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CNR ISMN

Organic photovoltaics: towards a sustainable future

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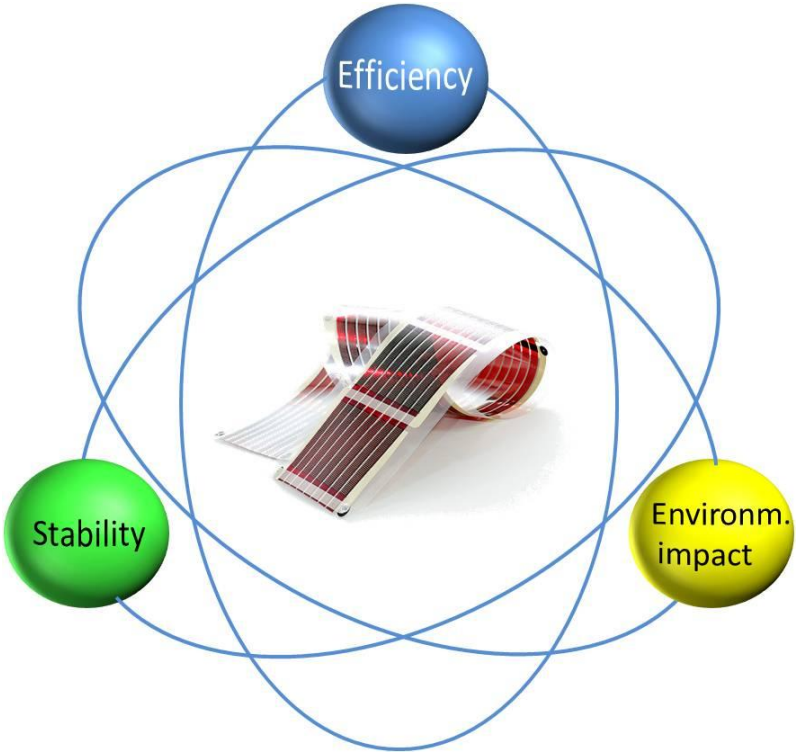
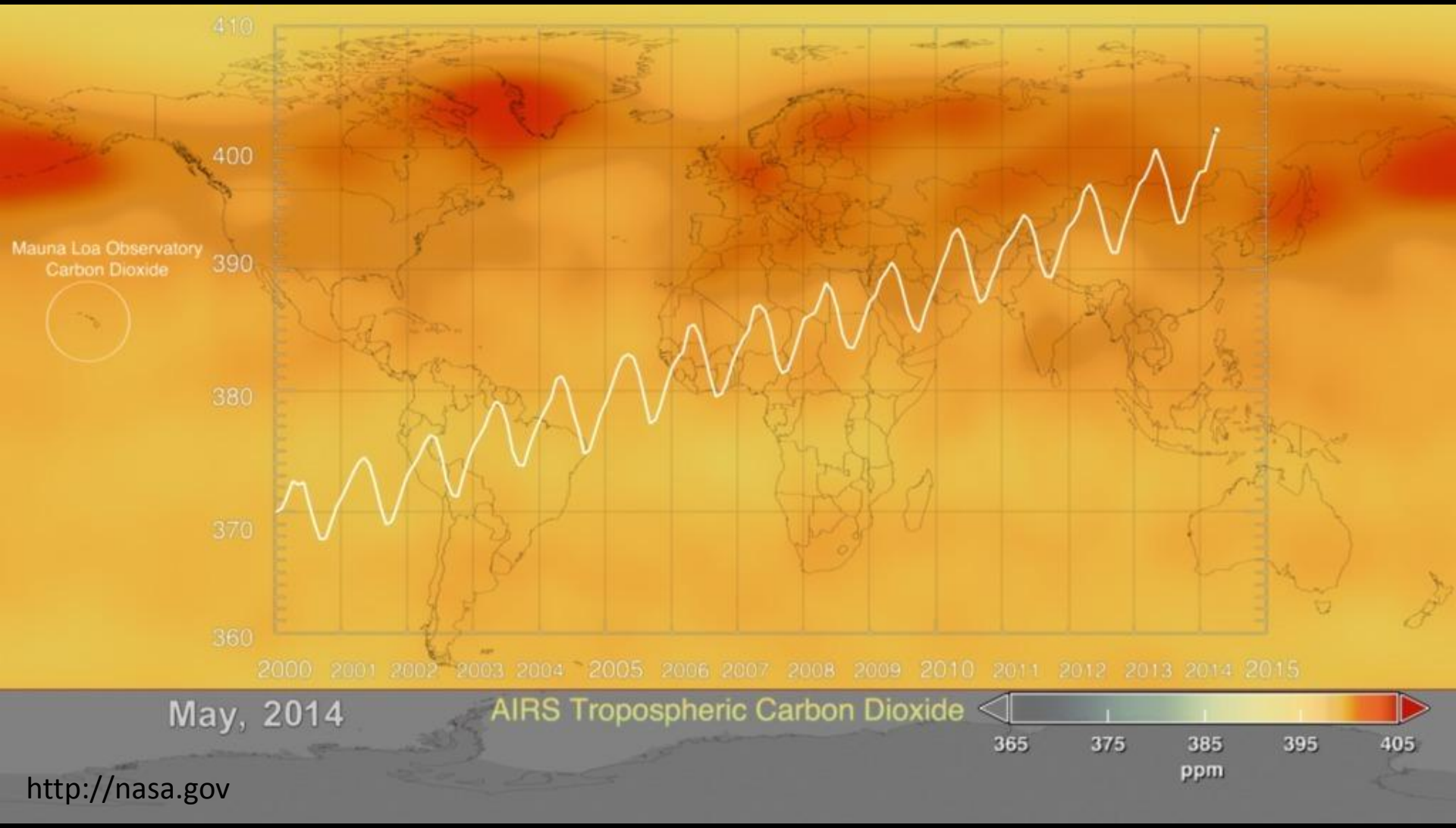
Outline





http://nasa.gov

Why organic photovoltaics?

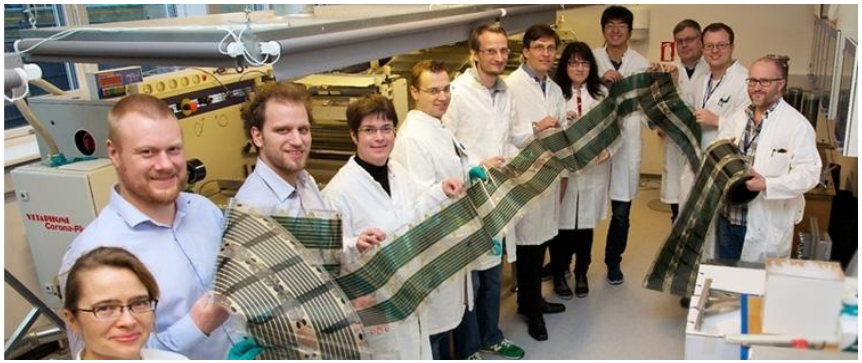
- ✓ Properties tunability
- ✓ High absorption coefficients
- ✓ Deposition from solution at low temperature
- ✓ Large area coverage (R2R process)
- ✓ Flexible and light-weight devices
- ✓ Low cost

SUNFLOWER project

InfinityPV

InfinityPV

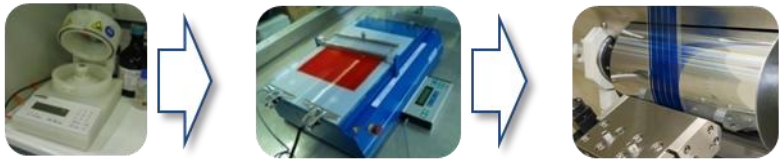
Toppan Forms



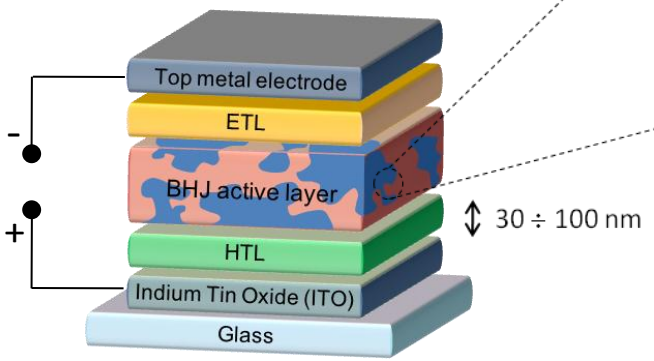
European project “ROTROT”

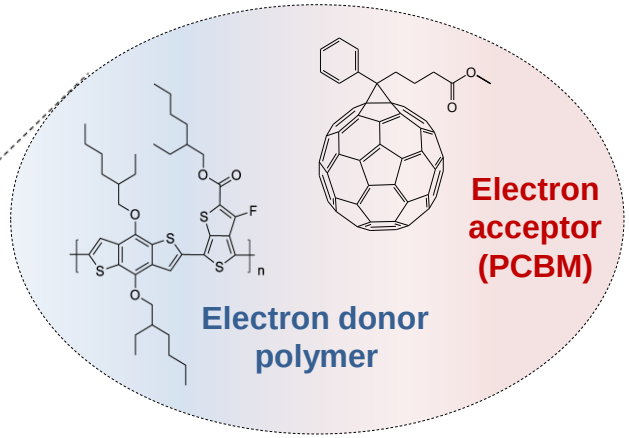
Milan – EXPO 2015

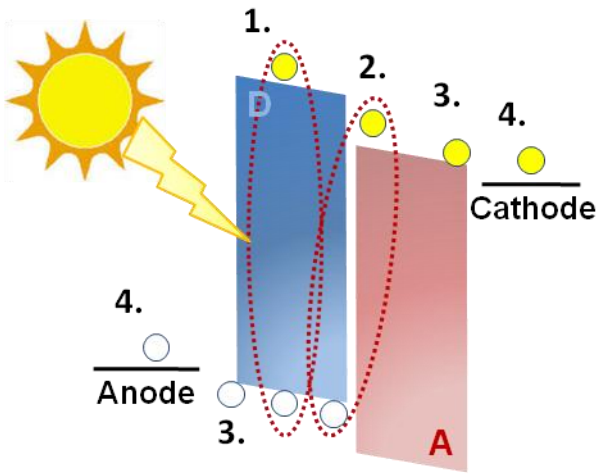
Bulk heterojunction (BHJ) polymer solar cells



Spin coating — Blade coating — Roll-to-roll

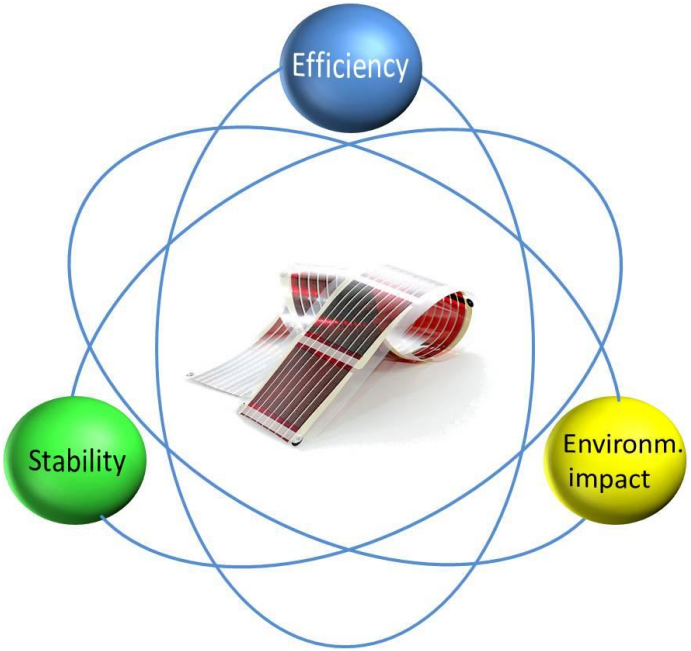




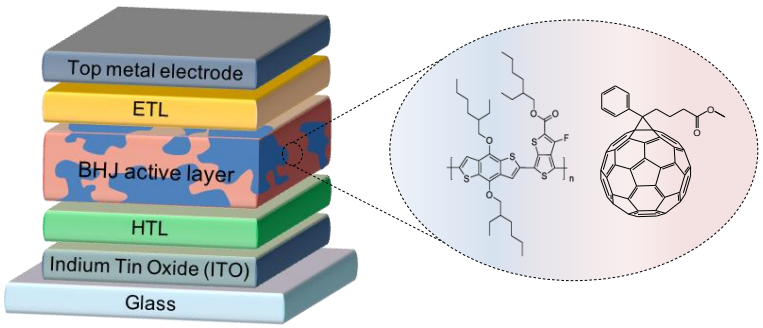


Operation mechanism

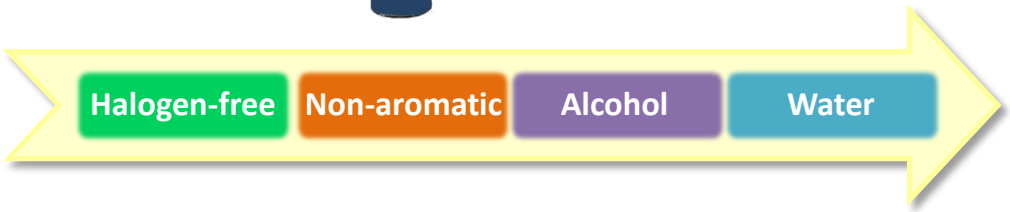
❑ Environmentally friendly processing and stability of organic solar cells



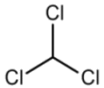
Environmentally friendly processing and stability



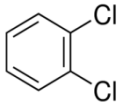
Active layer solution



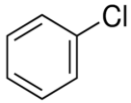
Halogenated solvents



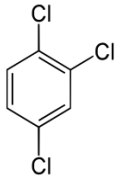
Chloroform (CF)



1,2-Dichlorobenzene (ODCB)

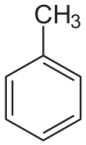


Chlorobenzene (CB)

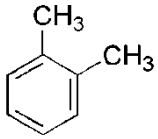


1,2,4-Trichlorobenzene (TCB)

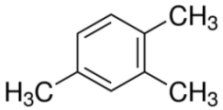
Halogen-free solvents



Toluene



O-Xylene

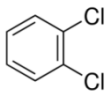


1,2,4-Trimethylbenzene

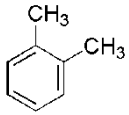
C. Chueh et al. *Energy Environ. Sci.* **2013**, *6,* 3241.
J. Zhao et al. *Nature En.* **2016**, *1,* 15027.
M. Seri et al. J. *Polym. Sci. A. Polym. Chem.* **2017,** *55,* 234.

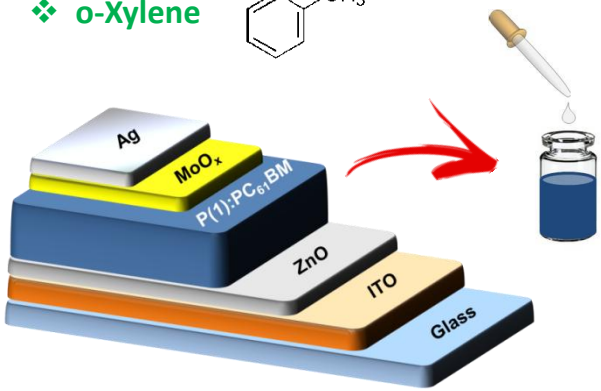
Environmentally friendly processing and stability

- 1,2-Dichlorobenzene (ODCB)

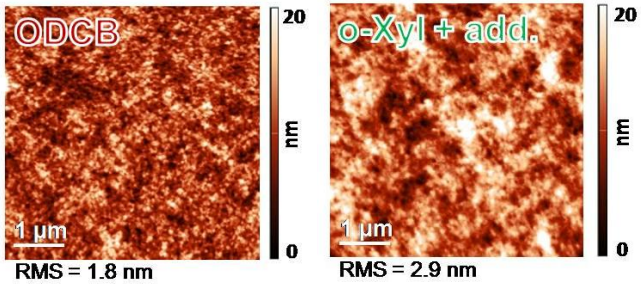


- o-Xylene





AFM images



The morphology of the active layer typically plays a crucial role on the device stability

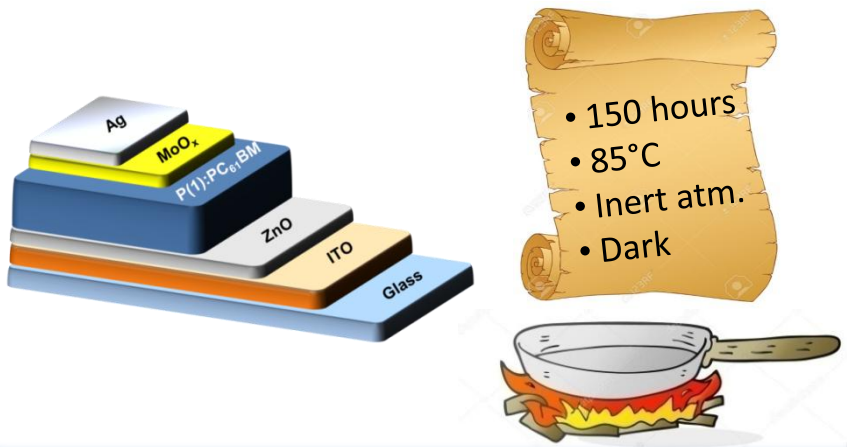
Active layer ratio [wt/wt]	Processing Solvent	Co-Solvent [v/v]	PCE [%]	V_{OC} [V]	J_{SC} [mA/cm^2]	FF [%]
P(1):PC_{61}BM (1:2)	ODCB	--	6.1	0.79	10.9	71
	o-xylene	--	2.2	0.79	5.5	51
	o-xylene	2.5 %	6.2	0.78	11.7	68

PCE = Power Conversion Efficiency

M. Bolognesi, M. Prosa et al. *Sol. Energy Mater. Sol. Cells* **2016**, *155*, 436.

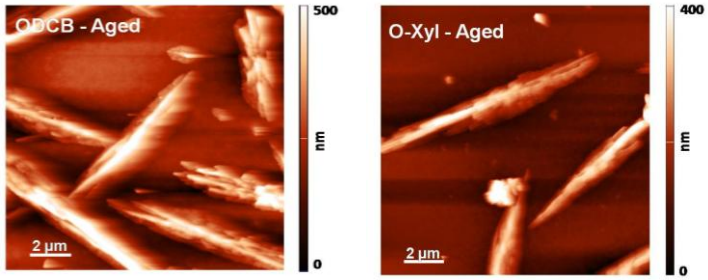
Environmentally friendly processing and stability

ISOS-D-2 standard testing protocol



AFM images (aged active layers)

ODCB **o-Xylene***



Relevant phase segregation.
Poor correlation with ΔPCE

Processing solvent	Device condition	PCE [%]	Δ PCE [%]	V_{OC} [V]	J_{SC} [mA/cm^2]	FF [%]
ODCB	Fresh	6.1	-49%	0.79	10.9	71
	After test	3.1		0.64	9.6	51
o-Xylene*	Fresh	6.2	-19%	0.78	11.7	68
	After test	5.0		0.73	10.9	62

*with 2.5% of co-solvent

M. Bolognesi, M. Prosa et al. *Sol. Energy Mater. Sol. Cells* **2016**, *155*, 436.

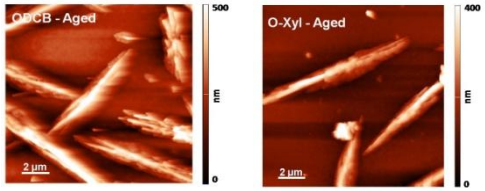
Environmentally friendly processing and stability

LSCM: Laser Scanning Confocal Microscopy

- Bulk morphology in the device
- Singlet emission from donor polymer

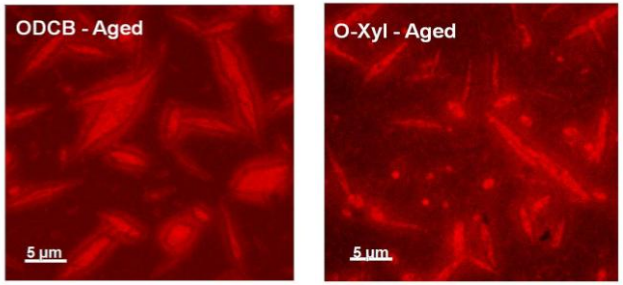
AFM images (aged active layers)

ODCB **o-Xylene***

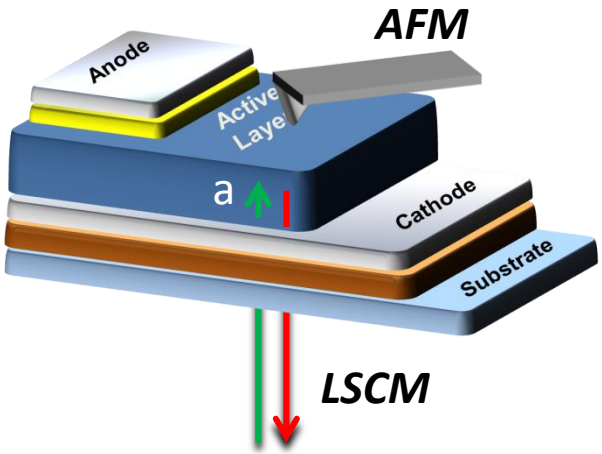


LSCM images (aged active layers)

ODCB **o-Xylene***



a



Measurement: *Outside the active area*

*with 2.5% of co-solvent

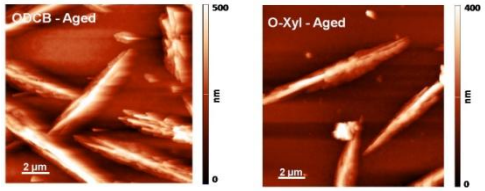
Environmentally friendly processing and stability

LSCM: Laser Scanning Confocal Microscopy

- Bulk morphology in the device
- Singlet emission from donor polymer

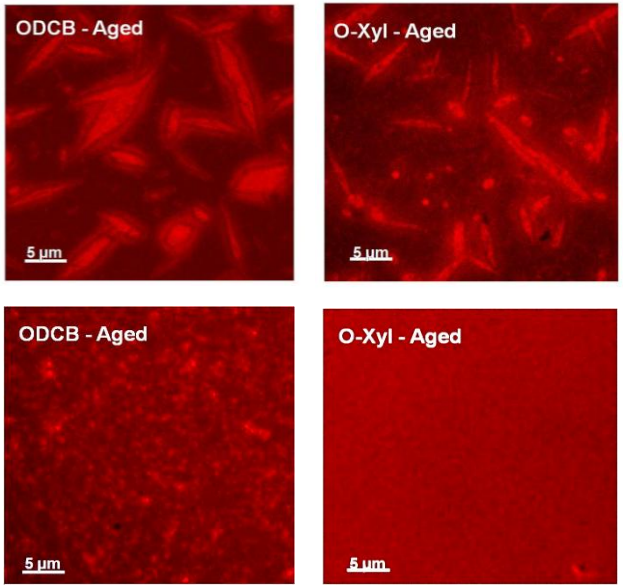
AFM images (aged active layers)

ODCB **o-Xylene***



LSCM images (aged active layers)

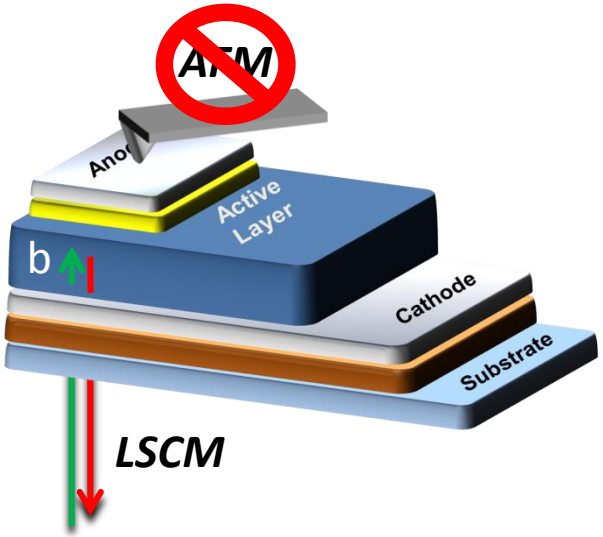
ODCB **o-Xylene***



a

b

Confinement effect of the top electrode



Measurement: *In the active area*

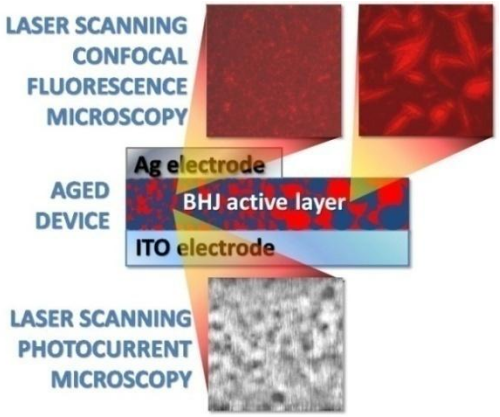
*with 2.5% of co-solvent

Take-home messages #1

- Chlorinated solvents can be **successfully replaced** by **environmentally friendlier** ones without affecting the photovoltaic performance.

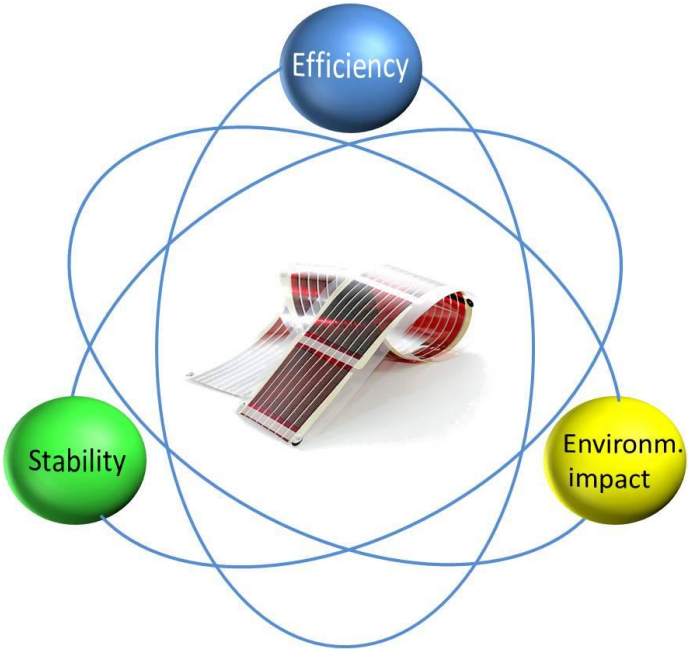
- The processing solvent of the active layer is of **relevant** importance for the **thermal stability** of photovoltaic device.

- Light-based imaging techniques (**LSCM**) offer the advantage to **analyze the degradation** of the photoactive film in a complete device.



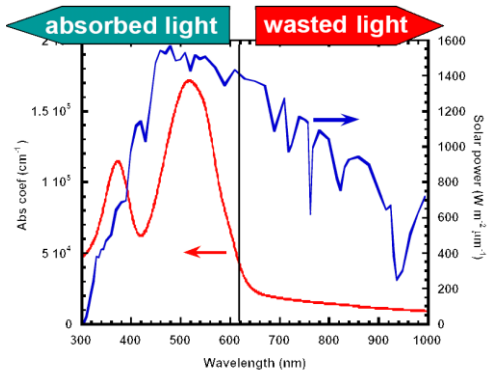
M. Bolognesi, M. Prosa et al. *Sol. Energy Mater. Sol. Cells* **2016**, *155,* 436.

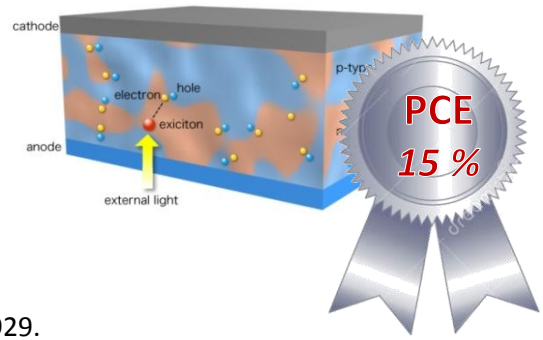
❑ Methods to improve the photovoltaic efficiency



Methods to improve the photovoltaic efficiency

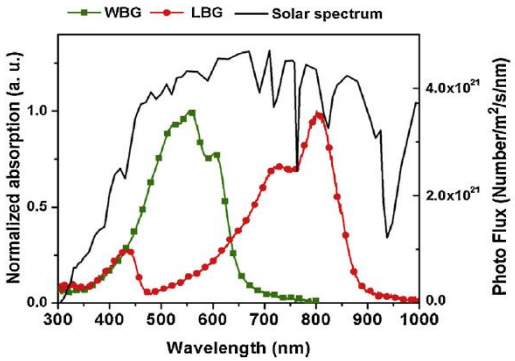
Single-junction architecture

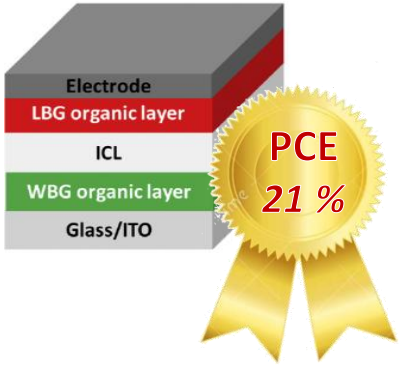


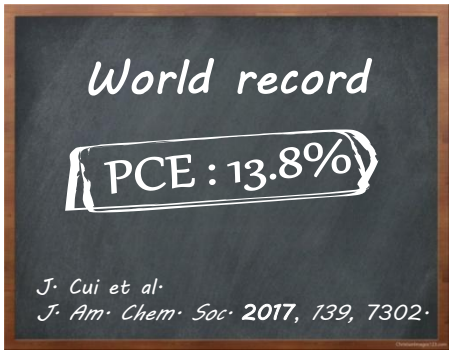


M. C. Scharber et al. *Prog. Polym. Sci.* **2013**, *38,* 1929.

Double-junction (tandem) architecture

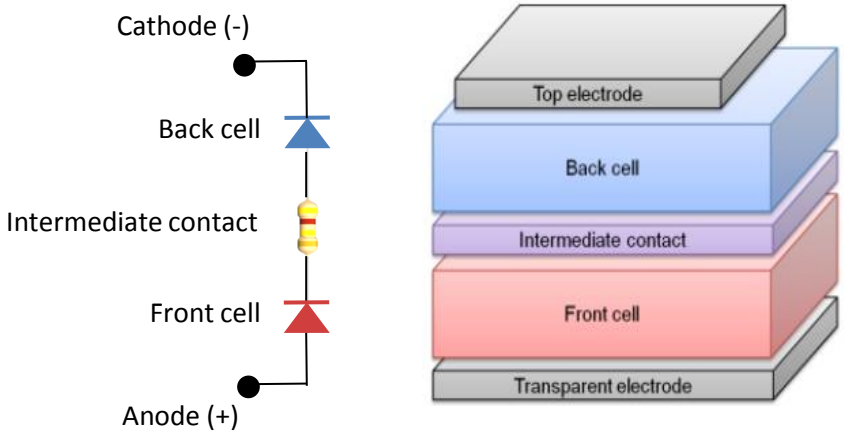






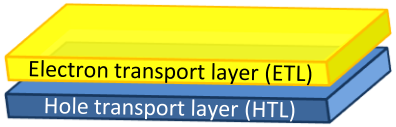
N. Li et al. *Adv. En. Mater.* **2014**, *4,* 1400084.
T. Ameri et al. *En. Environ. Sci.* **2009**, *2,* 347.

Methods to improve the photovoltaic efficiency



Series – connection

Interconnecting layer (ICL):

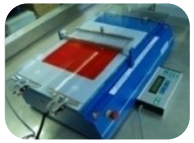


- ***Electrical***
  - Ohmic contact with the sub-cells
  - Balanced recombination of opposite charges
  - Low electrical resistance
- ***Optical***
  - Transparent
  - Optical spacer effect
- ***Chemical/physical***
  - Chemically inert
  - Physically robust
  - Compatible with mass production
- ***Others***
  - Good lifetime
  - Light stable
  - Thermal stable

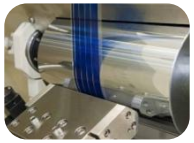
Methods to improve the photovoltaic efficiency

...towards roll-to-roll

Spin coating

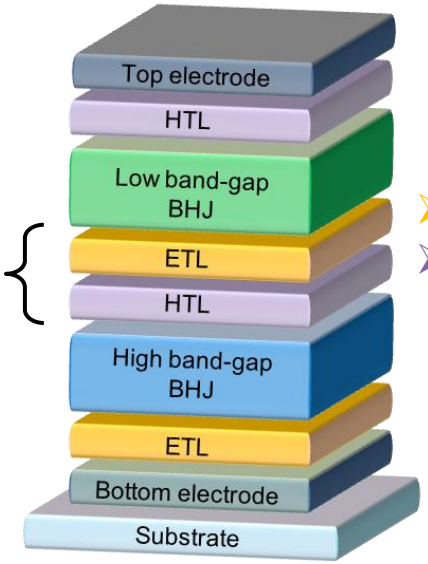


Blade coating

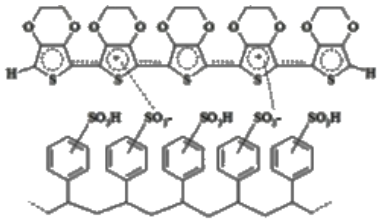


Roll-to-roll
Layer thickness ≈ 100 nm

Interconnection layer **(ICL)**



- **ZnO NPs**
- **PEDOT:PSS**

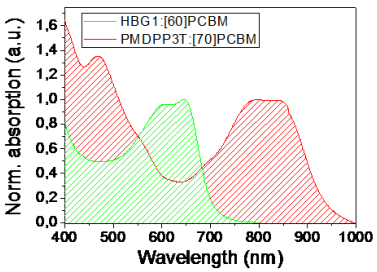


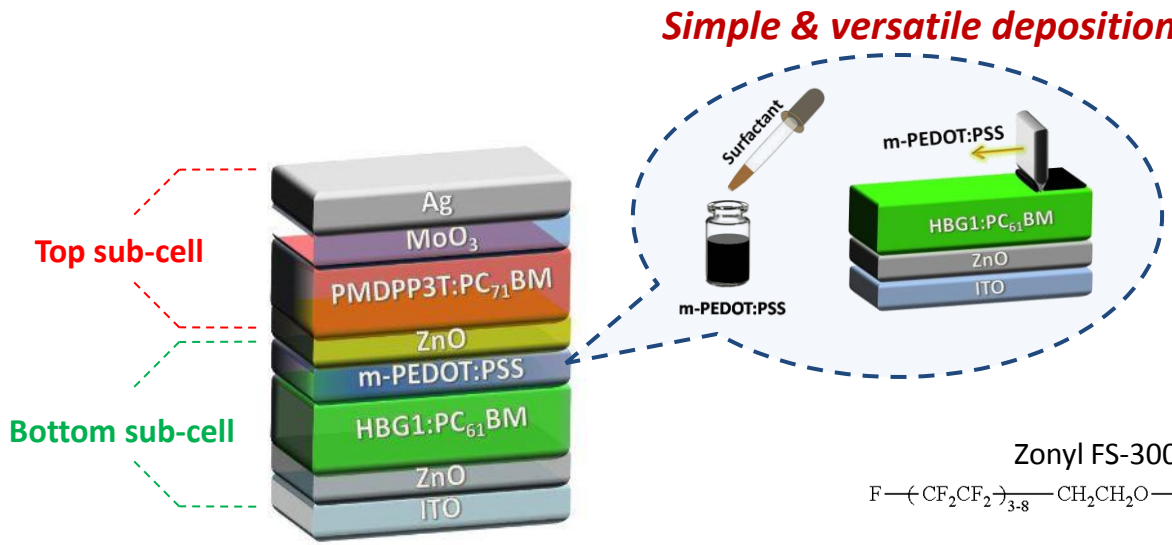
PEDOT:PSS
poly(3,4-ethylenedioxythiophene)
polystyrene sulfonate

Water-based dispersion

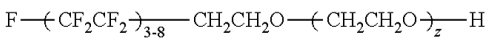
Difficult deposition over the hydrophobic organic active layer

Methods to improve the photovoltaic efficiency





Zonyl FS-300



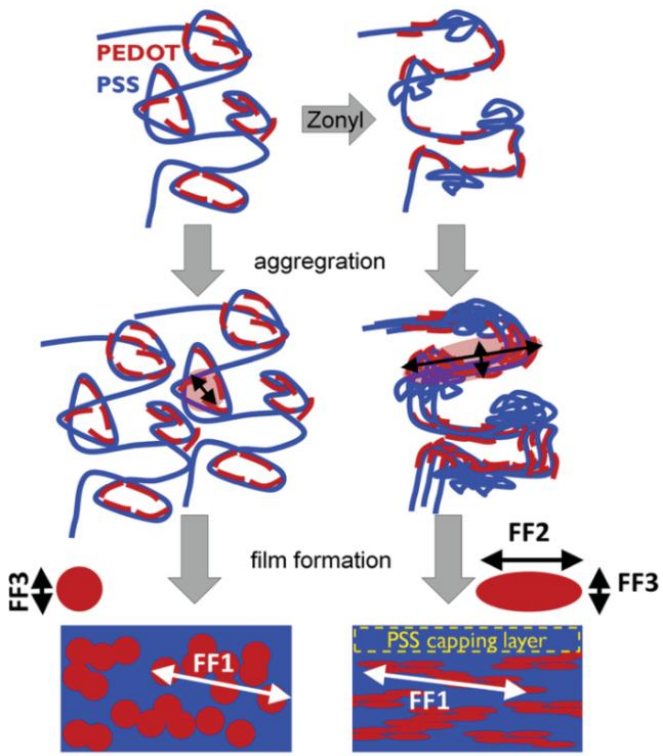
Device	J_{sc} [mA/cm^2]	V_{oc} [V]	FF [%]	PCE [%]
(Top) PMDPP3T:PC_{71}BM	14.9	0.58	62	5.3
(Bottom) HBG1:PC_{61}BM	10.4	0.77	62	4.9
Tandem A	8.2	1.25	45	4.5

The surfactant-modified PEDOT:PSS limits the tandem performance

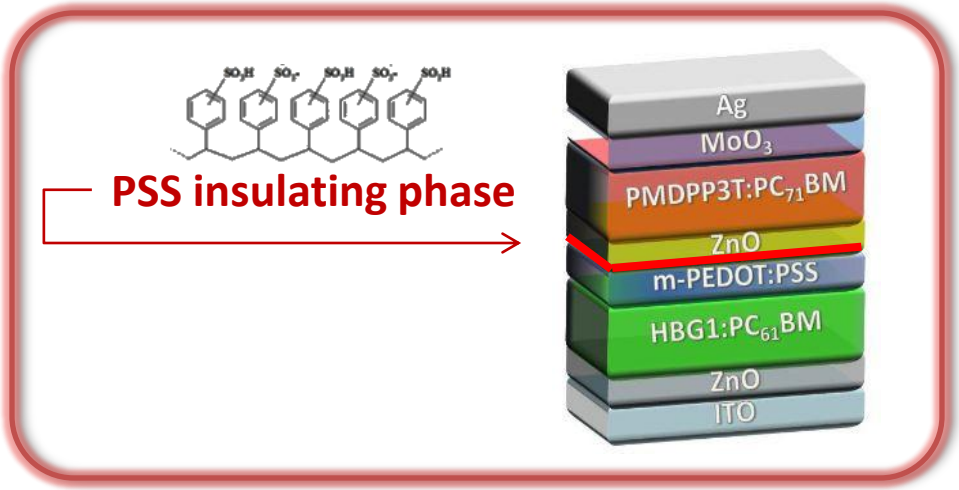
M. Prosa et al., *Adv. Mater. Interf.* **2016,** *3,* 1600770.

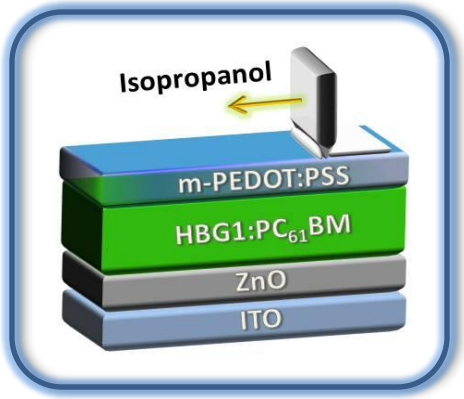
Methods to improve the photovoltaic efficiency

Effect of the surfactant



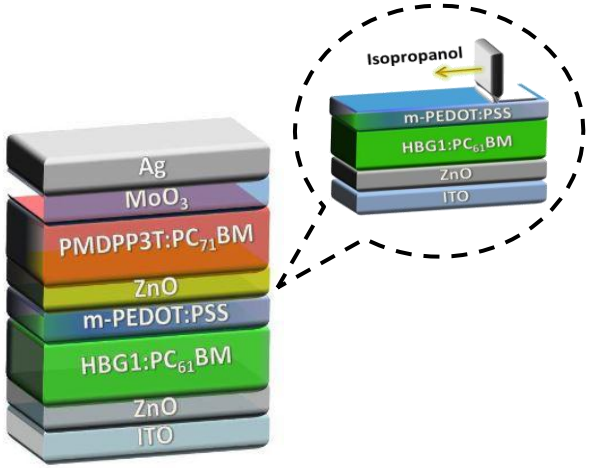
C. M. Palumbiny et al. *Adv. Electron. Mater.* **2016,** *2,* 1500377.

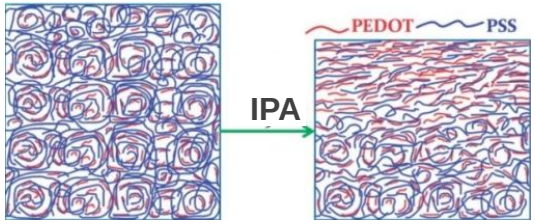




Isopropanol surface washing to remove the PSS capping layer

Methods to improve the photovoltaic efficiency





D. Alemu et al. *Energy Environ. Sci.*, **2012**, *5*, 9662.

Surface alcoholic treatment

- Partial dissolution of PSS insulating phase
- Reorganization of the PEDOT and PSS chains

Improved m-PEDOT:PSS/ZnO contact

Cell	Intermediate contact	PCE [%]	J_{sc} [mA/cm^2]	V_{oc} [V]	FF [%]
(Bottom) HBG1:PC_{61}BM	-	4.9	10.4	0.77	62
(Top) PMDPP3T:PC_{71}BM	-	5.3	14.9	0.58	62
Tandem A	Pristine	4.5	8.2	1.25	45
Tandem B	Isopropanol treated	7.6	9.5	1.34	60

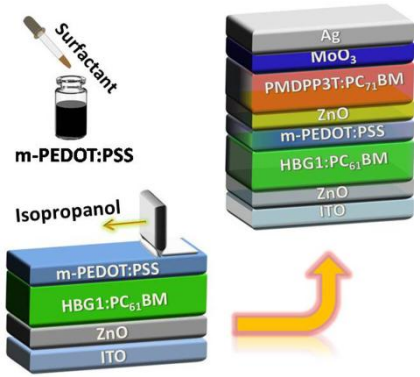
M. Prosa et al., *Adv. Mater. Interf.* **2016,** *3,* 1600770.

Take-home messages #2

- The introduction of surfactant in PEDOT:PSS (m-PEDOT:PSS) allows a **versatile deposition** over any hydrophobic active film;

- The presence of surfactant in the PEDOT:PSS interlayer of the ICL affects the performance of the resulting tandem device;

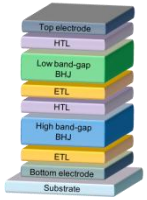
- IPA treatment over m-PEDOT:PSS is a fast approach, fulfilling the **industrial coating** requirements, to recover the properties of the intermediate layer of organic tandem solar cells.



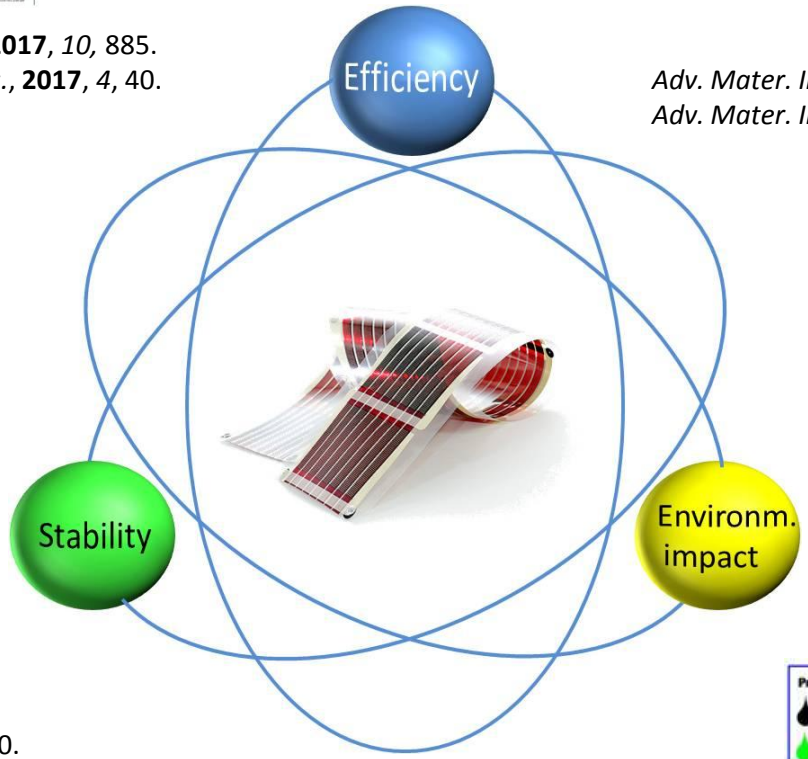
M. Prosa et al., *Adv. Mater. Interf.* **2016,** *3,* 1600770.

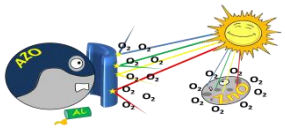
Summary and outlook

En. Environ. Sci. **2017**, *10,* 885.
Front. Energy Res., **2017**, *4*, 40.



Adv. Mater. Interf. **2017**, DOI: 10.1002/admi.201700776.
Adv. Mater. Interf. **2016**, *3,* 1600770.





ACS Appl. Mater. Interf. **2016**, *8,* 1635.
Sol. Energy Mater. Sol. Cells **2016**, *144,* 150.
Sol. Energy Mater. Sol. Cells **2015**, *141,* 240.

J. Polym. Sci. Part A Polym. Chem., **2017**, *55,* 234.
Sol. Energy Mater. Sol. Cells **2016**, *155,* 436.

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Thank you for your attention