Enhancing Concentrating Photovoltaic (CPV) Efficiencies with Photonics

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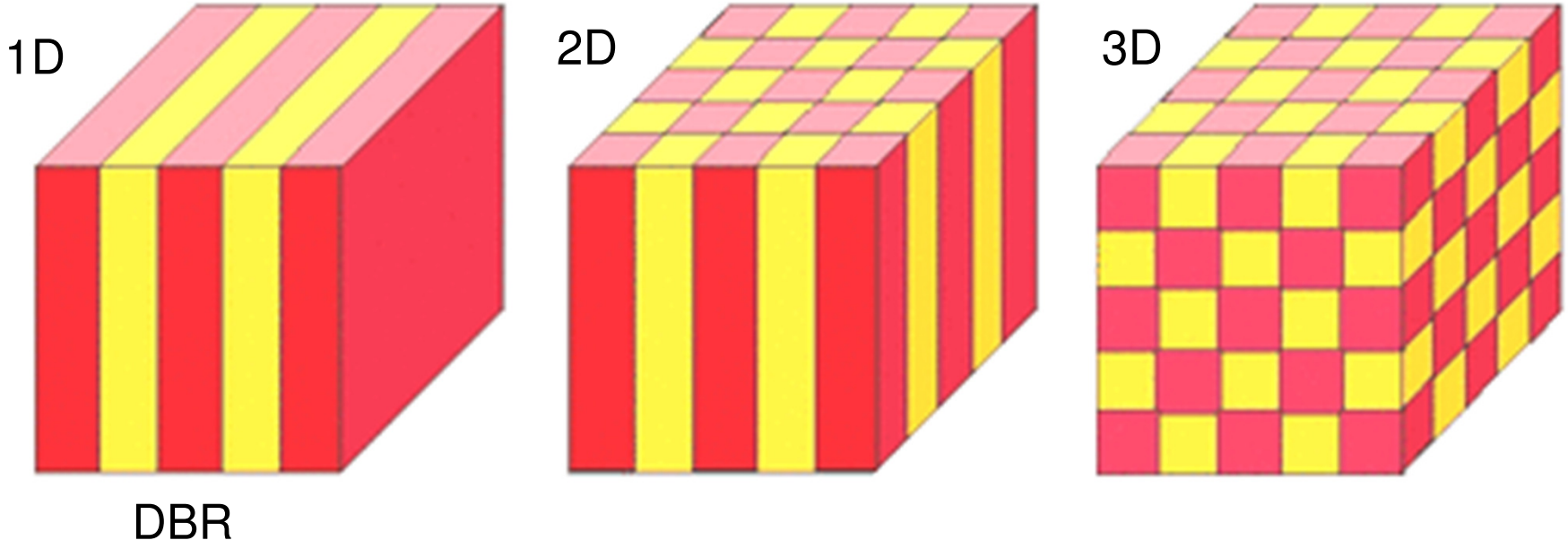
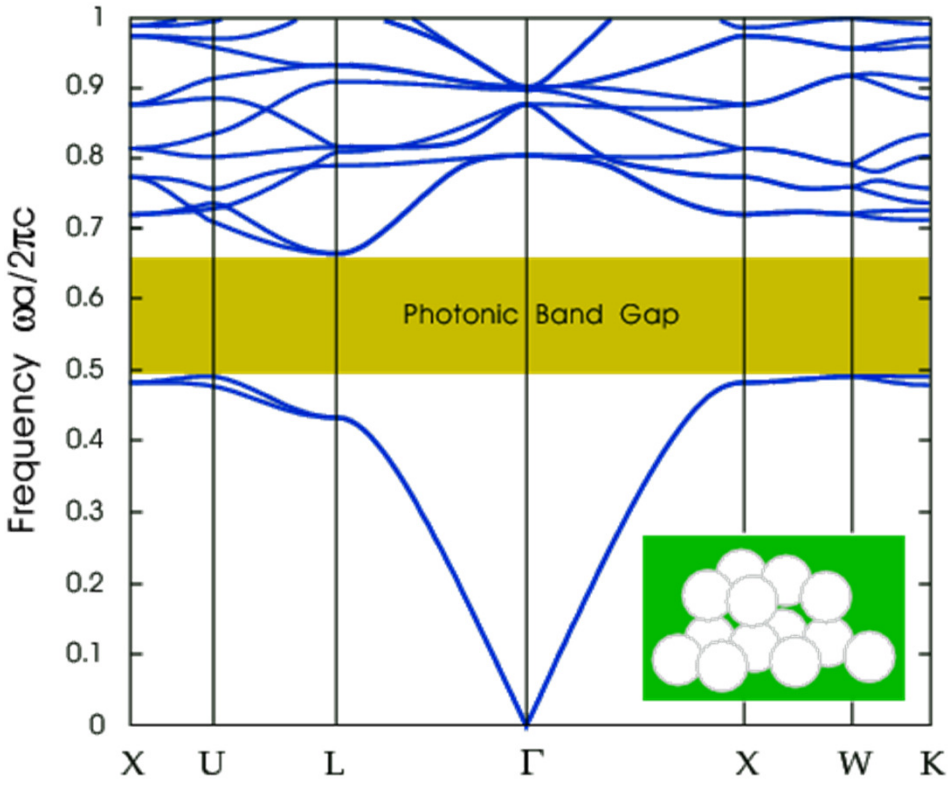
Photonic Crystals (PhCs)



- Periodic dielectric media
- Gives rise to EM Bloch modes, characterized by band structure

Photonic Bandgap (PBG)

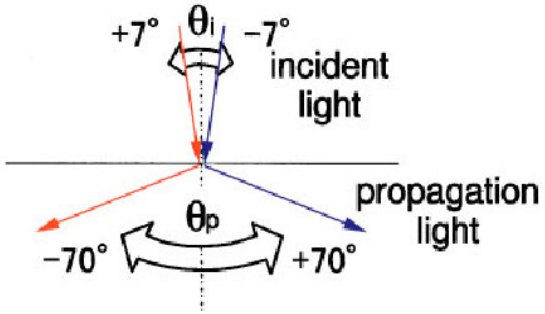
- A “gap” in the photonic band structure frequencies
- Ubiquitous for 1D structures, and some 2D and 3D structures
- Scale-invariance allows tuning over most EM frequencies

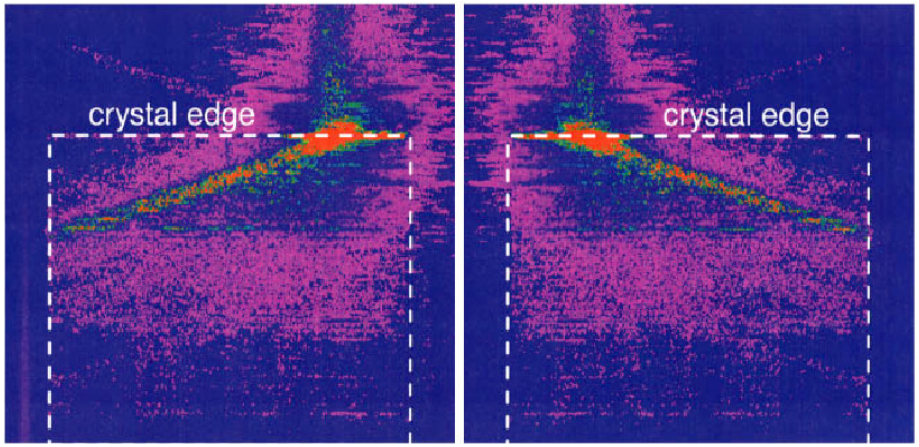


PBG for diamond structure

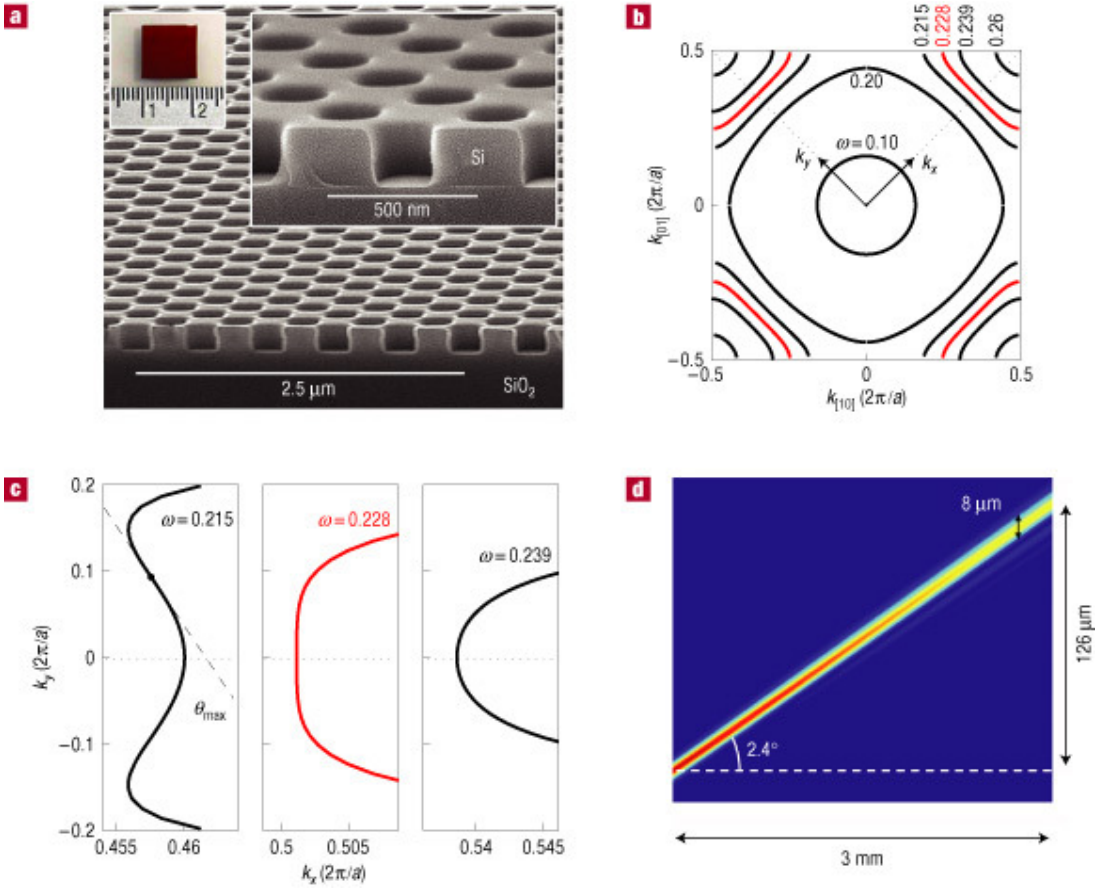
Joannopoulos *et al.*, *Photonic Crystals* (2008)

Low Loss Spectral Splitting I: Superprisms+Supercollimation



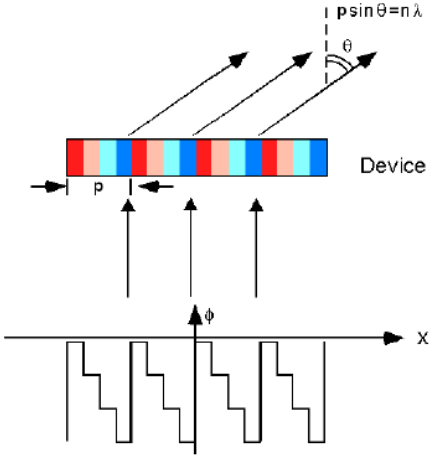


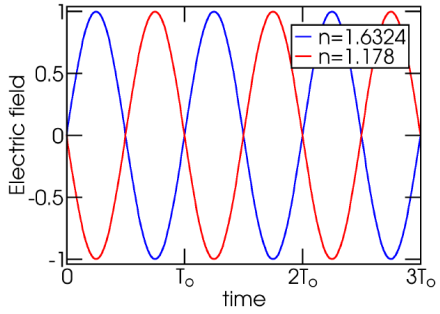
Kosaka, *PRB* **58**, R10096 (1998).



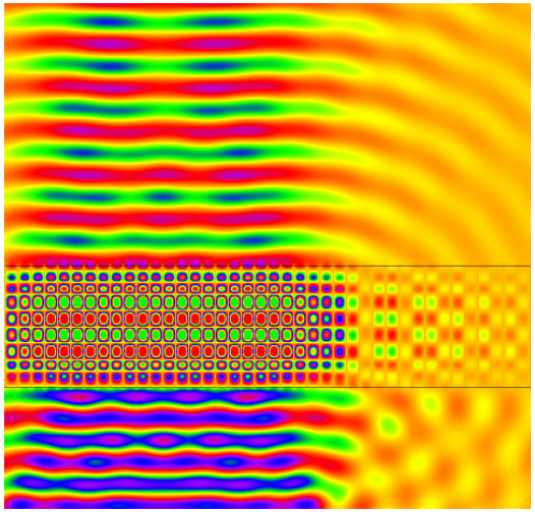
P. Rakich *et al.*, *Nature* (2006)

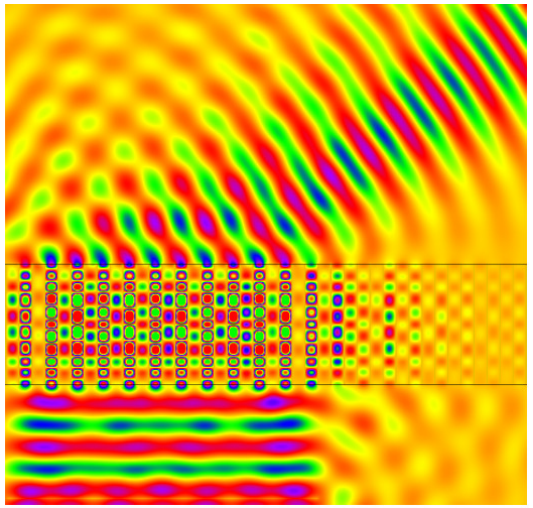
Low Loss Spectral Splitting II: Resonant Beam Steering





$$\cot\phi = \sum_i \frac{2}{\Gamma_i}(\omega - \omega_i)$$

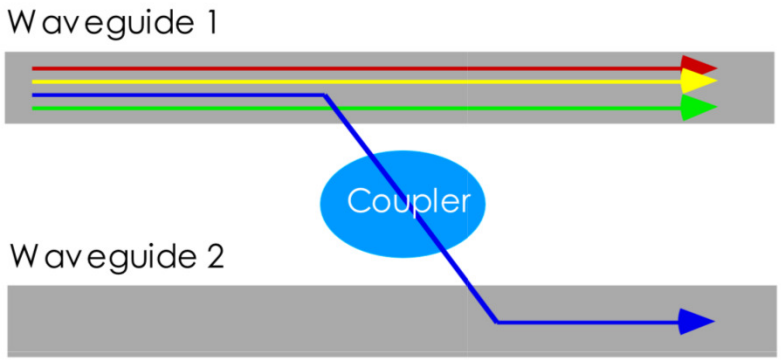




1st target frequency 2nd target frequency

P. Bermel, Ph.D. Thesis, MIT Physics (2007)

Low-Loss Spectral Splitting III: Channel-Drop Filters



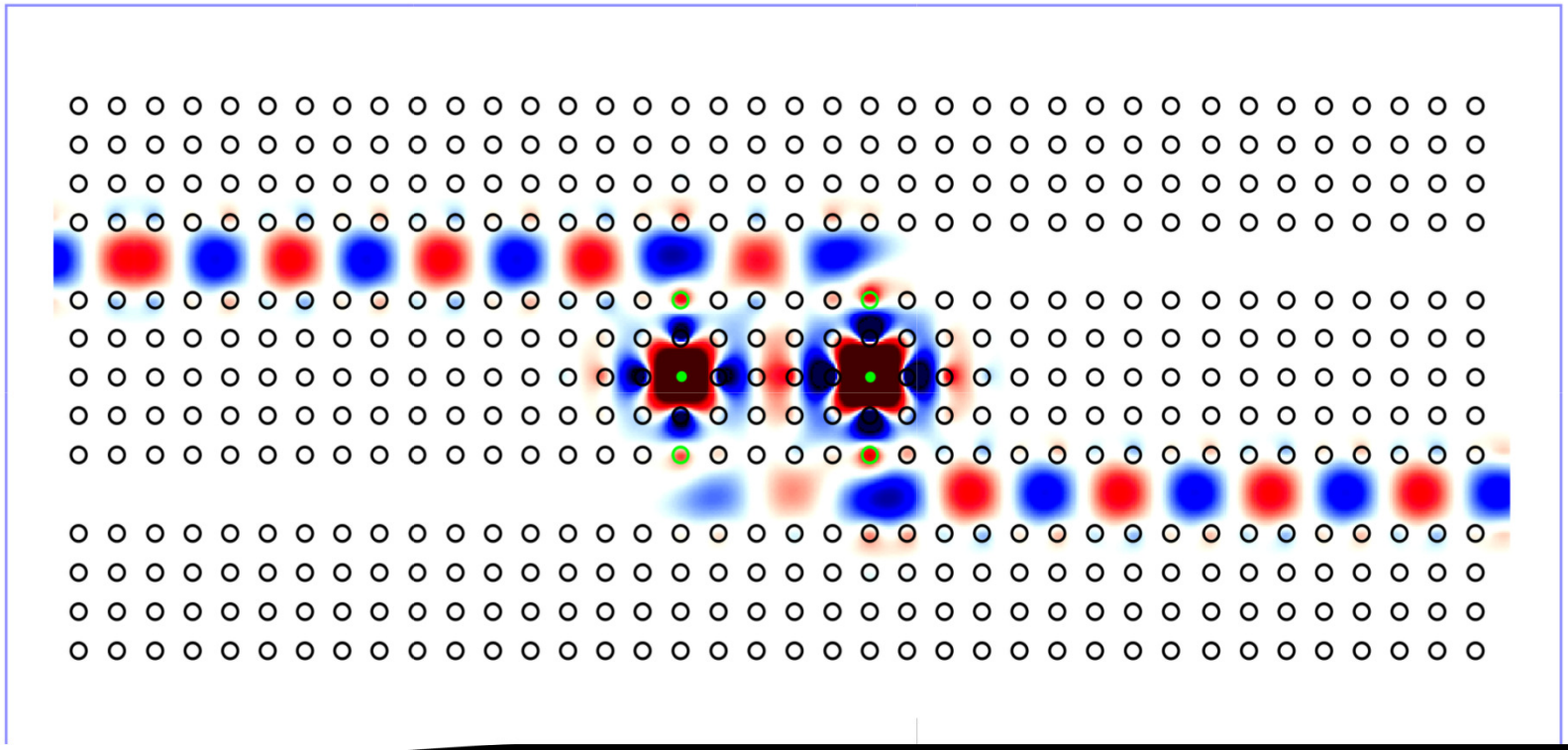
Criteria for Perfect Channel-dropping

Two resonant modes with even and odd symmetry

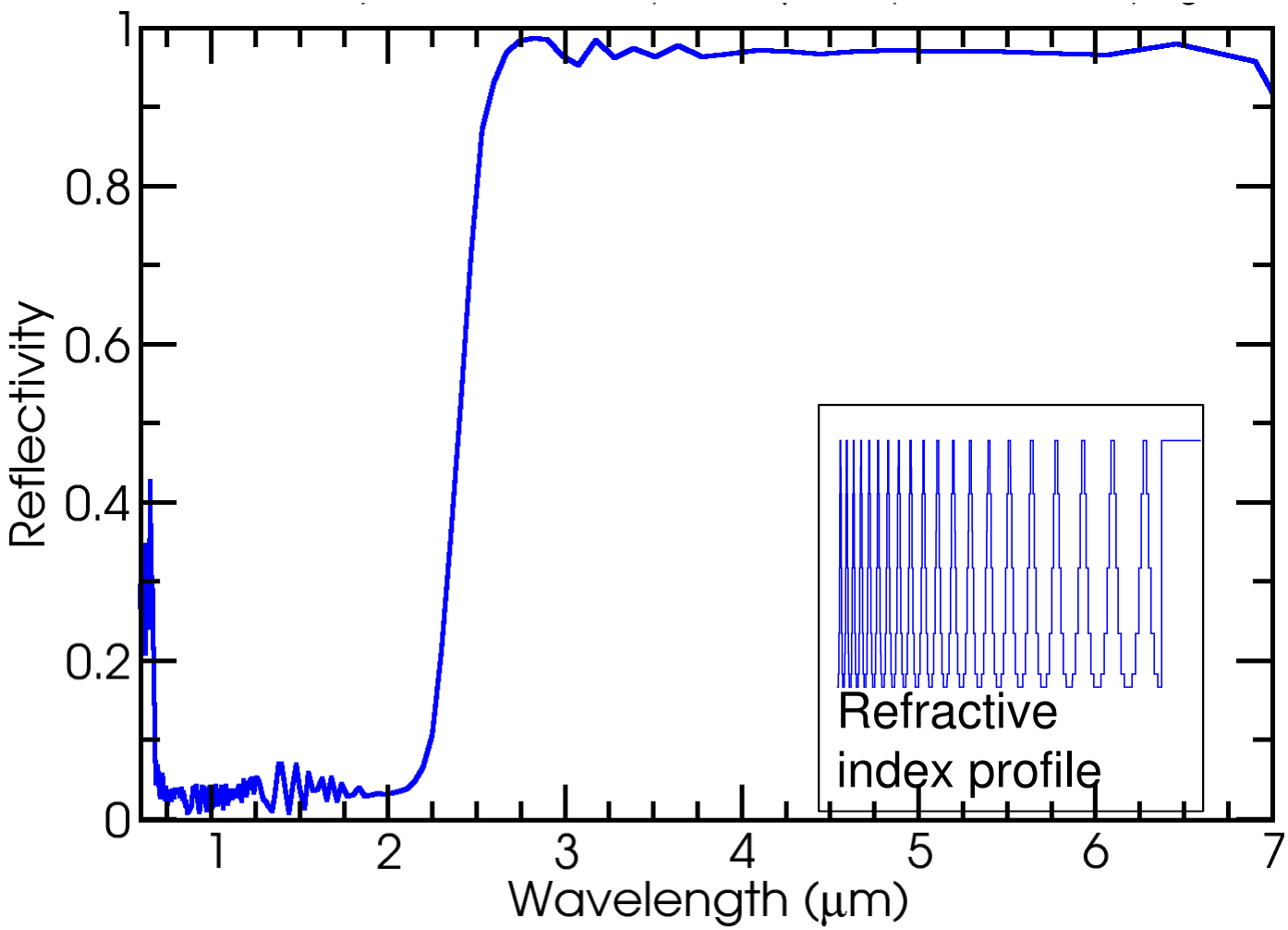
Modes must be degenerate

Modes must have equal decay rates

[S. Fan *et al.*, *Phys. Rev. Lett.* **80**, 960 (1998)]

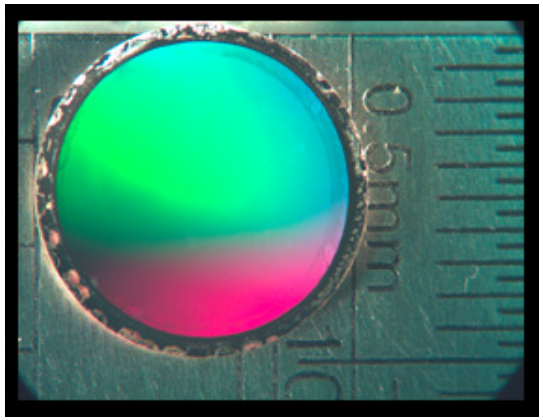


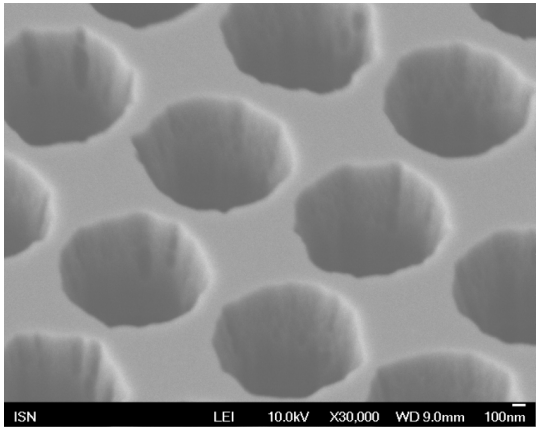
Photon Recycling with Rugate Filters



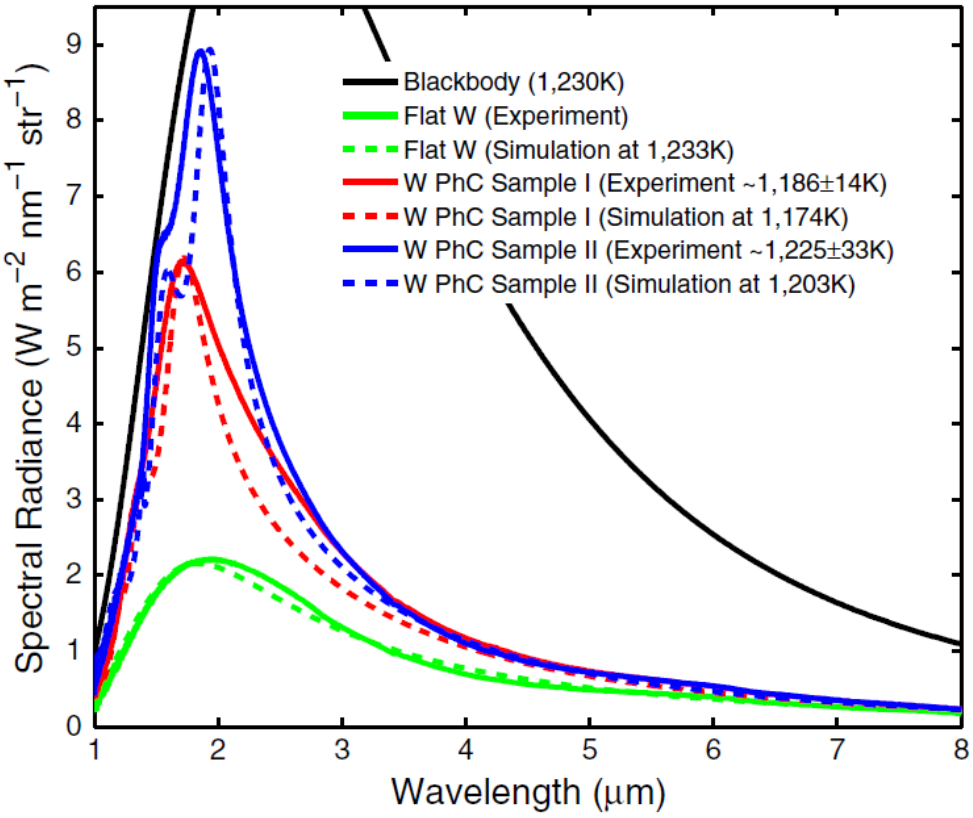
Can generate sharp cutoff with 60 periods of silicon oxynitride

PhC-Enhanced Radiative Absorption and Emission





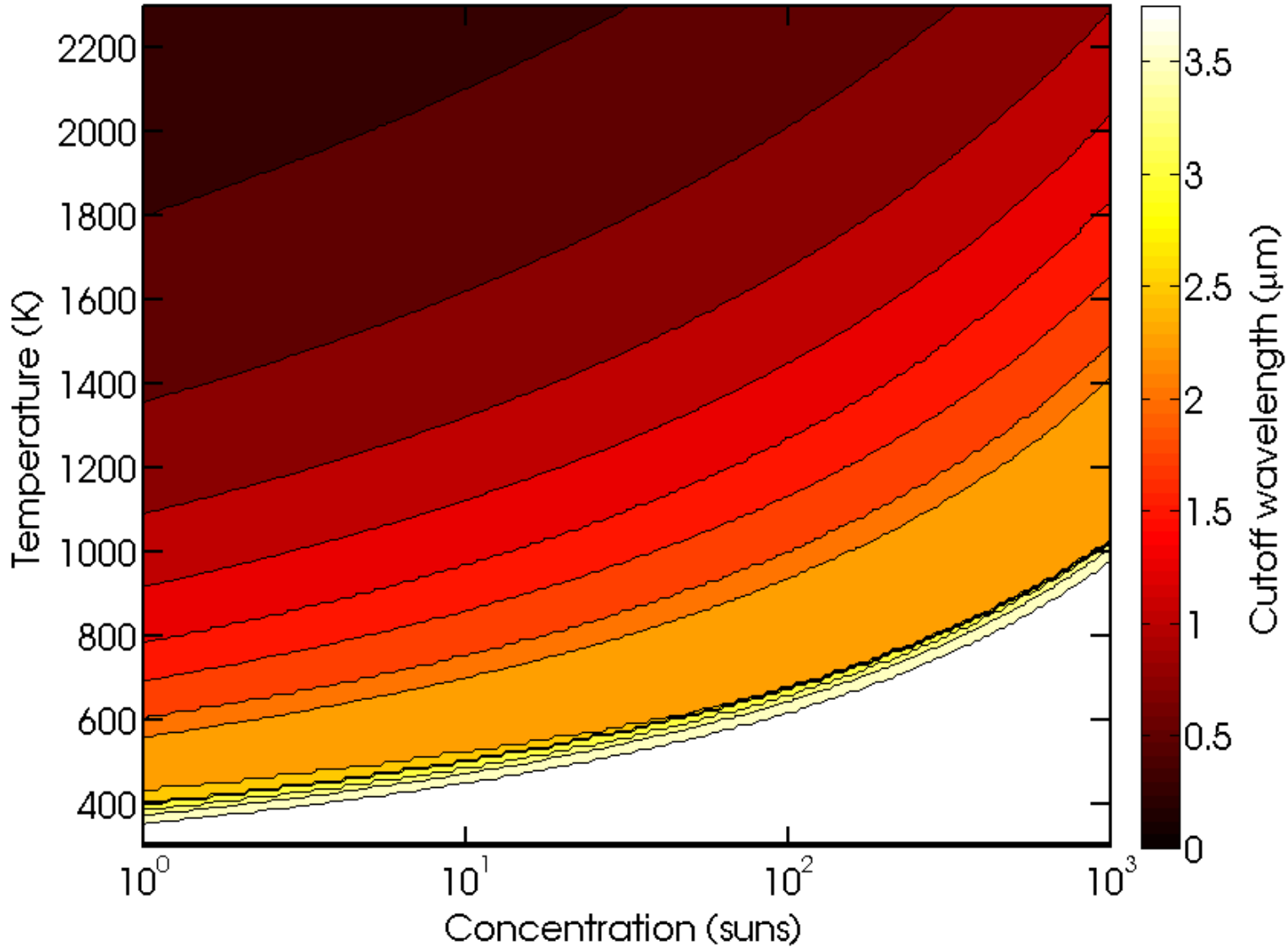
Fabricated Samples



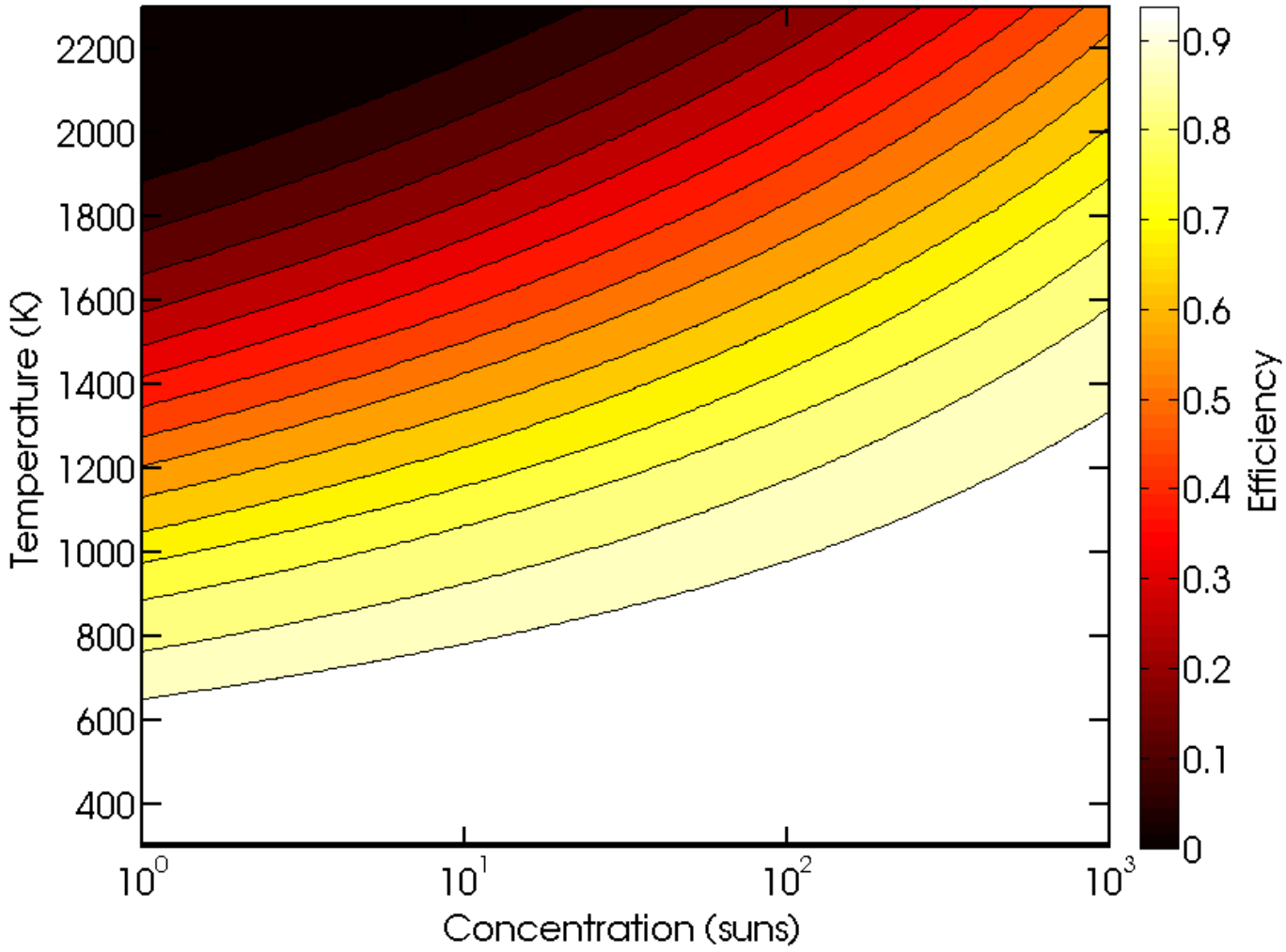
Measured Radiation Data

Y.X. Yeng et al., *PNAS* **109**, 2280 (2012)

Selective Absorber: Ideal Cutoff Wavelength

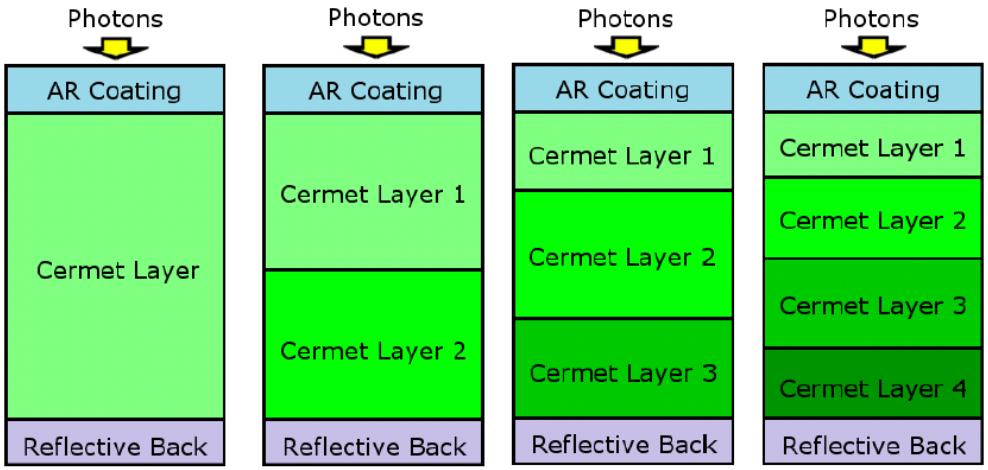


Selective Absorber: Maximum Thermal Transfer Efficiency



Cermet Selective Solar Absorbers: T=1000 K (100 suns)

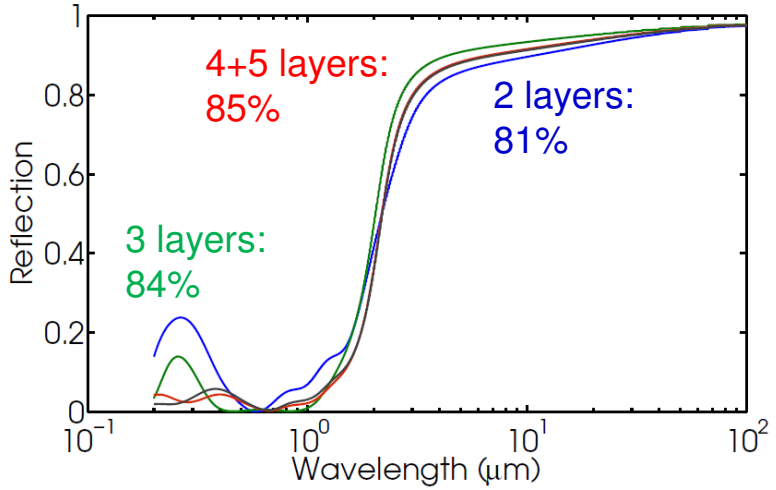
4 Selective Absorber Designs

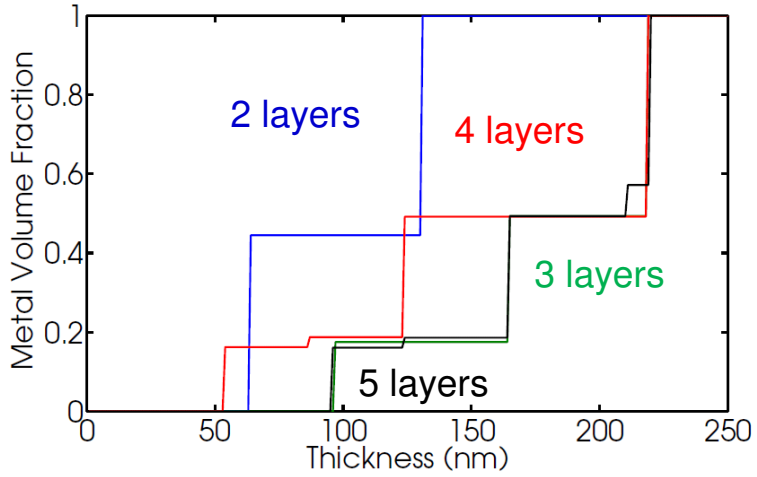


5 layer optimization yields:

$\eta_t = 85\%$; $\alpha = 95\%$

$\varepsilon = 17\%$





D. Chester *et al.*, *Opt. Express* **19**, A245 (2011).

Conclusions

- Photonics can enhance high-efficiency CPV application in a variety of ways:
  - Spectral splitting
  - High-performance filters
  - Selective solar absorbers for efficient utilization of MWIR
- Future work – integrate novel photonic crystal designs into reliable, high-performance systems

Acknowledgements

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