Powered Paint: Nanotech Solar Ink

Dr. Brian Korgel
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December 3, 2010
To Lower the Cost of Solar Energy...
To Lower the Cost of Solar Energy…
Change the way solar cells are made

Slow, high temperature vacuum processes
To Lower the Cost of Solar Energy...
Change the way solar cells are made

Print like newspaper

Slow, high temperature vacuum processes
To Lower the Cost of Solar Energy...
Change the way solar cells are made

Slow, high temperature vacuum processes

Print like newspaper

Photovoltaic Paints...?
To Lower the Cost of Solar Energy...
Change the way solar cells are made

Brittle and heavy
To Lower the Cost of Solar Energy...
Change the way solar cells are made

Brittle and heavy

Light and flexible
A Photovoltaic Device
How it works:
A Photovoltaic Device
How it works:

Start with a **semiconductor**...

(Examples of semiconductors include silicon, GaN, germanium...)
A Photovoltaic Device
How it works:

The semiconductor absorbs the light from the sun.
In the semiconductor, electrons are tied up in bonds between atoms
But when the semiconductor absorbs a photon
But when the semiconductor absorbs a photon, a free electron is created.
But when the semiconductor absorbs a photon, a free electron is created and a hole.
Both the electron and hole can move to create a photogenerated electrical current across the semiconductor.
A Photovoltaic Device
How it works:

Light absorption creates an electron and hole

\[ \text{Semiconductor 2} \]

\[ e^- \quad h^+ \]
But...need a force that will separate the electron and hole to create an electric current
A Photovoltaic Device
How it works:

Another semiconductor layer is needed
A Photovoltaic Device
How it works:

The two semiconductors form a p-n junction
The two semiconductors form a p-n junction that separates the electron and hole; this is the photovoltaic effect.
A Photovoltaic Device
How it works:

Electrical power can be generated
But we need metal electrodes on each side to extract the charge.
A Photovoltaic Device
How it works:

And a mechanical support
A Photovoltaic Device
How it works:

This is the basic design of every solar cell
What’s wrong with the existing technology?
What’s wrong with the existing technology?

A Solar Farms of PVs (of silicon)
What’s wrong with the existing technology?
It’s too expensive
What’s wrong with the existing technology?

It’s too expensive

Production cost of energy (DOE, 2002)
What’s wrong with the existing technology?

To compete with fossil fuels:

• Need < $1/Wp module cost
  - Current cost is $4.27/Wp

• Cost of power from fossil fuels is <¢4-10/kWh
  - Solar power stands at ¢20/kWh
What’s wrong with the existing technology?

- Need < $1/Wp module cost
  - Current cost is $4.27/Wp
- Corresponds to ~¢20/kWh

55% of the cost is in manufacturing the module

SolarBuzz.com
Silicon dominates the solar cell market
Silicon dominates the solar cell market

It’s relatively expensive
Silicon dominates the solar cell market

It's relatively expensive and mature
The Cost of Silicon

Source: Robert Margolis, NREL

http://pubs.usgs.gov/fs/2002/fs087-02/
The Cost of Silicon

The cost of silicon is high

Source: Robert Margolis, NREL

http://pubs.usgs.gov/fs/2002/fs087-02/
The Cost of Silicon

Processing silicon is energy intensive.

Source: Robert Margolis, NREL

http://pubs.usgs.gov/fs/2002/fs087-02/
The Cost of Silicon

2009, $4.27/W

2010, $3.59/W

Source: Robert Margolis, NREL

http://pubs.usgs.gov/fs/2002/fs087-02/
Estimated 14,000 MW capacity in 2010

Silicon PV’s work well and dominate the market
Silicon PV’s work well and dominate the market, but are too expensive for the long-term.
There are new Technologies on the Horizon:
There are new Technologies on the Horizon:

CdTe-based thin film solar cells: First Solar claims to have built modules at $0.98/W
There are new Technologies on the Horizon:

Organic materials-based solar cells

Roll-to-roll processing of polymer-based solar cells (Mekoprint A/S)

Konarka
But the cost of solar energy still needs to be reduced by about a factor of 10.

There are new Technologies on the Horizon:
Can we make a “solar” paint that can convert sunlight energy into electricity?
First, we need an ink:

Copper indium gallium selenide: CIGS
First, we need an ink:

→ Develop a chemical synthesis of CIGS nanocrystals
First, we need an ink:

→ Develop a chemical synthesis of CIGS nanocrystals

\[
\text{CuCl} + \text{InCl}_3 + 2\text{Se} \xrightarrow{\text{oleylamine, 240}^\circ\text{C}} \text{CuInSe}_2 \text{ nanocrystals}
\]
15 - 20 nm diameter CuInSe$_2$ nanocrystals

EDS:
- Cu(L) 26%
- In(L) 24%
- Se(L) 50%

Eg $\sim$ 1.0 eV
Synthesis of CuInS$_2$, CuInSe$_2$, and Cu(In$_x$Ga$_{1-x}$)Se$_2$ (CIGS) Nanocrystal “Inks” for Printable Photovoltaics

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Abstract: Chalcopyrite copper indium sulfide (CuInS$_2$) and copper indium gallium selenide (Cu(In$_x$Ga$_{1-x}$)Se$_2$; CIGS) nanocrystals ranging from ~5 to ~25 nm in diameter were synthesized by arrested precipitation in solution. The In/Ga ratio in the CIGS nanocrystals could be controlled by varying the In/Ga reactant ratio in the reaction, and the optical properties of the CuInS$_2$ and CIGS nanocrystals correspond to those of the respective bulk materials. Using methods developed to produce uniform, crack-free micrometer-thick films, CuInSe$_2$ nanocrystals were tested in prototype photovoltaic devices. As a proof-of-concept, the nanocrystal-based devices exhibited a reproducible photovoltaic response.
How does thin-film solar work?

2. Electrons gain energy.
3. A high-energy electron drifts into another semiconductor layer, leaving behind an electron vacancy.
4. The electron is collected by a transparent top electrode.
5. The energy from the electron is used to power a fluorescent light.
6. The ‘used’ electron transfers to the bottom metal contact layer (Molybdenum or stainless steel metal foil).
7. The electron travels to combine with an electron vacancy, completing the circuit.

Metal
n-type semiconductor
Nanocrystal ink
Metal
Glass or plastic support

Drawings are schematic/not to scale
Sources: Brian Korgel, UT

Robert Calzada AMERICAN-STATESMAN
1. Deposit metal foil onto a flexible substrate
2. Solution-deposit nanocrystals
3. Deposit heterojunction partner layers (CdS/ZnO)
4. Pattern metal collection grid

Nanocrystal PV Device Fabrication
Nanocrystal Film Formation

For the solar cell, need uniform films of nanocrystals.
### Standard Cell

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>0.341%</td>
</tr>
<tr>
<td>$V_{oc}$</td>
<td>329 mV</td>
</tr>
<tr>
<td>$J_{sc}$</td>
<td>3.26 mA/cm$^2$</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>0.318</td>
</tr>
</tbody>
</table>

![Diagram of a standard cell with layers of ZnO, CdS, CuInSe$_2$ nanocrystals, Mo, and Glass.]
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**Diagram:**
- **ZnO**
- **CdS**
- **CuInSe$_2$ nanocrystals**
- **Mo**
- **Glass**

**Graph:**
- Current Density (mA/cm$^2$) vs. Potential (V) for **Dark** and **Light** conditions.
Nanocrystal Film Formation

For the solar cell, need uniform films of nanocrystals.
CIS Nanocrystal PV device

Efficiency of 3.1%

Spray-deposited CuInSe$_2$ nanocrystal photovoltaics

Vahid A. Akhavan,$^{ab}$ Brian W. Goodfellow,$^{ab}$ Matthew G. Panthani,$^{ab}$ Dariya K. Reid,$^a$ Danny J. Hellebusch,$^a$ Takuji Adachi$^{bc}$ and Brian A. Korgel$^{*ab}$

**Fig. 3** (Top) Photographs of PVs fabricated by spray-depositing CIS nanocrystals on various substrates: (top left and right) glass and (top, middle) plastic (kapton). (Bottom) Illustration of the device layer structure as viewed from the top and from the side.

- $Voc = 476$ mV
- $Jsc = 8.3$ mA/cm$^2$
- $FF = 0.488$
- $\eta = 1.9\%$

**Efficiency of 2% on plastic**
Accomplished to date:

• Solar inks can be chemically synthesized
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• Solar cells can be fabricated with solar inks
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• Solar cells can be fabricated with solar inks on light-weight flexible substrates
Accomplished to date:

• Solar inks can be chemically synthesized

• Solar cells can be fabricated with solar inks

• Solar cells can be fabricated with solar inks on light-weight flexible substrates

The current challenge is to try to improve the power conversion efficiency up to >10%
Korgel group milestone chart for CIGS Nanocrystal PVs

Project conception (Sept., 2006)

3.1%
Extracting the photogenerated electrons and holes efficiently is currently the biggest challenge.
The highest efficiency devices have very thin nanocrystal layers that do not absorb all of the light.

~200 nm thick layer of nanocrystals on glass disc
Thicker nanocrystal layers absorb more light, but are less efficient.

While solar panels are hot with homeowners for warming the house and saving electricity, they're often rejected as costly and tricky to install. Now engineers are racing to make a more consumer-friendly version. One attractive candidate is solar ink. Applied with a spray gun, the ink allows builders and homeowners to turn windows, doors, and roofs into power-generating panels. Just spray it on the way you would on a model airplane, says Brian Korgel, the University of Texas at Austin chemical engineering professor who invented the technology. (The ink can also be printed on plastic sheets using an ink-jet-type printer.) He expects the ink to be available in three to five years.
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The challenge is to demonstrate commercially viable efficiencies of >10% (currently, the devices function at 3%)
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Dariya Reid

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Dr. Brian Korgel

Brian Korgel's research lab studies Nanotechnology, the field of applied science at the atomic and molecular scale. His group focuses on investigating size-tunable material properties, and the self-assembly and fabrication of nanostructures. This multidisciplinary research finds applications in microelectronics, photonics, photovoltaics, spintronics, coatings, sensors and biotechnology.