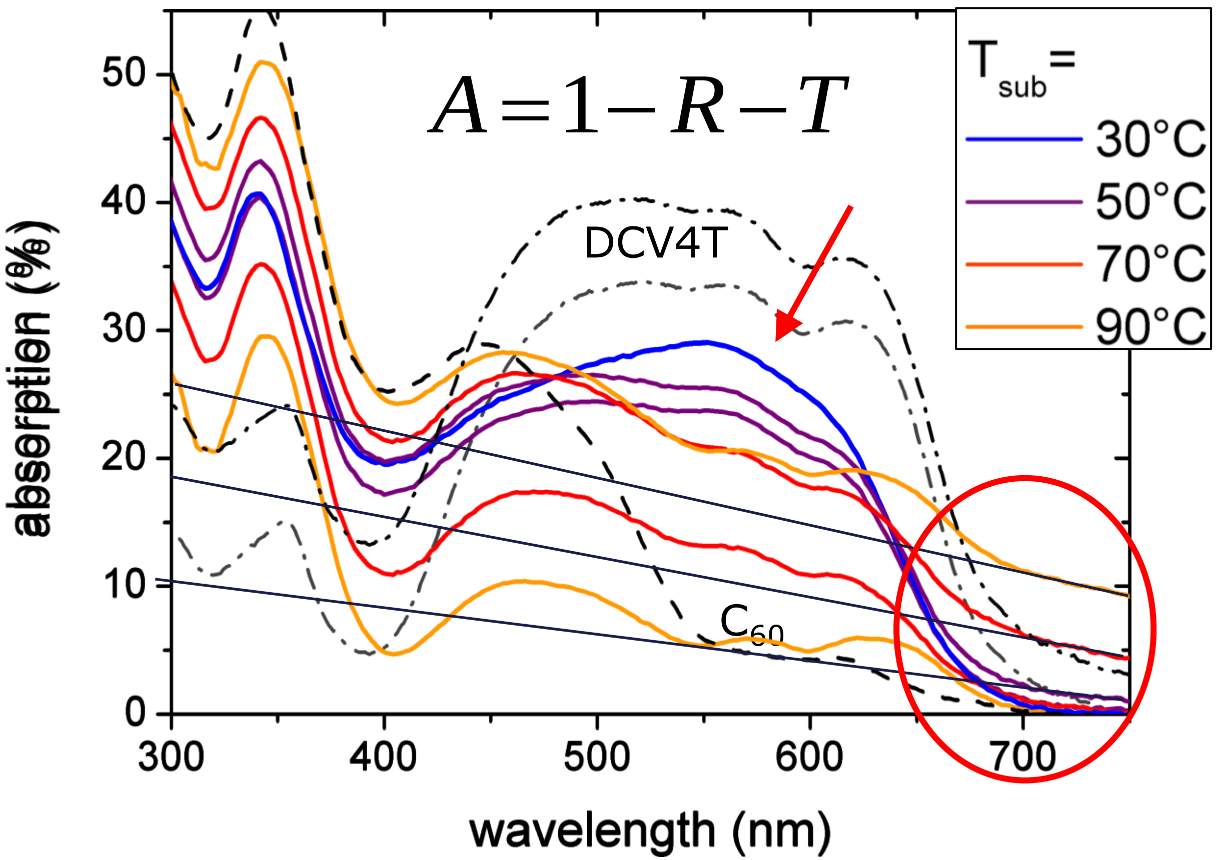


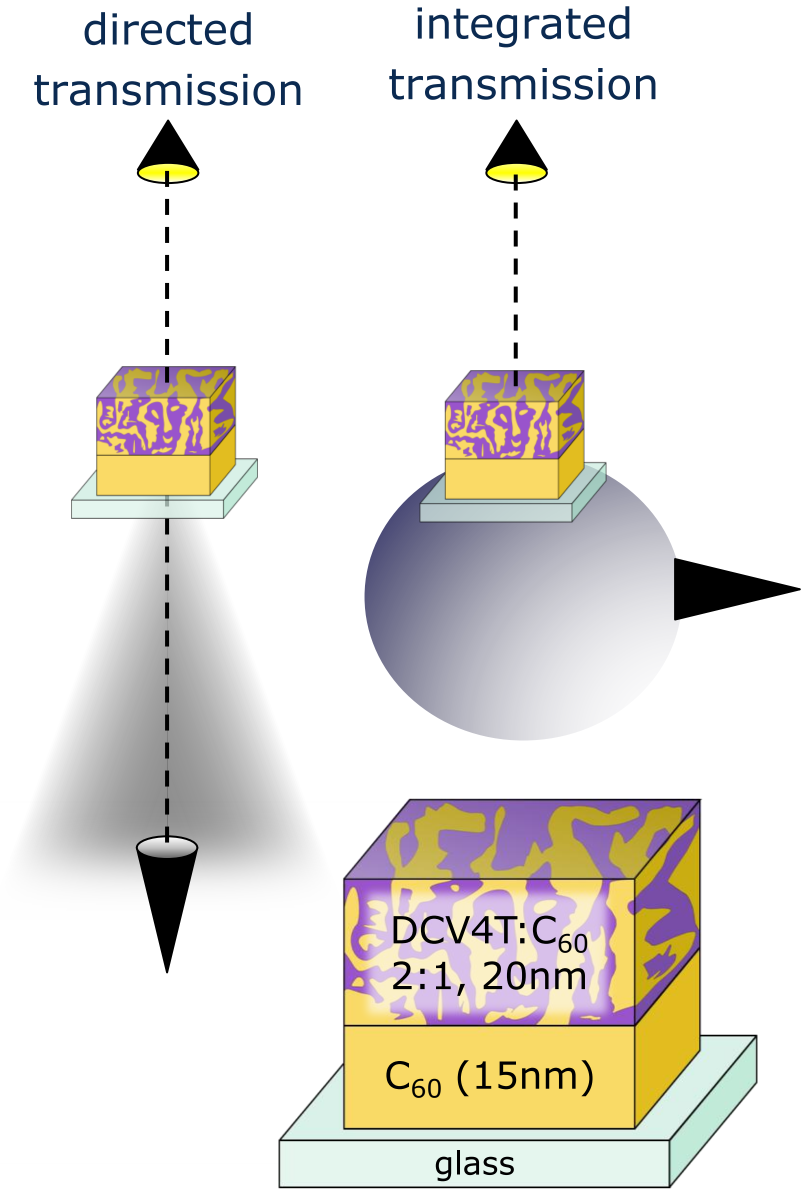




Substrate Heating
Blend Layer Absorption

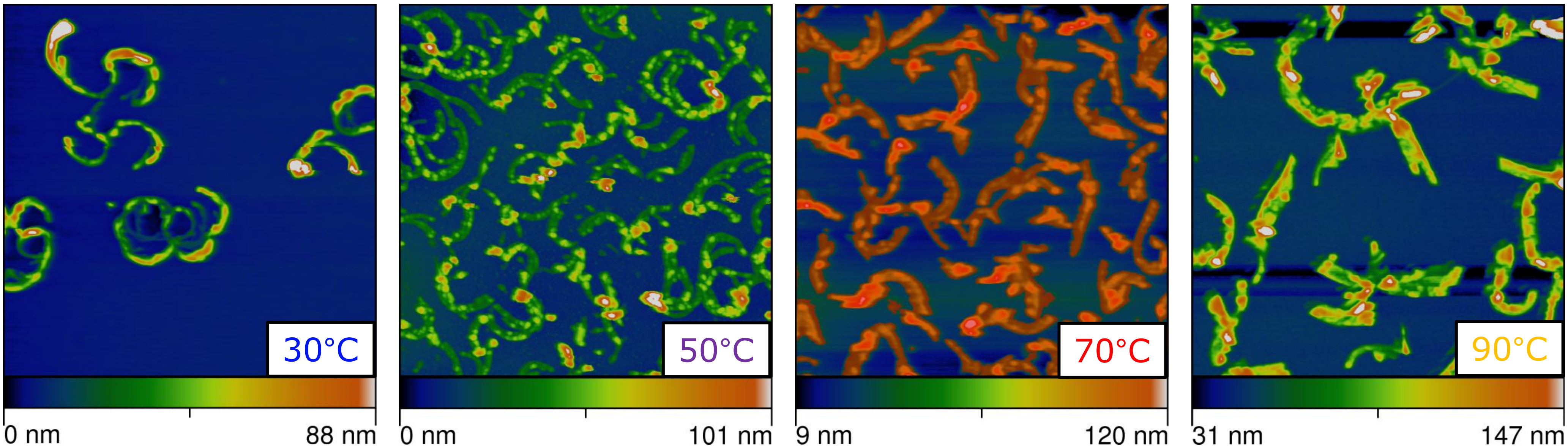
decrease in absorption → j_{sc}



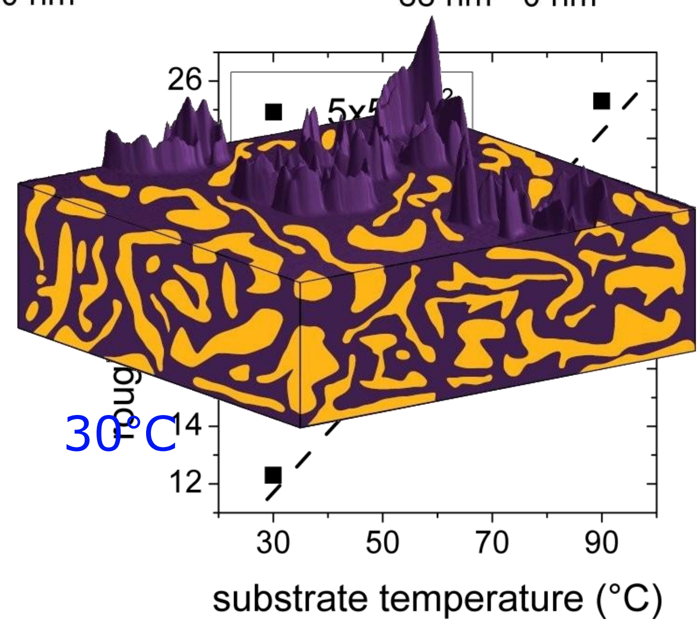


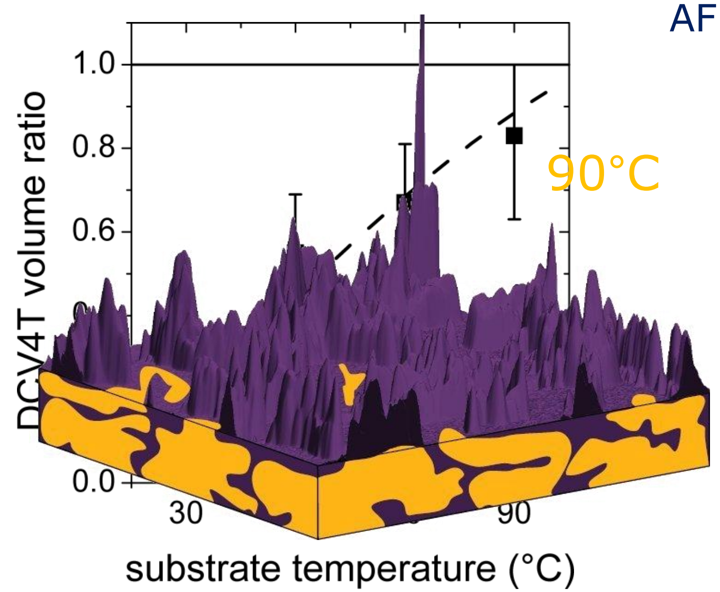
TECHNISCHE UNIVERSITÄT DRESDEN

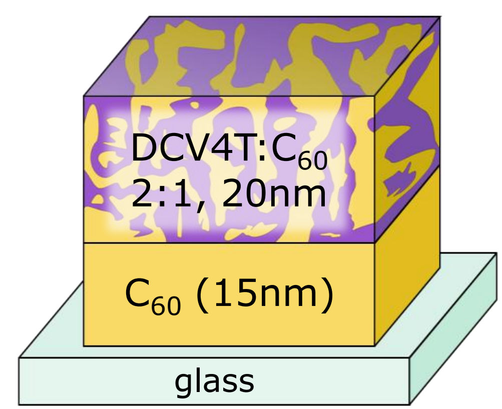
Substrate Heating
Blend Layer Topography (AFM)



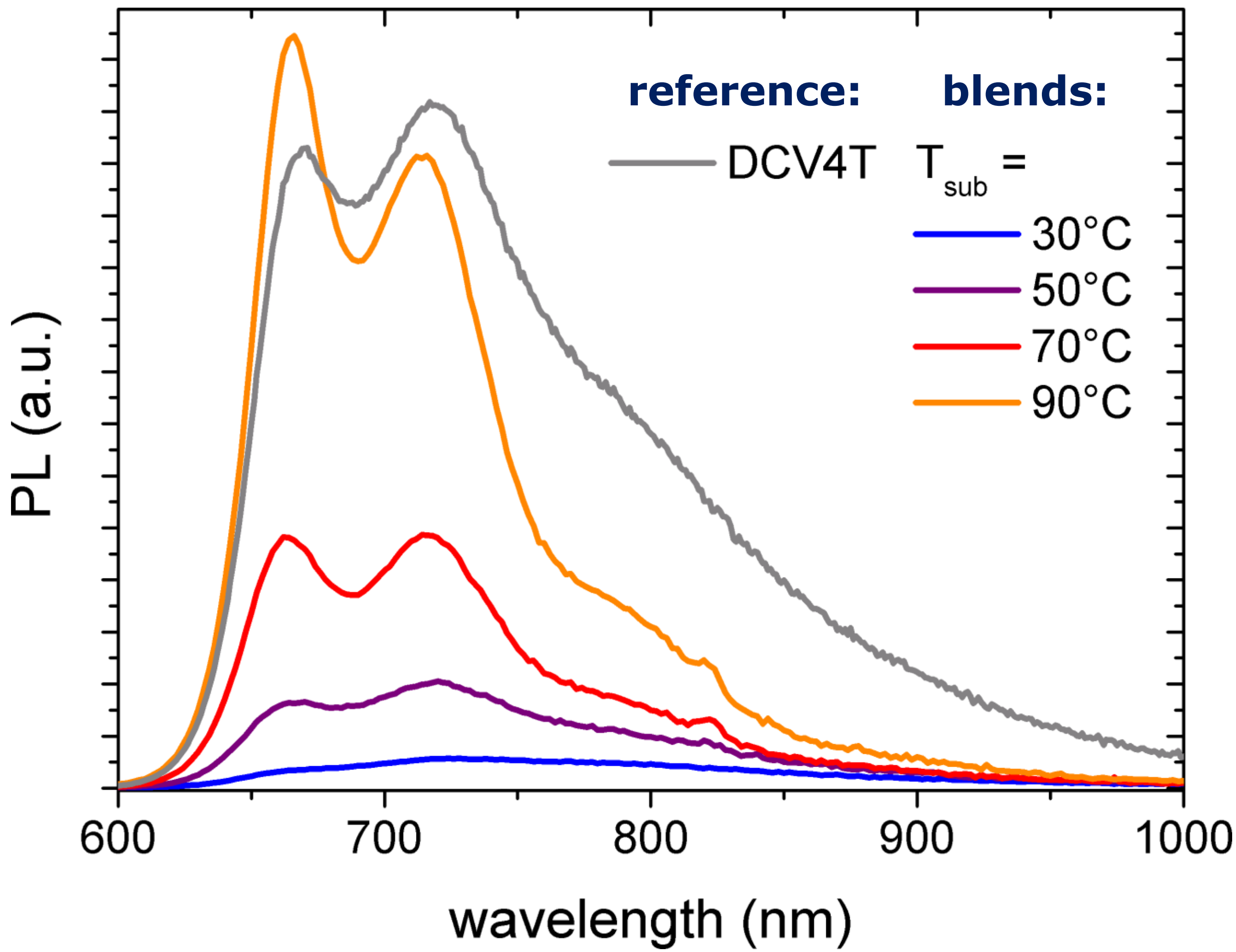
AFM-pictures taken by Franz Selzer

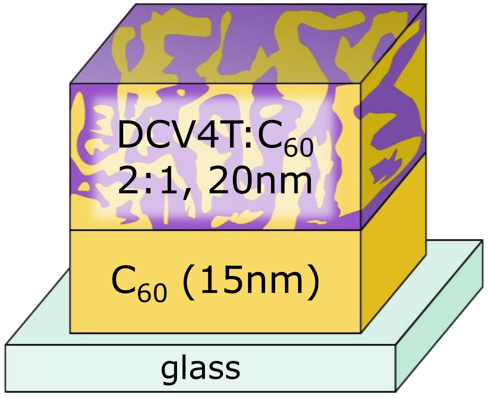


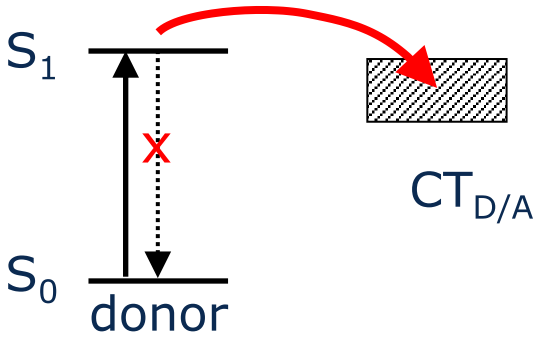




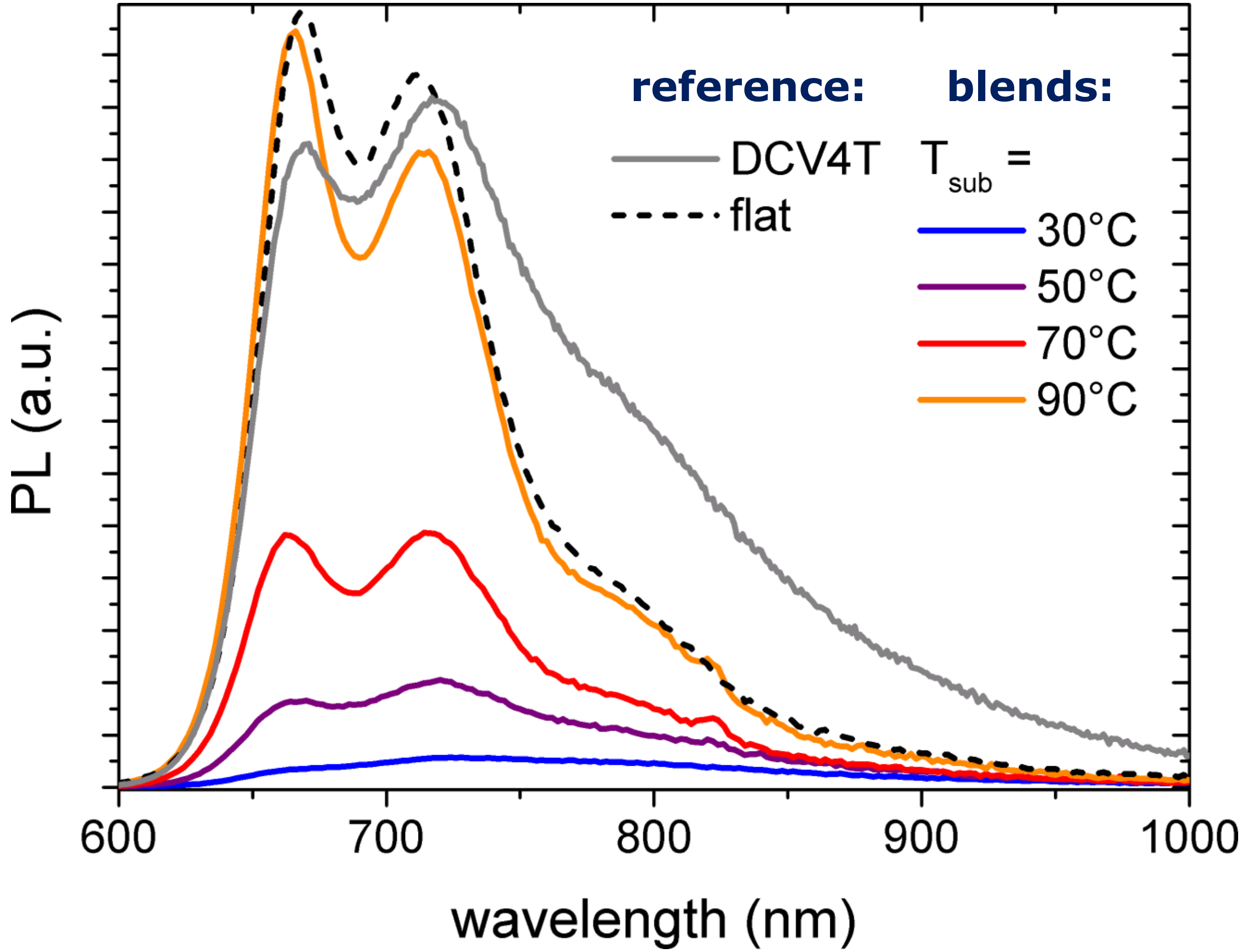
Substrate Heating
Photoluminescence Quenching

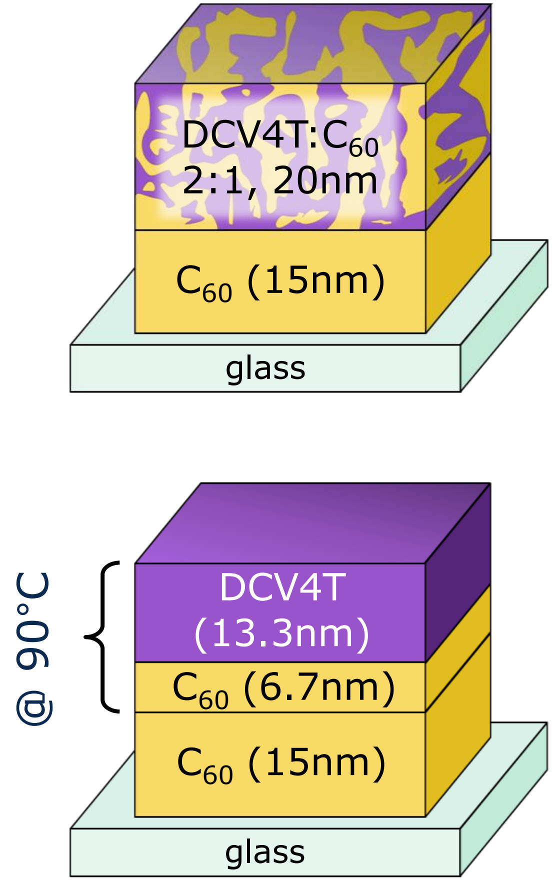






Substrate Heating
Photoluminescence Quenching





Substrate Heating
Structure Investigations (GIXRD)

- increased crystallinity of DCV4T and C_{60} phase : 30°C (blue) → 90°C (orange)
- Change in p-stacking direction (out-of-plane → in-plane reflections)
  = explanation for decrease in absorption (unfavorable molecule orientation to incoming light)