Solar Energy at UCR Riverside: From Materials and Devices to the Grid of the Future

May 2, 2013

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University of California, Riverside
Southern California Research Initiative for Solar Energy (SC-RISE)
www.scrise.ucr.edu
College of Engineering Center for Environmental Research and Technology (CE-CERT)
www.cert.ucr.edu
UC Riverside CE-CERT:

College of Engineering-Center for Environmental Research and Technology

- collaborative research center focused on air quality, transportation, and energy
- brings together academia, industry, and government to develop and assess new technologies
- interdisciplinary center of approximately 45 full-time faculty and staff plus 60 graduate and undergraduate students
- contracts and grant activity at approximately $10M per year
Cutting-Edge Fundamental Research

• Solar Thermal Material Research
Improving thermal storage and heat transfer by using the latent heat of eutectic materials used in CSP systems

• Organic PV Materials and Devices
Enhancing efficiency and stability of polymer-based solar cells by the incorporation of novel nanostructures

• High Performance Multilayer PVs
Increasing overall efficiency by tuning the effective band-gap in the cell structure and using tandem designs
Cutting-Edge Fundamental Research

• Biomimetic and Bioinspired Systems
  Developing photoredox materials for solar-energy conversion applications by studying charge separation and recombination

• Nanowires for Multi-Junction PVs
  Enhancing solar energy conversion by large-area solar cells based on NW arrays embedded in a polymer matrix

• Hydrogen as a Solar Fuel
  Production by electrolysis, used as energy storage and converted back to electricity by low-cost fuel cells
Cutting-Edge Fundamental Research

• Plasma Synthesis of Si Quantum Dots
  Multiple gas-phase (non-thermal) plasmas can are used in series to nucleate, grow and functionize the surface of the NCs with the final goal of realizing a semiconductor 'ink'.

• Structure-Directing Organic Scaffolds
  Harnessing the Molecular Mechanisms of Biomineralization for the Synthesis of Nanostructured Materials for PV Applications

• Graphene as an Electrode
  Large scale CVD growth of few layers of graphene for organic-based Photovoltaics
Dye Sensitized Solar Cells

Advantages of DSSCs
– Low processing cost
– Possibility relative high efficiency
– Simple manufacturing process
– Aesthetically pleasant

Issues on DSSCs
– How to convert light to electrical power efficiently
– How to make large area cell with high effectively
– How to achieve long-term stability of device
– How to reduce fabrication cost
Basic concept

Dye-sensitized solar cells

- Photoelectrode
- Dye
- Electrolyte
- Counter electrode
- Transparent electrode

Principles

- Energy diagram of DSSC operation

- Working electrode
- TiO₂
- Dye
- Electrolyte
- Counter electrode

- Light

1 Sun = 100 mw/cm²

Exitation: S* → S⁺ + e⁻

Diffusion

Injection: S⁺ + e⁻

Oxidation of 3 iodides to triiodides: 3I⁻ → I₃⁻ + 2e⁻

Re-reduction: S⁺ + e⁻ → S

Potential difference:

- 0.5V
- 0.9 V
- 0.4 V

Introduction
To improve DSSCs

- Photoelectrode
  - Novel metal-oxide nanocrystal with suitable energy level

- Dye
  - Panchromatic dyes for high efficiency
  - Organic dyes for low cost

- Electrolyte
  - Liquid state electrolytes for high efficiency
  - Solid state electrolytes for long-term stability

- Platinum layer
  - Novel reduction catalyst (ex: CNT, carbon black) for low cost

- Module
  - Tandem structure for high efficiency
  - Arrays for large area device
Research objective

- To make chemically cross-linked polymer gel electrolyte
- To make long-term stable DSSC with high efficiency by using the gel electrolyte

Chemical structure of PVP, cross-linking agent (CLA) and cross-linked PVP (C-PVP)
Procedure

Fabrication process of c-PVP gel electrolyte

- PVP + CL in PC solution
- Thermally cross-linking
- Ions added

<table>
<thead>
<tr>
<th>Ion</th>
<th>LiI</th>
<th>I₂</th>
<th>t-BP</th>
<th>GuNCS</th>
<th>MPII</th>
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<tbody>
<tr>
<td>Molar concentration (M)</td>
<td>0.2067</td>
<td>0.1250</td>
<td>2.0831</td>
<td>0.4129</td>
<td>Used as solvent</td>
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</tbody>
</table>
Results

- UV-vis spectra
Results

- SEM image (x2000, heating for 2 hours)

<table>
<thead>
<tr>
<th>Surface</th>
<th>130</th>
<th>140</th>
<th>150</th>
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<table>
<thead>
<tr>
<th>Cross-section</th>
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Experimental
Results

I-V curve with different heating time

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>J_{sc}(mA)</th>
<th>V_{oc}(mV)</th>
<th>F.F.(%)</th>
<th>Efficiency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC solvent liquid electrolyte</td>
<td>13.1</td>
<td>767.7</td>
<td>54.4</td>
<td>5.5</td>
</tr>
<tr>
<td>PVP+CL added electrolyte</td>
<td>12.0</td>
<td>777.8</td>
<td>57.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Heating 30 min</td>
<td>12.7</td>
<td>787.9</td>
<td>56.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Heating 60 min</td>
<td>11.5</td>
<td>767.7</td>
<td>58.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Heating 120 min</td>
<td>11.9</td>
<td>777.8</td>
<td>57.6</td>
<td>5.3</td>
</tr>
<tr>
<td>Heating 180 min</td>
<td>12.0</td>
<td>757.6</td>
<td>45.3</td>
<td>4.1</td>
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</tbody>
</table>
Results

- I-V curve with different ion concentration

<table>
<thead>
<tr>
<th>Concentration</th>
<th>$J_{sc}$ (mA)</th>
<th>$V_{oc}$ (mV)</th>
<th>F.F. (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td>7.70</td>
<td>715</td>
<td>75.2</td>
<td>4.14</td>
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<tr>
<td>20%</td>
<td>9.24</td>
<td>715</td>
<td>72.7</td>
<td>4.80</td>
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<tr>
<td>25%</td>
<td>9.76</td>
<td>724</td>
<td>72.2</td>
<td>5.10</td>
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<tr>
<td>30%</td>
<td>10.25</td>
<td>730</td>
<td>71.2</td>
<td>5.33</td>
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<tr>
<td>35%</td>
<td>9.29</td>
<td>714</td>
<td>71.8</td>
<td>4.76</td>
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</tbody>
</table>
Winston Chung Global Energy Center

PV, Wind, Battery and Electrical Distribution Issues

UC Solar Research Symposium

May 2, 2013

Dr. Sadrul Ula
University of California, Riverside
Bourns College of Engineering
Center for Environmental Research and Technology
• $10 million gift established:
  • Winston Chung Global Energy Center
  • Winston Chung Endowed Professorship in Energy Innovation
  • Winston Chung Endowed Professorship in Sustainability
• $3.3 million gift funded:
  • Six faculty research projects in energy storage
  • 1.1-megawatt battery storage project for Winston Chung Hall
    • 330 1,000-amp-hour rare-earth yttrium-iron-sulfate batteries
    • Can be charged during less costly off-peak hours
    • Delivers power to building during peak hours
The charter of Winston Chung Global Energy Center is to advance solutions for today’s energy storage demands, while developing far-sighted energy storage, generation, and distribution research and energy-use strategies for tomorrow’s applications. This center will take a holistic approach **to bridge the gap between industry and academia** to address **energy generation, storage, and distribution** needs and issues, broadly ranging from technical issues, economic development, and ecological wellness.
The Center will:

- Foster a premier academic environment of research and discovery in sustainable energy, with an initial focus on materials, storage and distribution issues
- Educate a diverse and distinguished engineering workforce that is dedicated to addressing global energy needs
- Offer tools and training that will increase the capacity of public and private planners, architects, engineers, utilities and developers to design and build energy-efficient community projects
- Reach out to global organizations and businesses as a partner in fostering clean energy storage solutions
- Inspire leadership and community action to address energy issues in California and the world.
Future Trends/Important Drivers

1. More renewable energy integrated into the system, California requirement 33% by 2020 (20% by 2013, 25% by 2016)
   • But solar and wind energy intermittent
   • Electrical storage needed for dispatch
   • Lithium-ion batteries are promising with deep discharge, repeated cycling & long life

2. Zero emission vehicles – all electric car, bus, truck, etc. – million vehicle infrastructure in CA by 2020; state fleet 10% by 2015, 25% by 2020
   • Causing more demand on the power grid

4. Adverse impact on power distribution lines
   - Uncontrolled intermittent power
   - Arbitrary EV charging
5. Lack of new transmission and distribution lines
   - Due to lack of right of way
   - Permitting hurdles
EV Charging Station with Battery Energy Storage: PV, Wind, and Smart Grid

Demand Curve for California

Communication & Control Center
UCR New Grid

- Integration of Renewable Energy Generation, Energy Storage, and EV Charging funded by SCAQMD
- Smart Grid Testbed
City and Utility Level 2 EV Chargers
Smart Building With Battery Energy Storage

- Store energy at off-peak - plentiful and cost effective electricity
- Deliver energy at peak demand - higher priced electricity and help solve power line capacity limit

**Peak Demand**
- Without Storage: 150 kW
- With Storage: 125 kW
Wind Power Generation with Battery Energy Storage

- Store energy at peak production
- Deliver Energy at lowest production

http://www.wcgec.ucr.edu/
<table>
<thead>
<tr>
<th>Identified Target Research Areas</th>
<th>Specific Area &amp; Tools needed</th>
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</thead>
</table>
| Battery materials research                               | Material science – coin cell development  
• WCGEC lab in MSE building  
• Six Winston funded projects                                                                                                                                  |
| Large battery demonstration                              | 1.1 MWh in WCH - Durability, cycling & reliability testing; sensors and instruments suitable for high V & I                                                                                                                   |
| 500 kW Solar PV intermittent power converted to valuable dispatch able power | Coupled to 1.1 MWh battery system at CE-CERT; monitoring and control instruments and power electronics components, battery management system                                                                                   |
| Electric vehicle charging from clean energy source       | Level 2 and level 3 fast chargers at CE-CERT; appropriate software and sensors for communication and control                                                                                                                  |
| Supervisory control and smart grid                       | Adapt commercial software and use student developed protocols                                                                                                                                                                |
| Power distribution system study                          | Solar PV power production characterization and quantification; battery charging and delivery for system peak load reduction; performance and energy quantification for the test bed with PV, battery and EV |
Students Build Mobile Solar Power System

› UCR student funded as the 1st project of Green Campus Action Plan (GCAP)
› Designed and built by engineering students: 6 kW capacity initially
› For use in campus events, e.g., concerts which use mobile diesel generators
› Eliminates emissions from small engines
› Future development of a version to reduce emissions by using smaller engines and batteries to supply varying mobile load instead of a large part loaded mobile engine running continuously