ECE 595, Section 10
Numerical Simulations
Lecture 34: Applications of Finite-Difference Time-Domain Simulations

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April 5, 2013

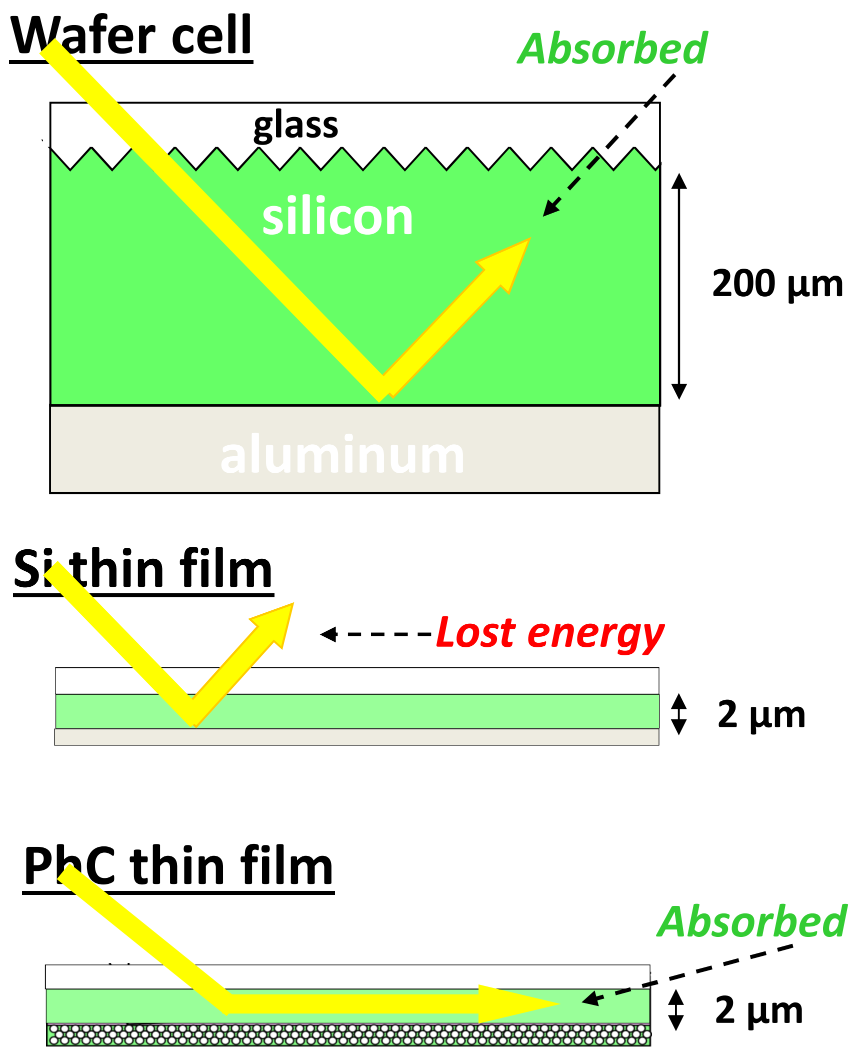
Recap from Wednesday

- Introduction to FDTD
- Special features of MEEP:
  - Perfectly matched layers
  - Subpixel averaging
  - Symmetry
  - Scheme (programmable) interface

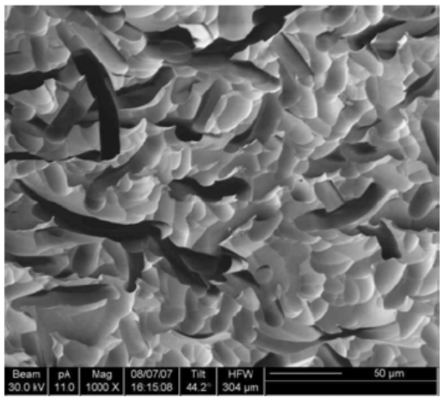
Outline

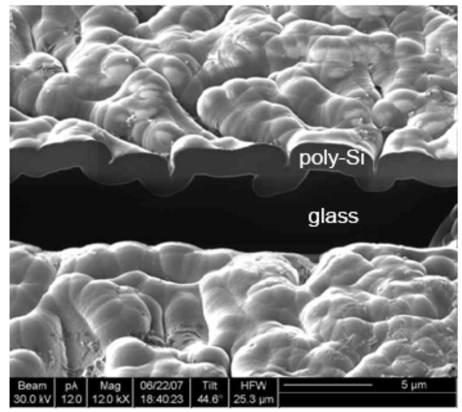
- Recap from Wednesday
- Periodic and randomly textured light-trapping structures
  - Overview
  - Experimental motivation
  - Computational setup
  - Simulated field evolution
  - Absorption spectra
- Front coatings
- Correlated random structures

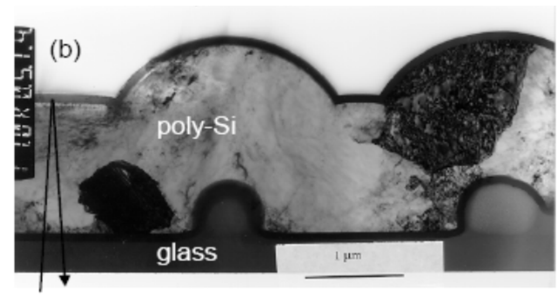
Example: Simulating Si PV Absorption



Different Geometric Light Trapping Approaches for Commercial μc-Si Cells



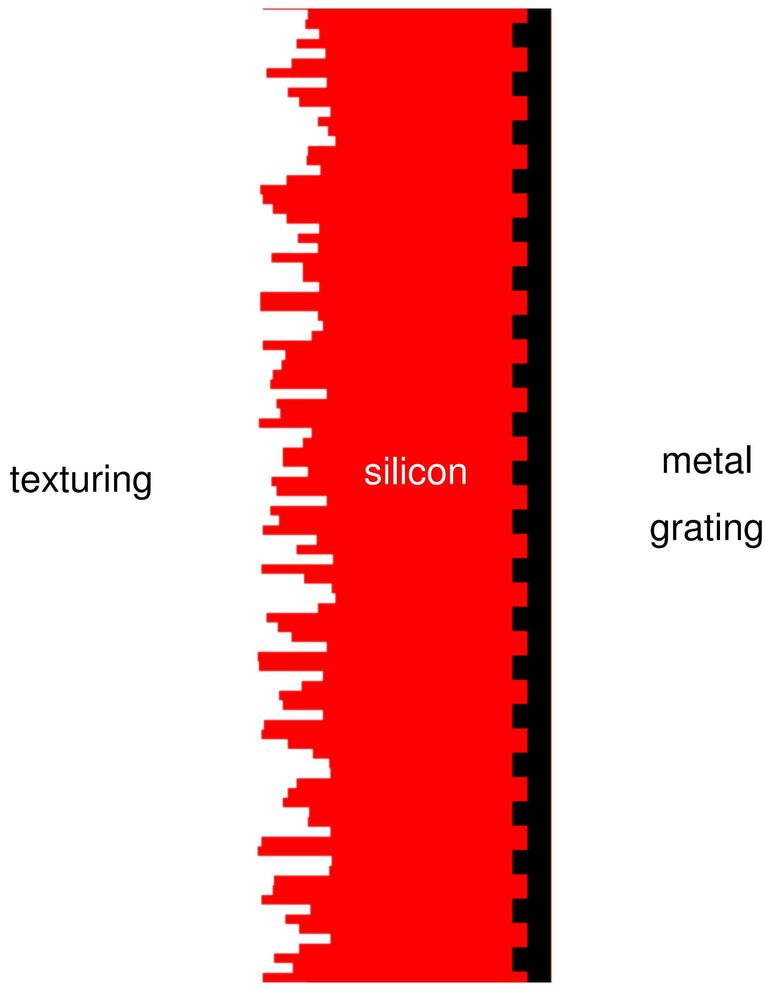




Treatment #1	Sand blast	Abrasion etch	Bead coat
Treatment #2	HF etch	HF etch	(used in our samples)
Feature depth	10-100 μm	500 nm	500 nm
Feature width	10 μm	1-5 μm	500 nm

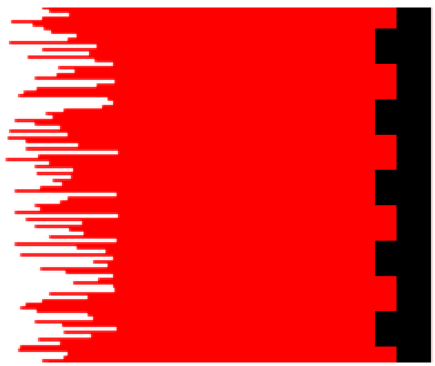
M.J. Keevers et al., “10% Efficient CSG Minimodules,”

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

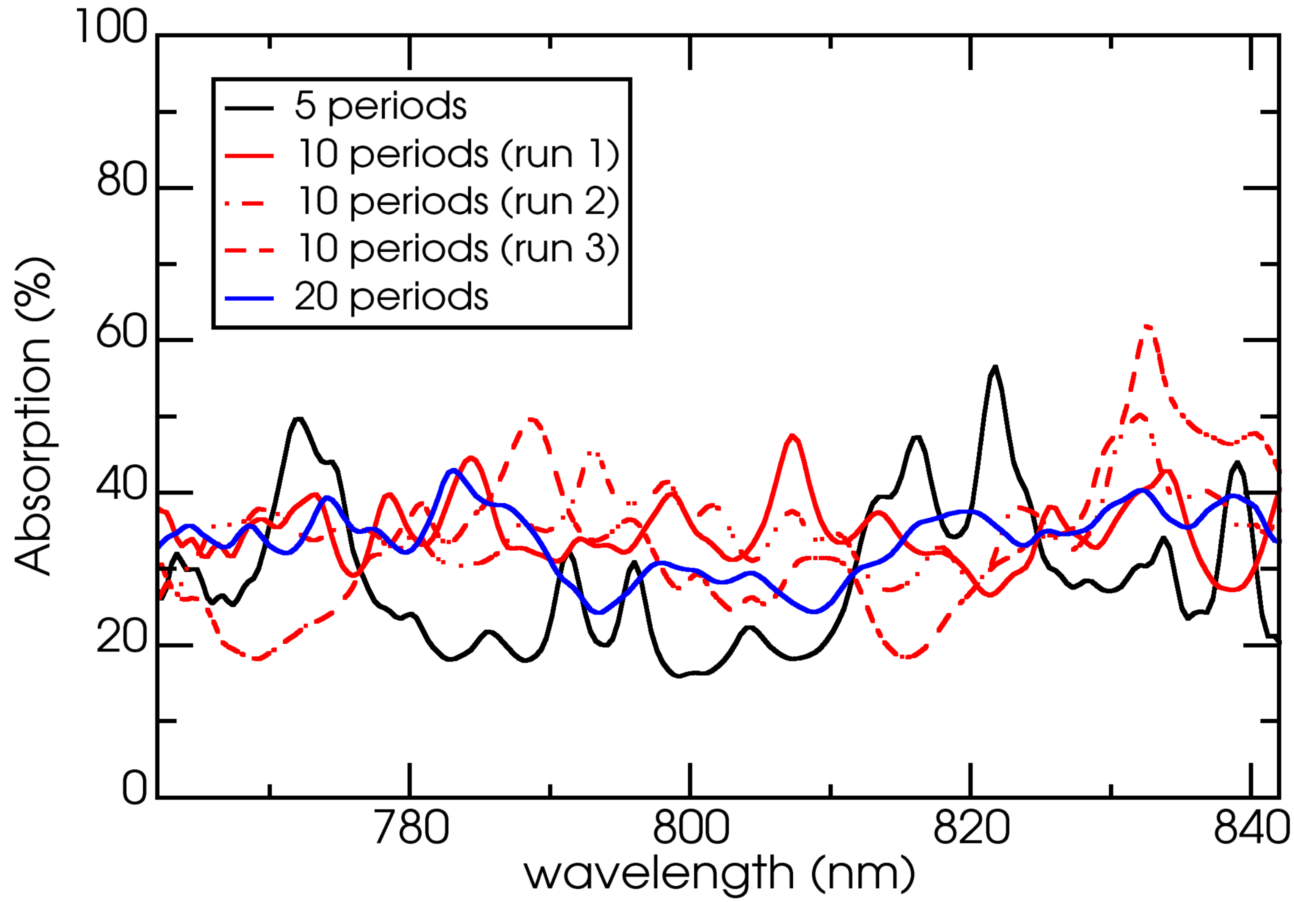


5 periods

10 periods

20 periods

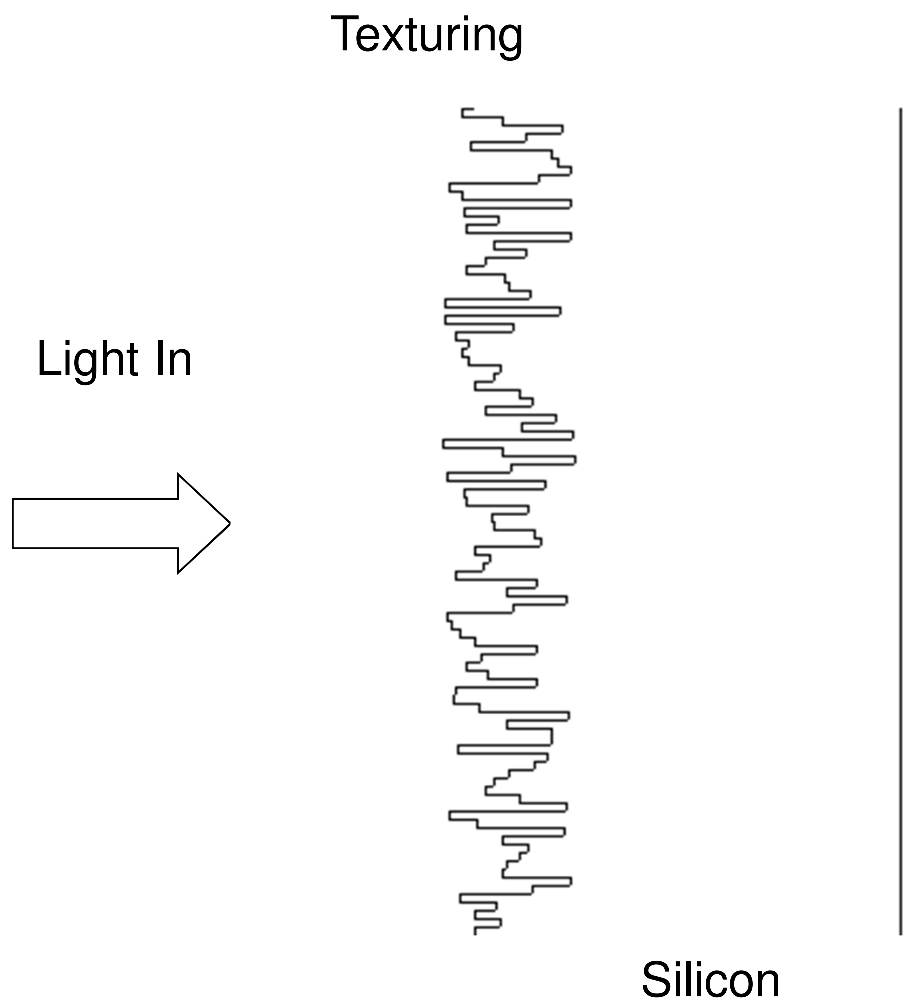
Varying spacing between features: absorption



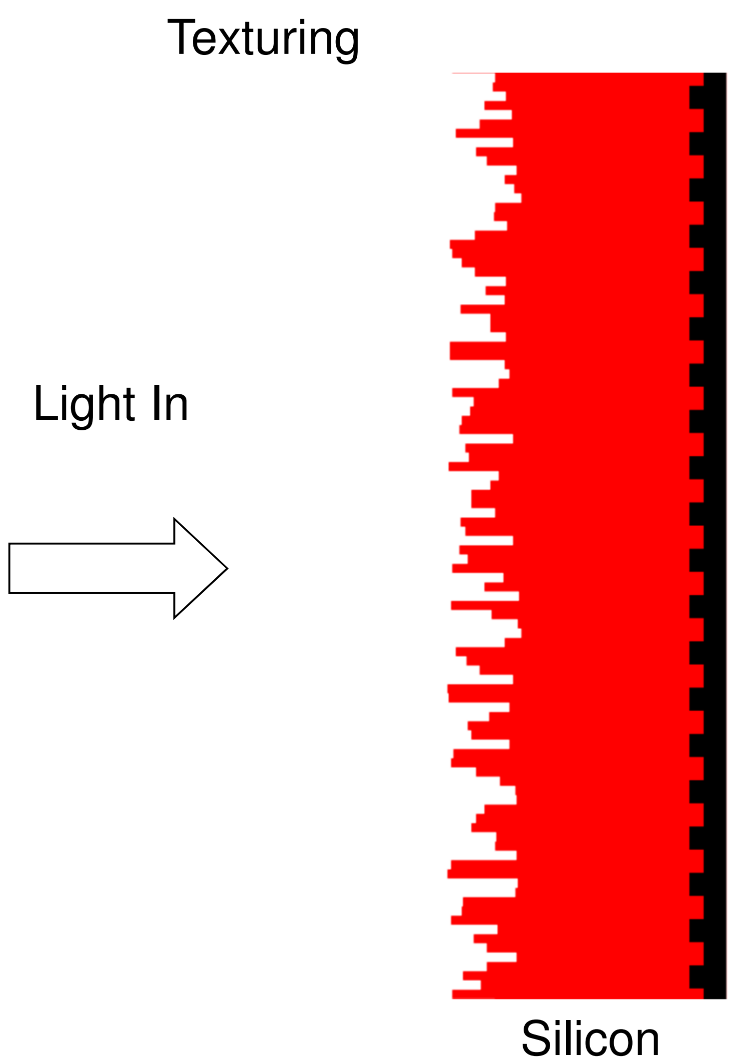
Sharp spectral features smoothed out with greater # periods and feature spacing

Propagation of Light in Planar Geometry

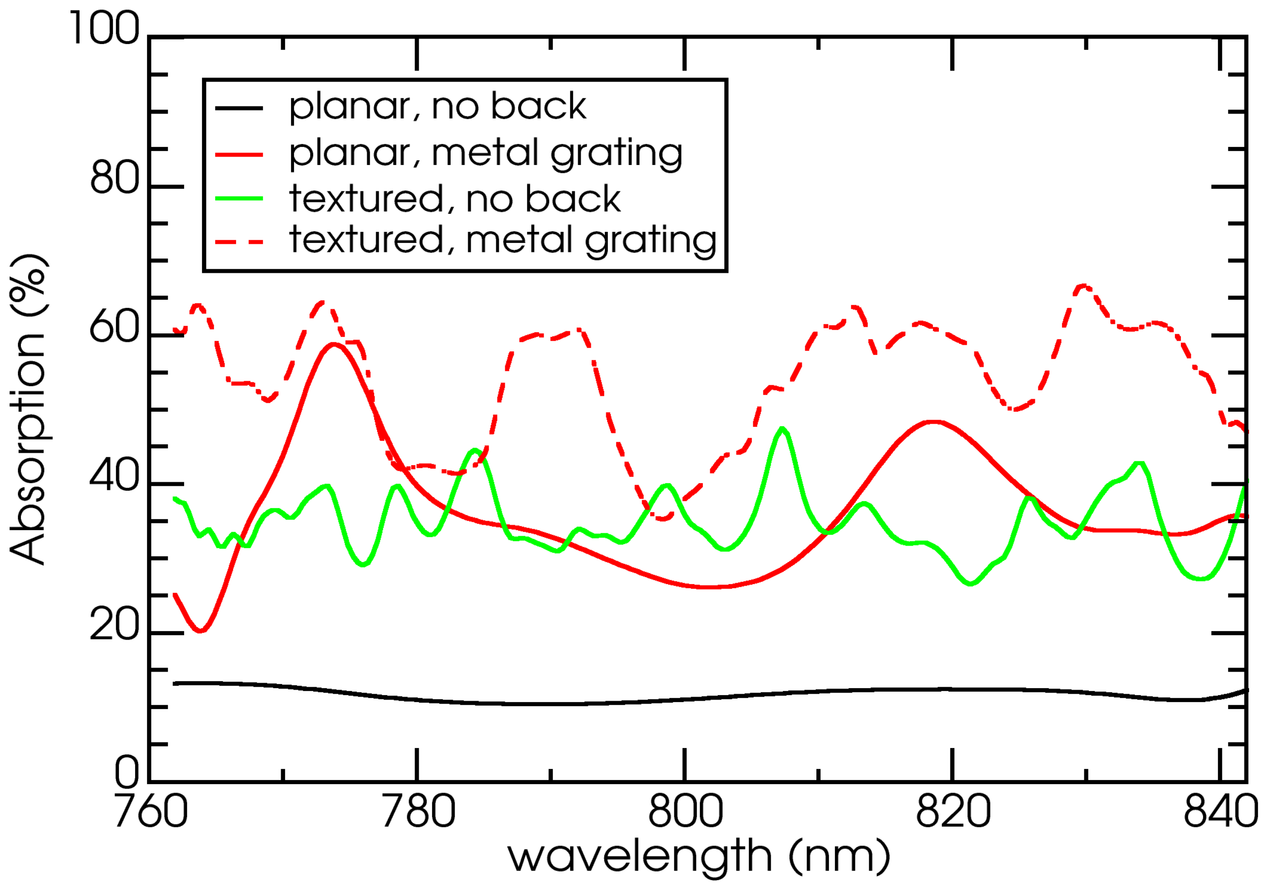
Propagation of Light in Textured Geometry (no backing)



Propagation of Light in Textured Geometry + Metal Grating



Four configurations tested in experimental measurements



Greatest overall performance with combined structures, which combines 2 sets of spectral features

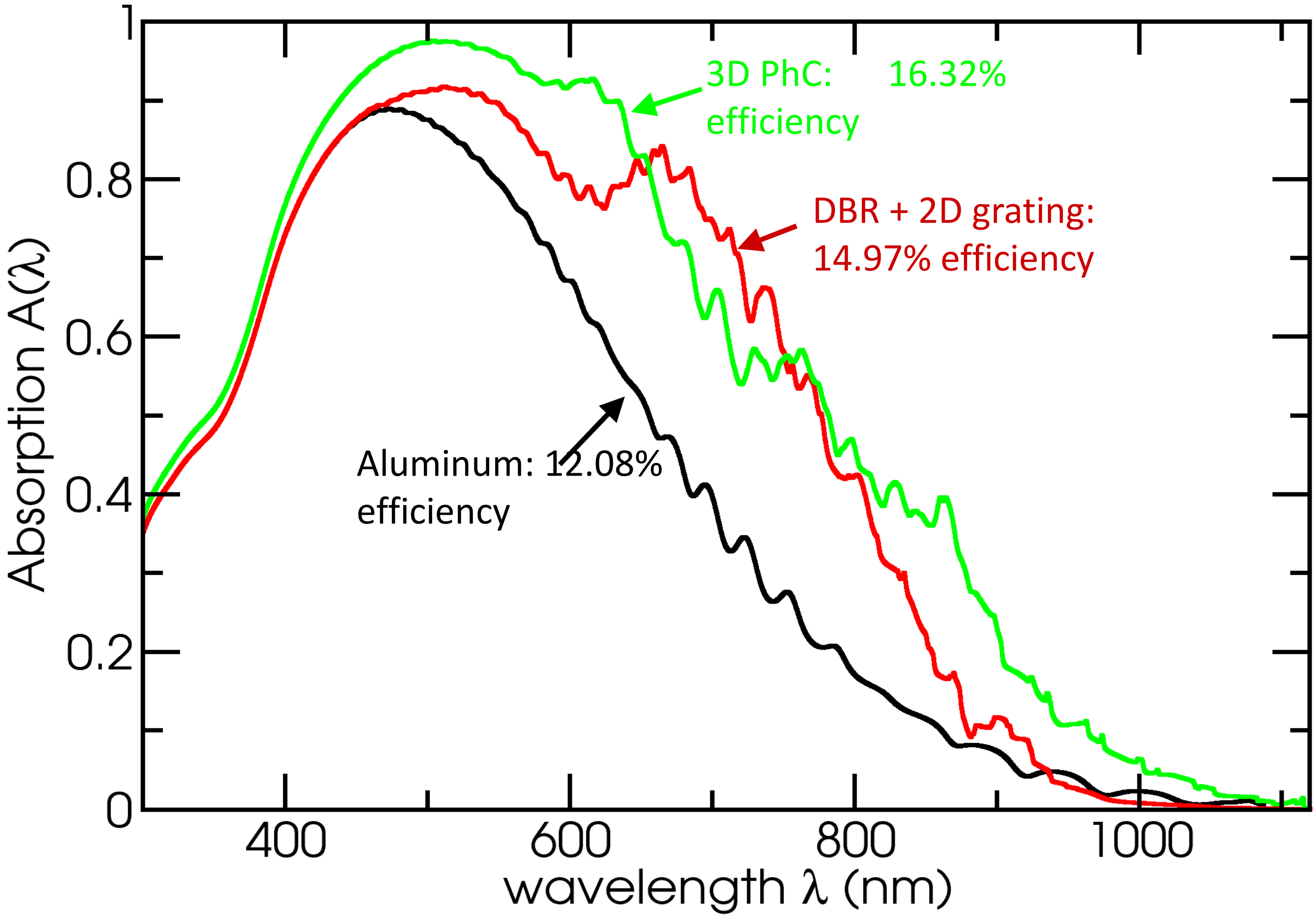
Four configurations tested in experimental measurements

Structure	Simulation (%)	Experiment (%)
Planar, no back	11	10
Planar, PhC back*	37	75
Textured, no back†	33	55
Textured, PhC back†	54	78

* Discrepancy most pronounced for photonic crystal structure with planar surface: possible causes?

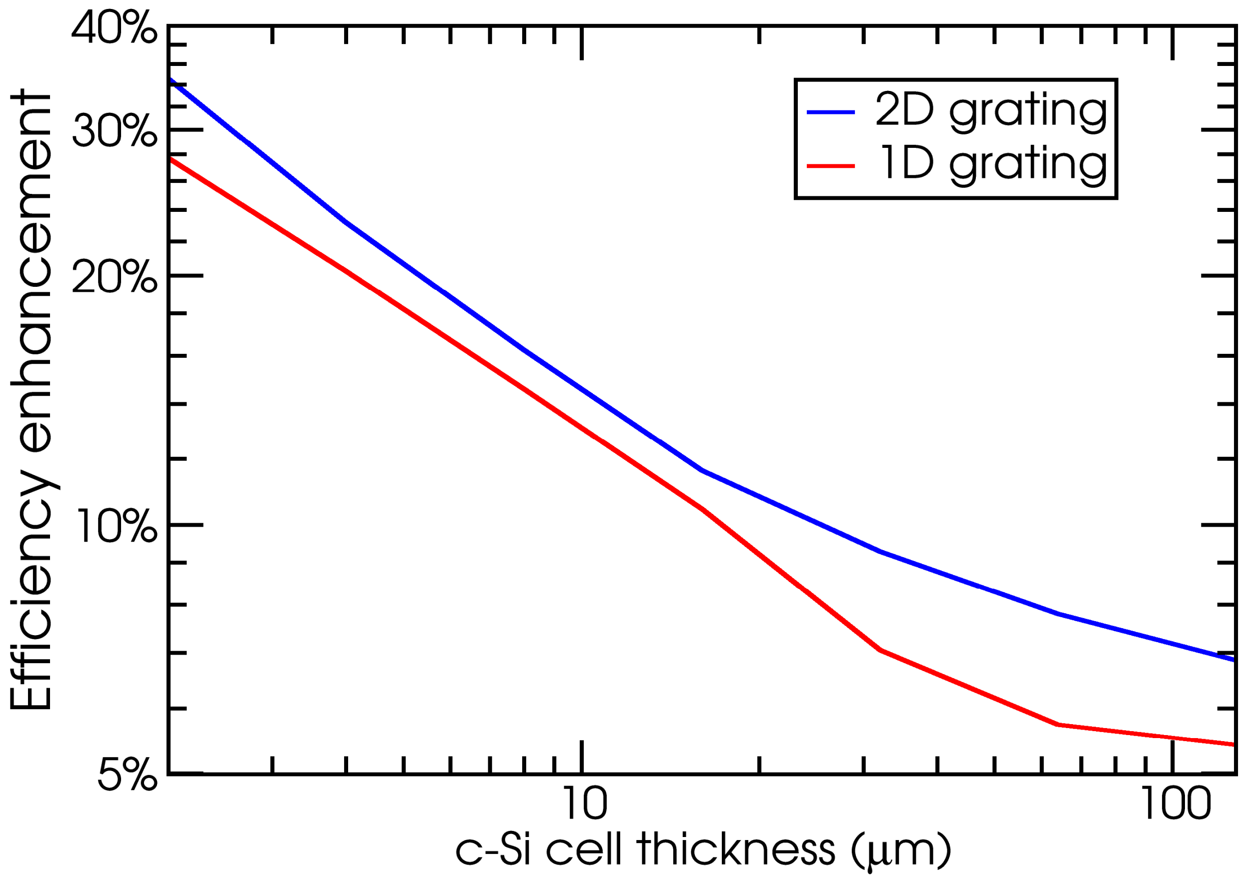
† Errors roughly equal

Calculated Absorption Spectrum for 2 μm μc-Si



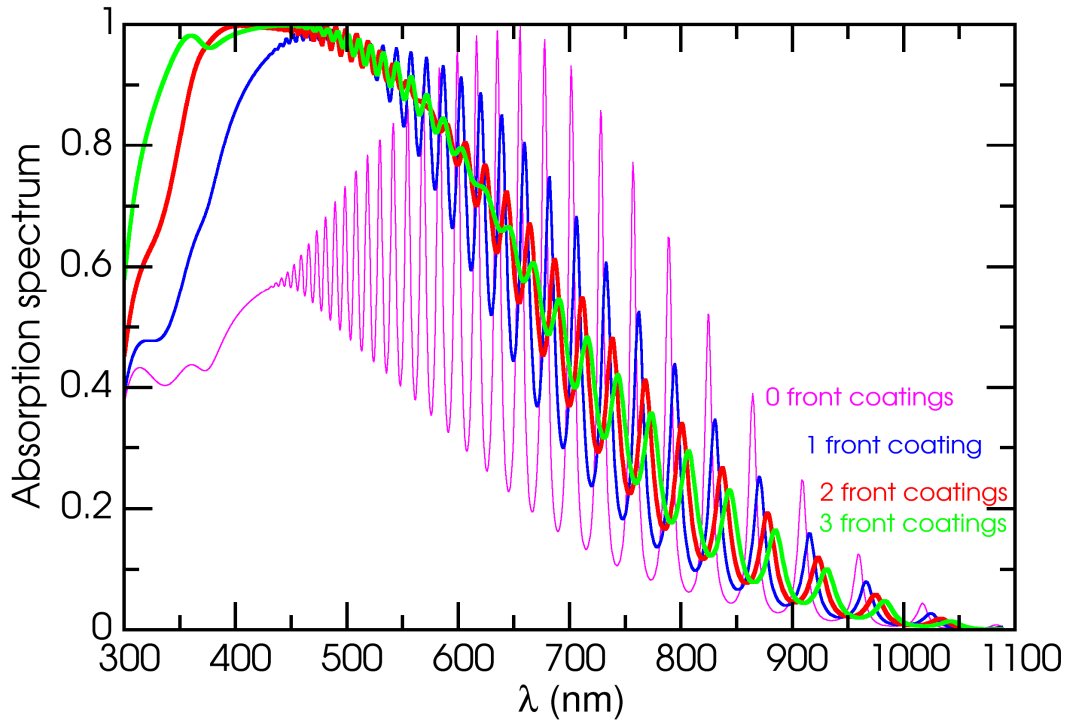
P. Bermel *et al.*, *Opt. Express* **15**, 16986 (2007)

Efficiency Enhancement of Period Structures



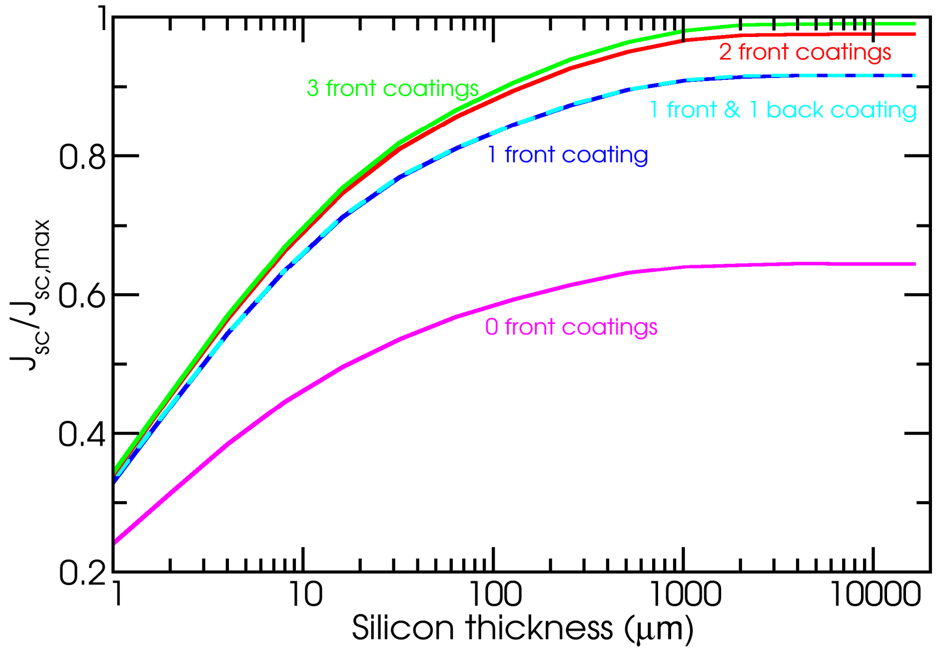
For optimized parameters, 2D grating efficiency enhancement ranges from 7% at 128 μm up to 35% at 2 μm

Example: Front Coatings for Thin-Film Si PV



- For thin films, adding front layers mainly improves blue/UV response

Efficiency vs. thickness and # of layers



layers	0→1	1→2	2→3
t=2 mm	39.9%	3.6%	0.6%
t=256 mm	42.2%	6.1%	1.4%

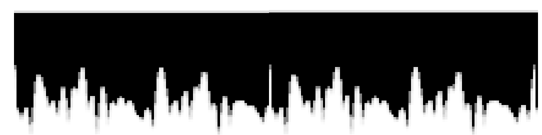
wafer-based cells see greater improvements with each successive layer

Example: Correlated Randomness

Combine gratings for each wavelength

inhomogeneous

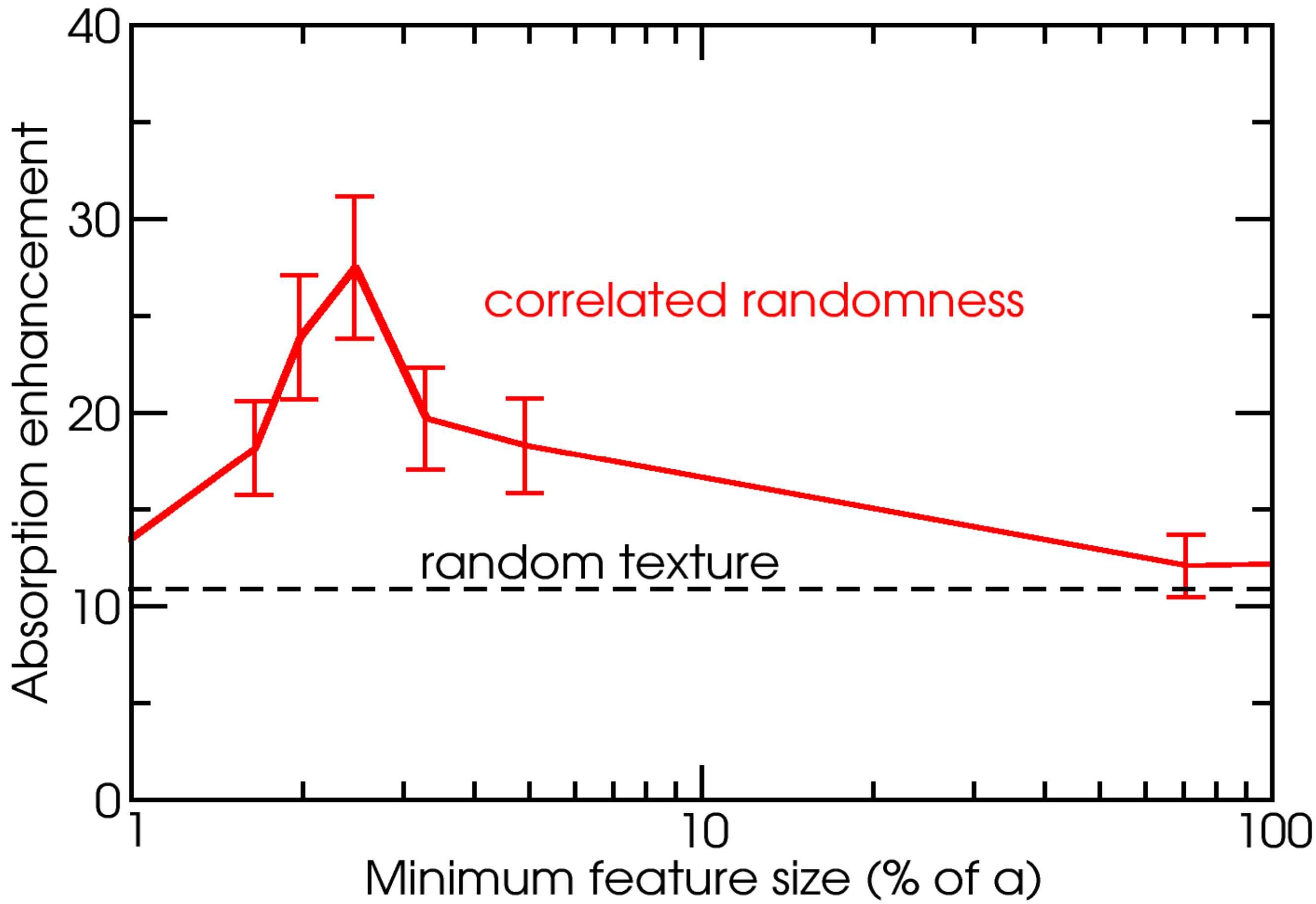
Combine periodicity with texturing in systematic fashion



homogeneous

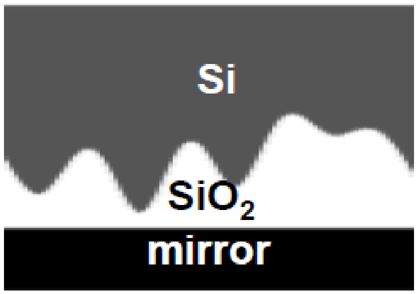
A.N. Bloch & P. Sheng, US Patent 4,683,160 (1987)
X. Sheng *et al.*, *Opt. Express* **19**, A841 (2011)

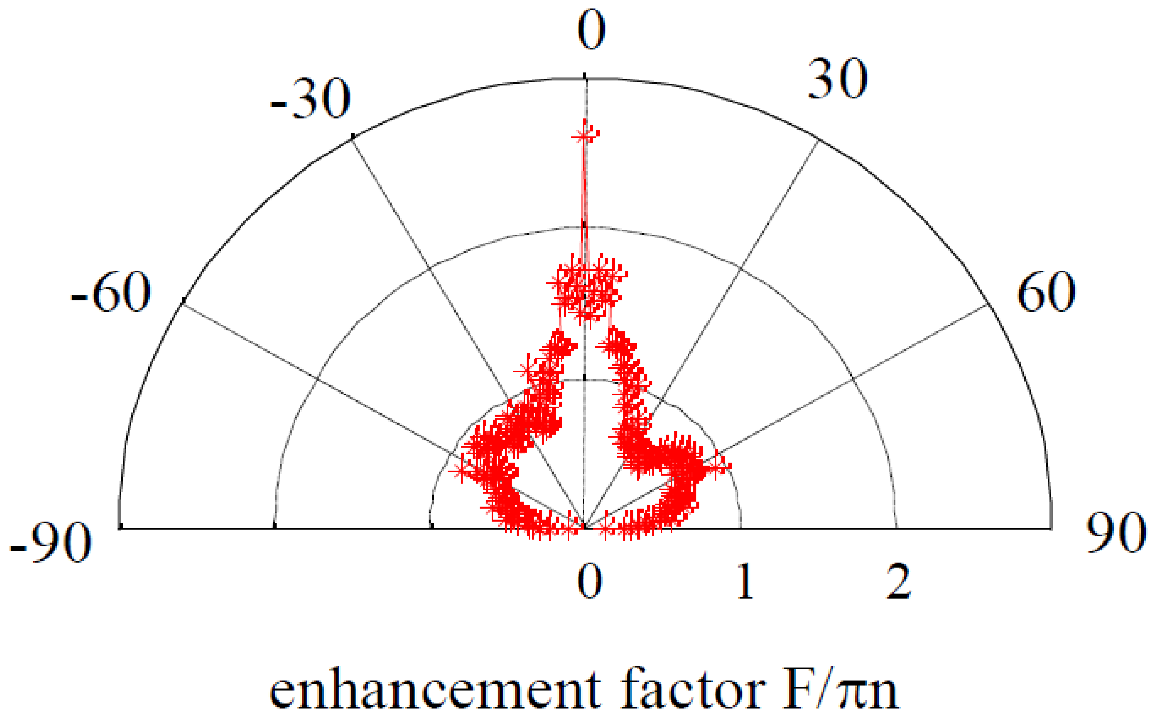
Correlated Randomness in 2D



For n=3.46 and 33% bandwidth (e.g., 500-700 nm)

Angle-Sensitive Solar Absorbers





X. Sheng *et al*., *Opt. Express* **19**, A841 (2011)

X. Wang et al., "Approaching the Shockley-Queisser Limit in GaAs Solar Cells", IEEE J. Photovolt. (2013).

Next Class

- Is on Monday, April 8
- Next time: we will discuss using finite-difference time domain software: MEEP
- Suggested reference: MEEP tutorial, http://jdj.mit.edu/wiki/index.php/Meep_Tutorial