Ink-jet printing of polymer solar cells

Plastic Optoelectronics workshop

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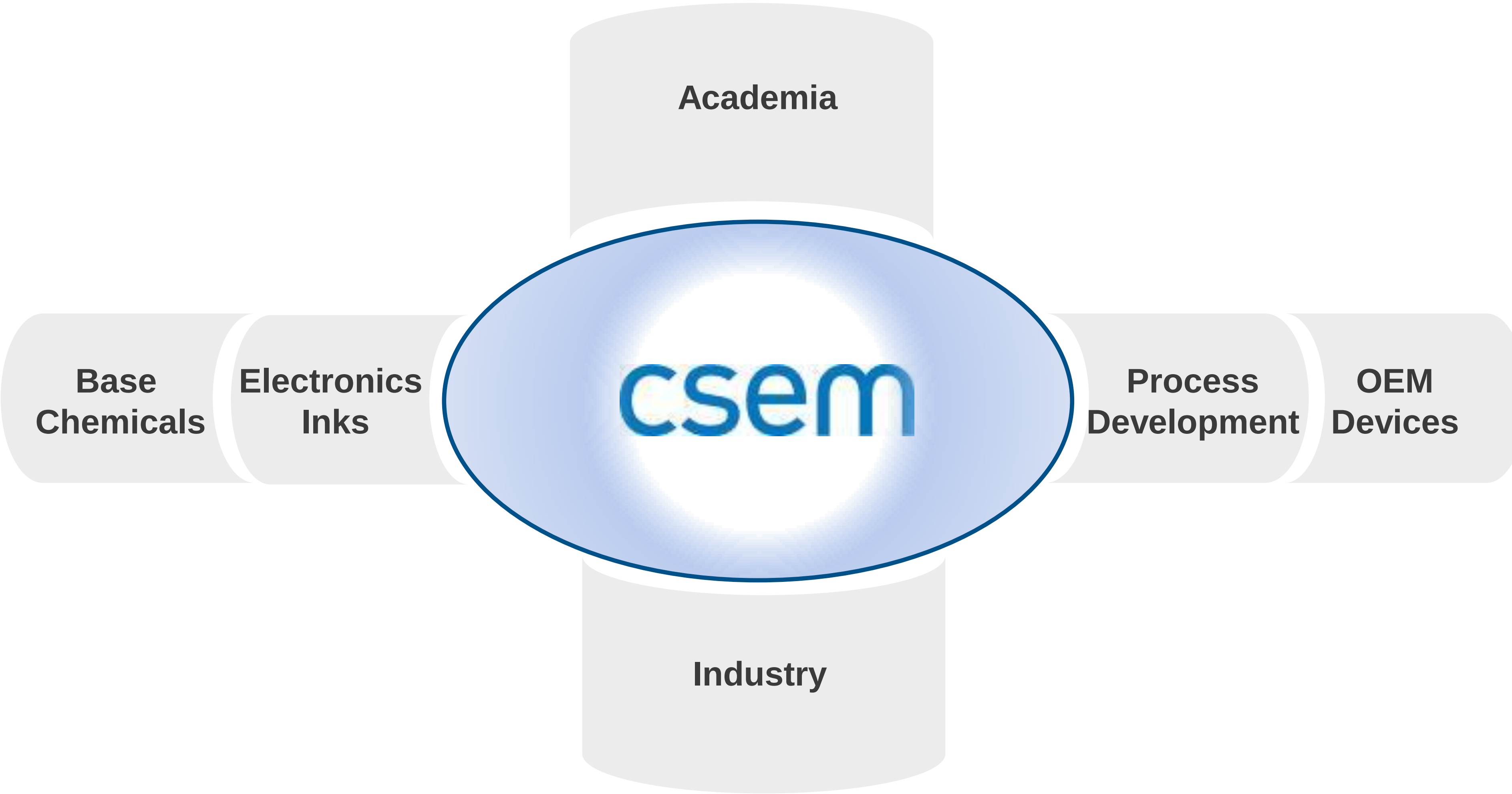
Section Polymer Optoelectronics, CSEM Basel, Switzerland

Outline

- CSEM
  - Group Polymer Optoelectronics

- Inkjet printing polymer solar cells
  - Novel low bandgap polymer
  - Solvent mixtures
  - Obtaining good uniformity
  - Efficient inkjet printed devices

Role of CSEM in organic electronics



Polymer Optoelectronics

- **Material & Device Optimization**

  Solution-processed
  - OLED
  - OFET
  - OPV

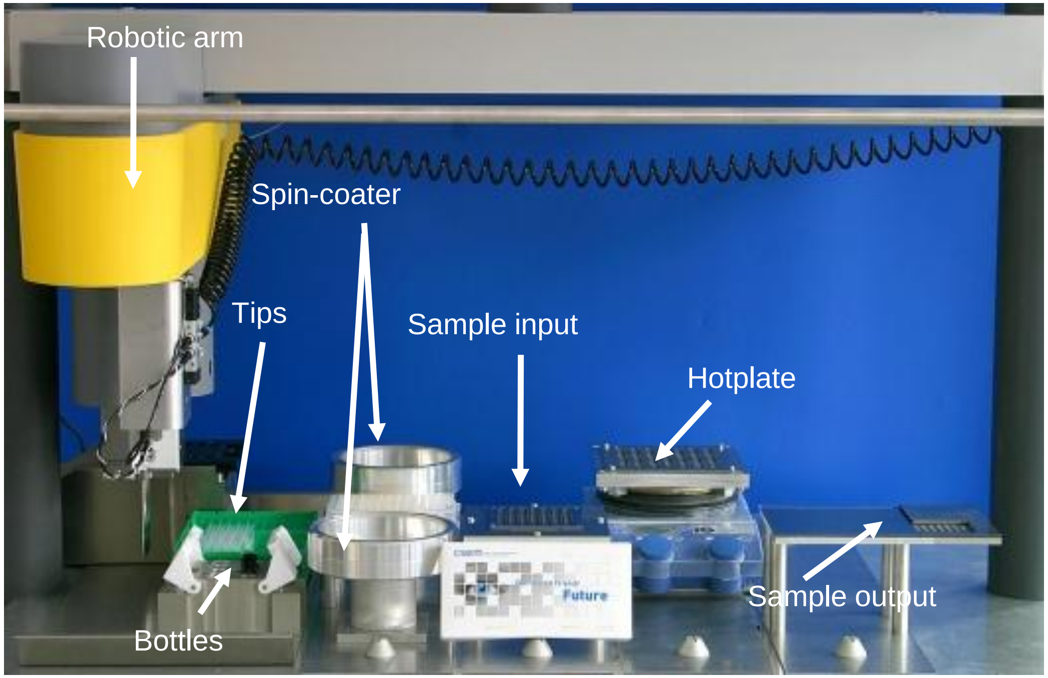
- **Integrated Organic Optoelectronic Systems**

  oLEDs & oPDs & oFETs

- **Additive Print Process Development**
  - Screen printing
  - Gravure printing
  - *Inkjet printing*

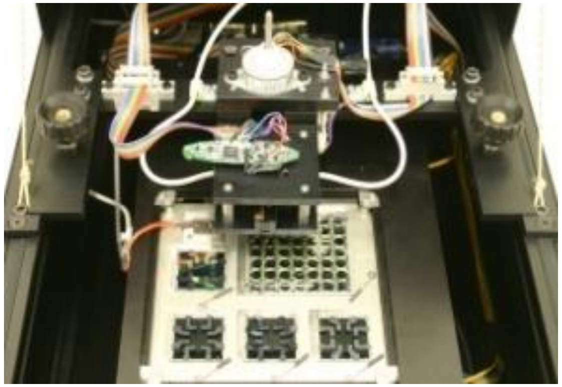
Polymer Optoelectronics

Automated device fabrication tool

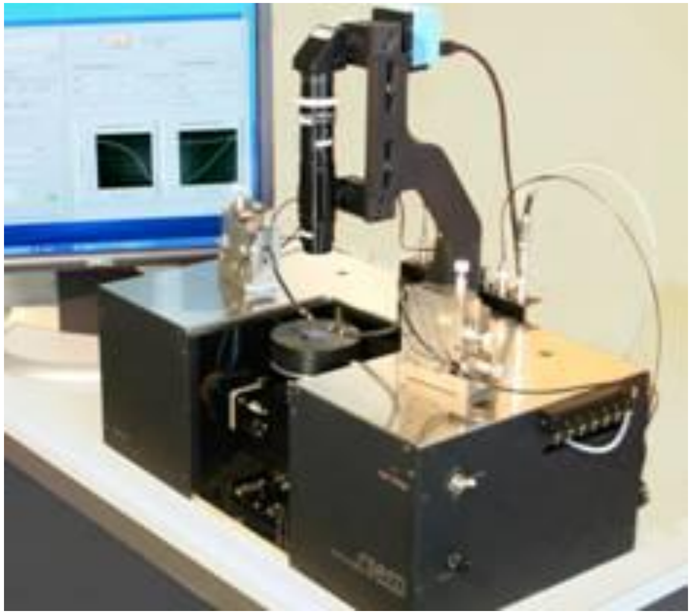


- High throughput fabrication
- Combinatorial testing

Automated OLED and OPV characterisation tool

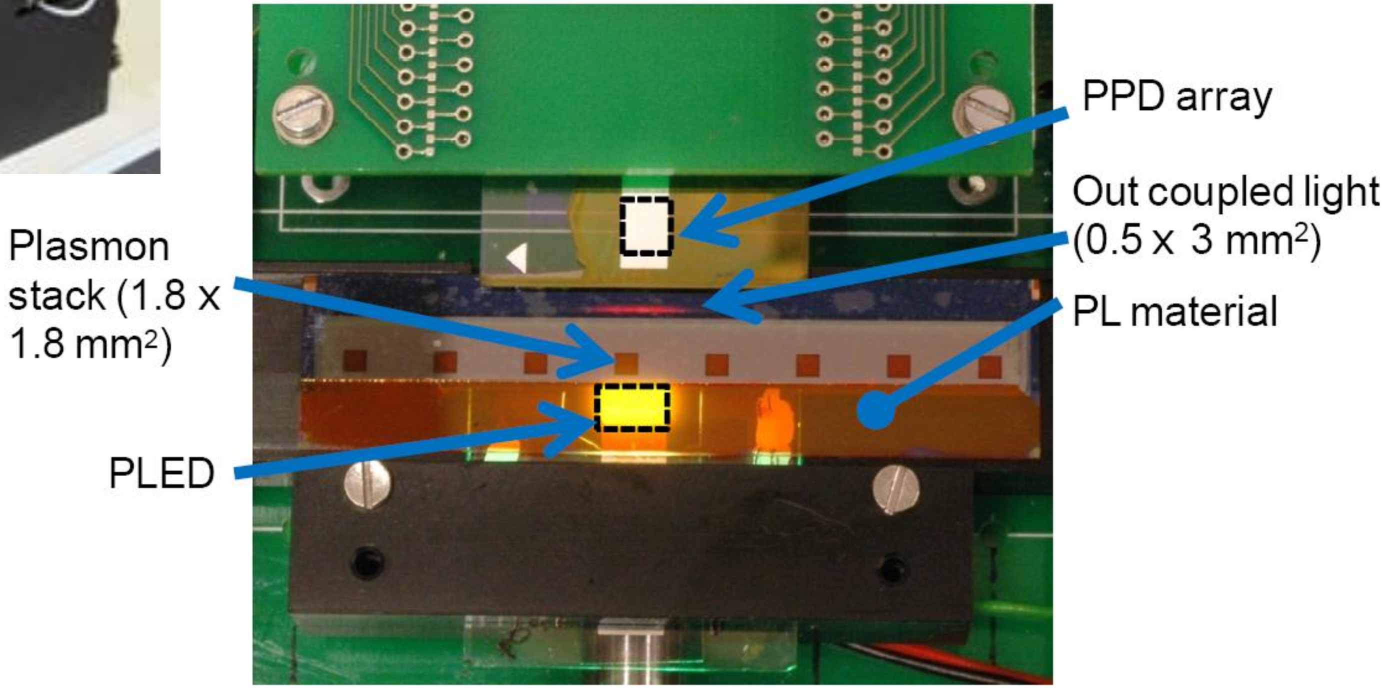


Polymer Optoelectronics



Automated OFET characterization tool

Integrated optoelectronic biosensors



Inkjet Printed OPV

Why inkjet printing

- Why inkjet printing?
  - *established technology,*
  - *printability in ambient conditions,*
  - *output (up to 150 m^2/h),*
  - *low cost,*
  - *flexibility,*
  - *digital patterning,*
  - *mass customization*

POLYMOL project APOLLO

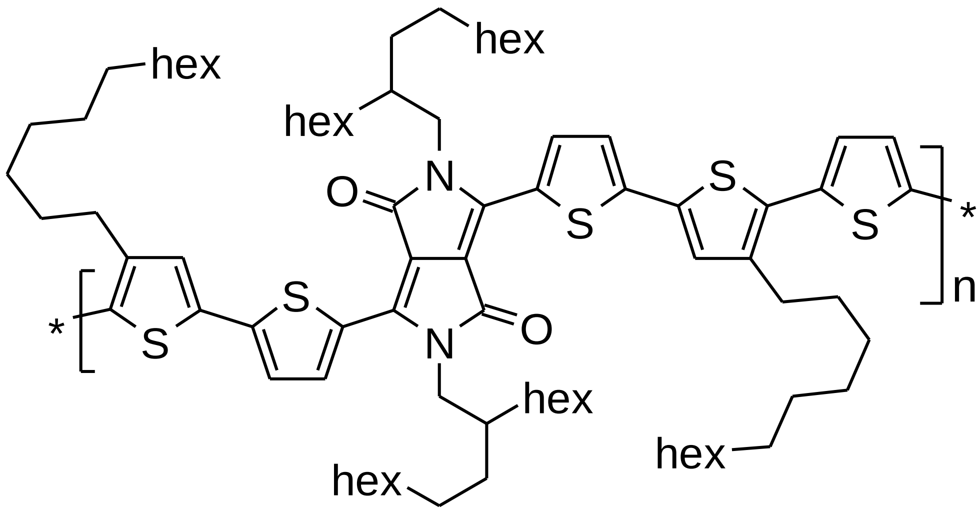
- Project goal: Inkjet printed solar cells with efficiency >5%.

- Project partners : BASF, ZHAW (Zurich University of Applied Sciences), TU Eindhoven, Universitat Jaume I

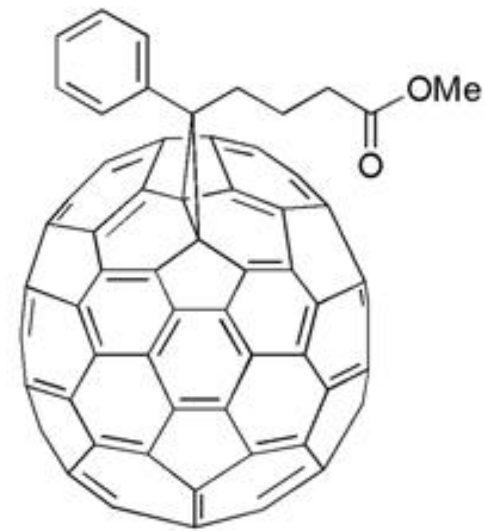
- Role of CSEM in APOLLO:

Materials

PT5DPP

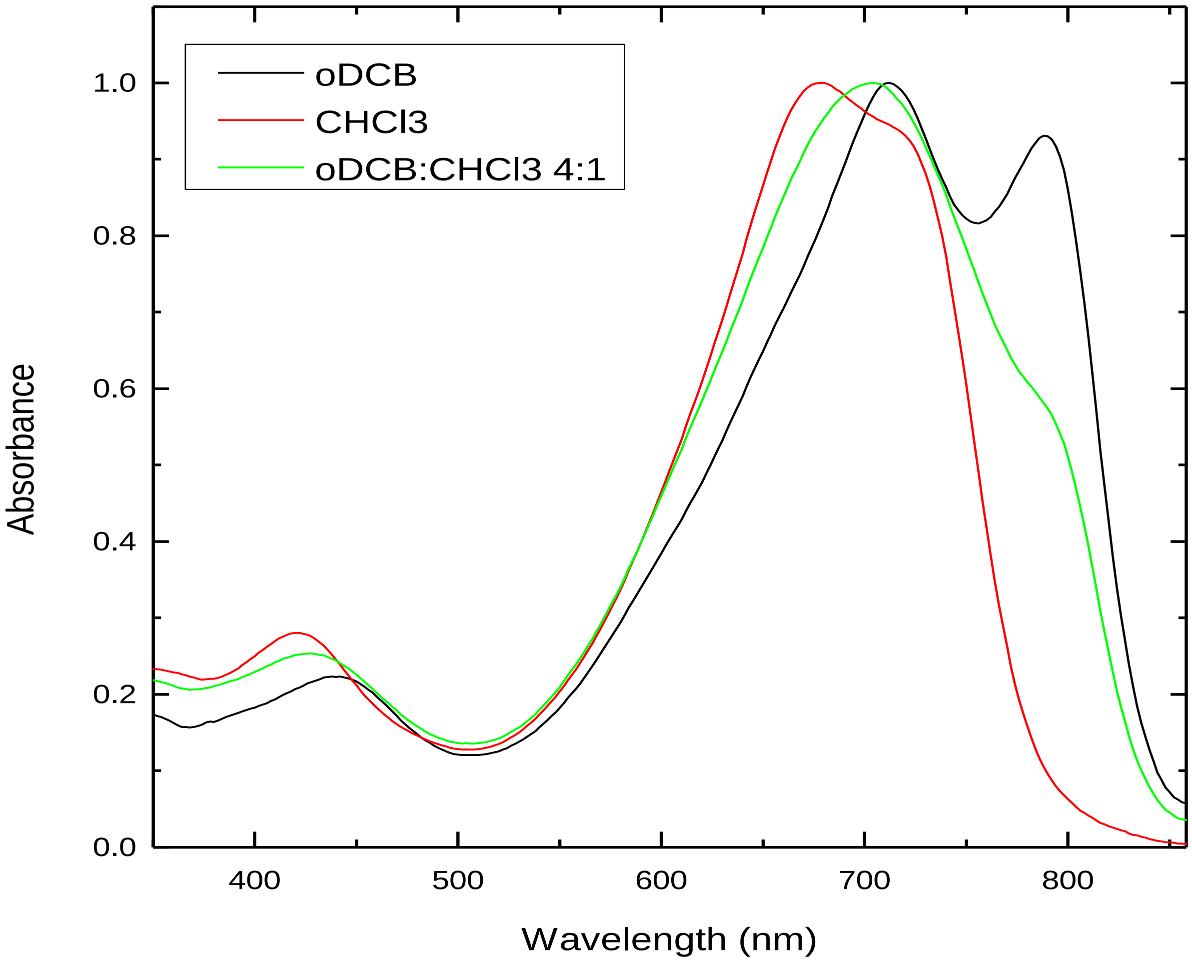


C70PCBM



PT5DPP was made available by BASF

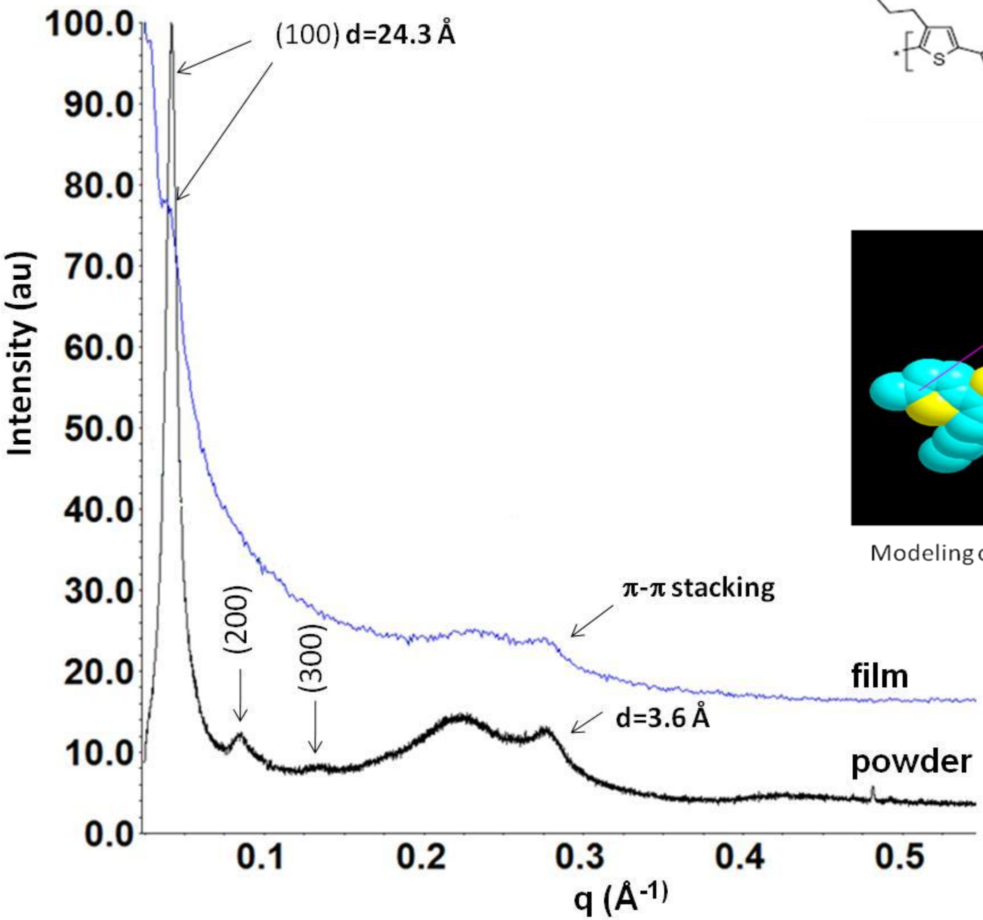
Solubility of PT5DPP

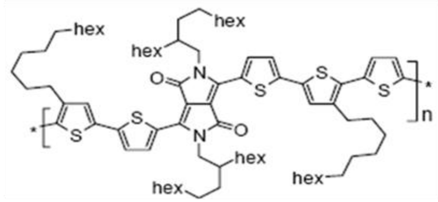


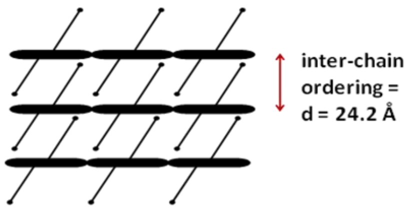
Aggregation in oDCB → favorable
Chloroform: lower boiling point needed for printing at RT

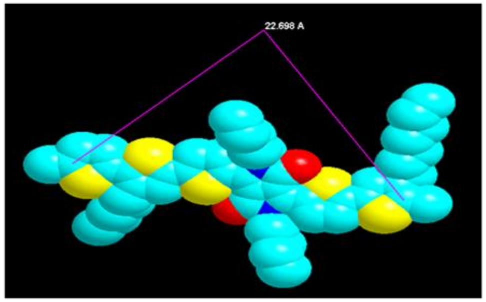
Structural ordering

PT5DPP on Si from oDCB

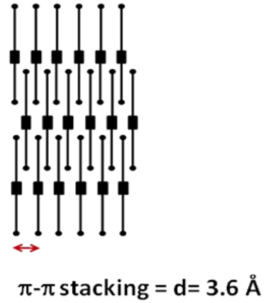








Modeling of one unit of the 1D polymer

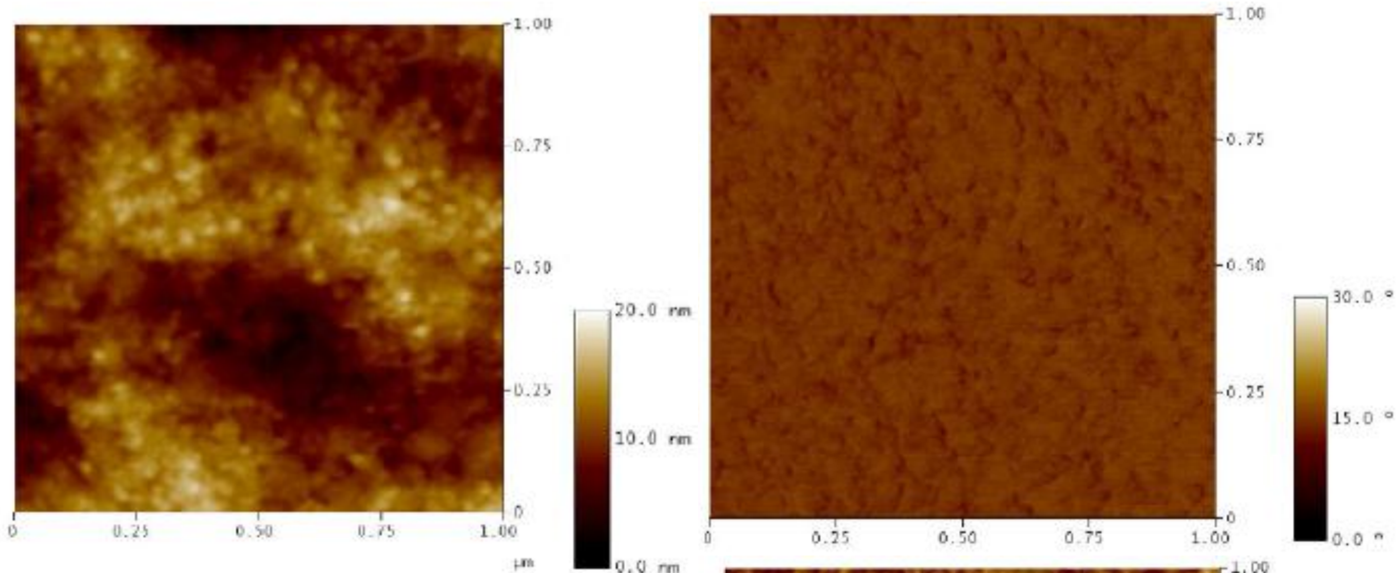


Structural ordering corresponding to the inter-chain spacing and the π-π stacking between the molecules.

Morphology

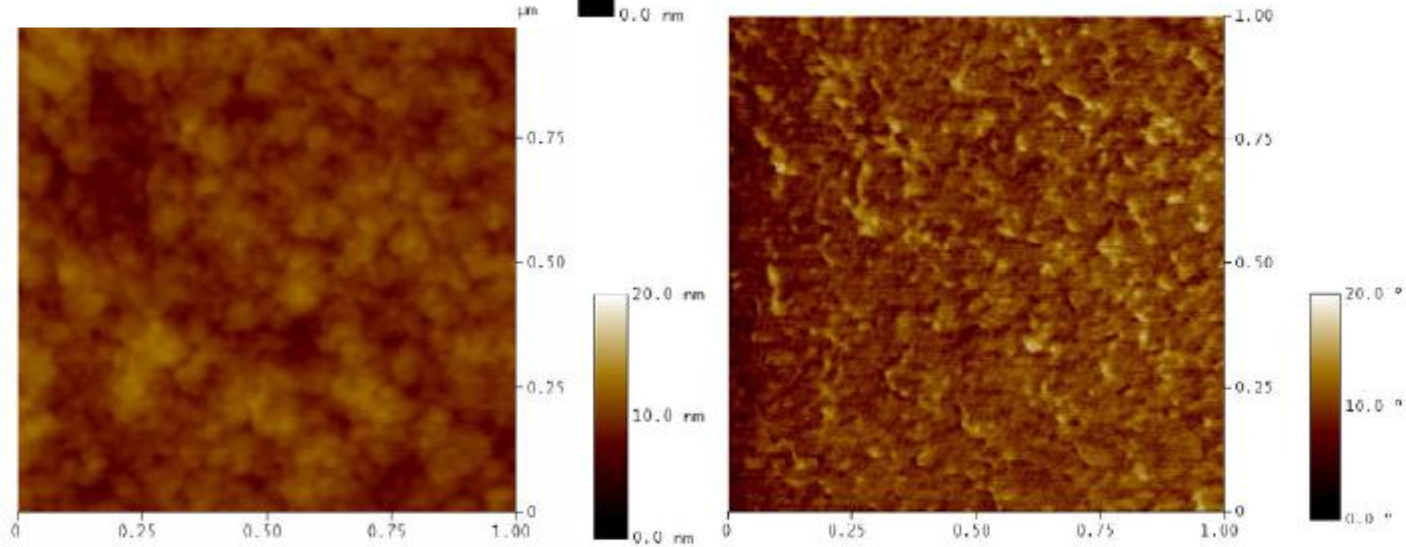
1:4 chloroform:oDCB

Best for printing



4:1 chloroform:oDCB

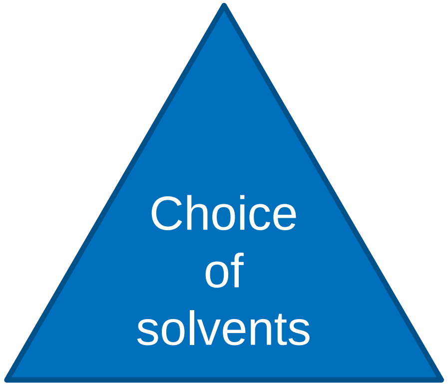
Best for spin coating



Solvent mixture

Balance between morphology, solubility and layer uniformity

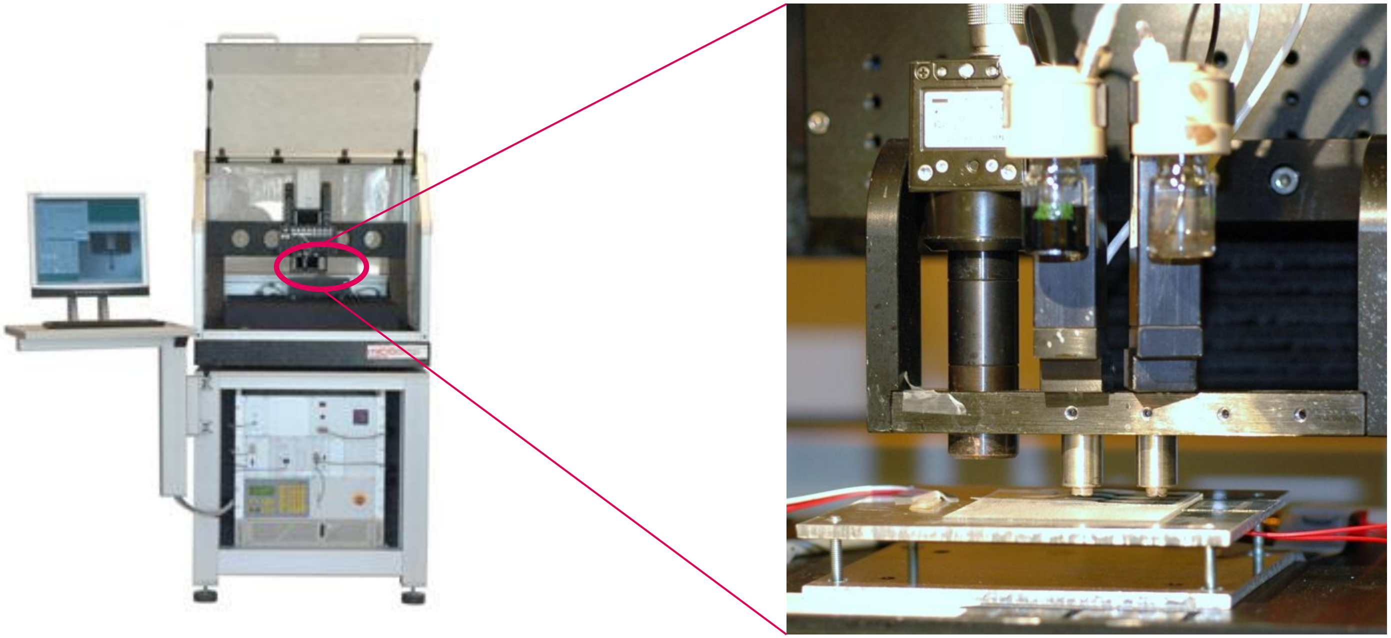
Solubility
- concentration
- drying rate/temperature



Morphology
- solvent mixture ratio
- drying rate/temperature

Layer uniformity
- viscosity/concentration
- drying rate/temperature

Inkjet printer

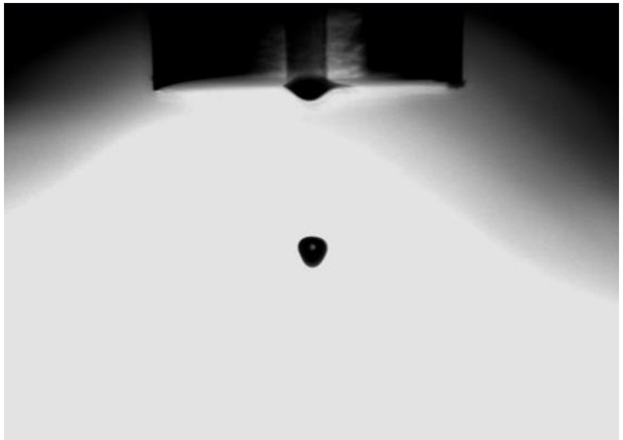


Microdrop single nozzle inkjet printer
• Nozzle diameter 30, 50 and 100 µm
• Heated nozzle tip
• Printing area 200 x 200 mm

Printing process: parameter exploration

Identified key parameters influencing stable drop formation and layer uniformity:

- Drop formation
  - voltage
  - pulse length
  - vacuum pressure

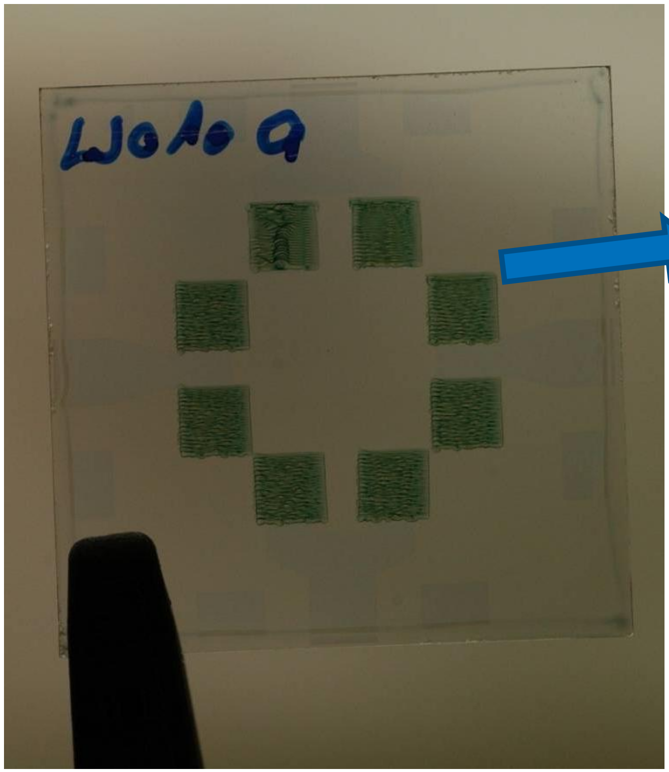


- Layer uniformity
  - dot spacing
  - print head temperature
  - substrate temperature
  - print speed
  - uni/bi-directional printing

These parameters depend on both solvent and material!

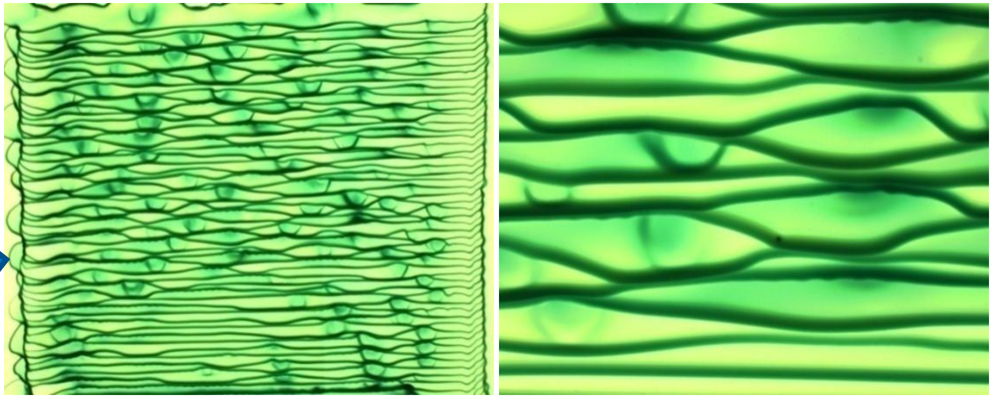
Printing process: obtaining layer uniformity

PEDOT coated ITO substrate

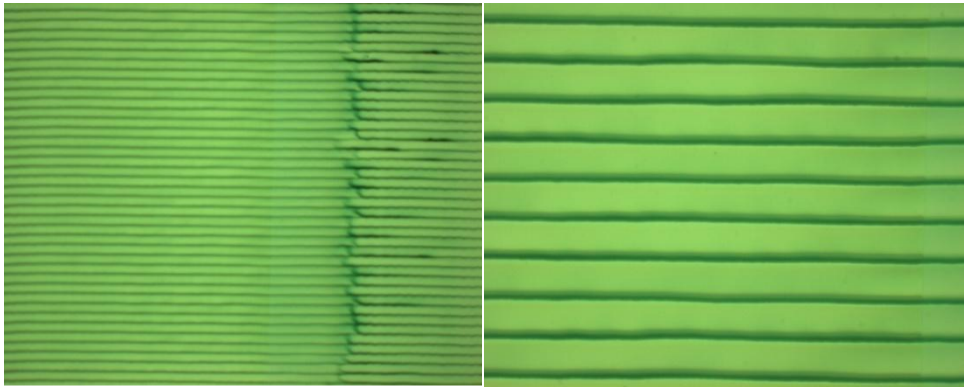


Microscope images (left: 2x2 mm^2, right 4x zoom)

1. *Dot spacing 0.05 mm*

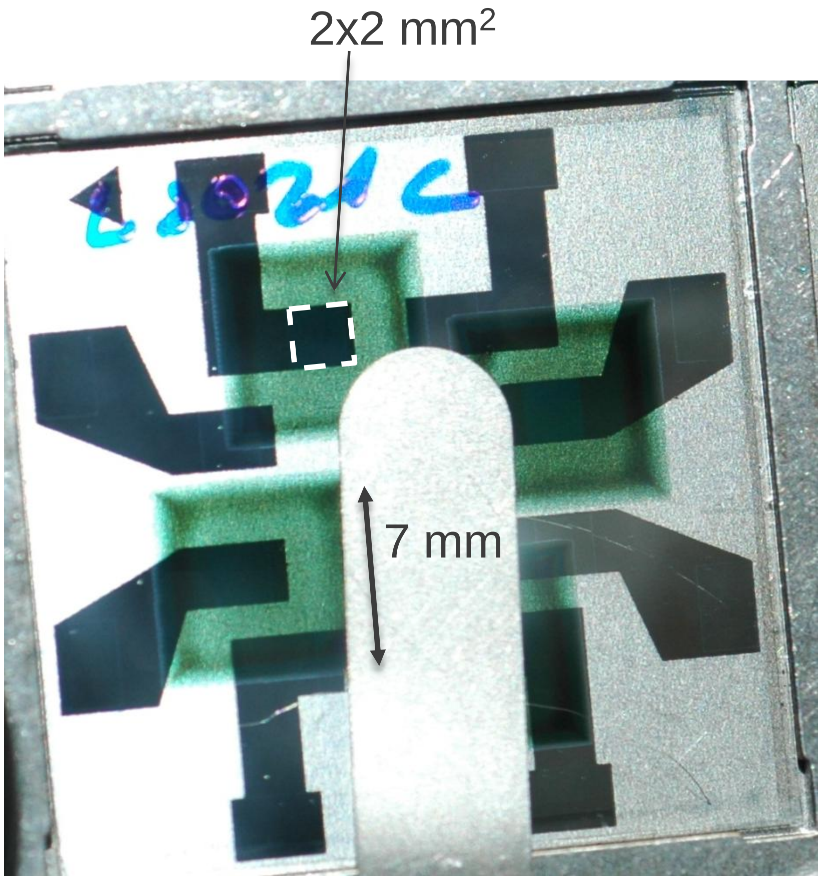


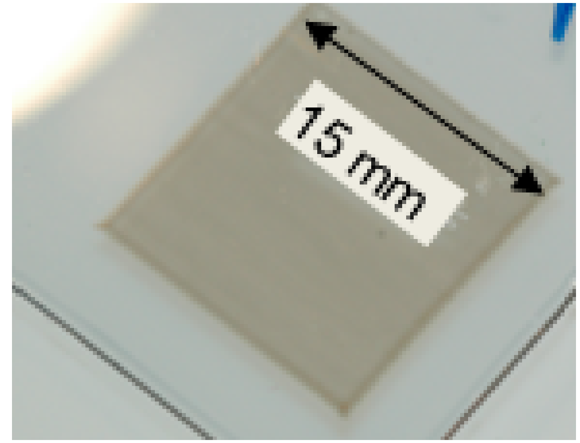
2. *Dot spacing 0.07 mm*

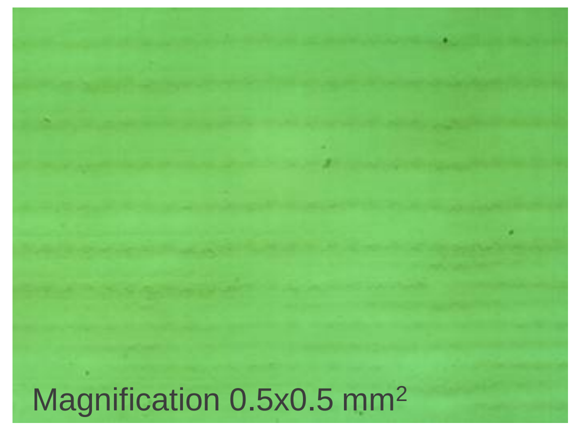


printing direction

Printed 2x2 mm^2 and 10x10 mm^2 devices





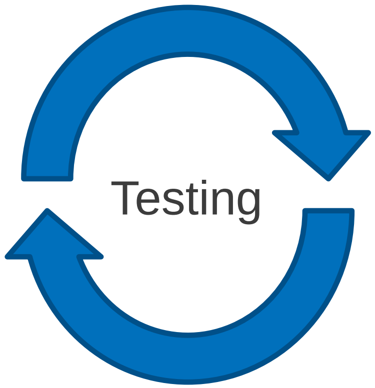


- Improvement in layer homogeneity
- Uniform 15x15 mm layers obtained by printing

Optimization

Start

Basis: knowledge from spin coated cells



- concentration
- solvent mixture
- polymer/PCBM ratio
- layer thickness

Printed Cell

Goal:

- stable single drop (jettable ink)
- homogeneous layer
- the right morphology

Optimization

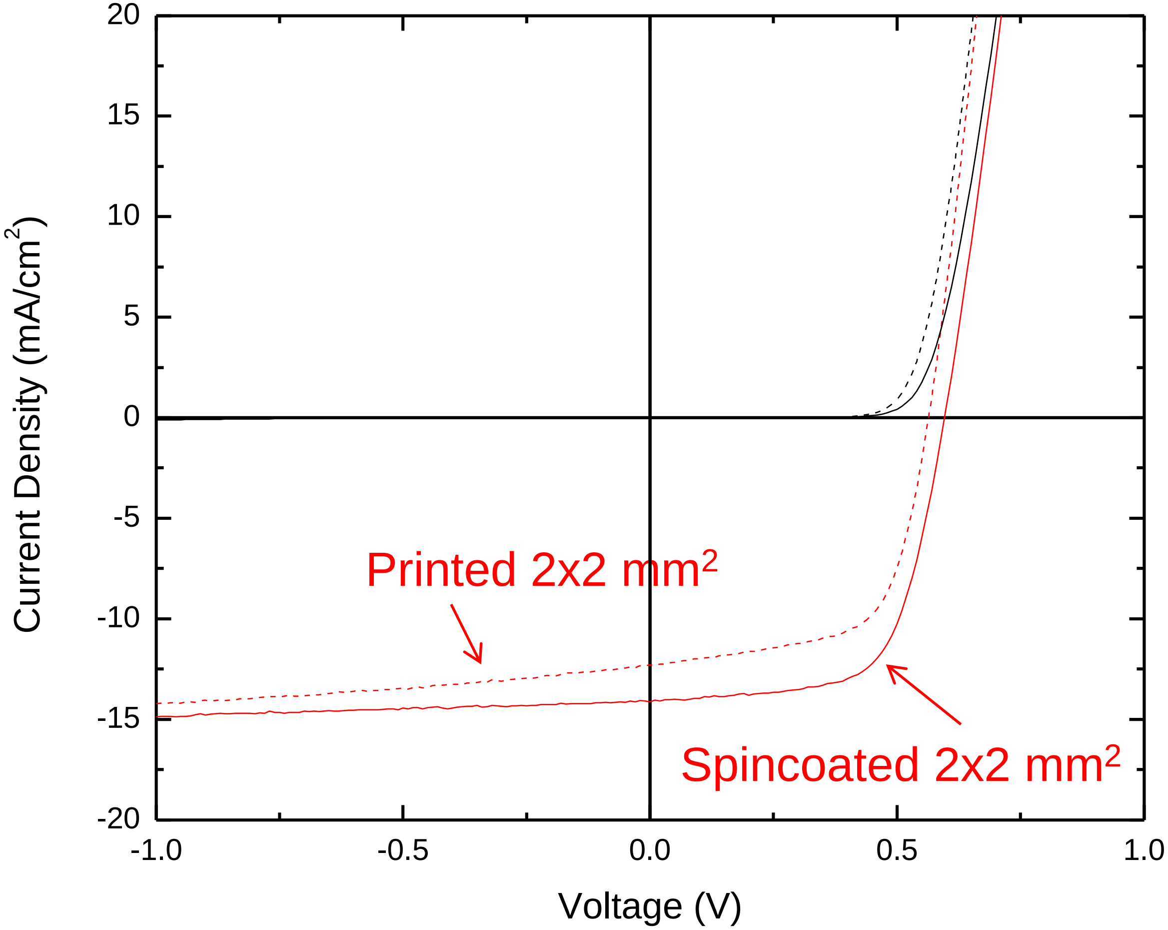
- Spin coated cells:
  - PCBM:polymer ratio → optimal ratio: 1:2
  - chloroform:oDCB ratio → best results with 80:20
  - Layer thickness → optimal thickness: ~90 nm

- Printed cells
  - Printing of ratios ≥ 40:60 resulted in clogging of nozzle

    → *Best printed cells sofar with 20:80 chloroform:oDCB*
  - Optimal thickness printed devices : ~140 nm

    → *Deposition method influences morphology*

Best results
2x2 mm^2



Spincoated 90 nm

V_{oc} = 0.60 V
J_{sc} = 14.1 mA/cm^2 (uncorrected)
FF = 0.65
mPP = 5.5 mW/cm^2

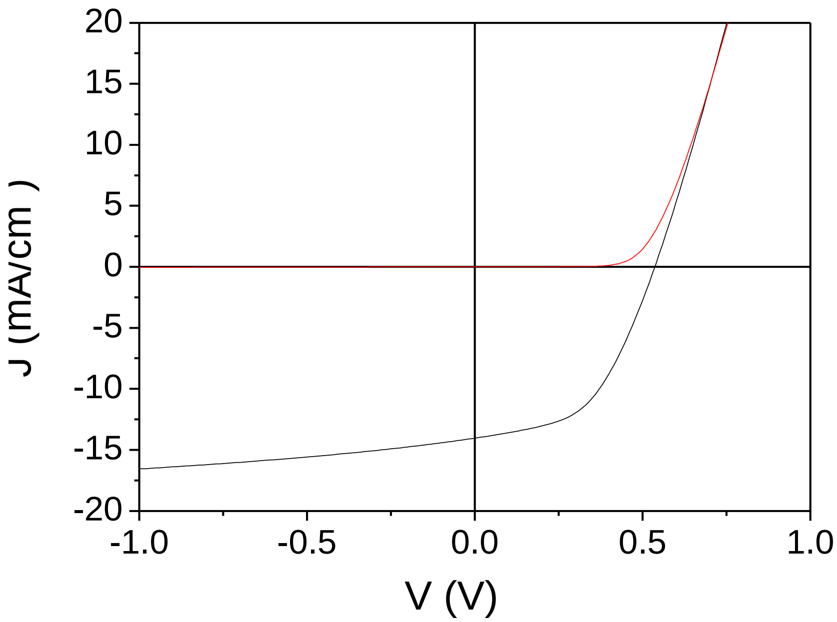
Printed 140 nm

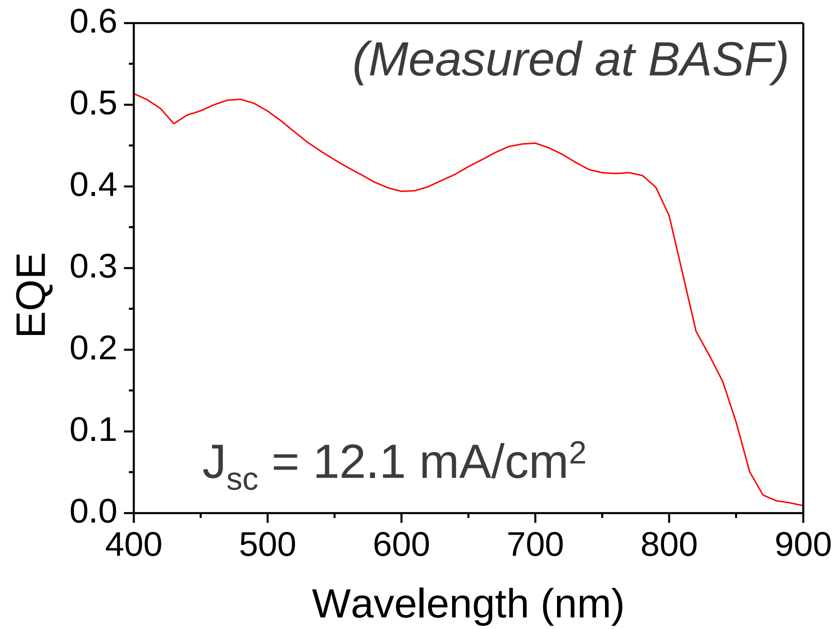
V_{oc} = 0.57 V
J_{sc} = 12.3 mA/cm^2 (uncorrected)
FF = 0.63
mPP = 4.4 mW/cm^2

Estimated efficiency: 4%

benchmark: 3.5% *C. N. Hoth, Nano Letters, 8 (2008) 2806*

Best results
10x10 mm²





thickness = 150 nm
V_{oc} = 0.55 V
J_{sc} = 14.0 mA/cm² (12.1 mA/cm² corrected)
FF = 0.51

Efficiency: 3.4%

Acknowledgements

- At CSEM:
  - Basel: Jürg Schleuniger, Giovanni Nisato, Marek Chrapa, Guillaume Basset
  - Neuchatel: Olha Sereda, Antonia Neels, Nicolas Blondiaux, Véronique Monnier

- APOLLO project partners :

BASF The Chemical Company — BASF

Zurich University of Applied Sciences zh aw — ZHAW

TU/e — TU Eindhoven

Universitat Jaume I

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Take home messages

CSEM:

- is an R&D company working with universities and industry
- is developing processes and technologies, also for organic electronics
- has presented ink-jet printed solar cells with 4% efficiency

Thank you for your attention!