Picturing Solar Cells

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2010: ~15,000,000,000,000 W (~15 TW)
2035: ~23,000,000,000,000 W (~23 TW)*

Ho Chi Minh City  *=IAE 2010 “current policies” projection for primary energy demand
We need materials that are:

- Abundant & cheap
- Low energy input
- Non-toxic
- Easy to manufacture

For powering society the scale is terawatts
Purple Box = 1 terawatt of solar cells (average)
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Orange area = annual production of polyethylene in North America
Can solar cells be as cheap as plastic wrap?

polyethylene = insulator = plastic wrap

trans-polyacetylene (semiconductor) can make electronic devices (Nobel Prize in Chemistry, 2000)

OLED displays are a real technology built on organic molecules
Scale Matters

Plastic solar cells require nanostructures that are 10-100 nm across.

CZTS and CIGS cells are composed of many microscopic grains.

Hillhouse et al. Prog. in Photovoltaics
The Exciton Bottleneck & Film Morphology

nanoscale morphology is critical to polymer photovoltaic performance

1) photoexcitation produces strongly bound excitons

2) pairs must be dissociated at an interface

3) excitons diffuse ~5-20 nm before decaying, but need 100-200 nm thick film to absorb incident light

4) carriers need pathways to electrodes or they can recombine
Scale Matters: The Small Picture

Device level view

These prototype solar cells contain features 10000X smaller than a human hair

Trying to understand them without microscopy is like trying to understand traffic flow in WA state from this altitude
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Trying to understand them without microscopy is like trying to understand traffic flow in WA state from this altitude.
Zooming In

• Where does current come from?
• Where are the traps?
Zooming In

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• Where are the traps?
Atomic Force Microscopy Basics

Invented by Binning Quate, & Gerber in 1986

Very sharp needle

Raster scanning

Can measure atom scale forces

Image from Opensource Handbook of Nanoscience and Nanotechnology via wikipedia
Atomic Force Microscopy (AFM) for Solar Cells

Conductive AFM

Photoconductive AFM

Electrostatic force microscopy (EFM)

Time-resolved EFM
Photoconductive Atomic Force Microscopy

Nanoscale tip collects current from solar cell surface
Example: Conductive Atomic Force Microscopy

slower drying leads to more fullerene on top
faster drying

slow drying leads to more fullerene on top:
- dark holes
  - 1.4x inc.
- dark electrons
  - 9x inc.

w/ C. Luscombe UW
ACS Nano v5 p3132-3140 (2011) – P3HT nanowire/fullerene blends
Example: Photoconductive Atomic Force Microscopy
Time-Resolved Electrostatic Force Microscopy

\[ \Delta Frequency = -\frac{\omega_o}{4k} \frac{\partial^2 C}{\partial z^2} \left( V_{\text{tip}} - V'_{\text{surface}} \right)^2 \]
Famous polymer blend

Not efficient but important as a model

Where does photocurrent come from?

(Image by Ana Arias now at UC Berkeley EE)
Time-Resolved Electrostatic Force Microscopy

Height

F8BT enriched e-acceptor

PFB domain e-donor

(spин-coated from xylene)

Charging Rate

Faster

0.8 1.0 1.2 arb. units

Slower

A picture can predict efficiency!

Limitations on Time Resolution

So we could not apply our time-resolved EFM to technique to the most efficient materials...
I. Pulse to induce transient behavior

II. Digitize raw cantilever signal

III. Average multiple traces at the same phase

IV. Hilbert transform to get amplitude, phase, frequency

\[ H(u)(t) = \hat{u}(t) = \lim_{\varepsilon \to 0} \frac{1}{\pi} \int_{-\varepsilon}^{\varepsilon} \frac{u(t + \tau) - u(t - \tau)}{\tau} d\tau \]
Improved Time Resolution by 1000X

Experiment, model, and numerical simulation all agree!

Raj Giridharagopal
Fast trEFM Methods Are Suitable for The Best Materials

Fast trEFM Methods Are Suitable for The Best Materials

New microscopes invented at UW (and housed in the MoIIES building) allow us to take pictures of the inner workings of new solar cell materials.
Scale Still Matters

MoS$_2$ Catalyst Particle

Si Li-Ion Battery Anode

Polymer Nanowire Solar Cell

Bi$_2$Te$_{3-y}$Se$_y$ Thermoelectric

MRS Bulletin: July 2012 Issue (Editors: Balke, Bonnell, Ginger, Kemerink)
Energy Solutions Must Include:

- Clean Energy Sources
- Better Energy Storage
- Efficient Energy Usage
- Better Distribution

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