Macroporous TiO$_2$ Photoanodes for High Efficiency PSI-Based Biohybrid Photovoltaics

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Introduction

Photosystem I (PSI)
PSI is a protein complex residing within chloroplast of photosynthetic organisms.

Dye-Sensitized Solar Cell (DSSC)
DSSC is a thin film solar cell with a dye-sensitized photoanode.

Problem: PSI is too large to get in to the TiO$_2$ coating.
Mesoporous TiO$_2$: Pore size less than 50nm
Macroporous TiO$_2$: Pore size greater than 100nm

Our approach:
make macroporous TiO$_2$ coating with pore size larger than the diameter of PSI through sacrificing templating.

Methods

Templating materials:
- Oil-in-water emulsion
- 60% paraffin oil, 40% water, Span 80, and Tween 80.
- Polystyrene latex
- Aqueous suspension; 1 µm in diameter.

Procedure:
Make a TiO$_2$ dispersion with templating materials
Doctorblade the templated TiO$_2$ dispersion on FTO
Sinter the film at 500 °C for 30 mins

Doctorblading:
TiO$_2$ is spread out on FTO by a razor blade.

Results of Macrotemplating

Templated macroporous films have been made from TiO$_2$ powder:
- SEM: macroporous films exhibit high porosity and interconnected pores. Templated by 60% oil-in-water emulsion and 1 µm polystyrene

Control: untemplated film
Cross section

Cross section

UV-Vis Spectrophotometry: after soaked in PSI solution for three days, macroporous films demonstrate high PSI incorporation.

Macroporous TiO$_2$ film turns green after soaking in 1µM PSI solution:

Electrochemical Analysis

Macroporous films exhibit significant enhancement in power and efficiency:

<table>
<thead>
<tr>
<th>Cell</th>
<th>$P_{max}$ (µW/cm$^2$)</th>
<th>Efficiency</th>
<th>Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>macroTiO$_2$</td>
<td>9</td>
<td>0.10%</td>
<td>- (<em>a</em>)</td>
</tr>
<tr>
<td>macroTiO$_2$:monoPSI</td>
<td>46</td>
<td>0.48%</td>
<td>5.0 x a</td>
</tr>
<tr>
<td>macroTiO$_2$:monoPSI/multiPSI</td>
<td>82</td>
<td>0.86%</td>
<td>9.0 x a</td>
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<tr>
<td>mesoTiO$_2$</td>
<td>26</td>
<td>0.27%</td>
<td>- (&quot;a&quot;)</td>
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<tr>
<td>mesoTiO$_2$:monoPSI</td>
<td>39</td>
<td>0.41%</td>
<td>1.1 x b</td>
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<tr>
<td>mesoTiO$_2$:monoPSI/multiPSI</td>
<td>33</td>
<td>0.34%</td>
<td>1.2 x b</td>
</tr>
</tbody>
</table>

Conclusion

- Macroporous TiO$_2$ films have been successfully made. They exhibit high porosity and interconnected meso (less than 50nm in diameter) and macro (on the order of micrometer) pores under SEM.
- The macroporous TiO$_2$ films demonstrate increased absorbance of PSI according to UV-Vis spectrophotometry.
- Using the designed macroporous TiO$_2$ film as a photoanode largely enhances the overall power and efficiency of PSI-based biohybrid photovoltaics due to the high integration of PSI and TiO$_2$.

Future Work

Further research will be carried to:
- continue to study the effect of the added porosity on PSI and TiO$_2$ interface through cell performance studies;
- to reduce diffusional constraints by raising the mediator concentration.

References

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Scientific Reports 2012, 2, 234

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