Ink-jet printing of polymer solar cells

Plastic Optoelectronics workshop
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Outline

• CSEM
  o Group Polymer Optoelectronics

• Inkjet printing polymer solar cells
  o Novel low bandgap polymer
  o Solvent mixtures
  o Obtaining good uniformity
  o Efficient inkjet printed devices
Role of CSEM in organic electronics
Division Thin Film Optics

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*
Automated device fabrication tool

• High throughput fabrication
• Combinatorial testing

Automated OLED and OPV characterisation tool
Automated OFET characterization tool

Integrated optoelectronic biosensors

Plasmon stack (1.8 x 1.8 mm²)

PPD array
Out coupled light (0.5 x 3 mm²)
PL material

PLED
Inkjet Printed OPV
Why inkjet printing

- Why inkjet printing?
  - established technology,
  - printability in ambient conditions,
  - output (up to 150 m²/h),
  - low cost,
  - flexibility,
  - digital patterning,
  - mass customization
POLYMOL project APOLLO

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

- Project partners:
  - BASF
  - ZHAW
  - TU Eindhoven
  - Universitat Jaume I

- Role of CSEM in APOLLO:

  **Materials** → **Ink formulation** → **Printing process** → **Devices & Basic charact.** → **Advanced charact.**

  - Materials:
    - solvents
    - wetting
    - uniformity
    - solubility
  - Ink formulation:
    - uniformity
    - thickness
    - morphology
  - Printing process:
    - encapsulation
  - Devices & Basic charact.:
    - simulations
    - photoCELIV
    - impedance spectroscopy

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PT5DPP was made available by BASF
Solubility of PT5DPP

Aggregation in oDCB $\rightarrow$ favorable
Chloroform: lower boiling point needed for printing at RT
Structural ordering corresponding to the inter-chain spacing and the $\pi-\pi$ 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

Choice of solvents
Inkjet printer

- Microdrop single nozzle inkjet printer
  - Nozzle diameter 30, 50 and 100 µm
  - Heated nozzle tip
  - Printing area 200 x 200 mm
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 mm², right 4x zoom)
1. *Dot spacing 0.05 mm*

2. *Dot spacing 0.07 mm*

printing direction
Printed 2x2 mm² and 10x10 mm² devices

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

Start

Basis: knowledge from spin coated cells

Testing

• 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:
  o PCBM:polymer ratio \rightarrow \text{optimal ratio: 1:2}
  o chloroform:oDCB ratio \rightarrow \text{best results with 80:20}
  o Layer thickness \rightarrow \text{optimal thickness: \sim 90 nm}

• Printed cells
  o Printing of ratios \geq 40:60 resulted in clogging of nozzle
    \rightarrow \text{Best printed cells sofar with 20:80 chloroform:oDCB}
  o Optimal thickness printed devices : \sim 140 nm
    \rightarrow \text{Deposition method influences morphology}
Best results
2x2 mm²

Spincoated 90 nm

\(V_{oc} = 0.60 \text{ V}\)
\(J_{sc} = 14.1 \text{ mA/cm}^2\) (uncorrected)
FF = 0.65
mPP = 5.5 mW/cm²

Printed 140 nm

\(V_{oc} = 0.57 \text{ V}\)
\(J_{sc} = 12.3 \text{ mA/cm}^2\) (uncorrected)
FF = 0.63
mPP = 4.4 mW/cm²

Estimated efficiency: 4%
benchmark: 3.5%  C. N. Hoth, Nano Letters, 8 (2008) 2806
**Best results**

10x10 mm²

![Graph](image)

- **EQE** vs **Wavelength (nm)**
- **J (mA/cm²)** vs **V (V)**

- **EQE**
- **Wavelength (nm)**

- **J<sub>sc</sub> = 12.1 mA/cm²**

**Results**

- **thickness = 150 nm**
- **V<sub>oc</sub> = 0.55 V**
- **J<sub>sc</sub> = 14.0 mA/cm² (12.1 mA/cm² corrected)**
- **FF = 0.51**

**Efficiency: 3.4%**
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• APOLLO project partners:

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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!