Organic Solar Cells

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http://www.astropix.com/HTML/G_SUN/SUN1.HTM
Some advice
1. Read literature. 
As much as you can stand. 
Don’t believe any of it.
2. Your advisor is probably wrong. Define your own problems.
To your

Fellow group members
Graduate students
Advisor
Scientists/engineers

Be fiercely critical.
While remaining civil.
4. Collaborate!
1\textsuperscript{st}, 2\textsuperscript{nd} or 3\textsuperscript{rd} author? Doesn’t matter. A lost opportunity does.
Try.
**Global Exergy Flux, Reservoirs, and Destruction**

Exergy is the useful portion of energy that allows us to do work and perform energy services. We gather exergy from energy-carrying substances in the natural world we call energy resources. While energy is conserved, the exergetic portion can be destroyed when it undergoes an energy conversion. This diagram summarizes the exergy reservoirs and flows in our sphere of influence including their interconnections, conversions, and eventual natural or anthropogenic destruction. Because the choice of energy resource and the method of resource utilization have environmental consequences, knowing the full range of energy options available to our growing world population and economy may assist in efforts to decouple energy use from environmental damage.

Prepared by Wes Hermann and A.J. Simon
Global Climate and Energy Project at Stanford University (http://gcep.stanford.edu)
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After Nate Lewis (Caltech)
230x230 mile\(^2\) @ 10% \sim 3.3TW \\
1.7\% of the landmass of the US

\[
\frac{(230 \times 1600m)^2 \times 6\text{kWh/m}^2/\text{day}}{24\text{h/day}} = 3.3\text{TW}
\]
Covering less than 1% of the land with solar cells could meet our electricity needs.

6 Boxes at 3.3 TW Each
Approaches to Lowering the Cost of Solar Energy

- Silicon + MEMS
- Organic Materials
- Solar Thermal
- Nanostructures

Source: Konarka
Approaches to Lowering the Cost of Solar Energy

Silicon + MEMS

Organic Materials

Source: Konarka

Solar Thermal

Nanostructures

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$/Wp: A more direct measure of the cost of a solar cell technology

$$
\frac{\text{Cost} \ [\$/m^2]}{\text{Efficiency} \ [%] \times 1000 \text{W/m}^2}
$$
$/Wp: A more direct measure of the cost of a solar cell technology

\[
\frac{\text{Cost} [\$/m^2]}{\text{Efficiency} [%] \times 1000 \text{W/m}^2}
\]
$/Wp:  A more direct measure of the cost of a solar cell technology

$$\frac{\text{Cost} [\$/m^2]}{\text{Efficiency} [\%] \times 1000 \text{W/m}^2}$$
• Abundant: ~100,000 tons/year
• Mature industry/markets
• Low-cost: ~1$\text{/g} \rightarrow 17\text{¢}/m^2
• Non-toxic
• Can be purified to high degree
• Stable
High Throughput = Low Cost

• Example: Applied Films
• 50nm Al, 1000m/min, ~2m wide $\rightarrow$ 
  $\sim 100,000 m^2/\text{hr}$
• 100 machines would need ~1 years 
to make all the PV cells we need @
  10%

Cell Efficiencies

Power conversion efficiency (%)

- Polymer: solution processed
- Small molecule: vacuum

α-Si data from C. Wronski

AM1.5 100mW/cm²

Year


α-Si

Low-cost? Stable? Non-toxic? Abundant?
Where Are We Going?

Device structure: 100nm TCO/(Dn:An/20nm buffer/0.5nm Ag)_3/100nm Ag

Assumptions:
• FF=0.7
• $qV_{oc}=Eg-0.5eV-0.3eV$

Results:
• $J_{sc}=13.97mA/cm^2$
• $V_{oc}=2.37V$
• PCE=23.2%
Organic Solar Cells
@ Stanford

15 faculty in SOE
Center for Advanced Molecular Photovoltaics

Director: Michael McGehee
Deputy Director: Peter Peumans

Technological mission
Revolutionize the global energy landscape by developing the science and technology for stable, efficient molecular photovoltaic (solar) cells.

Educational mission
Help KAUST become one of the world’s greatest universities.
CAMP: Center for Advanced Molecular Photovoltaics

• $25M/5yr grant from KAUST (Global Research Partnership program)
• Led by McGehee and Peumans
• 16 PIs (12 @ Stanford)
• Mission: develop stable, mass-manufacturable, organic solar cells with an efficiency of 15% or more

Director: Mike McGehee
Deputy Director: Peter Peumans
Reiner Dauskardt, Yi Cui
Mark Brongersma, Shanhui Fan
Stacey Bent, Zhenan Bao
Gerry Fuller, Alberto Salleo

Industrial Affiliates:
AMAT, Solvay, Plextronics, Konarka, Unidym, Vitex, Southwall, G24I, Global Photonic Energy Corp.
Transparent electrode
Active organic layers
Metal electrode

Substrate

~100nm
Photon absorption
Exciton diffusion

Molecular packing
Exciton dissociation

$$qV_{OC} \approx E_g - 0.5\text{eV} - 0.3\text{eV}$$
Charge-pair dissociation

Electric field at DA junction is important
5 Carrier collection

Appropriate nanostructure
Problems
Optical Absorption
V-Shaped Light Trap Concept

Deposit solar cell on shaped substrate
Substrate cost increases
Active materials use increases
Efficiency increases

Plasmonic Solar Cells

Metal nanostructures localize electromagnetic energy on the nanometer lengths scale

Geometry

Absorbed Power Density

Exciton Density

PTCBI

CuPc
Electrostatically-Assisted Aerosol Deposition

Fujimori, Dinyari, Lee and Peumans
Increased CuPc/PTCBI Cell Performance

Fujimori, Dinyari, Lee and Peumans, in press
Transparent Electrode
Transparent Electrodes

- Limited transparency
- Brittle
- Expensive
- Requires high temperatures
Carbon Nanotubes Show Promise
Metal Gratings?

![Graph showing solar transmissivity vs. sheet resistance for different materials and grating layer thicknesses. The graph includes data for silver gratings, ITO, and CNT mesh. The y-axis represents solar transmissivity, and the x-axis represents sheet resistance (Ω/sq). Various labels indicate specific conditions such as 400nm period, 40nm linewidth, and measurements at 10nm, 20nm, and 30nm thicknesses.](image-url)
Transparent Ag nanowire mesh
A Solution-Processed Transparent Metal

Geminate Charge-Pair Dissociation
Intrinsic (i.e. undoped) materials

\[ F = (\Delta - 0.3\text{eV})/qd = 10^5 \text{V/cm} \]
\[ \Delta = 0.8\text{eV} \]
\[ d = 50\text{nm} \]

Liu, Zhao, Rim and Peumans, accepted in *Adv. Mater.*
Geminate Pair Separation Requires High Fields

DA interface helps separate geminate pairs, but high fields are still needed

Onsager (1938)

3D Monte Carlo simulation results


Electrical Doping is Required to Enhance Electric Field at DA Interface

donor and acceptor are highly doped

donor is highly doped, acceptor ~ intrinsic

p doped  n doped
Band Diagram To Scale

Depletion layer extends over ~20nm
Available potential drop is concentrated over 20nm: High fields

Recombination in Bulk Heterojunctions

Simulated BHJ structure

Planar Cell

BHJ Cell
Possible Mechanism

Donor

Polymer

DA interface

PCBM or C_{60}

Accepter

\delta E


420 meV shift

Abs [Normalized]

Increasing Aggregated Content

wavelength [nm]

Internal Quantum Efficiency

-1.0

0.0

0.5

1.0

-0.5

0.0

0.5

Voltage [V]

176 meV

200 meV

300 meV
Assumptions:
• FF=0.7
• $qV_{OC} = E_g - 0.5eV - 0.3eV$

Results:
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Year


2012

20%
Questions?

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