Light Management Optimization of Upconversion-Based Solar Cells using Genetic Algorithms

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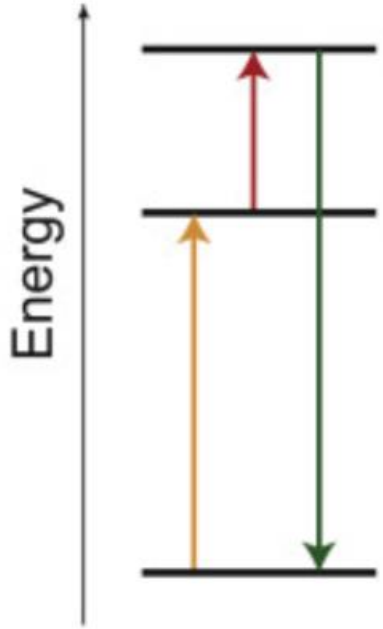
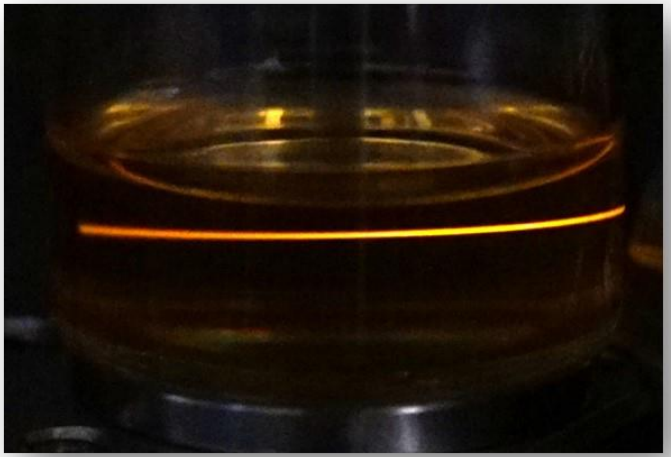
Upconversion

- High-energy photon emission
  - Sequential absorption of two low-energy photons
- Applications
  - Disease treatment
  - Imaging
  - Solar Cells



D.G. Sellers, et al., Sol. Energy Mater. Sol. Cells **155**, 446 (2016).

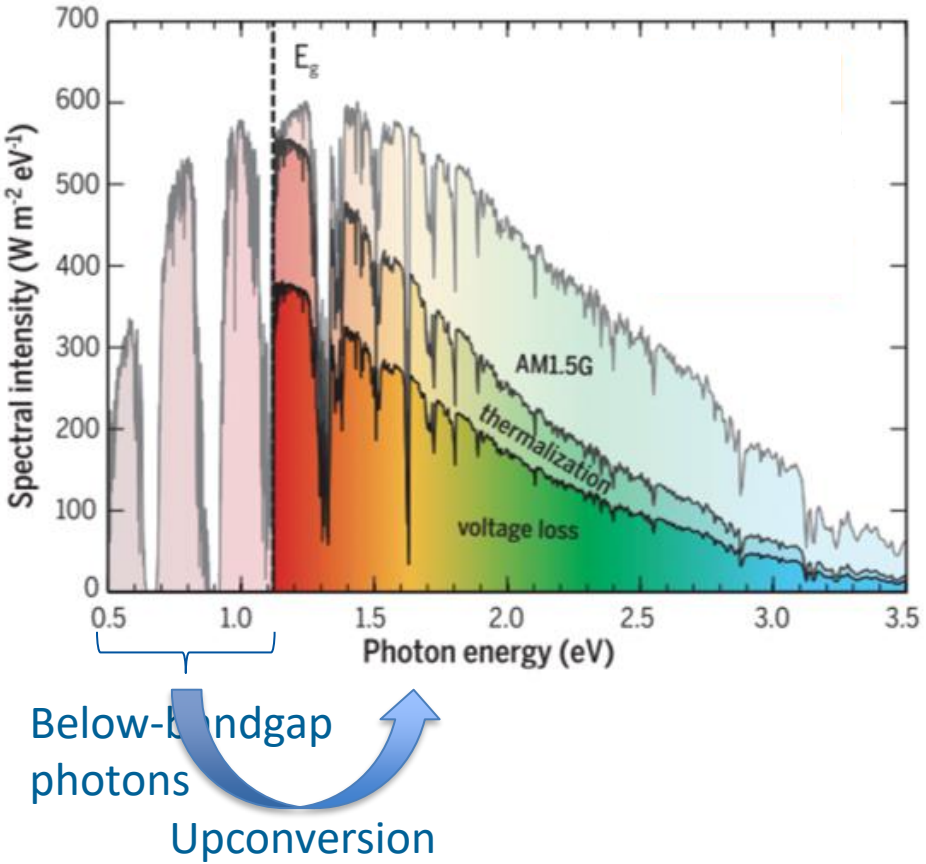


Christopher C. Milleville, et al., *ACS Nano* **13**, 1, 489 (2019).

Solar Energy Harvesting

- Photons below bandgap
  - Not Absorbed
  - Loss Mechanism
- Upconversion
  - Expands accessible range

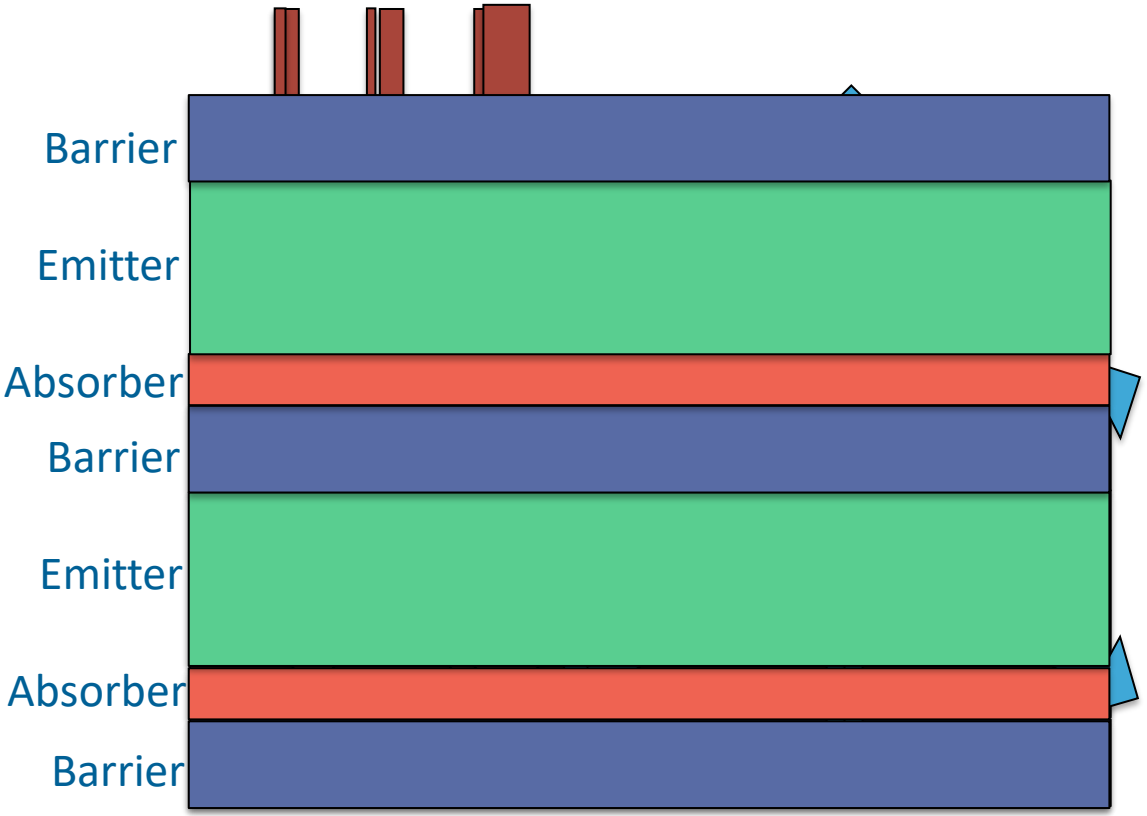
Upconverted photons → higher efficiency



A. Polman, et al., Science (80-.). **352**, (2016).

Upconversion Structure

- Layered Structure
  - Incident below-bandgap absorption
  - Upconverted, above-bandgap emission



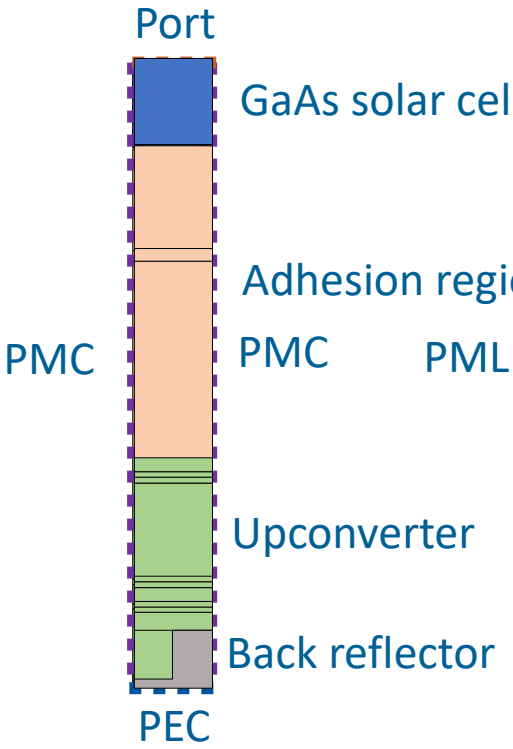
Understanding of total performance is complex

Two Models

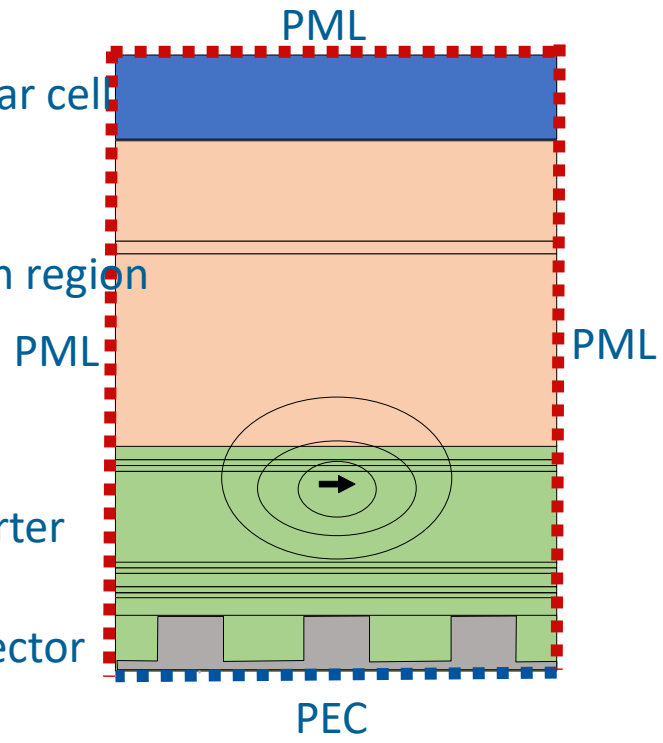
- Wave Optics module
- Different test geometries
  - Flat structure
  - Square grating
  - Photonic crystal
- Each test geometry
  - Different # of upconverter layers

PML - Perfectly matched layer
PMC - Perfect magnetic conductor
PEC - Perfect electric conductor

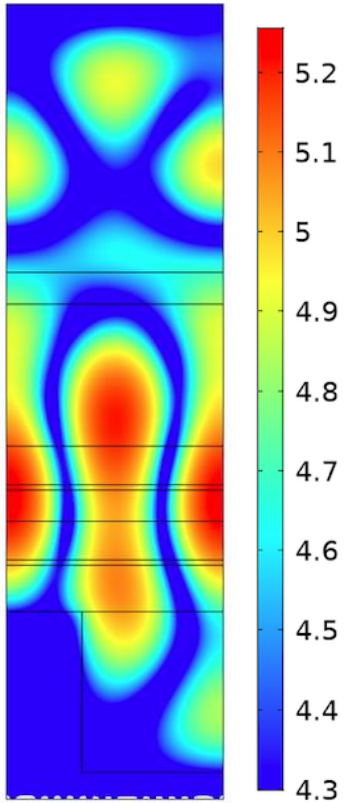
λ = 0.873-1.35 μm

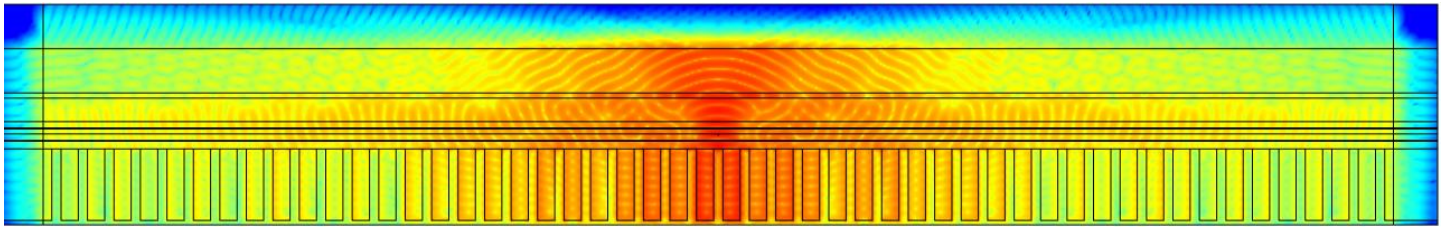


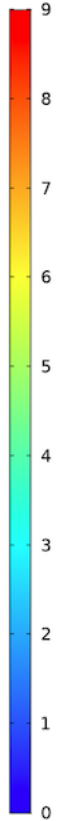
λ = 0.873 μm



Typical Modeled E-fields

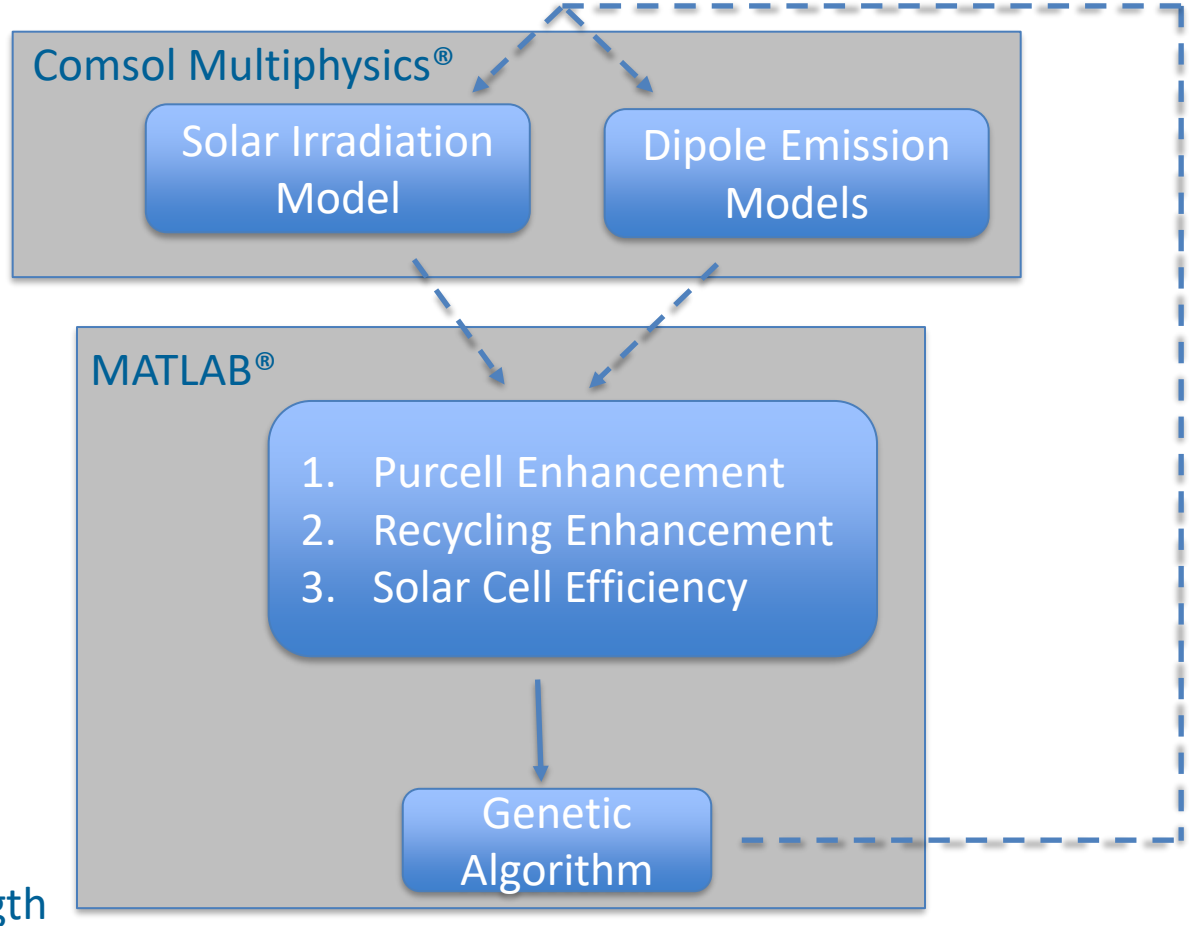






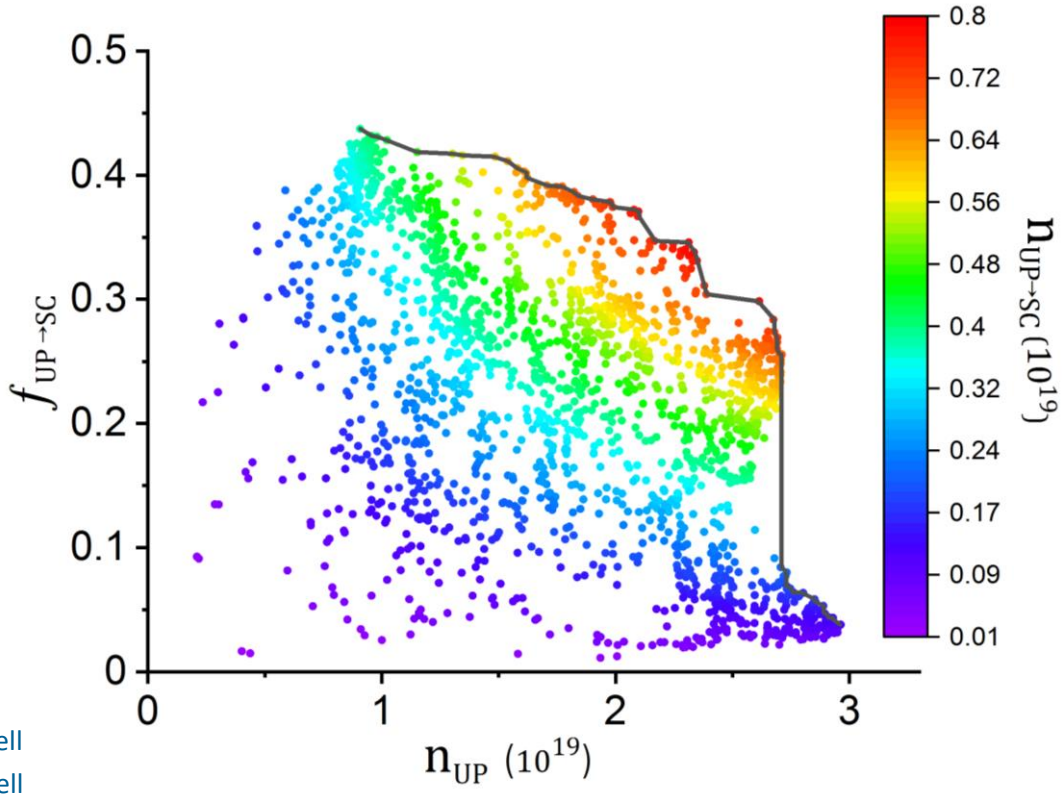
Modeling Workflow

- LiveLink™ for MATLAB®
- Genetic algorithm (GA)
  - 30 generations
  - 30 members
- Parameters adjusted:
  - Layer thicknesses
  - Pitch
  - Fill factor
  - Height
- Wave Optics
  - 4 elements/wavelength



Multiobjective GA

- Multiobjective GA
  - Pareto front
- Highest performing solutions (red)
  - Indicates a compromise



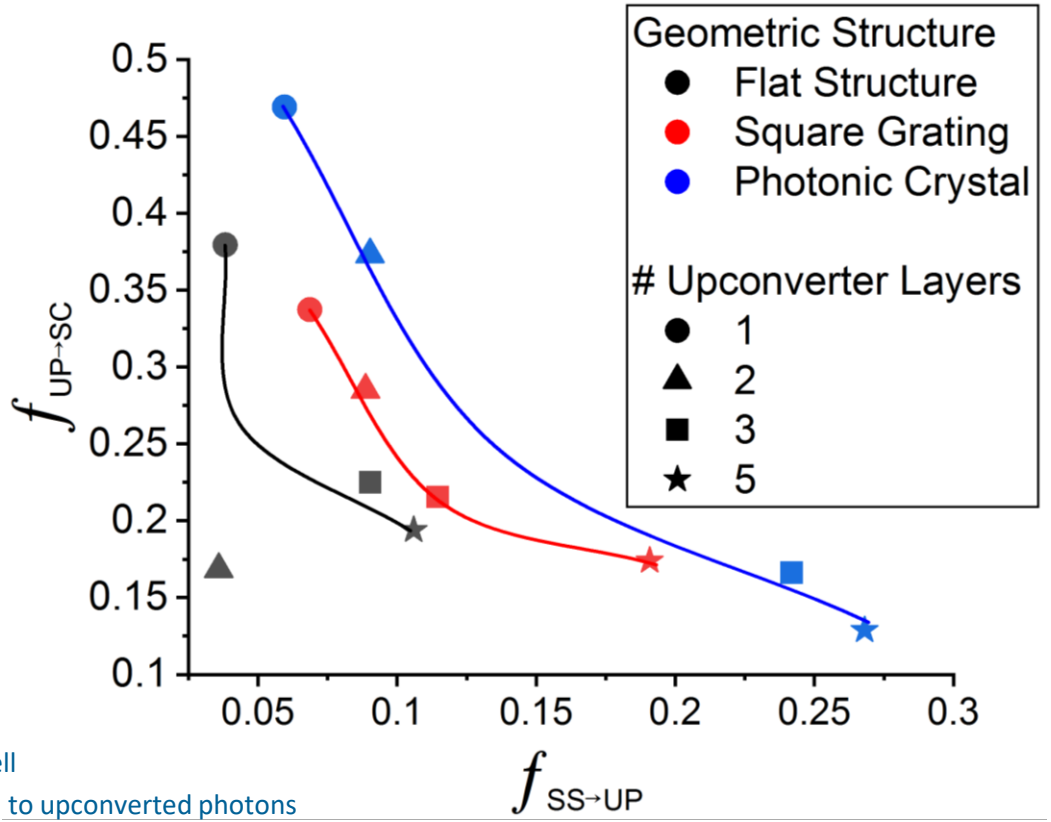
n_{UP} : Number of upconverted photons created

$n_{UP\rightarrow SC}$: Number of upconverted photons delivered to solar cell

$f_{UP\rightarrow SC}$: Fraction of upconverted photons delivered to solar cell

Performance Maximization Trends

- Single objective GA
- # layers ↑ :
  - Incident radiation ↑
  - Dipole emission ↓
- Photonic crystal
  - Highest performing

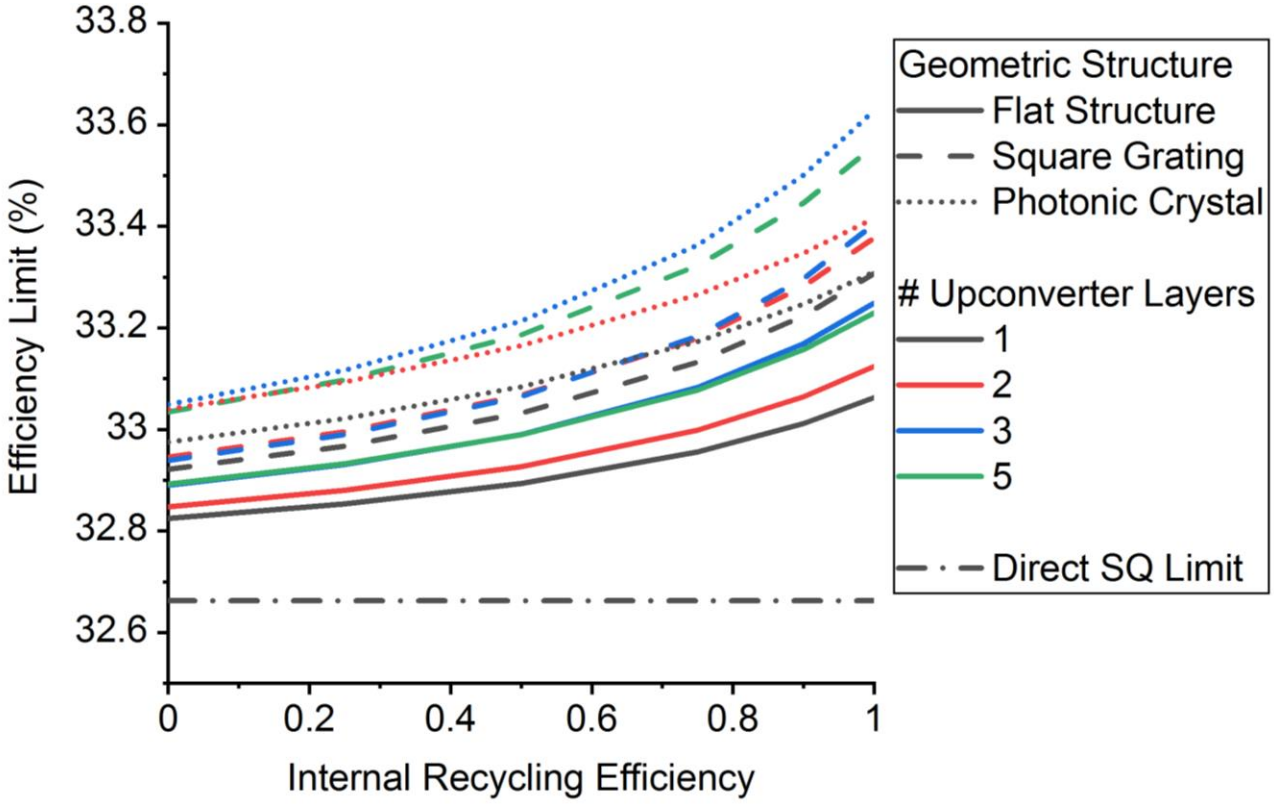


$f_{UP\rightarrow SC}$: Fraction of upconverted photons delivered to solar cell

$f_{SS\rightarrow UP}$: Fraction of incident solar spectrum photons converted to upconverted photons

Solar Cell Efficiency Limits

- Photonic crystal highest performing
- Photon recycling
  - Typically >70% internal recycling efficiency
  - ~1% efficiency limit increase



Conclusion

- Inherent compromise
  - Solar radiation absorption
  - Dipole emission directivity
- Photonic crystal
  - Highest performing
- ~1% efficiency limit increase
  - Significant for established technology
- Insights for more advanced designs

Acknowledgements

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