Nanostructures for Solar Cells

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Principle of Operation

Semiconductor p-n junction

- Band gap enables photogeneration of carriers (ideal: 1.34 eV)
- n and p type doping ⇒ asymmetric electrodes (exciton separation)
Solar cell characteristics

- **Short-Circuit Current** ($I_{sc}$)  For $V = 0$, $I = I_{sc}$
- **Open-Circuit Voltage** ($V_{oc}$)  For $I = 0$, $V = V_{oc}$
- **Fill Factor** ($FF$)  
  \[ FF = \frac{P_{max}}{I_{sc} \times V_{oc}} \]
- **Power Conversion Efficiency** ($\eta$)  
  \[ \eta = \frac{P_{max}}{P_{in}} = \frac{(I_{max} \times V_{max})}{P_{in}} = FF \times \{ (I_{sc} \times V_{oc}) / P_{in} \} \]
  \[ P_{in} = 100 \text{ [mW/cm}^2\text{]} \]

\[ P_{sun} = \int b(E)E \, dE \]
Motivation

Silicon Solar Cell
- Power conversion efficiency up to 24% in lab.¹
- High energy consumption at fabrication
- Cost-intensive fabrication

Organic Solar Cell
- Low energy consumption at fabrication
- Inexpensive fabrication
- Mechanically flexible on appropriate substrates
- Only 5% achieved in lab.¹

Issues

To harvest more photons from a wide spectral range:
- Develop new absorber system that responds to IR
To improve the efficiency beyond the limit of 5%:
- Fabricate ordered nanostructures to improve photo-induced charge separation and transport

¹ Source: Solar Cells Lab.
Issues in Organic Photovoltaics

Photoabsorption & exciton generation

Exciton transport & separation

Hole transport

Organic photovoltaics

Control of LUMO of an electron acceptor
Control of electron affinity of an acceptor
Unique properties of nanomaterials

- High electrical conductivity (10^4 S/cm for metallic (10,10) SWNTs\(^2\)) and electron affinity (CdS, CdSe, CdTe, InP, GaAs etc.)
- 1-, 2- and 3-D assemblies
- Controlled electronic and surface properties by various components, morphologies, and chemical modifications\(^3,4\)

Optical property of CdSe quantum dots with different size\(^3\)

Electrical band gap energy of CdSe\(_x\)Te\(_{1-x}\) tetrapodal nanocrystals\(^2\)
Short-circuit current ($J_{sc}$): 3.12 mA/cm$^2$
Open-circuit voltage ($V_{oc}$): 0.714 V
Fill factor (FF): 47.7 %
Power conversion efficiency ($\eta$): 1.06 %
under AM 1.5 conditions.$^5$
Short-circuit current ($J_{sc}$): 1.40 mA/cm²
Open-circuit voltage ($V_{oc}$): 0.858 V
Fill factor ($FF$): 49.6 %
Power conversion efficiency ($\eta$): 0.6 % under AM 1.5 conditions.
Hybrid nanostructures

Quantum dots as charge separator and generator

Carbon nanotubes as the supporter to improve charge separation and transport

Direct assembly

Hybrid nanostructures

[Diagram showing energy levels and charge interactions]
Material synthesis

- p-MWCNT in EtOH
- Cu₂S/MWCNT in CHCl₃

Chemical reactions:
- HNO₃/H₂SO₄
- Cu(acac)₂/ elemental S
- Oleylamine, \( \triangle \)

Graphs:
- p-MWCNT
- Cu₂S NCs
- Cu₂S/MWCNT

Solar Cells Lab.
0.05M Cu(acac)$_2$

0.1M Cu(acac)$_2$

Hexagonal chalcocite $\beta$-Cu$_2$S (JCPDS no. 26-1116; $a = 3.961$ Å, $c = 6.722$ Å).

Fig. 1

Fig. 2
1.5M Cu(acac)$_2$
Solar cell fabrication

Short-circuit current ($J_{sc}$): 0.57 mA/cm$^2$
Open-circuit voltage ($V_{oc}$): 0.32 V,
Fill factor ($FF$): 44 %
Power conversion efficiency ($\eta$): 0.08 %
under AM 1.5 conditions.

Fig. 4
Conclusion

1. Single-crystalline hexagonal-phase $\beta$-Cu$_2$S NCs were grown in situ on acid-functionalized MWCNTs by the solvothermal method.

2. The morphology of the Cu$_2$S NCs was varied from spherical particles (avg. size 4 nm) to triangular plates (avg. size 12 nm) by increasing the concentration of the precursors.

3. The lattice matching between the (002) planes of Cu$_2$S and the (002) planes of the MWCNTs is thought to be an important factor in the growth of the Cu$_2$S NCs on the surface of the MWCNTs.

4. The photovoltaic device fabricated from the blends of Cu$_2$S-MWCNT and P3OT responds more sensitively than those fabricated using Cu$_2$S NCs or MWCNTs alone.

5. The maximum power conversion efficiency was found to be 0.08%. Direct, efficient electron transport from the photoexcited Cu$_2$S NCs to the MWCNTs would enhance their photocurrents.


