Multilayer Organic Photovoltaic Cells

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http://www.yuma-solar.com/pvl.htm
Motivation

- Solar energy is abundant
- Current Si based PV systems are expensive
- Organic PV cells are cheap but inefficient
  - Large Si wafer plant – 88,000m² per year
  - Offset printing 1-10 hours for same area
  - Typical power efficiency: 2-4%
- Multilayer organic cells can have higher efficiencies than traditional single cells

Brabec, C.J.; et.al. *MRS Bull.* **30**, 50 – 52. 2005
Multilayer cells

- What are multilayer or tandem organic PV cells?
- What advantages do these have over regular cells?
- What are the materials challenges facing improvement of these devices?
The multilayer cell

- Series connection of two organic PV cells
- Active layers are a mix of donor and acceptor materials
Advantages over single layer cells

- Polymers have narrow absorption bands
- Multiple active layers allow absorption over a wider range of the spectrum

Multilayer cell performance

<table>
<thead>
<tr>
<th>Donor</th>
<th>Front</th>
<th>Back</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCPDTBT</td>
<td>P3HT</td>
<td></td>
</tr>
<tr>
<td>Acceptor</td>
<td>PCBM</td>
<td>PC$_{70}$BM</td>
</tr>
</tbody>
</table>

FF = 0.67  
$\eta$ = 6.5%

General challenges

- Many variables
  - Donor & acceptor materials (2 pairs)
  - Interlayer material
  - Layer thickness
  - Layer order
- Device optimization is complicated
  - 200 cell designs tested
  - “Inverted” cell – small bandgap material in the front, not intuitive
- Need predictive technique to streamline process

Optical calculations

- Goal: balanced cell
- Potential improvements: 9% with thicker PCPDTBT layer

Challenges for interlayer materials

The interlayer should be:
- transparent (usually)
- conductive (for electrons or holes)
- a mediator of electron – hole recombination
- compatible with adjacent materials
- deposited with solution based techniques

- Thin metal layers – used in early cells, but coming back
- ITO – high work function, bad contacts
- TiO\textsubscript{x} – best performance so far, solution process

Conclusion

- Multilayer cells are in early stage of development
- Room for improvement in:
  - Interlayers
  - Processing
  - Active materials
- Cell architecture optimization: calculation & experiment
Polymers

- **P3HT**: poly(3-hexylthiophene)
- **PCBM**: [6,6]-phenyl-C61 butyric acid methyl ester
- **PC70BM**: [6,6]-phenyl-C71 butyric acid methyl ester
- **PCPDTBT**: poly[2,6-(4,4-bis-(2-ethylhexyl)-4H-cyclopenta[2,1-b;3,4-b']dithiophene)-alt-4,7-(2,1,3 benzothiadiazole)]
- **PEDOT**: poly(3,4-ethylenedioxylenethiophene)
- **PSS**: polystyrene sulfonic acid
Intelayes and optical cavities

The multilayer cell

- Series connection of two organic PV cells
- Each active layer is a mixture of donor and acceptor materials
  
  $J_{sc} = 7.8 \text{mA/cm}^2$
  $V_{oc} = 1.24 \text{V}$
  $FF = 0.67$
  $\eta = 6.5\%$