

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

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April 5, 2013

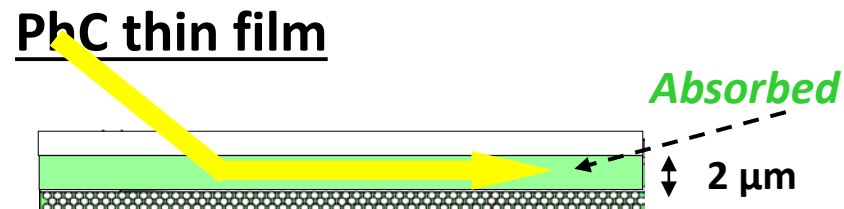
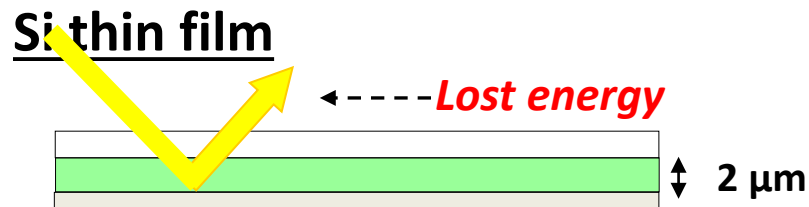
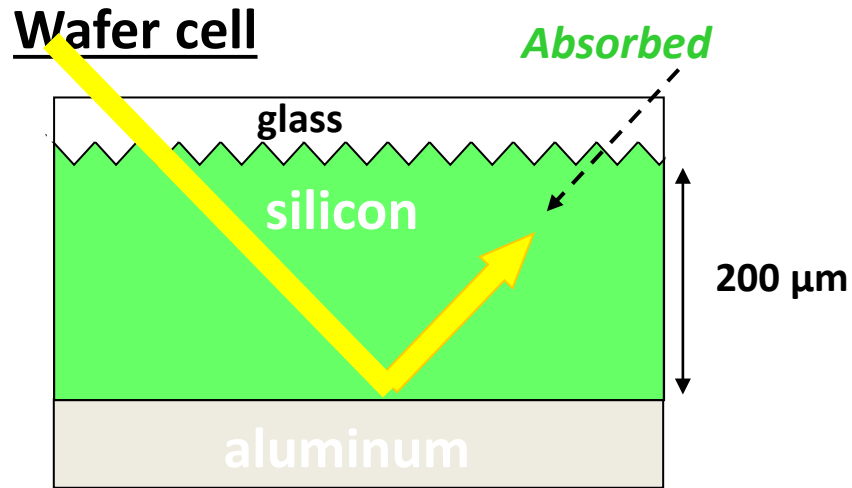
Recap from Wednesday

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

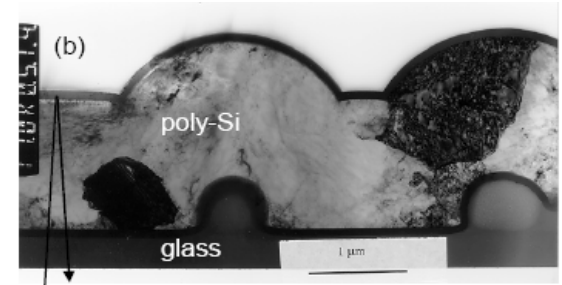
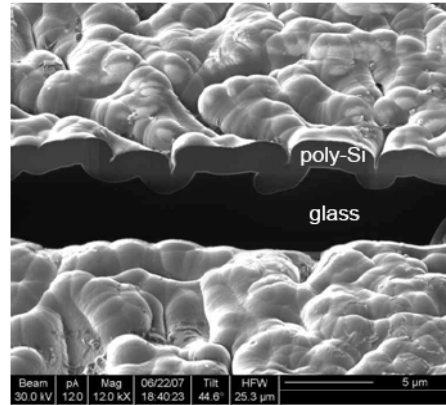
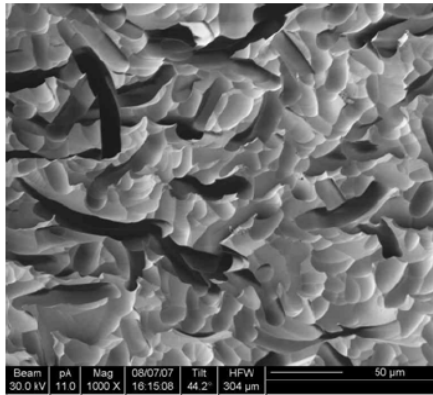
Outline

- 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



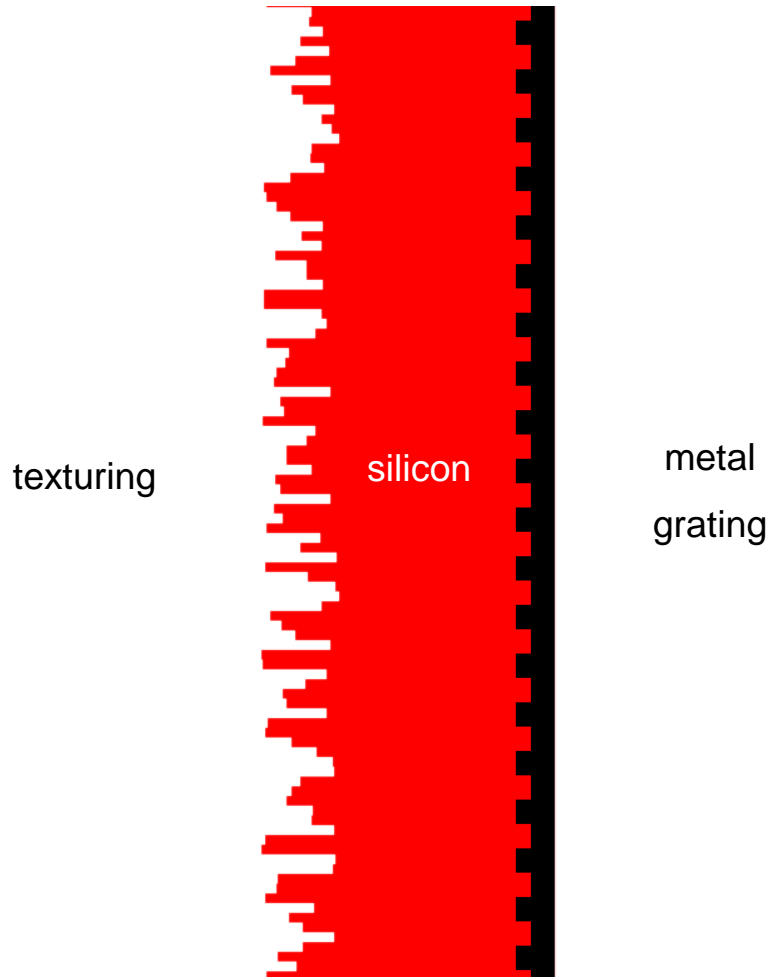
Different Geometric Light Trapping Approaches for Commercial $\mu\text{c-Si}$ Cells



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

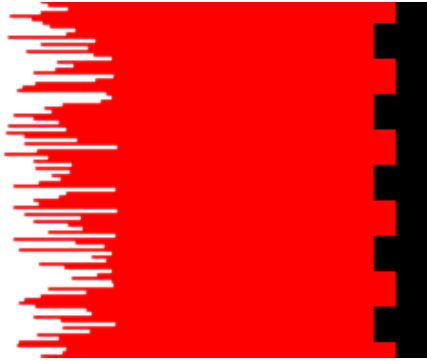
M.J. Keevers et al., “10% Efficient CSG Minimodules,”

Computational Set-up

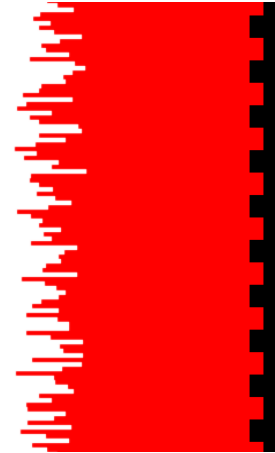


- Thickness of film = our experimental samples ($1.47\ \mu\text{m}$)
- Four geometries tested
- Random texturing:
 - Uniform height distribution over 500 nm
 - Distance between features varies
- Photonic crystal:
 - Reflection captured by metal
 - Diffraction captured by grating (optimized for this thickness)

Varying spacing between features



5 periods

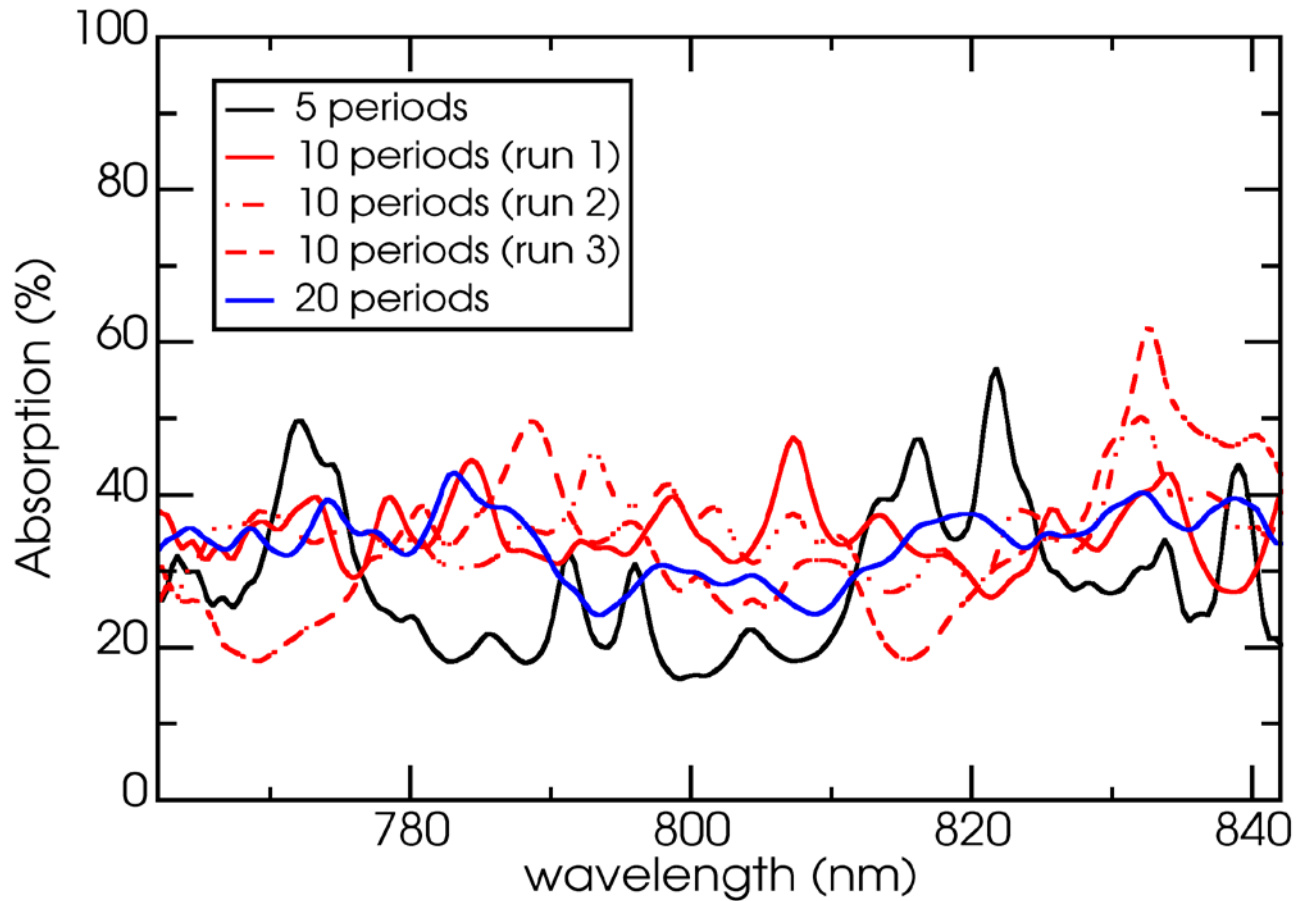


10 periods



20 periods

Varying spacing between features: absorption



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

Propagation of Light in Planar Geometry

Light In

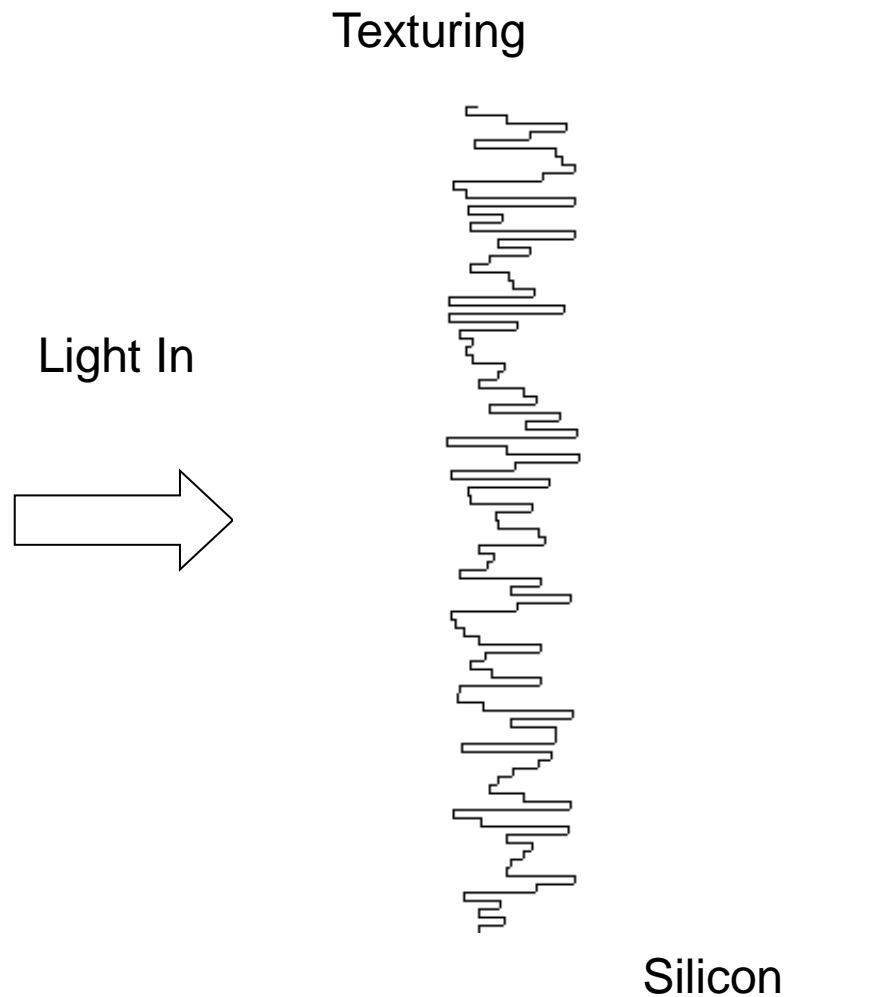


Silicon

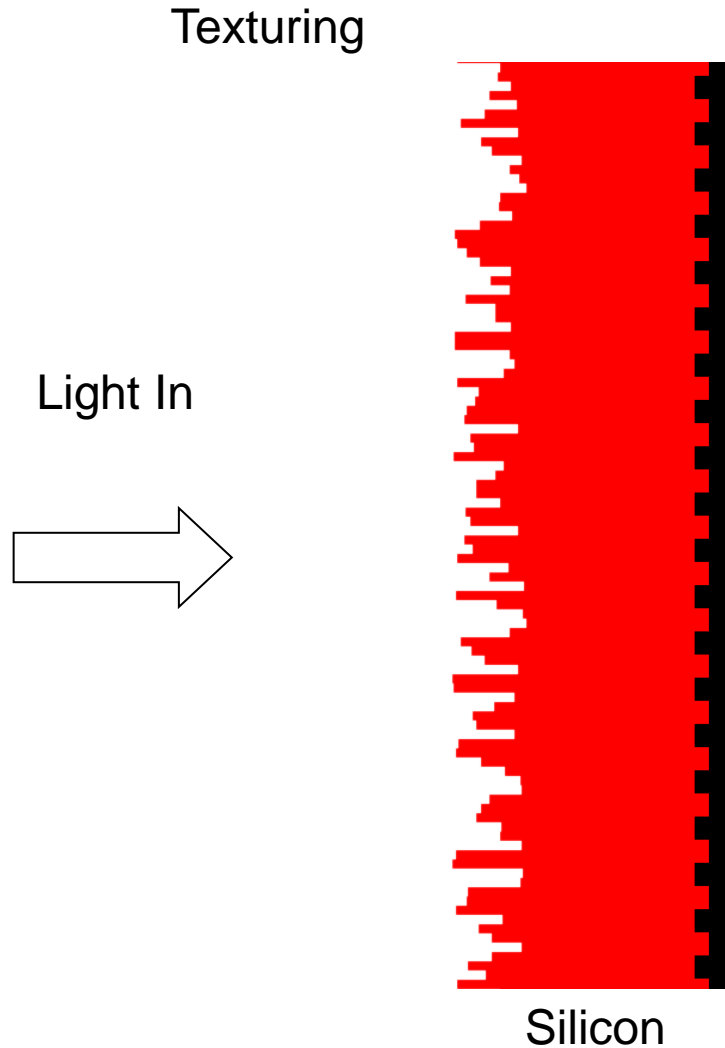


Metal
backing

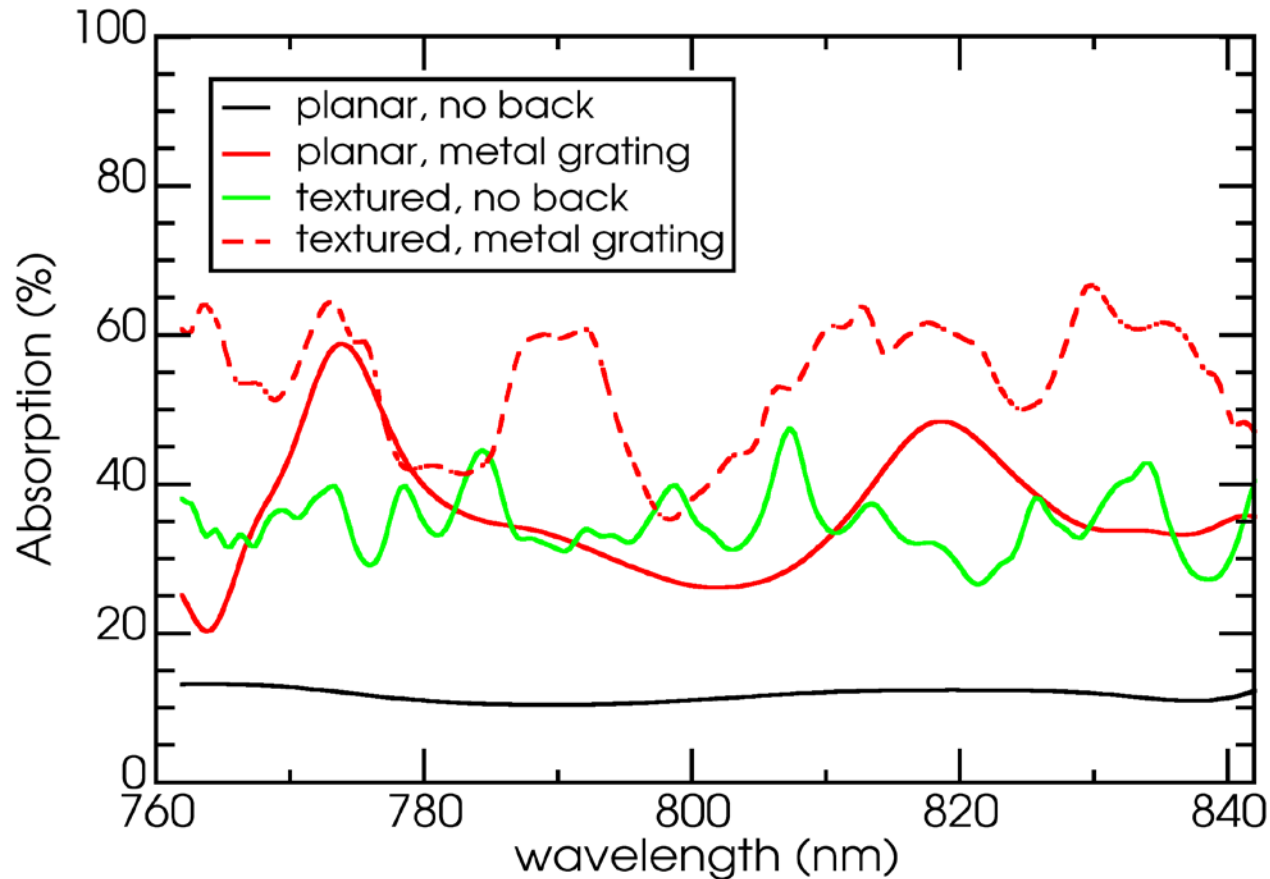
Propagation of Light in Textured Geometry (no backing)



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

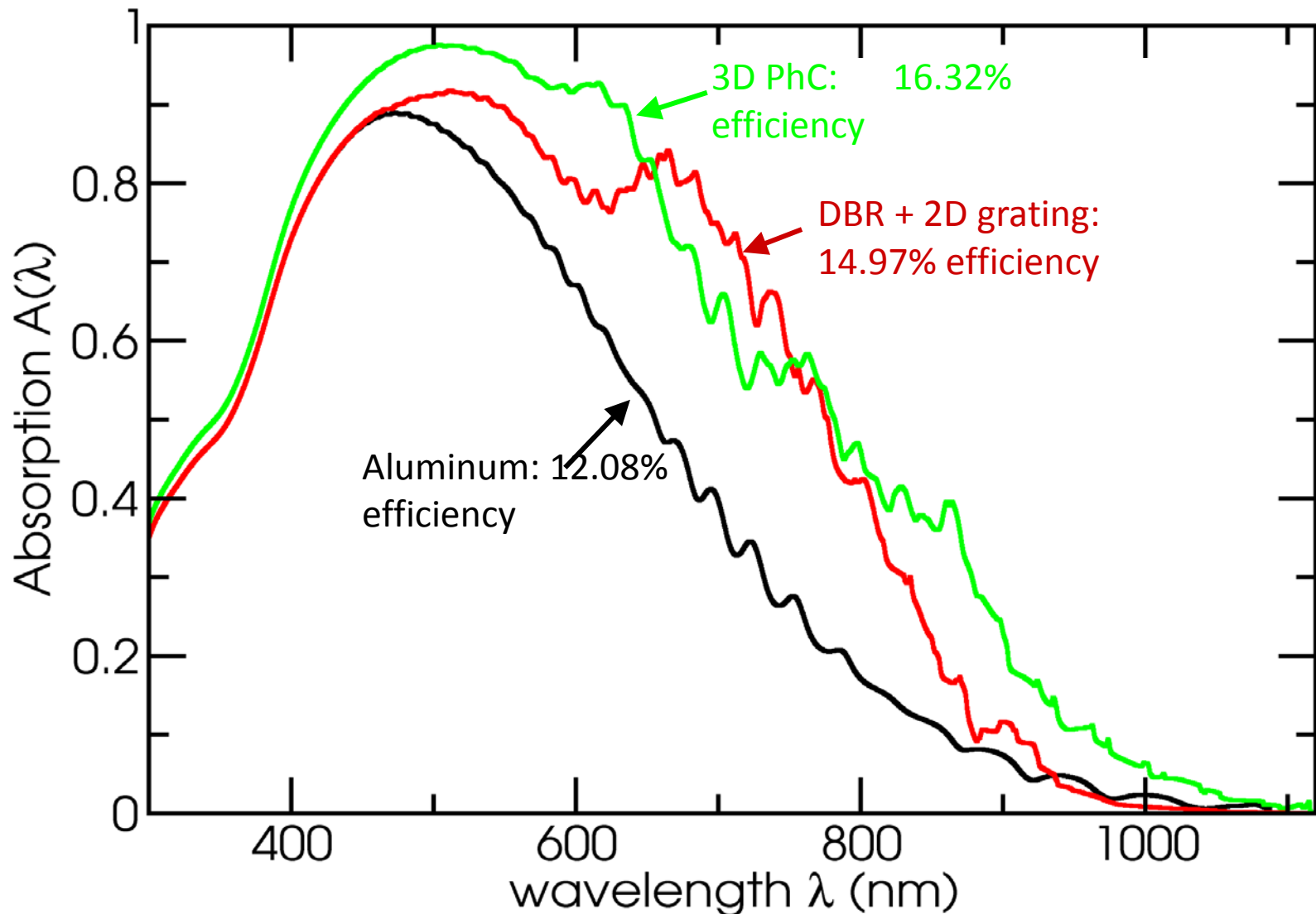
Four configurations tested in experimental measurements

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

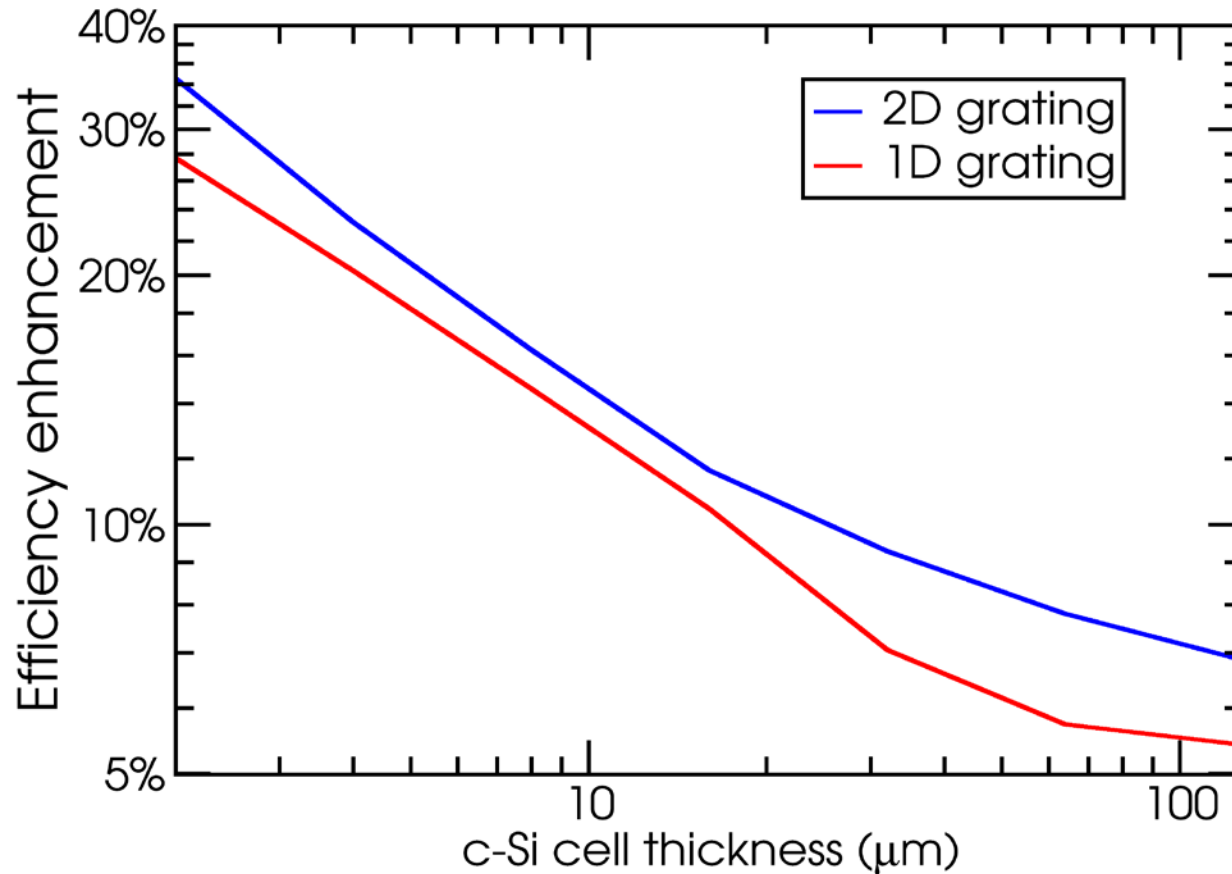
* Discrepancy most pronounced for photonic crystal structure with planar surface: possible causes?

† Errors roughly equal

Calculated Absorption Spectrum for 2 μm $\mu\text{c-Si}$

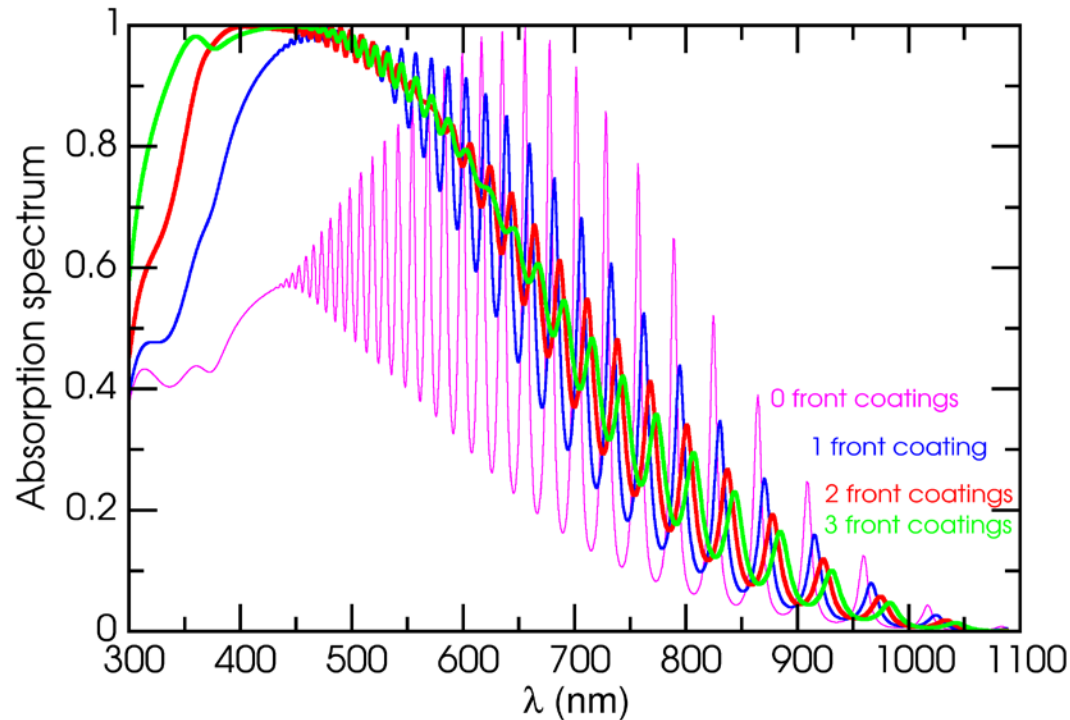


Efficiency Enhancement of Period Structures



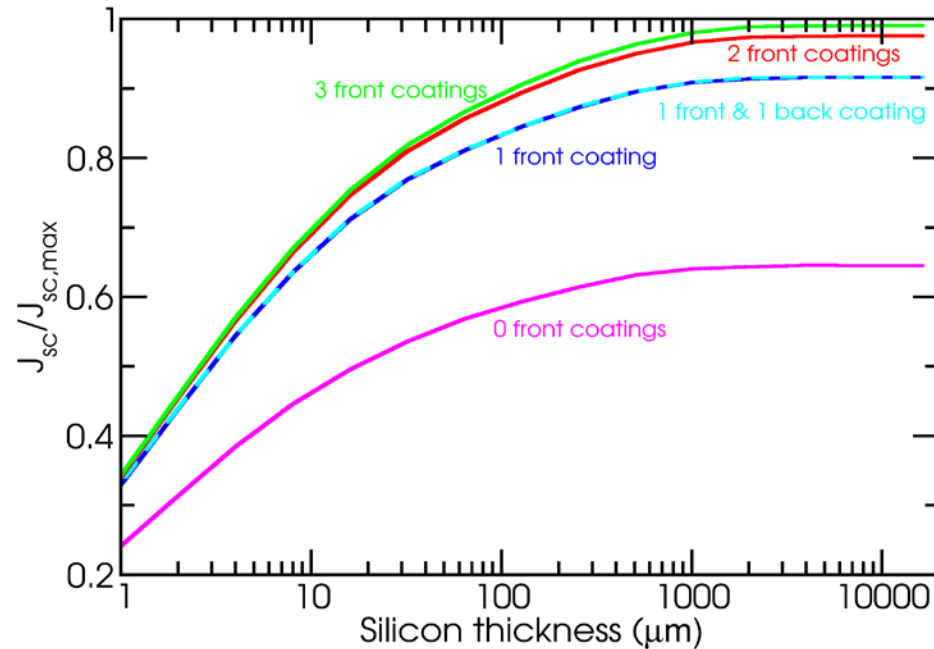
For optimized parameters, 2D grating efficiency enhancement ranges from 7% at 128 μm up to 35% at 2 μm

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%

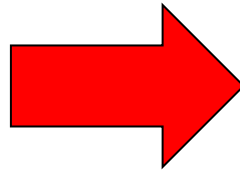
wafer-based cells see greater improvements with each successive layer

Example: Correlated Randomness

Combine gratings for each wavelength



inhomogeneous



Combine periodicity with texturing in systematic fashion

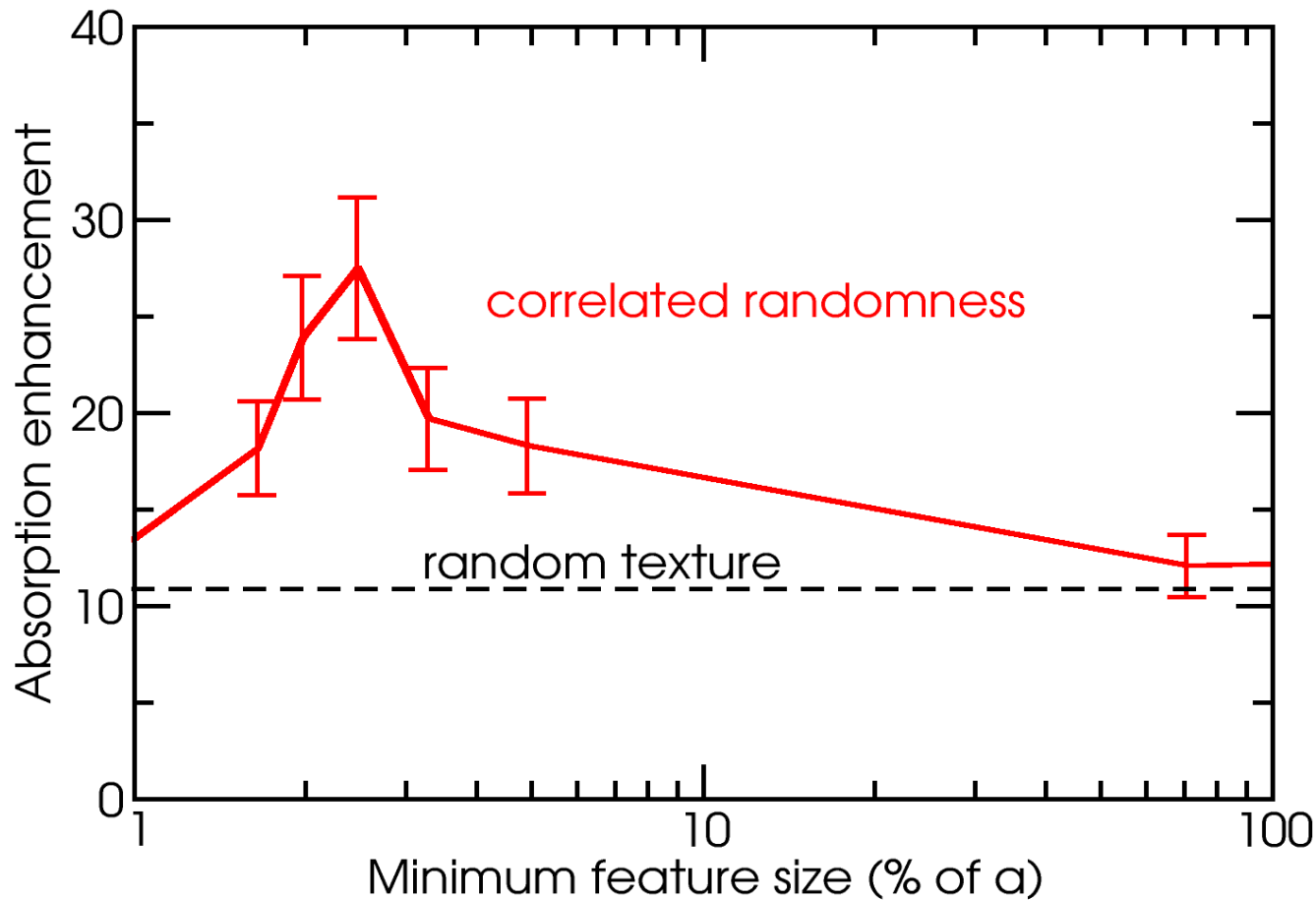


homogeneous

A.N. Bloch & P. Sheng, US Patent 4,683,160 (1987)

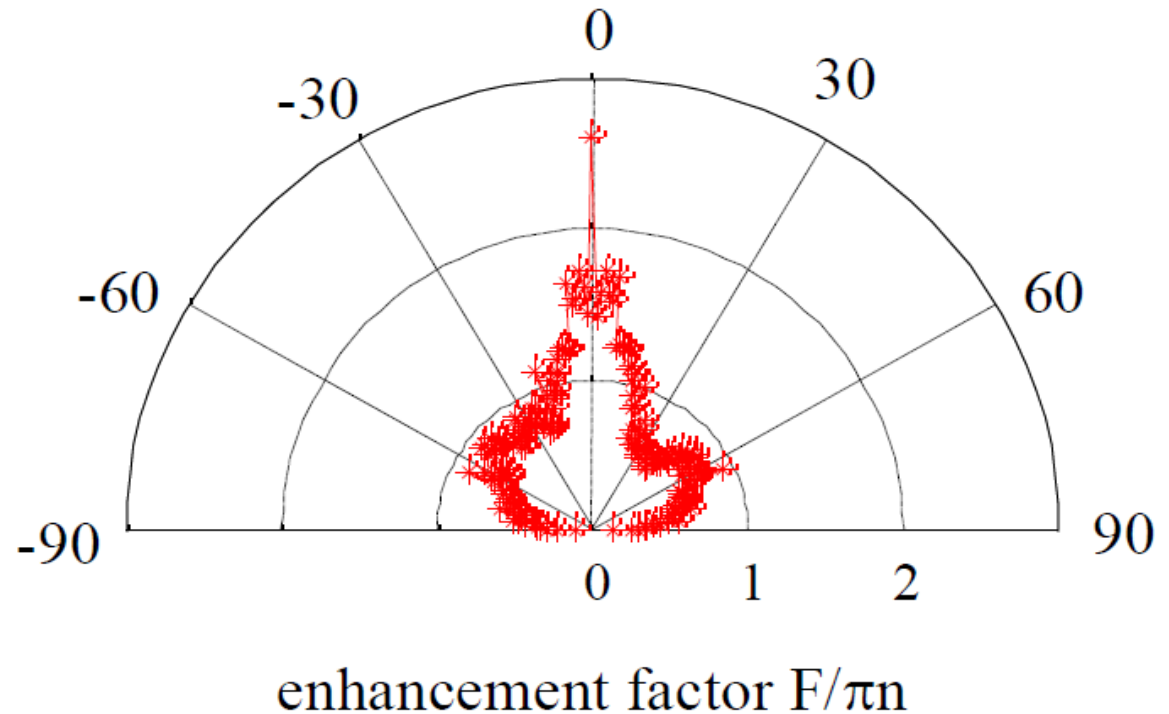
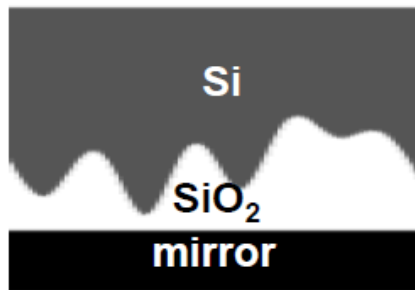
X. Sheng *et al.*, *Opt. Express* **19**, A841 (2011)

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