Polymer/Organic solar cells

Martijn Wienk
Molecular Materials & Nanosystems (M₂N)

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Polymer solar cells

Flexible

Printable

Konarka, Riso, Solar Ivy, Holst Centre
Polymer solar cells

- Mixture of e-donor (polymer) with e-acceptor (fullerene)
- Charge carrier generation at interface only
- Prospect of large scale reel-to-reel production
- Efficiencies increase, but still modest
Polymer solar cells

Selective contacts:
- High work function PEDOT for holes
- Low work function metal for electrons
Typical materials

Semiconducting polymers
- electron donating
- hole conducting
- good absorbers

Buckminster fullerenes
- electron accepting
- electron conducting
- poor absorbers

Deposited from mixed solution
Choosing the right polymer absorber

Fundamental losses

Energy loss (eV) $E_{\text{gap}} - eV_{\text{oc}}$

Trade-off between current and voltage

EQE = 0.65
FF = 0.65

Theoretical Efficiency [%]
Band gap tuning

Donor-Acceptor materials

Mathieu Turbiez, Arjan Zoombelt, Johan, Bijleveld, Weiwei Li, Koen Hendriks
Recent polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>$E_g$ (eV)</th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>$V_{oc}$ (V)</th>
<th>FF</th>
<th>EQE$_{max}$</th>
<th>PCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDPP3TaltTPT</td>
<td>1.44</td>
<td>15.9</td>
<td>0.74</td>
<td>0.67</td>
<td>0.59</td>
<td>8.0</td>
</tr>
<tr>
<td>PDPPTPT</td>
<td>1.50</td>
<td>14.0</td>
<td>0.80</td>
<td>0.67</td>
<td>0.58</td>
<td>7.4</td>
</tr>
<tr>
<td>PDPPP3T</td>
<td>1.33</td>
<td>15.4</td>
<td>0.67</td>
<td>0.69</td>
<td>0.49</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Pushing the limits

### Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>$V_{oc}$ (V)</th>
<th>$J_{sc, sr}$ (mA/cm²)</th>
<th>FF</th>
<th>PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>0.43</td>
<td>20.5</td>
<td>0.54</td>
<td>4.8</td>
</tr>
<tr>
<td>Selene</td>
<td>0.34</td>
<td>17.6</td>
<td>0.50</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Koen Hendriks, Weiwei Li.
Multi-junctions

- $E_{\text{gap}} = 1.0\ \text{eV}$
- $E_{\text{gap}} = 0.75\ \text{eV}$
- $E_{\text{gap}} = 1.5\ \text{eV}$

Photon energy (eV)

Intensity (W m$^{-2}$ eV$^{-1}$)

Transmission

Thermalization

Wide gap

Narrow gap

Intermediate gap

PCBM

Glass

ITO
Challenge: solution processing

Hole transporting layer

Conversion contact

Electron transporting layer

$E_g = 1.3 \text{ eV}; \text{ PCE} = 5.8\%$

$E_g = 1.9 \text{ eV}; \text{ PCE} = 5.8\%$

TEM cross section

Al

Narrow gap absorber

PEDOT

ZnO

Wide gap absorber

PEDOT

ITO

Glass

Joachim Loos
Tandem cell performance 8.9%

<table>
<thead>
<tr>
<th>$J_{sc}$ (mA/cm$^2$)</th>
<th>$V_{oc}$ (V)</th>
<th>FF</th>
<th>PCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.56</td>
<td>1.46</td>
<td>0.62</td>
<td>8.90</td>
</tr>
</tbody>
</table>

PCDTBT front cell
PMDPP3T back cell

Weiwei Li & Alice Furlan. J. Am. Chem. Soc. 2013, 135, 5529
1+2 Triple junctions

![Diagram of 1+2 Triple junctions]

- Tandem
- 3-Junction

<table>
<thead>
<tr>
<th></th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>$V_{oc}$ (V)</th>
<th>FF (-)</th>
<th>PCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tandem</td>
<td>9.56</td>
<td>1.46</td>
<td>0.62</td>
<td>8.9</td>
</tr>
<tr>
<td>3-Junction</td>
<td>7.34</td>
<td>2.09</td>
<td>0.63</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Weiwei Li & Alice Furlan. J. Am. Chem. Soc. 2013, 135, 5529
Solar energy storage: H2O splitting

\[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 \]

\[ E^0_{\text{H}_2\text{O}} = 1.23 \text{ V} + \text{overpotential (} \zeta_{\text{O}_2} - \zeta_{\text{H}_2} \text{)} \]

\[ V_{\text{H}_2\text{O}} > 1.4 \text{ V} \]

In practice

$\zeta_{O_2} = 0.23 \text{ V}$
$\zeta_{H_2} = 0.03 \text{ V}$

Solar To Hydrogen (STH) efficiency =

\[
(J_{op.} \times V_{op.}) \times \frac{1.23 \ V}{V_{op.}} = J_{op.} \times 1.23 \ V = 5.41\%
\]

$J_{MPP} = 4.63 \text{ mA/cm}^2$
$V_{MPP} = 1.44 \text{ V}$

$J_{op.} = 4.40 \text{ mA/cm}^2$
$V_{op.} = 1.49 \text{ V}$

Serkan Esiner, photograph Bart Overbeke
Summary

- **Band gap control**: 2.0 eV and 1.1 eV

- **8.9% efficient tandem**:

- **9.6% efficient triple junction**

- **Chemical storage**
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