Example: Simulating Si PV Absorption

Si thin film

PhC thin film

Wafer cell

Absorbed

Lost energy
Different Geometric Light Trapping Approaches for Commercial μc-Si Cells

<table>
<thead>
<tr>
<th>Treatment #1</th>
<th>Sand blast</th>
<th>Abrasion etch</th>
<th>Bead coat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment #2</td>
<td>HF etch</td>
<td>HF etch</td>
<td>(used in our samples)</td>
</tr>
<tr>
<td>Feature depth</td>
<td>10-100 μm</td>
<td>500 nm</td>
<td>500 nm</td>
</tr>
<tr>
<td>Feature width</td>
<td>10 μm</td>
<td>1-5 μm</td>
<td>500 nm</td>
</tr>
</tbody>
</table>

M.J. Keevers et al., “10% Efficient CSG Minimodules,”

ECE 695, Prof. Bermel

3/31/2017
Correlated Randomness

Combine gratings for each wavelength

Combine periodicity with texturing in systematic fashion

inhomogeneous

homogeneous

Correlated Randomness in 2D

For $n=3.46$ and 33% bandwidth (e.g., 500-700 nm)
Angle-Sensitive Solar Absorbers

From flat to totally random structures via correlated random textures


Fig. 4.7. Plan view SEM image of porous silica AR layer formed by vapour-etch method [56].
Experimental absorption versus simulated absorption

Experiment

Simulation (3D QCRF-FDTD)


MEEPPV: https://nanohub.org/tools/meeppv

Solar cell schematic
MEEPPV: [https://nanohub.org/tools/meeppv](https://nanohub.org/tools/meeppv)

Output animations
MEEPPV: [https://nanohub.org/tools/meeppv](https://nanohub.org/tools/meeppv)
MEEPPV: https://nanohub.org/tools/meeppv
Computational Set-up

- Thickness of film = our experimental samples (1.47 μm)
- Four geometries tested
- Random texturing:
  - Uniform height distribution over 500 nm
  - Distance between features varies
- Photonic crystal:
  - Reflection captured by metal
  - Diffraction captured by grating (optimized for this thickness)
Varying spacing between features

5 periods

20 periods

10 periods
Propagation of Light in Planar Geometry

Light In

Silicon

Metal backing
Propagation of Light in Textured Geometry (no backing)
Propagation of Light in Textured Geometry + Metal Grating
Calculated Absorption Spectrum for 2 μm μc-Si

Aluminum: 12.08% efficiency

3D PhC: 16.32% efficiency

DBR + 2D grating: 14.97% efficiency

Efficiency Enhancement of Period Structures

For optimized parameters, 2D grating efficiency enhancement ranges from 7% at 128 μm up to 35% at 2 μm
Thin c-Si Solar Cell Designs
Incorporating Plasmonics

Plasmonics can double path length from ideal light trapping

Random texturing on the front and back surfaces, deposited conformally

Periodic (grating-like) texturing on the front and back surfaces, deposited conformally

Random texturing on the front surface combined with a back plasmonic nanoparticle
Simulation Methodology

Volume-Integrated Finite-Difference Time Domain Method

Flexible Flux Plane Finite-Difference Time Domain Method

Simulation Methodology

Flexible flux planes offer rapid frequency-sensitive integration of parasitic losses.
Periodically Textured Cells: Theory and Experiment

Detailed comparison of experimental and simulated total absorption, and the parasitic component

Electric field energy distribution, with enhancement observed near the Ag/ZnO interface

Randomly Textured Cells: Theory and Experiment

Comparison of experimental and simulated total absorption, and the parasitic component

Electric field energy distribution, with enhancement observed near the Ag/ZnO and c-Si/ZnO interfaces

Ag Nanoparticle Cells: Theory and Experiment

Comparison of experimental and simulated total absorption, and the parasitic component

Electric field energy distribution, with enhancement observed throughout the structure, except Ag

Ag Nanoparticle Cell Absorption Enhancement

The diagram shows the absorption spectra of Ag nanoparticles (Ag NPs) and their effect on cell absorption. The black line represents the absorption with NPs, while the red line represents the absorption without NPs. The graph indicates a significant enhancement in absorption with NPs, particularly in the wavelength range of 400 to 1100 nm.

Key observations:
- Absorption with NPs (black line) shows a 65% enhancement compared to absorption without NPs (red line).
- Absorption without NPs (red line) has a 10% absorption rate at the same wavelength range.

This diagram was created for ECE 695, Prof. Bermel, on 4/14/2015.
Ag Nanoparticle Cell Absorption Enhancement

Ag NP Cell Absorption Enhancement

Again, the Ag nanoparticle increases field power throughout most of the structure, except the Ag itself; removing NPs cancels out most of this effect.

Optimizing Ag Nanoparticle Cell Absorption

$J_{sc} = 36.6 \text{ mA/cm}^2$

$J_{refl} = 5.0 \text{ mA/cm}^2$

$J_{sc} = 26.1 \text{ mA/cm}^2$

$J_{par} = 3.7 \text{ mA/cm}^2$

Max $J_{sc} = 43.8 \text{ mA/cm}^2$

Effective path length: 700x enhancement

Optimizing Ag NP Cell Front Texture

Optimal correlated random front surface texture

Completely random front surface texture

Next Class

• Next time: we will continue finite-difference time domain techniques
• Suggested reference: S. Obayya’s book, Chapter 5, Sections 4-6