Laser printed and sintered Ag nanoparticle metal-grids as bottom electrode for ITO-free organic photovoltaics

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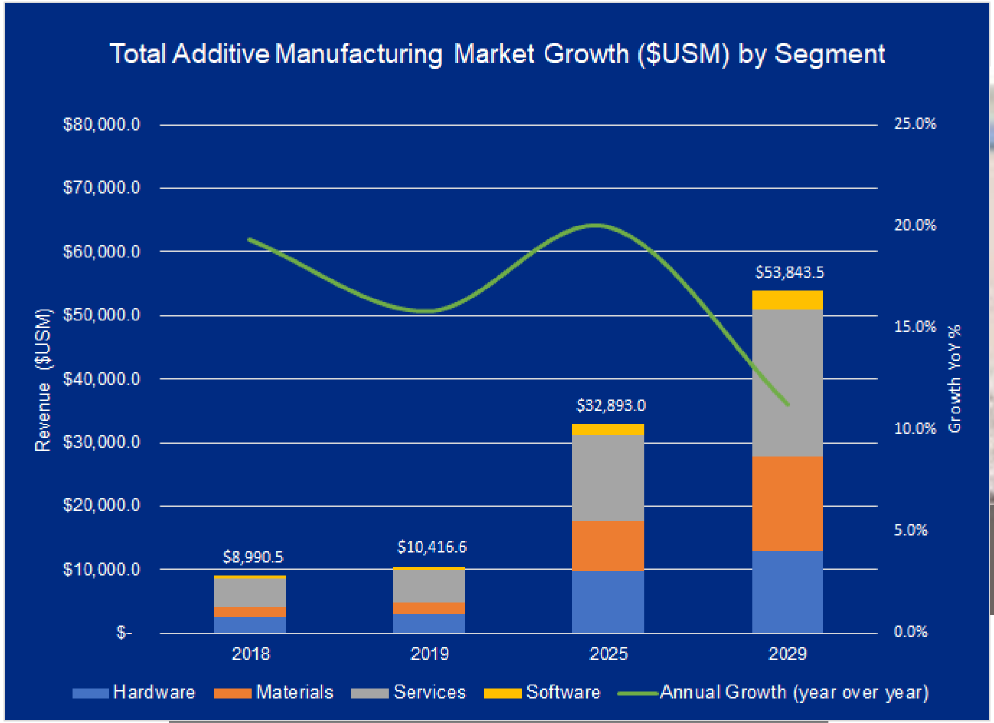
Additive manufacturing

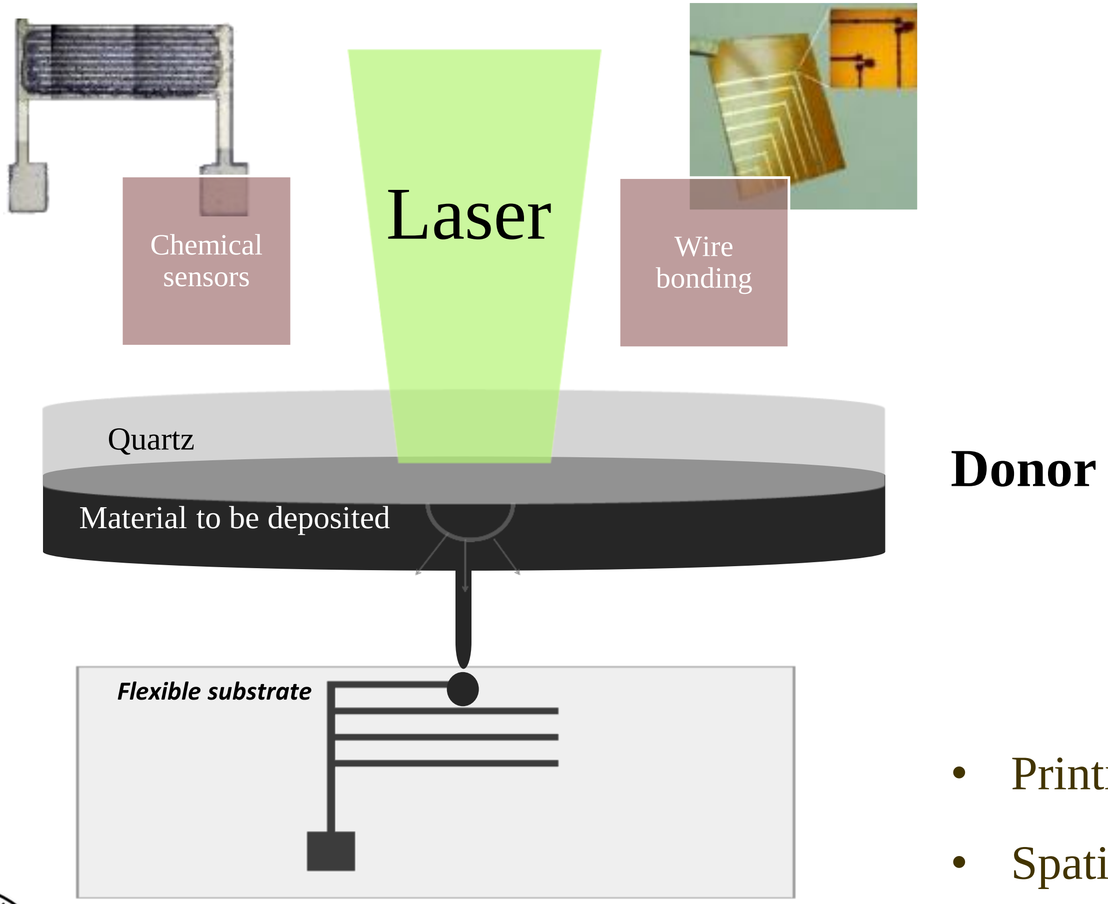


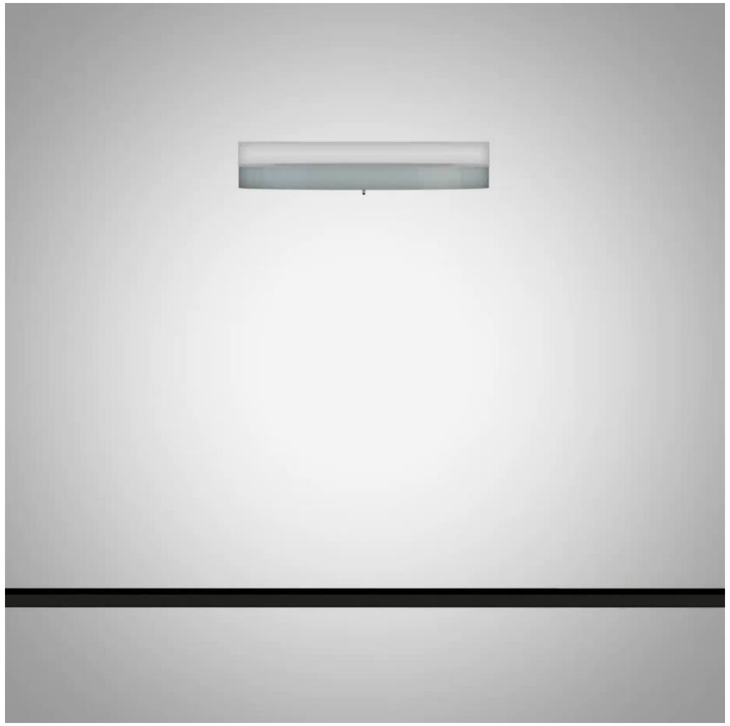
SmarTech Markets Publishing

Flexible circuits

Smart displays

Laser induced forward transfer

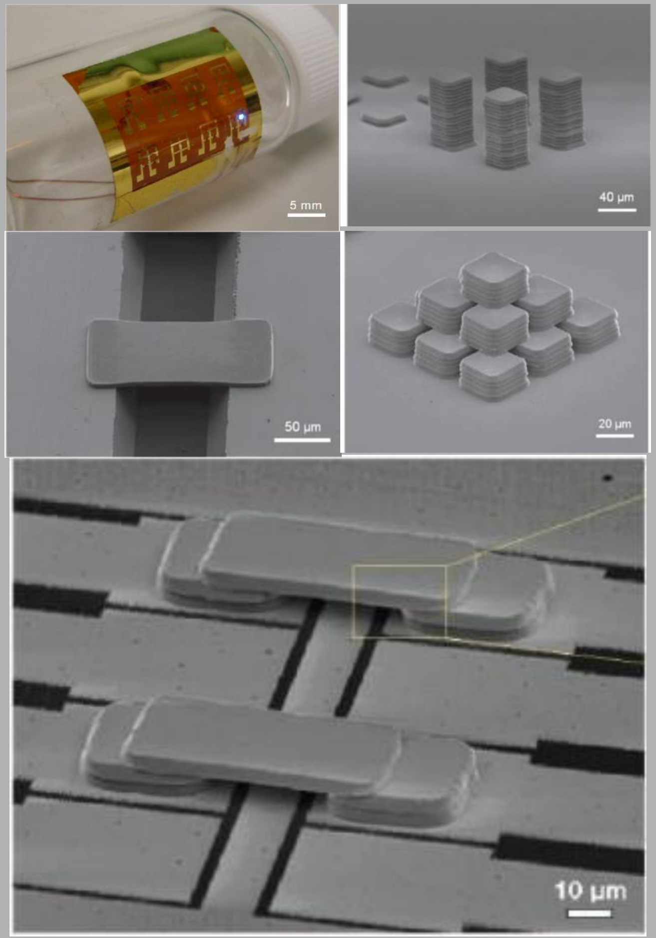




- Printing in solid, liquid phase and 2D materials
- Spatial resolution down to 10 μm for liquid and sub-micron for solid phase
- Printing of inorganic, organic, biological materials

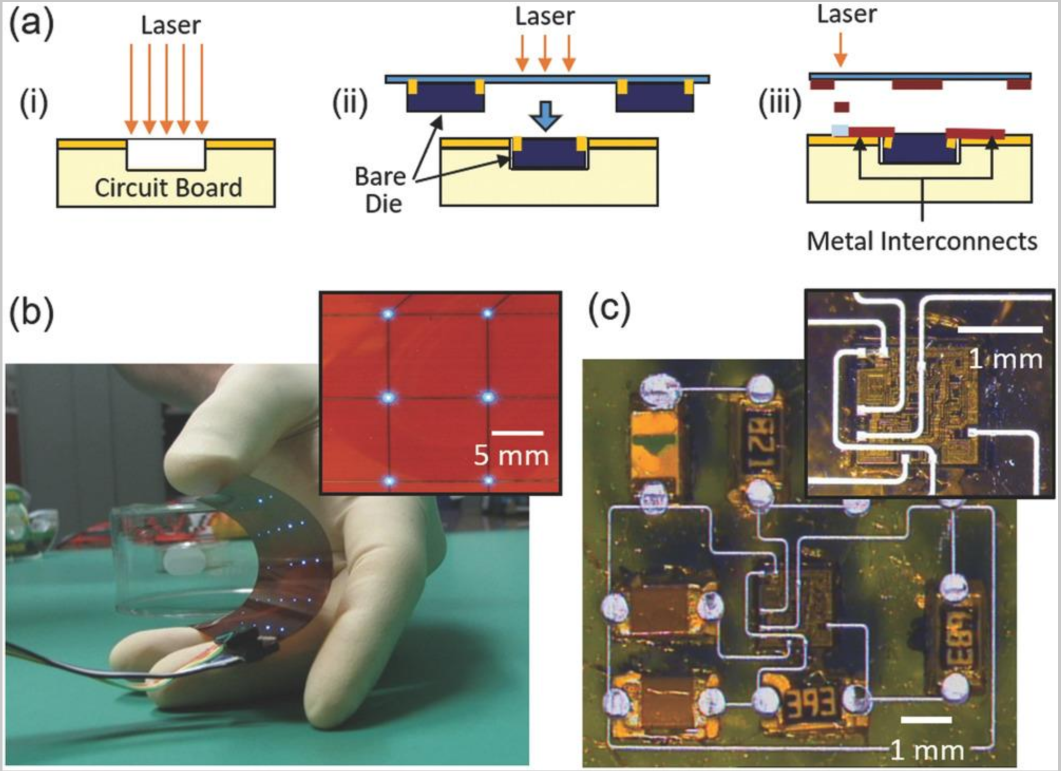
LIFT applications

Printing Silver Nanopastes for interconnection bonding of Au pads



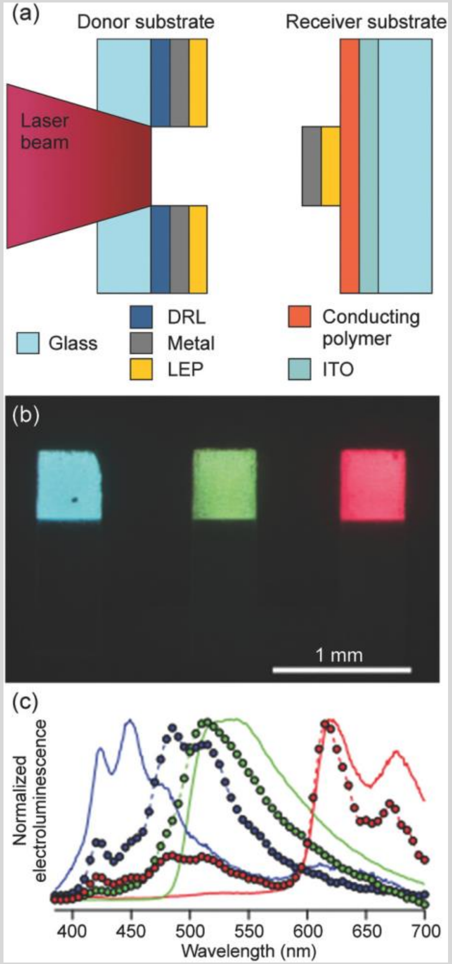
Wang et al., Adv. Mater., 22, 4462–4466, (2010)

Laser mediated embedded electronics



A. Piqué, R. C. Y. Auyeung, H. Kim, N. A. Charipar, S. A. Mathews, J. Phys. D: Appl. Phys. 2016, 49, 223001.

Single-step laser printing of multistack OLEDs through a DRL



J. Shaw-Stewart, T. Lippert, M. Nagel, F. Nüesch, A. Wokaun, Appl. Phys. Lett. 2012, 100, 203303

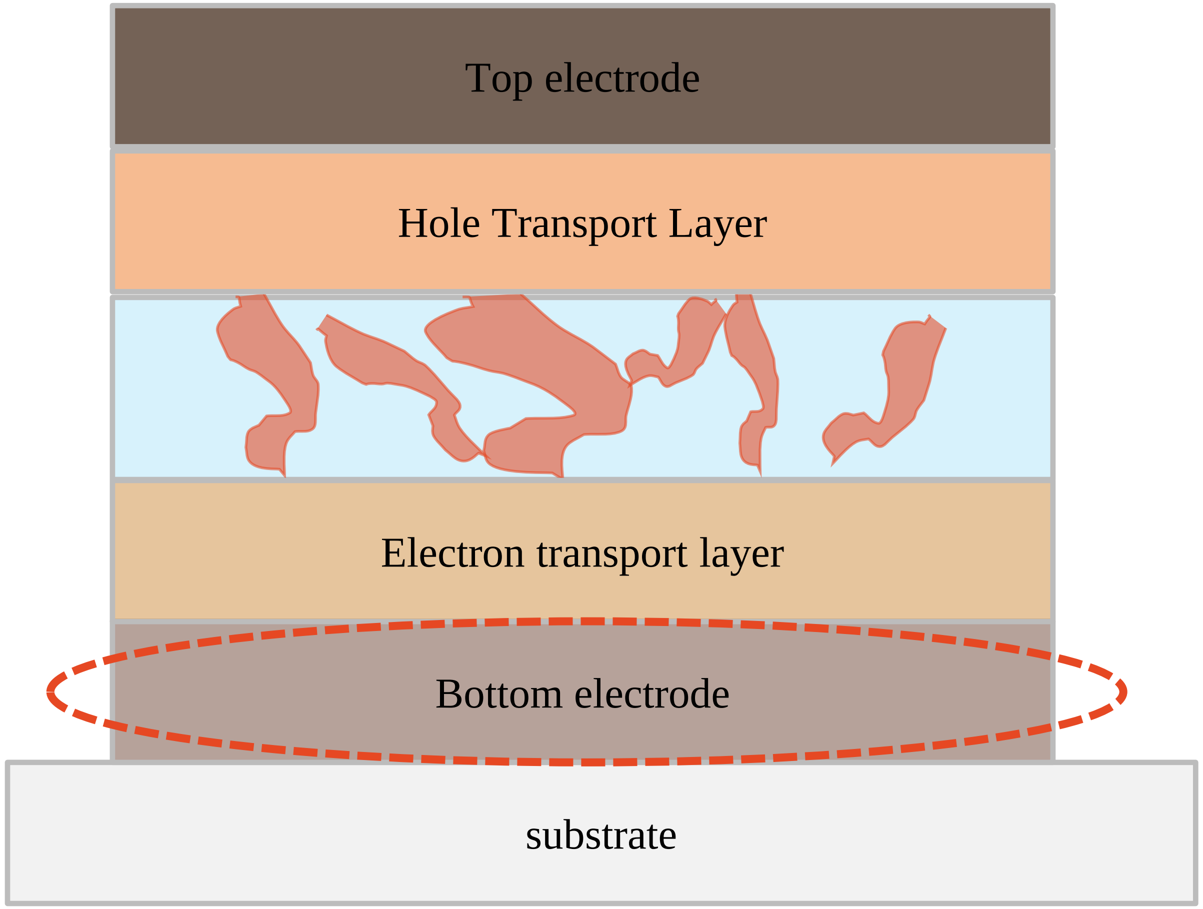
Organic photovoltaics

- ✓ Lightweight
- ✓ Inexpensive
- ✓ Flexible
- ✓ Customizable on the molecular level
- ✓ Less adverse environmental impact

- ✖ OPVs 17% PCE / standard silicon 18-22% PCE
- ✖ OPVs 17 watts/m^2 / standard silicon 200 watts/m^2

Organic photovoltaics

OPV stack schematic representation



ITO bottom electrode:

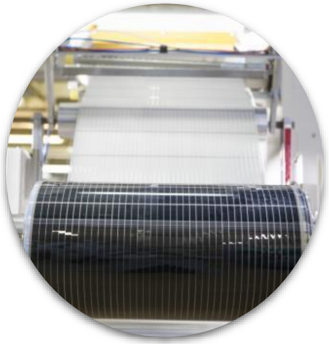
- ✖ Overall cost increase
- ✖ Brittle, incompatible with flexible substrates

✓ **Conductive, transparent, cost-effective** alternative material

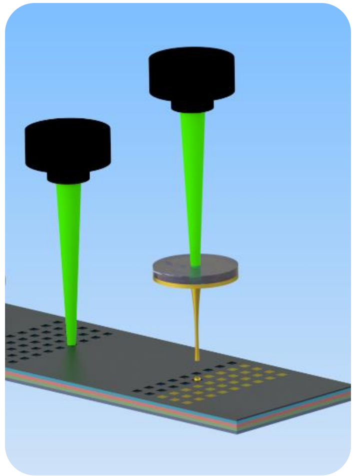
LIFT & roll to roll for OPVs

ROLA-FLEX

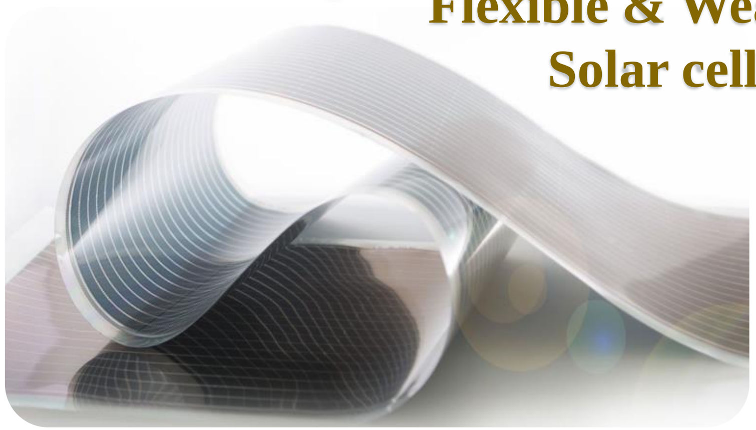
Roll to Roll



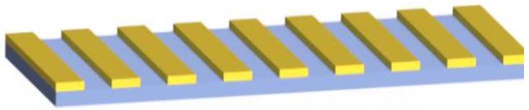
Laser Printing + Laser sintering



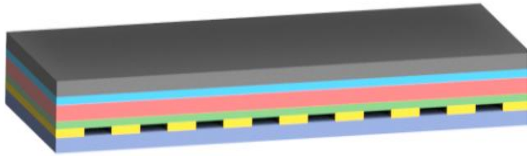
Flexible & Wearable Solar cells



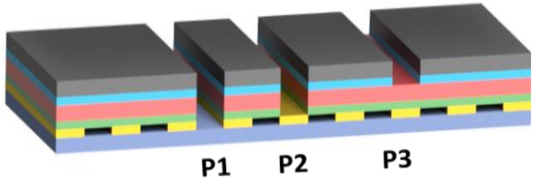
Step 1. Bottom electrode fabrication by LIFT printing and sintering of metal grids



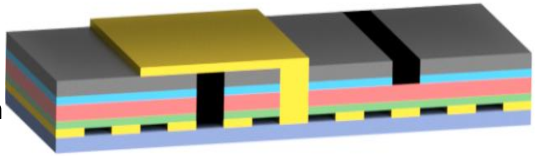
Step 2. R2R free form manufacturing of transport layers, photoactive layer and top electrode



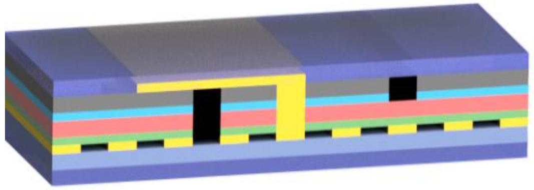
Step 3. P1, P2 and P3 scribes formation with laser patterning



Step 4a. Isolating ink printing
Step 4b. Metal nanoparticle ink LIFT printing for interconnection

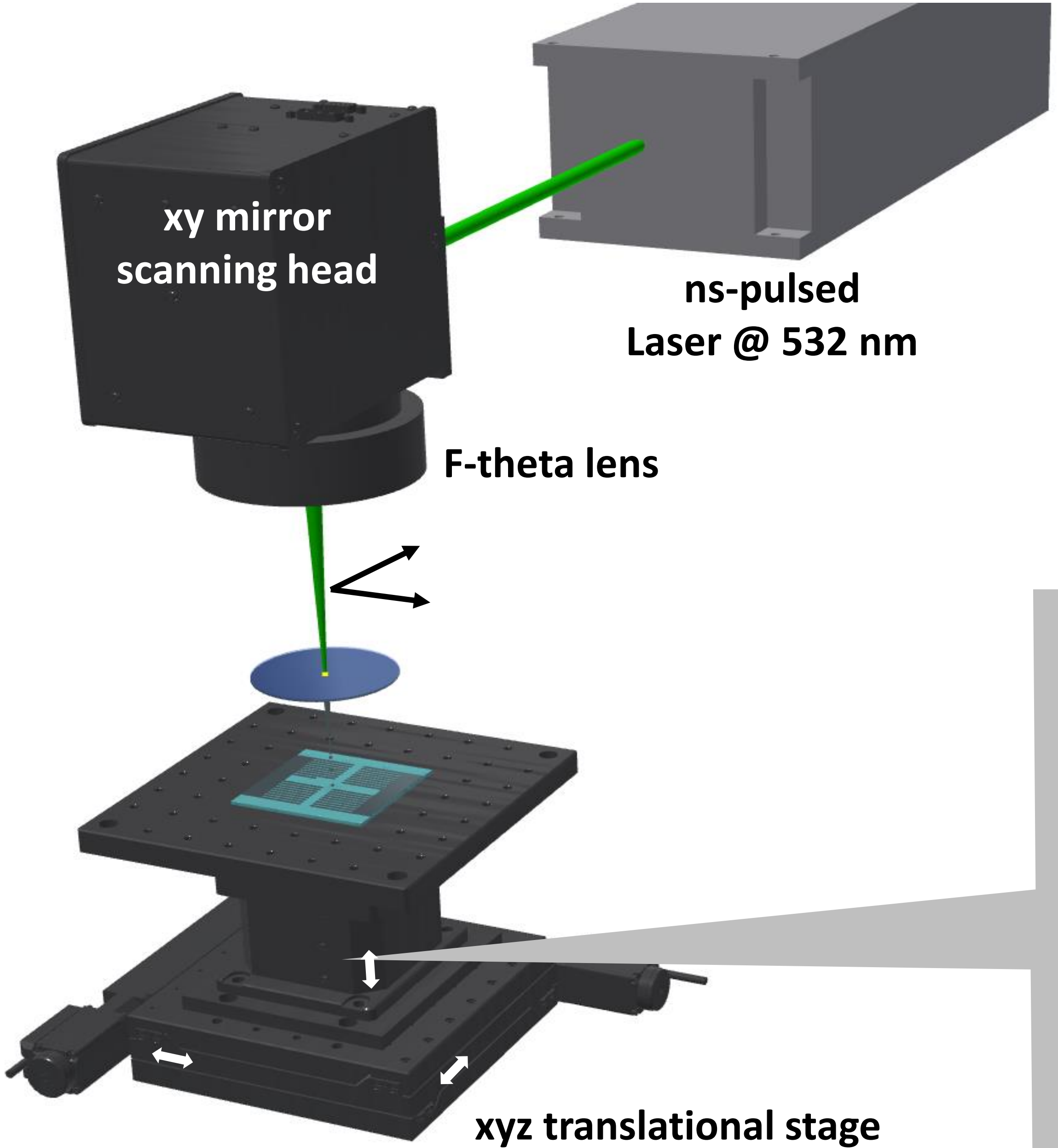


Step 5. Encapsulation

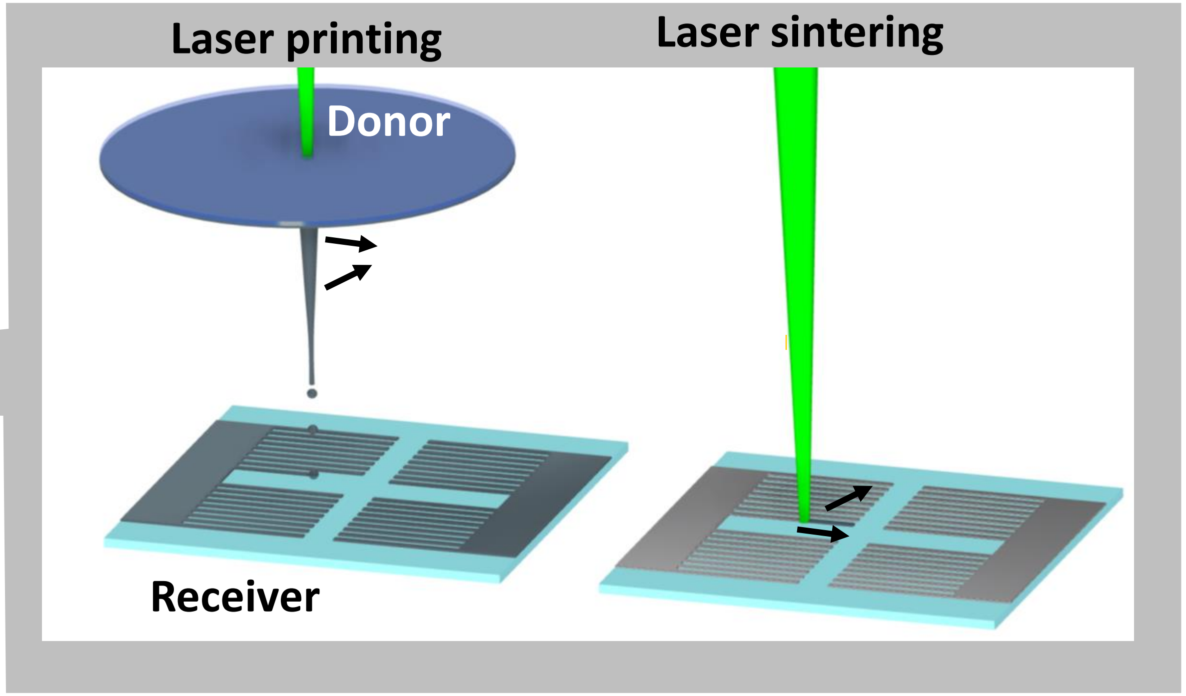


- **substrate**
- **Ag NP ink**
- **ETL (n-type metal oxide)**
- **Photoactive layer**
- **HTL (p-type metal oxide)**
- **Metal electrode (Ag), anode**
- **Isolating ink**
- **Encapsulation layer**

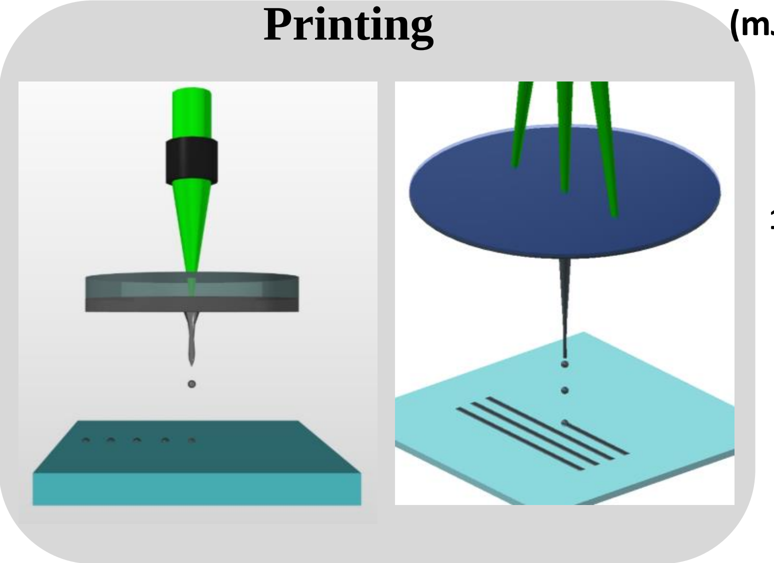
Experimental setup



2 step solar cell bottom electrode fabrication



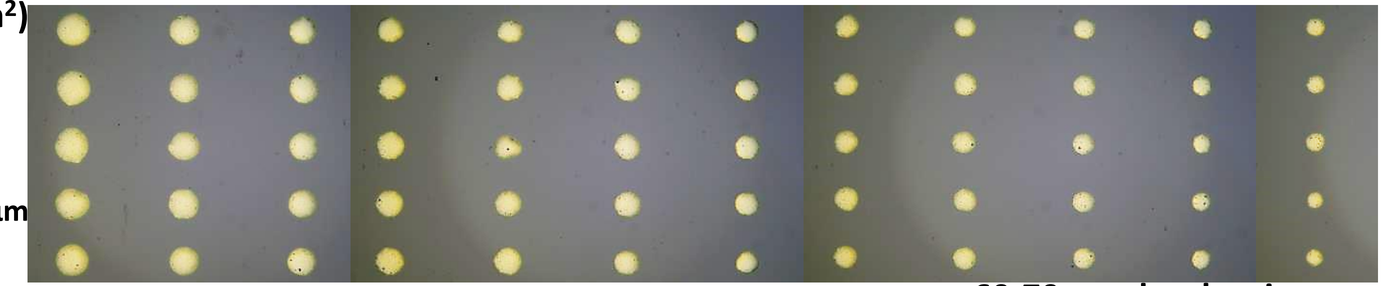
Bottom electrode printing



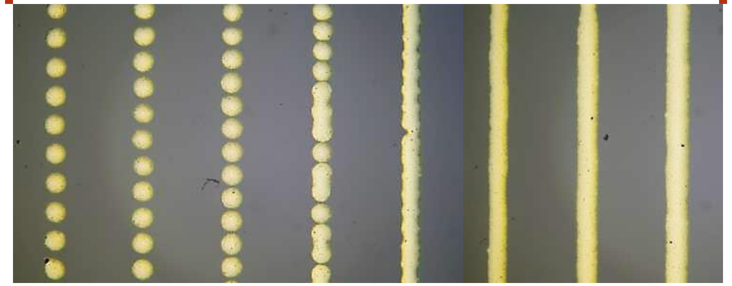
Fluence (mJ/cm^2)

220 170 165 160 150 140 135 130 125 120 110 105

100 µm



60-70 µm droplet size



Step (µm)

100 90 80 70 60 50 40 30

60-70 µm line width

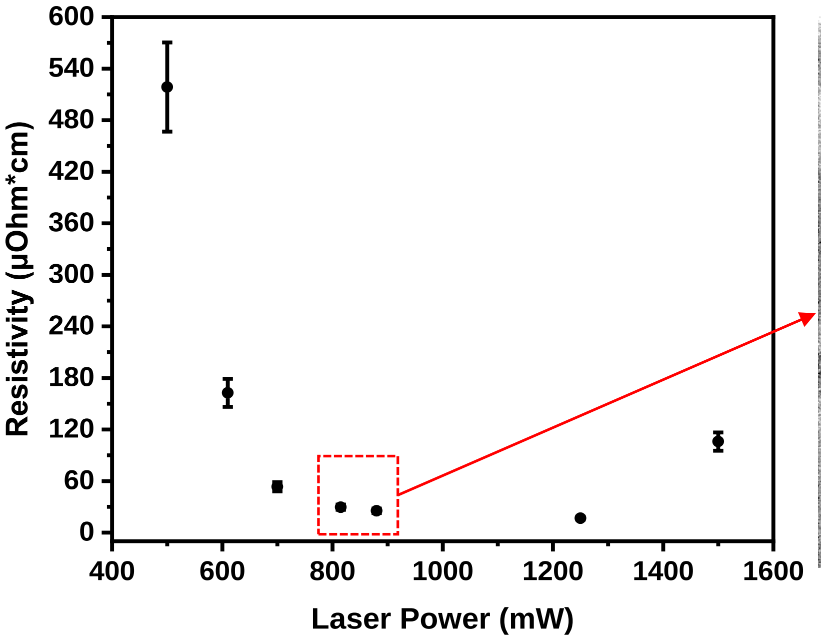
- Printing pattern morphological investigation (1250 nm + 70 µm width)
- Optical transmittivity investigation 6-9-12 lines cells permitting 82%-77%-70% respectively (ITO cell ~81% optical transmittance)

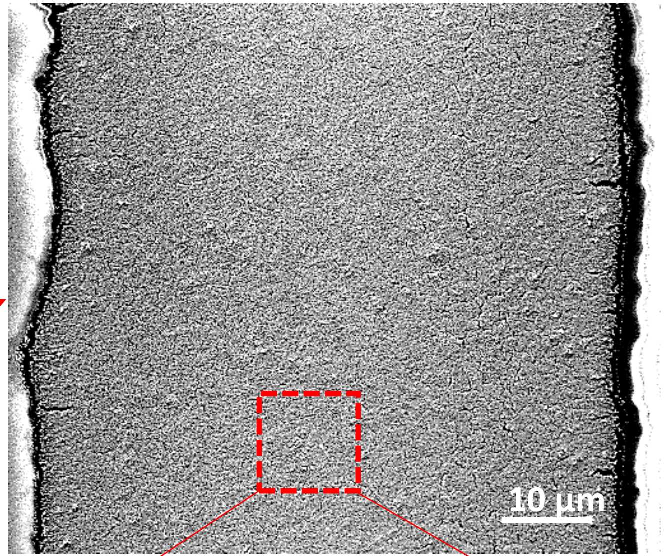
D6 $\propto$ 15% coverage area

D9 $\propto$ 21% coverage area

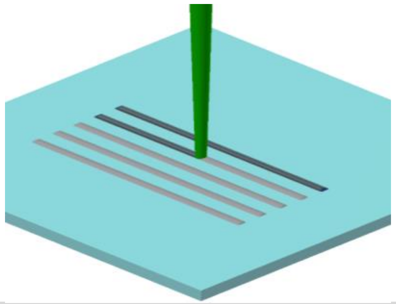
D12 $\propto$ 30% coverage area

Bottom electrode sintering

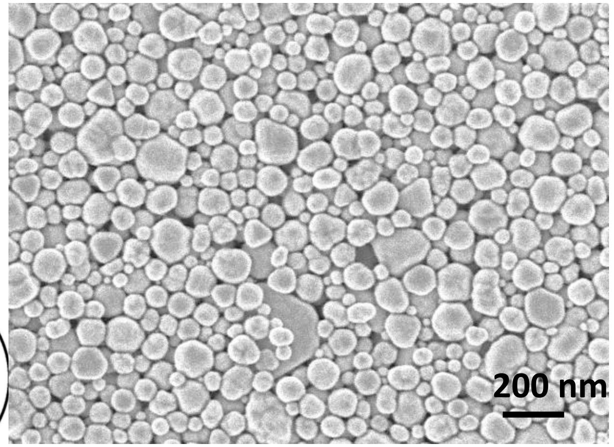




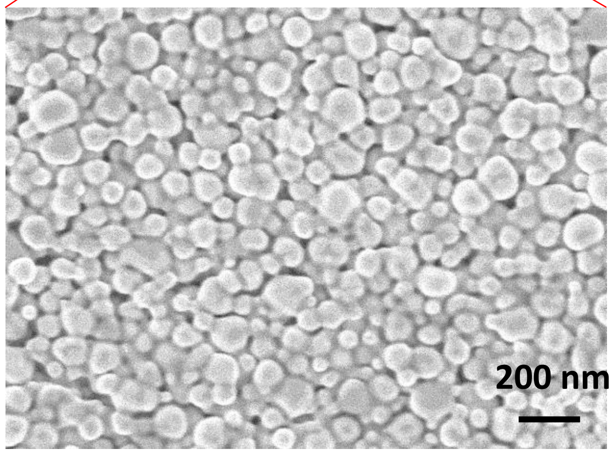
Sintering



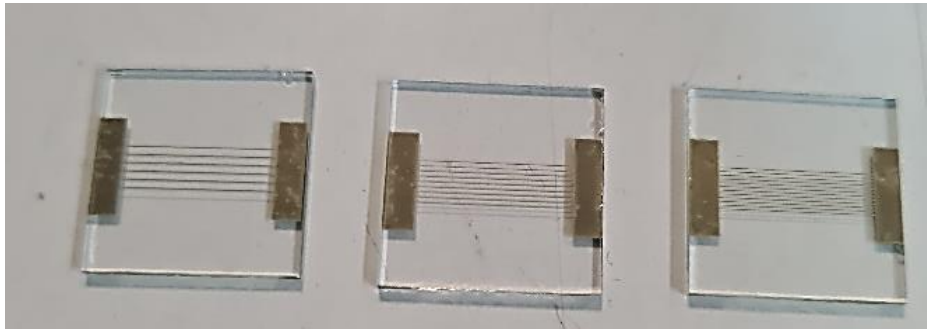
Resistivity
27 μOhm*cm (ITO 30 μOhm*cm)



Non-sintered



850 mW laser sintered line

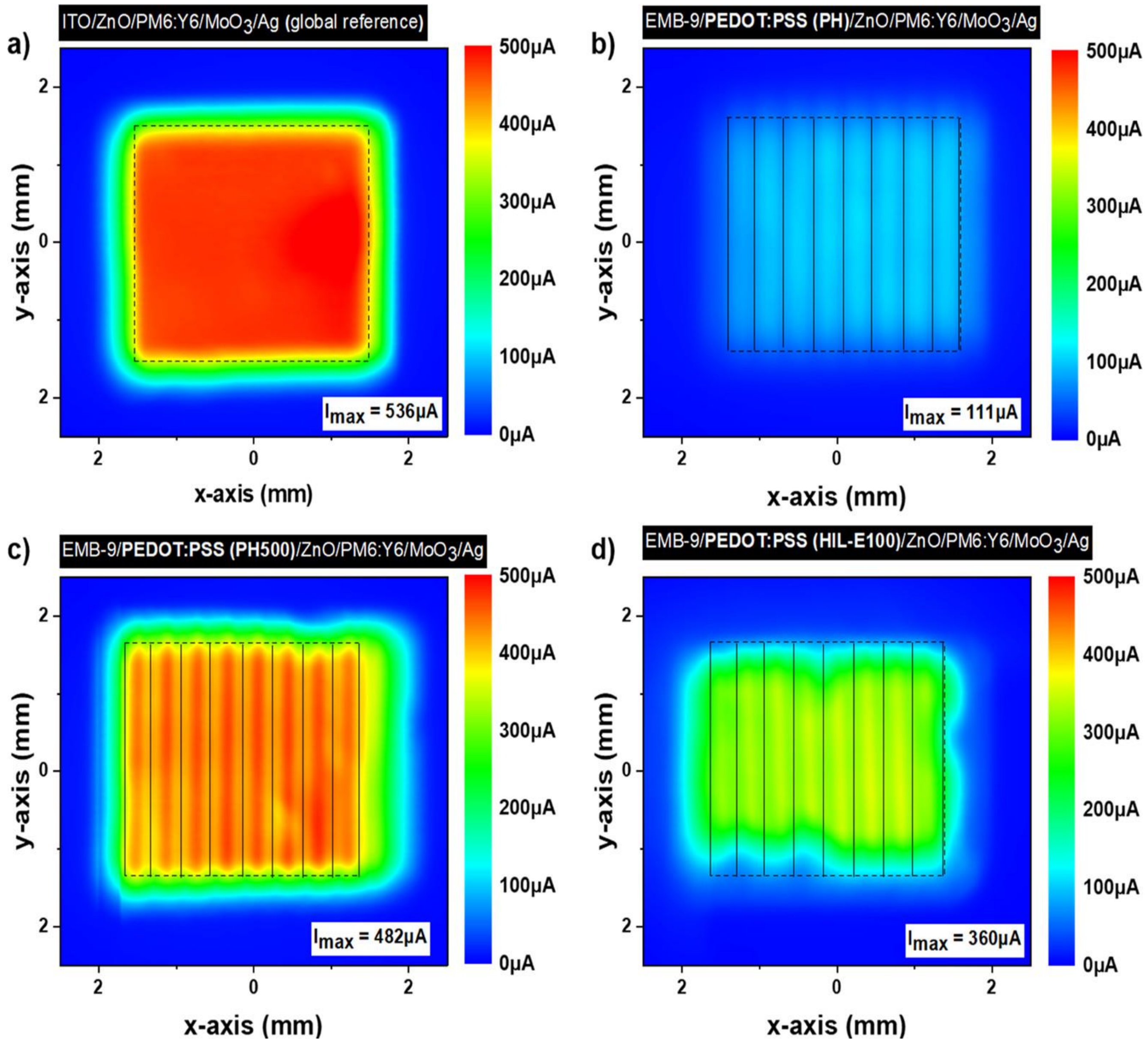


6 lines design
4.76 Ω*cm^2

9 lines design
2.02 Ω*cm^2

12 lines design
1.93 Ω*cm^2

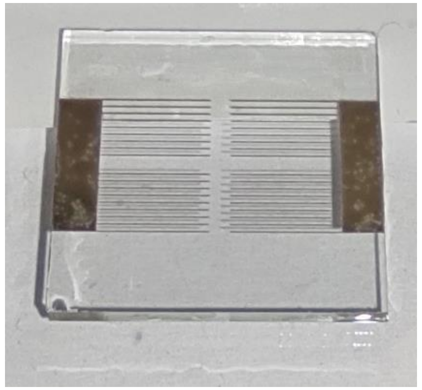
Electron transport layer & photocurrent mapping



PH500 formulation

- **482 μA (reference ITO-based device 536 μA)**
- **FF of 52.5% and**
- **8.9% PCE**

9-lines design cells



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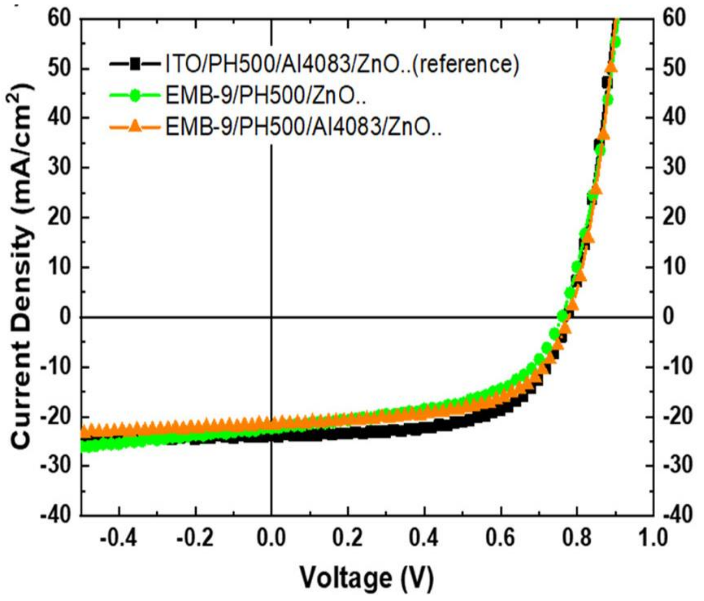
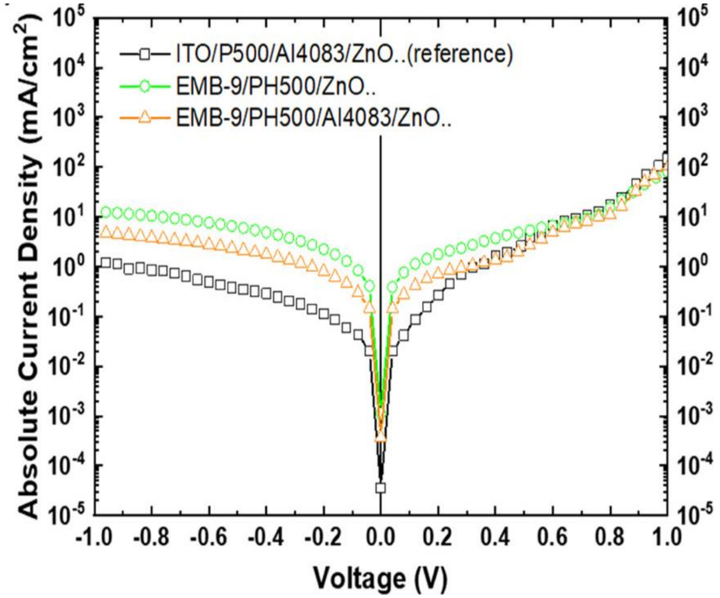
Electron transport bilayer





PH500 + AI4083 formulation

- **11% PCE**

bottom electrode	V_{oc} [V]	J_{sc} [mA/cm^2]	FF [%]	PCE [%]
ITO/PH500/ZnO..	0.76	26.8	59.6	11.7 ± 0.3 (12.1)
ITO/PH500/AI4083/ZnO..	0.78	24.5	66.7	12.8 ± 0.5 (13.5)
EMB-9/PH500/ZnO..	0.76	22.5	52.5	8.4 ± 0.5 (8.9)
EMB-9/PH500/AI4083/ZnO..	0.78	21.2	60.5	10.4 ± 0.4 (11.0)

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In Conclusion…

- LIFT printed conductive grid displayed suitable morphological characteristics (1250 nm thickness, 70 um width)
- Printed bottom electrode exhibited high conductivity (27 μOhm*cm) and transparency (77%) values
- Fabrication of highly efficient ITO-free solar cells (11%)
- Processes and materials compatible with flexible substrates
- Potential combination of implemented processes with standard industrial techniques

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- *A. Ioakeimidis*
- *A. Kabla*
- *S. Melamed*
- *F. de la Vega*

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Thank you