Thermal stability and reproducibility enhancement of organic solar cells by tris(hydroxyquinoline)gallium dopant forming a dual acceptor active layer

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Outline

• Advantages of Organic Solar Cells (OSCs)
• Operating Principle of OSCs
• Problem Statement
• Research Objective
• Methodology
• Results & Discussion
• Conclusions
Advantages of OSCs

• Cost effective.
  * Simple fabrication process.
  * Minimal material usage

• Light weight.

• Mechanical flexibility.

• Easily controlling their materials properties.
Operating Principle of OSCs

Photonic energy

Donor        Acceptor

Cathode

Anode

LUMO

HOMO

Exciton generation
• Few exciton dissociations
• Weak carriers transport
• Non-complementary absorption of sunlight
• Stability issues

Efficiency of OSC reached to 1% in 1986 (Tang, 1986) to 5% in 2005 (Xue et al., 2005), and more recently to up to 13% thanks to the molecular optimization (Zhao et al., 2017a)
- Inexact contacts between the donor/acceptor and their corresponding electrodes
- Non-complementary absorption of sunlight
- Stability issues
Research Objective

• All solution-processed OSCs based on ternary active layers

• Improving thermal stability and reproducibility of OSCs by adding a secondary acceptor
Methodology

Oligo-thiophene (DH6T) + Fullerene (C_{61}) + Gaq3/Alq3
Methodology

OSCs based on ternary (a) and binary (b) organic composites
Results and Discussion

The diagram shows the absorbance (a.u.) as a function of wavelength (nm) for different molar fractions of GaQ3. The absorbance is plotted on the y-axis, and the wavelength on the x-axis. The absorbance values for 0%, 12.4%, 29.8%, and 41.4% GaQ3 are represented by different markers: black circles, blue squares, red stars, and white circles, respectively.

- **Blueshift**: The absorbance bands shift to the blue as the molar fraction of GaQ3 increases, indicating a decrease in wavelength.
- **Redshift**: The absorbance bands also shift to the red as the molar fraction of GaQ3 increases, indicating an increase in wavelength.

An inset graph shows the energy band (eV) as a function of the molar fraction of GaQ3. The energy band increases with the molar fraction, indicating a non-monotonic change of absorption and $E_g$. The experimental data points are shown as blue circles, and the fitted formula is represented by a red line.
Results and Discussion

- Broadened absorption (redshift)
- Absorbance, Normalized (a.u.)
- Wavelength (nm): 320 to 880
- Gaq3
- PCBM
- DH6T
- Vibronic shoulder
Results and Discussion
For P3HT:PCBM:F8BT and PTB7:PCBM:F8BT, the point of inversion is at 120 °C, as reported by Shang et al. (2015, Journal of Materials Science: Materials in Electronics, 26, 5708-5714).
# Results and Discussion

<table>
<thead>
<tr>
<th>Devices</th>
<th>Annealing T (°C)</th>
<th>$J_{sc}$ (mA/cm²)</th>
<th>$V_{oc}$ (V)</th>
<th>$n$</th>
<th>$R_s$ (Ω)</th>
<th>$R_{sh}$ (Ω)</th>
<th>FF %</th>
<th>η %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH6T:PCBM</td>
<td>25</td>
<td>0.63</td>
<td>0.30</td>
<td>3.81</td>
<td>887</td>
<td>5502</td>
<td>26.2</td>
<td>0.06</td>
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<td>DH6T:PCBM:Gaq3</td>
<td>25</td>
<td>1.31</td>
<td>0.77</td>
<td>3.76</td>
<td>573</td>
<td>6775</td>
<td>26.7</td>
<td>0.27</td>
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<td>DH6T:PCBM:Gaq3</td>
<td>140</td>
<td>1.50</td>
<td>0.65</td>
<td>2.23</td>
<td>367</td>
<td>4730</td>
<td>28.7</td>
<td>0.28</td>
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<tr>
<td>DH6T:PCBM:Gaq3</td>
<td>180</td>
<td>1.55</td>
<td>0.66</td>
<td>1.94</td>
<td>310</td>
<td>4836</td>
<td>29.3</td>
<td>0.30</td>
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<tr>
<td>DH6T:PCBM:Gaq3</td>
<td>220</td>
<td>1.22</td>
<td>0.68</td>
<td>1.96</td>
<td>337</td>
<td>5814</td>
<td>26.5</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Results and Discussion

- **Batch #1 (25 °C)**
  - STDEV = 0.008062

- **Batch #2 (140 °C)**
  - STDEV = 0.008042

- **Batch #3 (180 °C)**
  - STDEV = 0.009106

- **Batch #4 (220 °C)**
  - STDEV = 0.00866
Results and Discussion

- \( \eta \) (decrement rate = -2.1e-4 %/hr)
- \( FF' \) (decrement rate = -0.011 %/hr)

Graph showing the change in \( \eta \) and \( FF' \) over time (hour).
Results and Discussion

(a) Gaq3 (25 °C)

(b) Gaq3 (180 °C)
Nanorods formed

c) Gaq3 (255 °C)

d) DH6T:Gaq3 (25 °C)
donor-acceptor moieties
phase separation

e) DH6T:PCBM:Gaq3 (25 °C)
Gaq3 molecules

degradation
Conclusion

• Addition of 29% molar fraction of Gaq3 into the devices active layer has considerably improved the thermal stability, photo-absorption and reproducibly.

• The power and efficiency of the devices were increased by an order of 5.8

• Higher thermal stability compared to that of the reported P3HT:PCBM:F8BT and PTB7:PCBM:F8BT based solar cells
Thank you

Q & A