Morphology of bulk heterojunction systems for polymer-based photovoltaics

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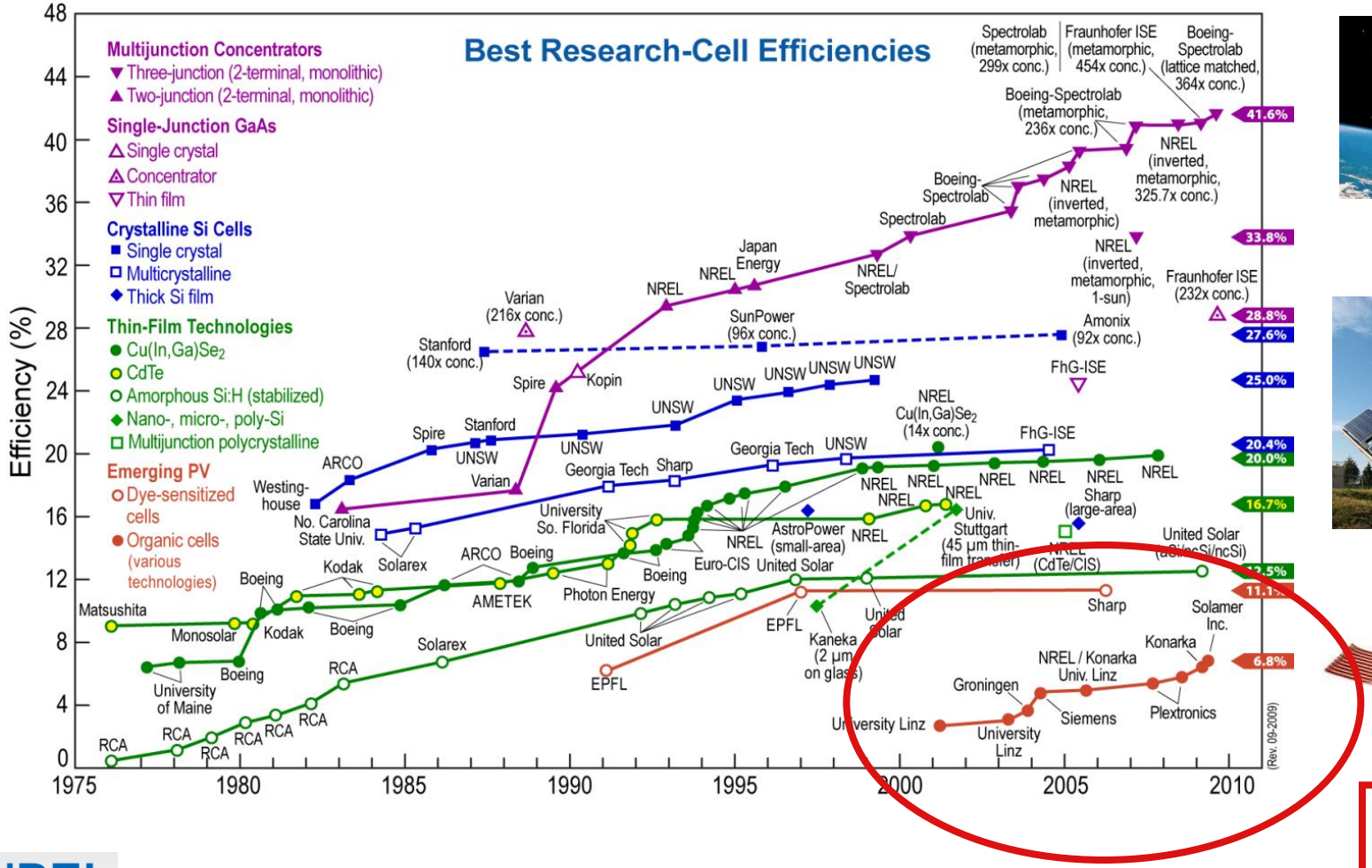
Conventional photovoltaics

First Solar Inc.

solarpaneltips.org

- energy-consuming production
- high vacuum treatment needed
- mechanically inflexible
- expensive encapsulation

Efficiencies



spacetoday.org

solarpaneltips.org

konarka.com

8.3 % in 2010

NREL NATIONAL RENEWABLE ENERGY LABORATORY

2008 Solar Technologies Market Report, Jan 2010

Polymer-based technology

konarka.com

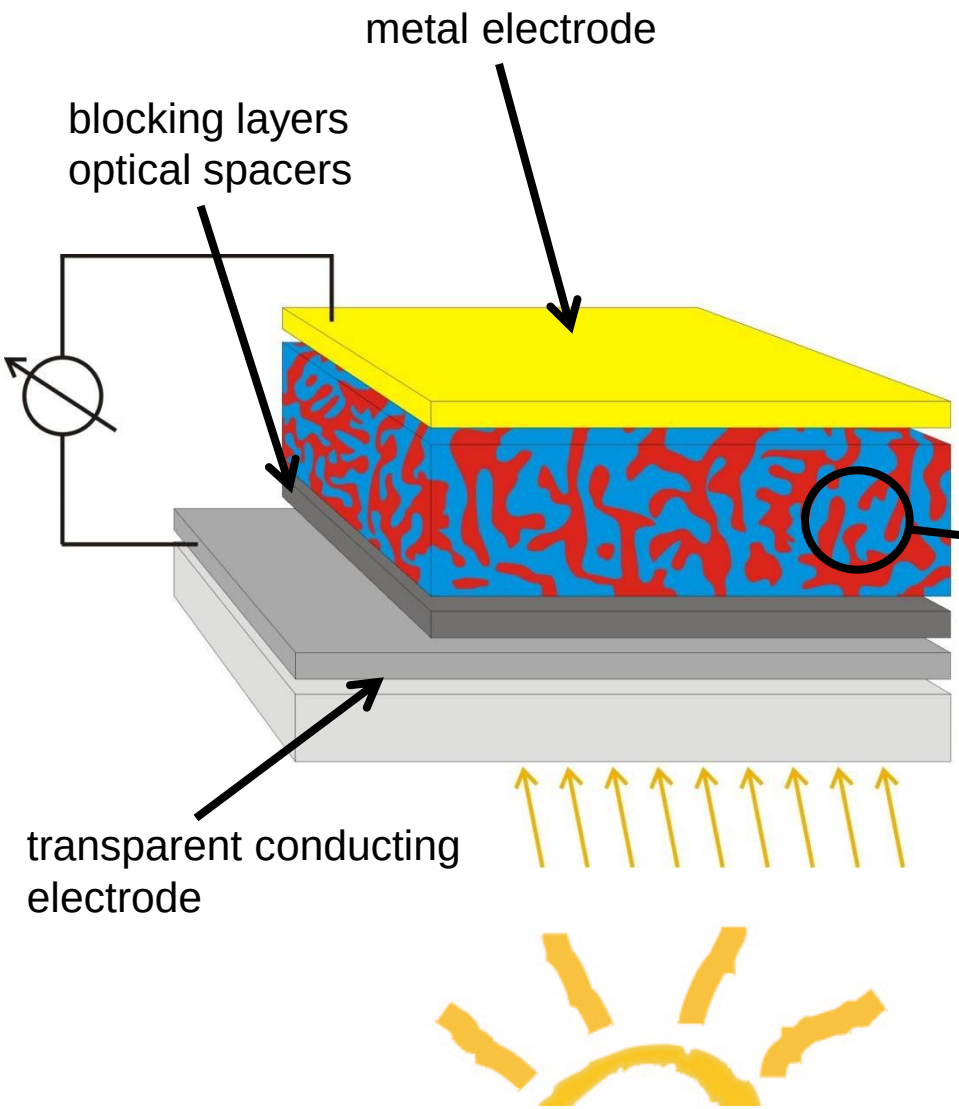
konarka.com

konarka.com

konarka.com

solopower.com

Organic solar cell

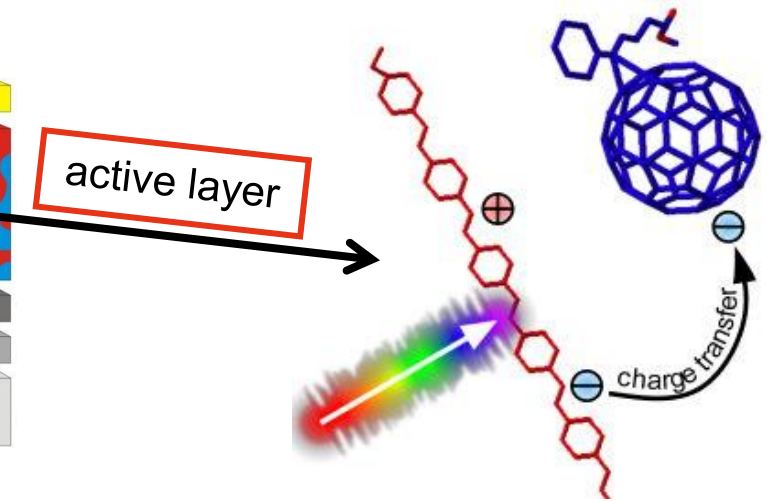


organic materials

i) high absorption coefficient

ii) high exciton binding energy (~ 1 eV)

□charge carrier separation at interfaces

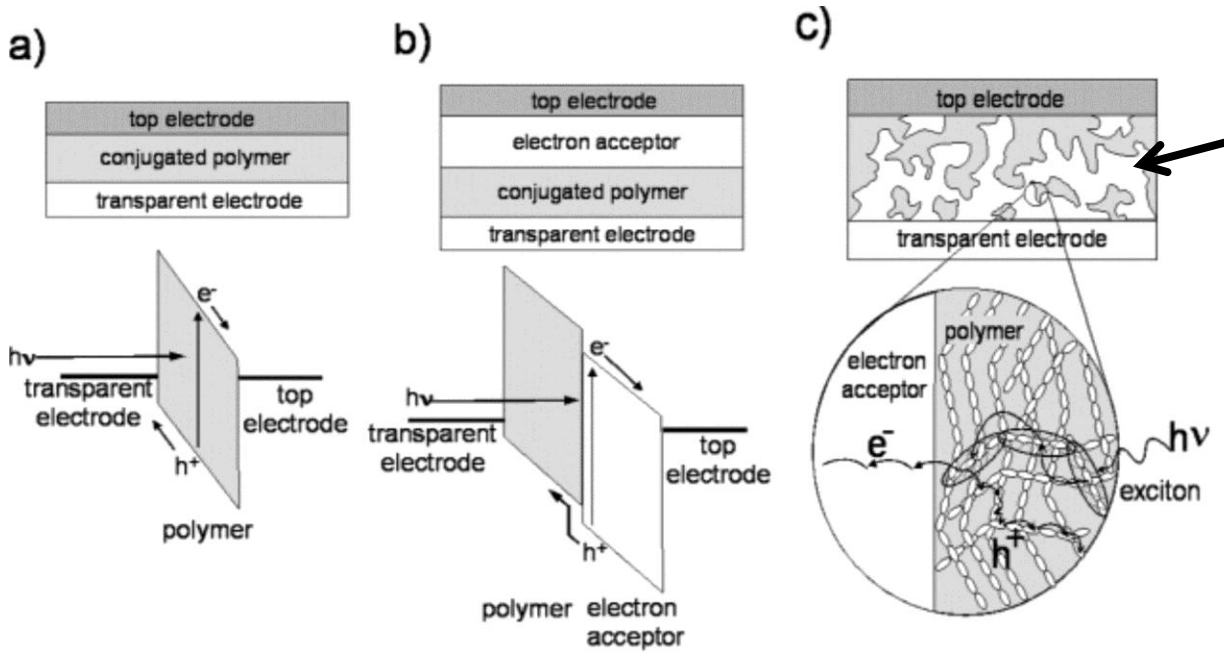


short exciton diffusion length (~ 10 nm)

□performance strongly depending on morphology

G. Yu et al., *J. Appl. Phys.*, 78, 4510 (1995)

Morphologies



bulk heterojunction

self assembly process

- chemical structure
- solvent
- blending ratio
- post production treatments

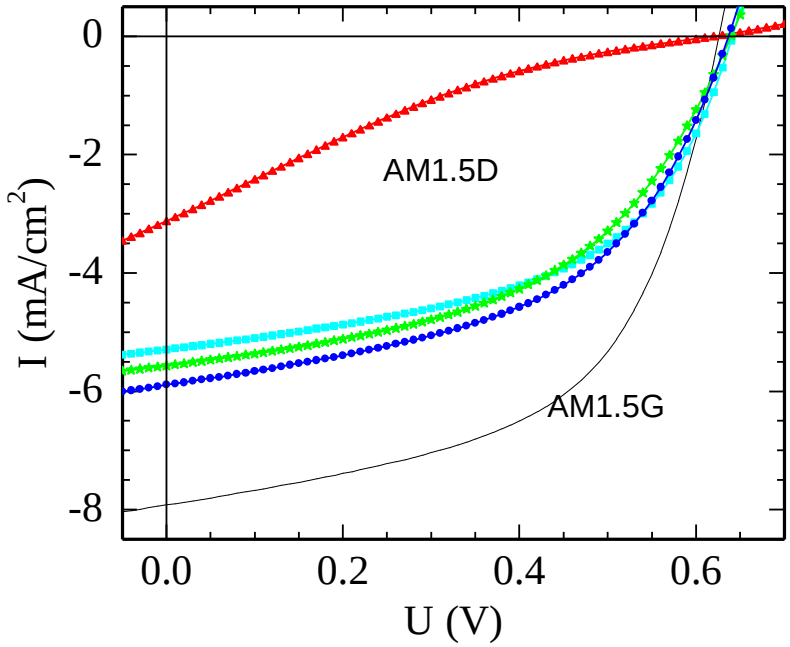
interfacial area ~ free charge carrier creation

efficiency

K. M. Coakley et al. *Chem. Mater.,16,* 4533 (2004).
M. A. Ruderer et al. *Soft Matter*, 7, 5482 (2011).

Solvent dependent morphologies

electronic characteristics

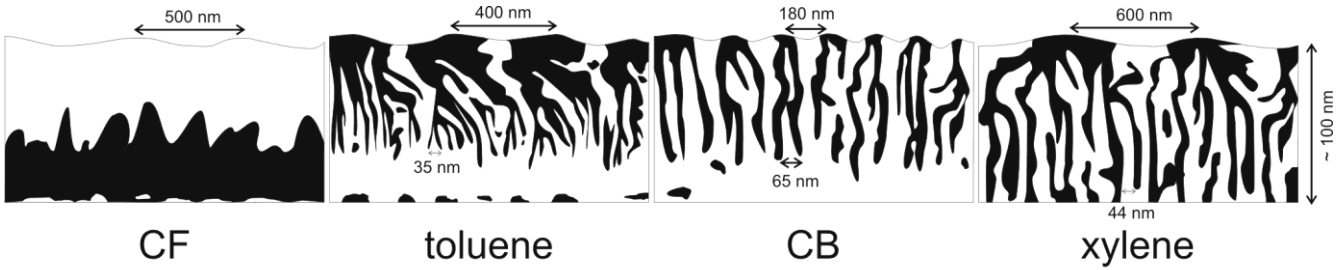


1. high interfacial area

influence of blending ratio

2. high conductivity

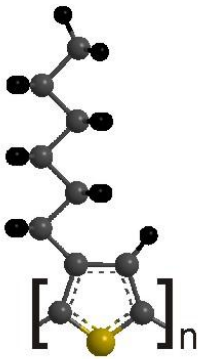
polymer crystallinity



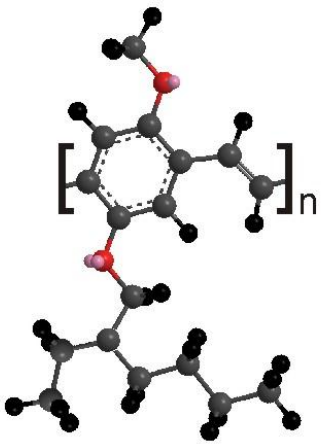
Poster: Shuai Guo

M. A. Ruderer et al. *Adv. Funct. Mater.* (2011), in press.

morphology of bulk heterojunctions



blending ratio



P3HT

poly(3-hexylthiophene-2,5-diyl)

M_w = 16 kg/mol

MEH-PPV

poly[(1-methoxy)-4-(2-ethylhexyloxy)-p-phenylenevinylene]

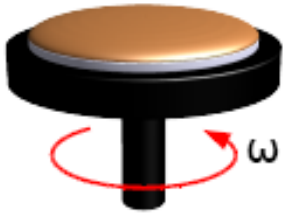
M_w = 2600 kg/mol

M.A. Ruderer et al. *ChemPhysChem*, 10, 664 (2009).

Blending ratio

dissolve polymer in chloroform with different blending ratios

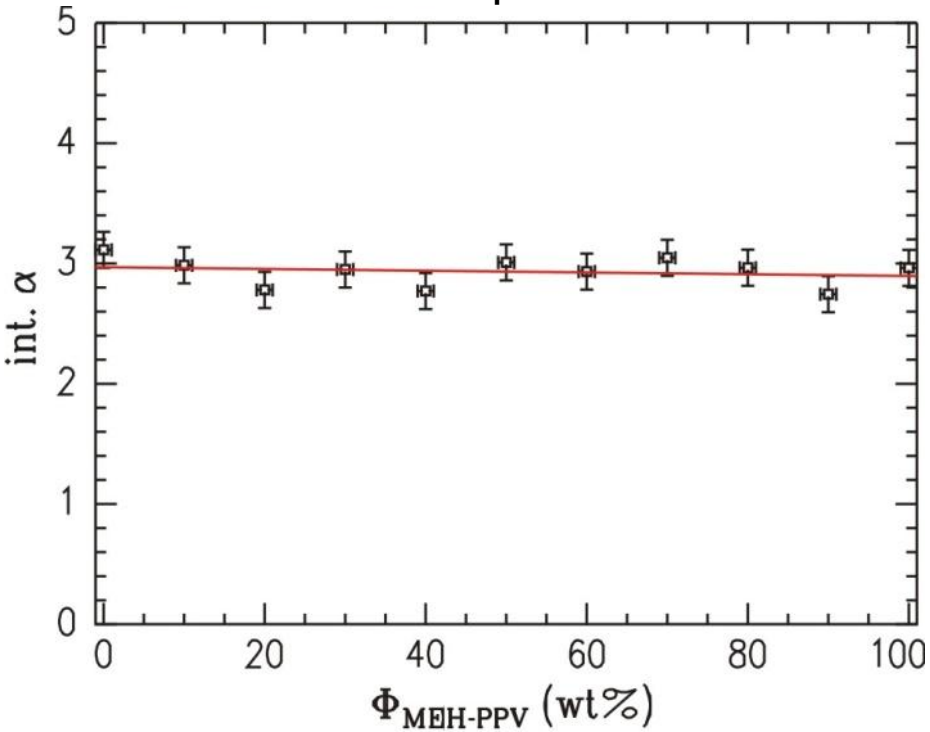
thin films via spin coating



substrates:

acidic cleaned glass slides

absorption

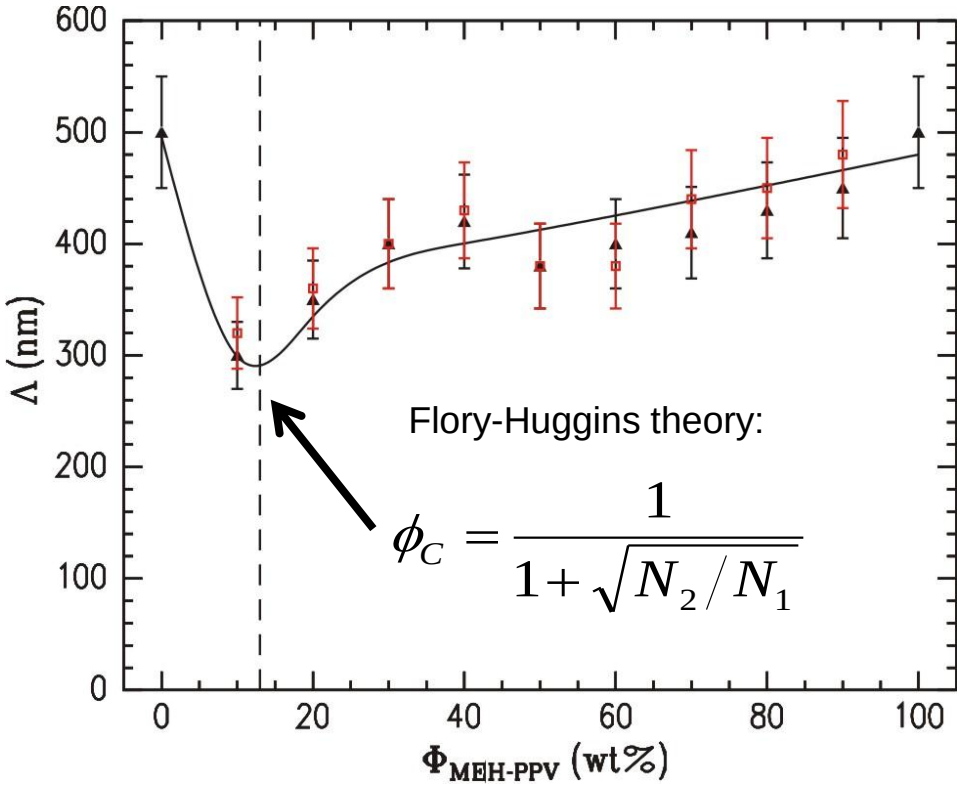


- homogeneous polymer films with constant thickness

- blending ratio independent absorption
- no preferred blending ratio

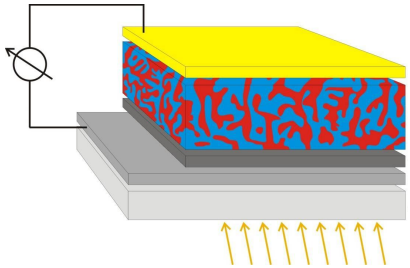
Blending ratio

lateral inner film structure



Flory-Huggins theory:

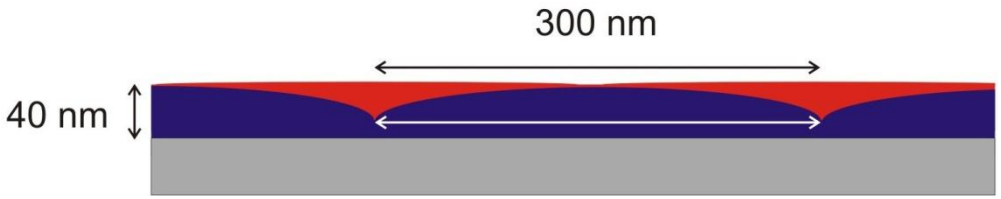
$$\phi_C = \frac{1}{1+\sqrt{N_2/N_1}}$$



accessible with scattering techniques (GISAXS)

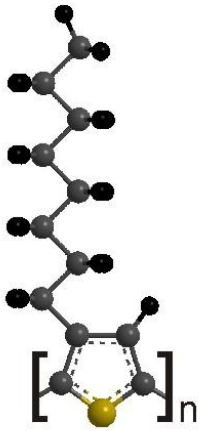
- 10 nm – 2 µm

- good estimation of minimal structure size with Flory-Huggins theory



M.A. Ruderer et al. *ChemPhysChem*, 10, 664 (2009).

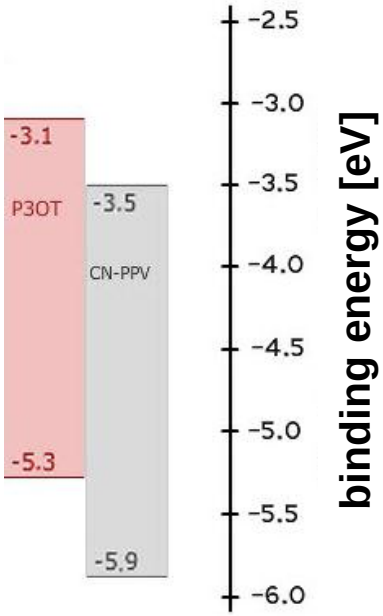
crystallinity in bulk heterojunctions

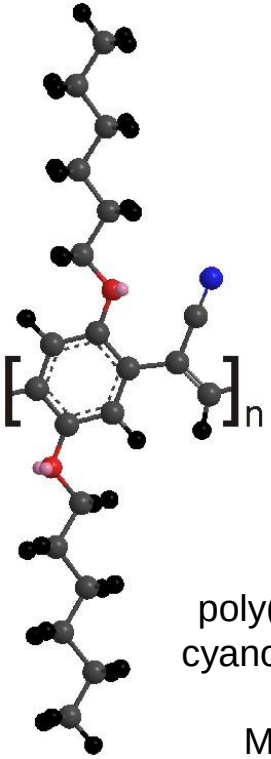


P3OT

poly(3-octylthiophene-2,5-diyl)

M_w = 34 kg/mol





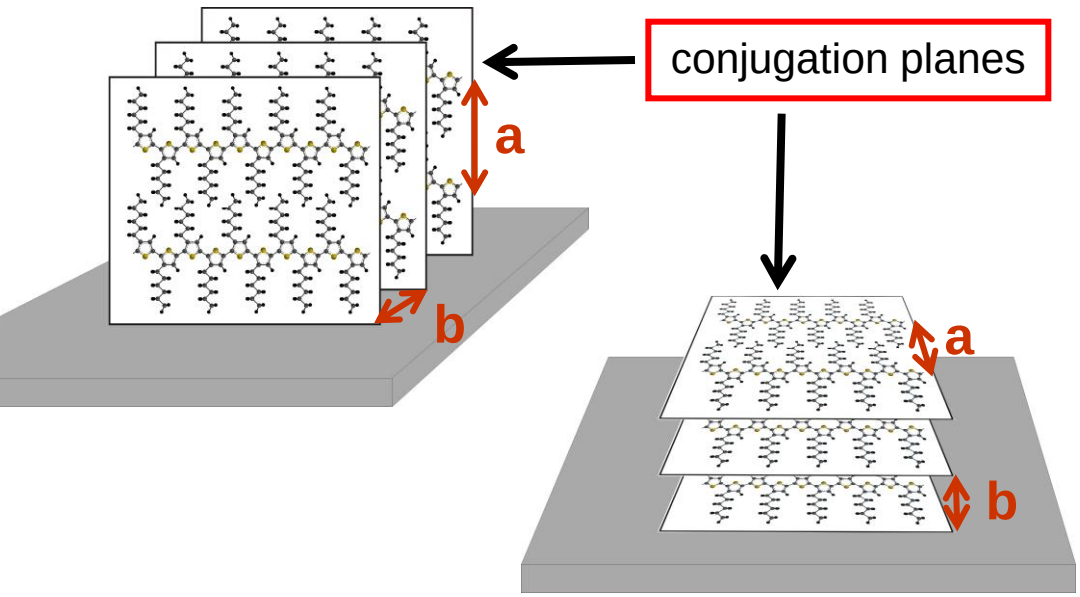
CN-PPV

poly(2,5-di(hexyloxy) cyanoterephthalyliden)

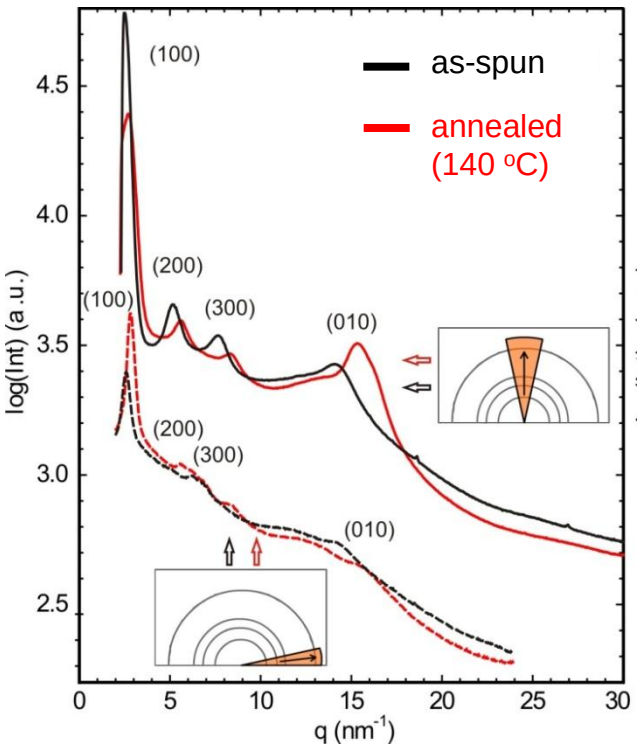
$M_w \approx$ 29 kg/mol

M.A. Ruderer et al. *J. Phys. Chem. B*, 114, 15451 (2010).

Crystallinity



P3OT



molecular arrangement/crystalline structure

- accessible with scattering techniques (GIWAXS)
- resolution 2 Å – 5 nm

increased crystallinity

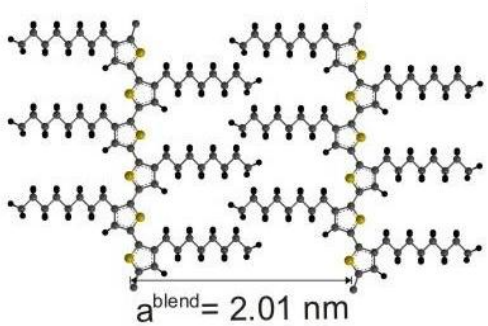
higher charge carrier mobility

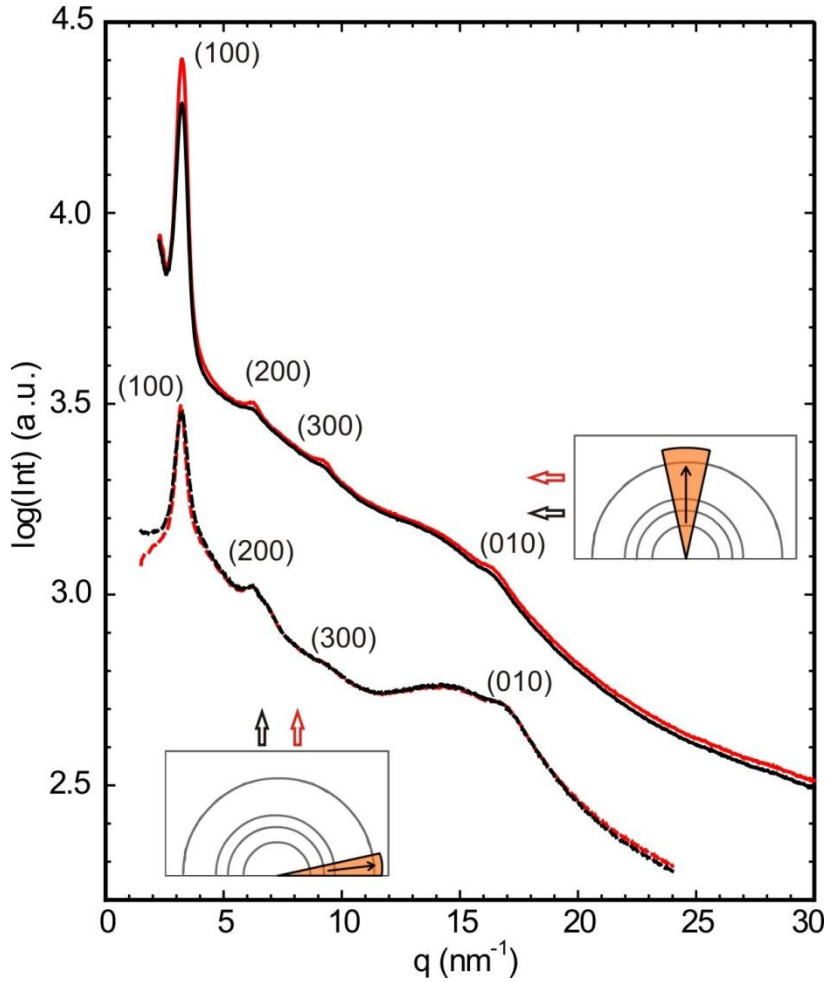
similar results for CN-PPV

Bulk Heterojunction Film

P3OT:CN-PPV

P3OT





no signal from CN-PPV

blending retards crystallization □ low performance

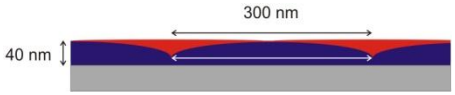
M.A. Ruderer et al. *J. Phys. Chem. B*, 114, 15451 (2010).

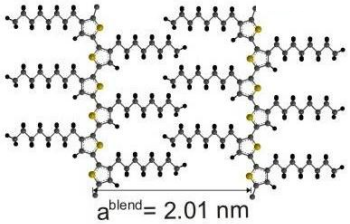
Summary

a) organic solar cells preparation
self assembly process

b) minimal structure size at critical blending ratio
predicted by theory

c) retardation of crystallization due to blending
low photovoltaic performance





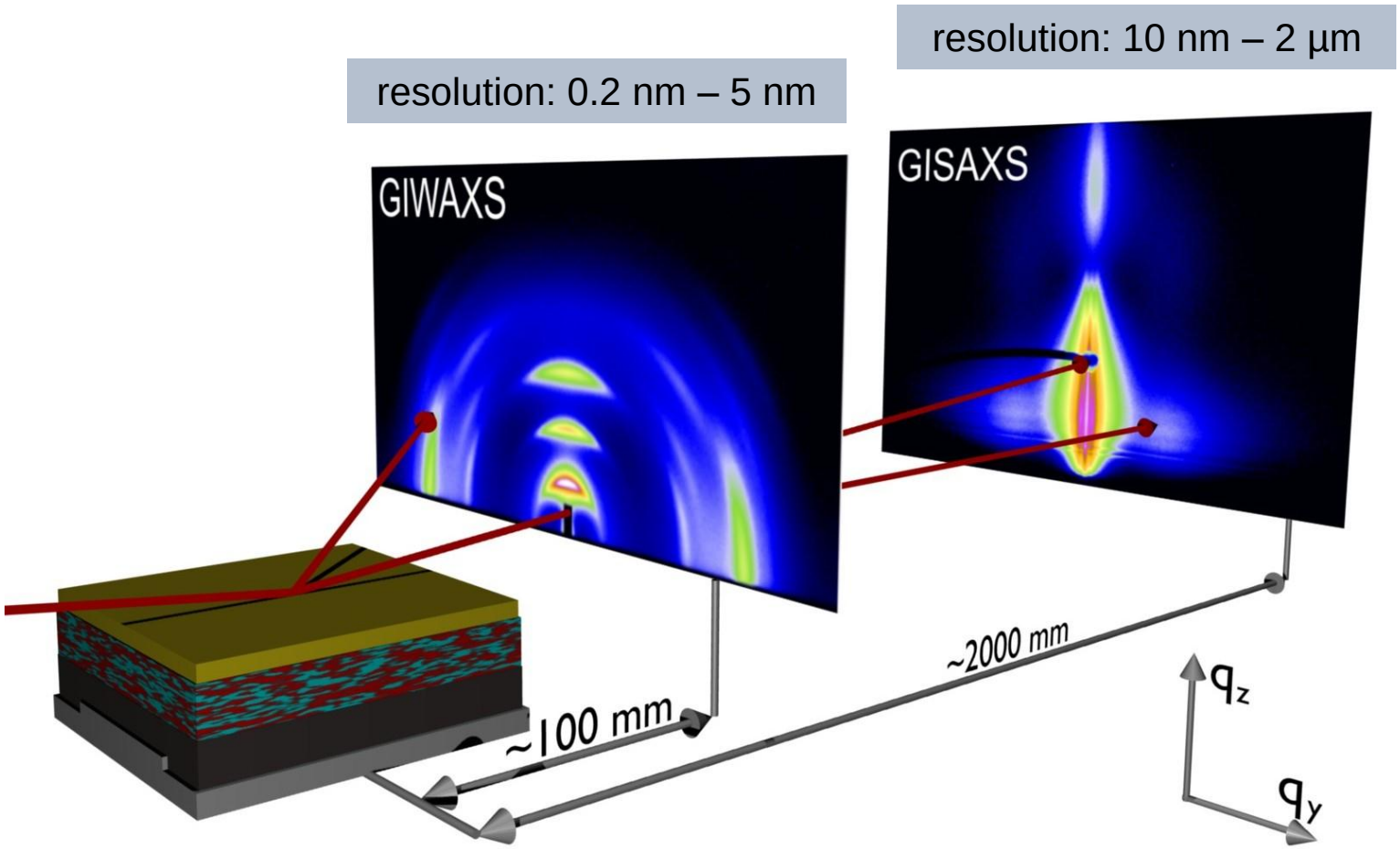
Internal morphology is crucial for photovoltaic performance!

Funding:

COMP INT Materials Science of Complex Interfaces

Elitenetzwerk Bayern

Bavarian State Ministry of Science, Research and Art
International Graduate School “Material Science of Complex Interfaces“

Thank you!

Grazing incidence wide/small angle scattering