Organic photovoltaics: towards a sustainable future

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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
Bulk heterojunction (BHJ) polymer solar cells

Spin coating  Blade coating  Roll-to-roll

Electron donor polymer
Electron acceptor (PCBM)

Top metal electrode
ETL
BHJ active layer
HTL
Indium Tin Oxide (ITO)
Glass

30 ÷ 100 nm

1. 2. 3. 4.
Anode Cathode

Operation mechanism
Environmentally friendly processing and stability of organic solar cells
Environmentally friendly processing and stability

Halogenated solvents

- Chloroform (CF)
- 1,2-Dichlorobenzene (ODCB)
- Chlorobenzene (CB)
- 1,2,4-Trichlorobenzene (TCB)

Halogen-free solvents

- Toluene
- 1,2,4-Trimethylbenzene
- O-Xylene

1,2-Dichlorobenzene (ODCB)

- o-Xylene

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

Environmental friendly processing and stability

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

$PCE = Power Conversion Efficiency$

ISOS-D-2 standard testing protocol

- 150 hours
- 85°C
- Inert atm.
- Dark

AFM images (aged active layers)

ODCB

After test

ΔPCE [%]

ODCB - Aged

O-Xyl - Aged

Relevant phase segregation.
Poor correlation with ΔPCE

<table>
<thead>
<tr>
<th>Processing solvent</th>
<th>Device condition</th>
<th>PCE [%]</th>
<th>ΔPCE [%]</th>
<th>V_{oc} [V]</th>
<th>J_{sc} [mA/cm²]</th>
<th>FF [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODCB</td>
<td>Fresh</td>
<td>6.1</td>
<td>-49%</td>
<td>0.79</td>
<td>10.9</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>After test</td>
<td>3.1</td>
<td></td>
<td>0.64</td>
<td>9.6</td>
<td>51</td>
</tr>
<tr>
<td>o-Xylene*</td>
<td>Fresh</td>
<td>6.2</td>
<td>-19%</td>
<td>0.78</td>
<td>11.7</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>After test</td>
<td>5.0</td>
<td></td>
<td>0.73</td>
<td>10.9</td>
<td>62</td>
</tr>
</tbody>
</table>

*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

*with 2.5% of co-solvent

**AFM images (aged active layers)**

**LSCM images (aged active layers)**

**Measurement:** Outside the active area
**LSCM**: Laser Scanning Confocal Microscopy

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

**Confinement effect of the top electrode**

*with 2.5% of co-solvent*
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.

Methods to improve the photovoltaic efficiency
Methods to improve the photovoltaic efficiency

Single-junction architecture


Double-junction (tandem) architecture

Methods to improve the photovoltaic efficiency

**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

Interconnection layer (ICL)

- PEDOT:PSS
- ZnO NPs
- PEDOT:PSS

...towards roll-to-roll

Spin coating ➔ Blade coating ➔ Roll-to-roll

Layer thickness ≈ 100 nm

Difficult deposition over the hydrophobic organic active layer

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

Water-based dispersion

 Mario Prosa - DSCTM Conference 2017
### Device Performance

<table>
<thead>
<tr>
<th>Device</th>
<th>$J_{sc}$ [mA/cm²]</th>
<th>$V_{oc}$ [V]</th>
<th>FF [%]</th>
<th>PCE [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Top) PMDPP3T:PC$_{71}$BM</td>
<td>14.9</td>
<td>0.58</td>
<td>62</td>
<td>5.3</td>
</tr>
<tr>
<td>(Bottom) HBG1:PC$_{61}$BM</td>
<td>10.4</td>
<td>0.77</td>
<td>62</td>
<td>4.9</td>
</tr>
<tr>
<td>Tandem A</td>
<td>8.2</td>
<td>1.25</td>
<td>45</td>
<td>4.5</td>
</tr>
</tbody>
</table>

The surfactant-modified PEDOT:PSS limits the tandem performance.

Methods to improve the photovoltaic efficiency

Effect of the surfactant


Isopropanol surface washing to remove the PSS capping layer
# Methods to improve the photovoltaic efficiency

## Surface alcoholic treatment
- Partial dissolution of PSS insulating phase
- Reorganization of the PEDOT and PSS chains

Improved m-PEDOT:PSS/ZnO contact

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### Table: Photovoltaic Parameters

<table>
<thead>
<tr>
<th>Cell</th>
<th>Intermediate contact</th>
<th>PCE [%]</th>
<th>$J_{sc}$ [mA/cm$^2$]</th>
<th>$V_{oc}$ [V]</th>
<th>FF [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Bottom) HBG1:PC$_{61}$BM</td>
<td>-</td>
<td>4.9</td>
<td>10.4</td>
<td>0.77</td>
<td>62</td>
</tr>
<tr>
<td>(Top) PMDPP3T:PC$_{72}$BM</td>
<td>-</td>
<td>5.3</td>
<td>14.9</td>
<td>0.58</td>
<td>62</td>
</tr>
<tr>
<td>Tandem A</td>
<td>Pristine</td>
<td>4.5</td>
<td>8.2</td>
<td>1.25</td>
<td>45</td>
</tr>
<tr>
<td>Tandem B</td>
<td>Isopropanol treated</td>
<td>7.6</td>
<td>9.5</td>
<td>1.34</td>
<td>60</td>
</tr>
</tbody>
</table>

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.


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Thank you for your attention