Efficient Modeling of Subwavelength Diffractive Elements

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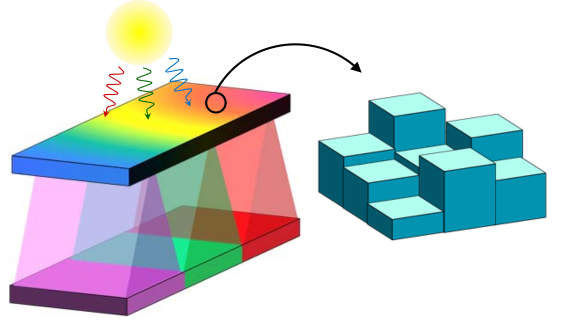
Abstract

Solar cell efficiency can be improved by using multiple independently connected solar junctions and an optical system that laterally splits different wavelengths of sunlight into the appropriate solar cells. Such a spectral splitter can be made by using a textured dielectric that diffracts light. The simplest way to model a diffractive element is by approximating the texture as a thin phase shift mask; however, at subwavelength feature sizes, this model neglects the effects at the edges of the pixels. In this work, we propose a new method of modeling these edge effects by dividing the mask into equal vertical layers, in which each layer can be efficiently simulated by scalar diffraction.

Spectral Splitting Photovoltaics

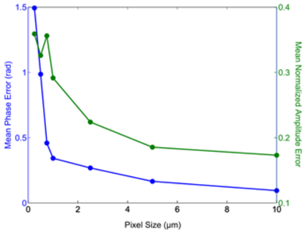


Multi-junction solar cells are more efficient than single-junction solar cells due to reduced spectrum losses. Furthermore, independently connected cells are more efficient than series connected cells because there is no current-matching involved. One way of independently connecting cells is by placing them laterally; however, a spectral splitter is needed.

One way to achieve spectral splitting is by using diffraction. A textured dielectric can act as a diffractive mask that does not absorb sunlight. This design can be optimized at multiple angles of incidence, which helps capture diffuse light. Subwavelength features provide more degrees of freedom for the optimization. Design can be optimized at multiple angles of incidence, which helps capture diffuse light. Subwavelength features provide more degrees of freedom for the optimization.

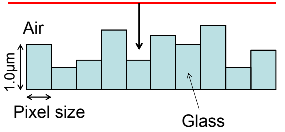
Thin Mask Model Validation

Near-field Error

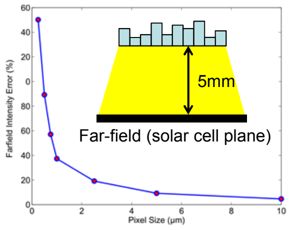


This plot shows how the error in the electric field (TM component) between the Lumerical FDTD data and the thin mask model varies with pixel size. The error increases for smaller pixels because of increasing interactions between the pixels.

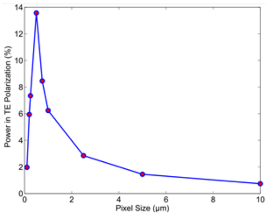
Plane Wave (λ = 800nm, TM Polarization)



The error in the far-field image, found using scalar diffraction approximation, also increases with decreasing pixel size.

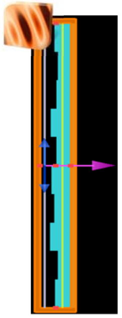


Polarization Leakage

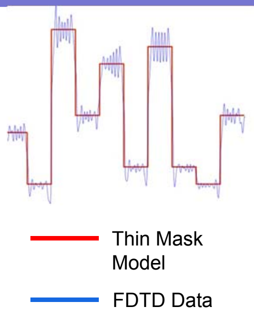


As pixel size decreases, more power in the TM polarization leaks into the TE polarization due to scattering at the edges. In addition, the reflected power increases due to the increasing surface area of the air-glass interface.

Existing Simulation Methods

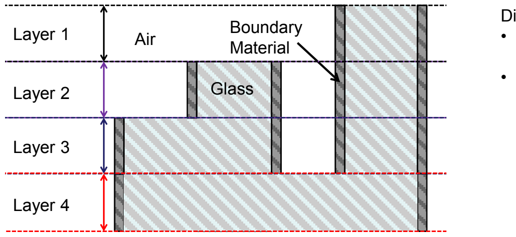


FDTD (Finite Difference Time Domain) method exactly solves Maxwell's equations. This method is not practical on a ~1mm^2 scale because this would take a long time leading to a unacceptably long optimization design cycle.



The **thin mask model** approximates each pixel as a simple phase shift, independent of neighboring pixels. This model is valid for pixels larger than the wavelength. This breaks down at subwavelength features because it neglects the interactions between the pixels.

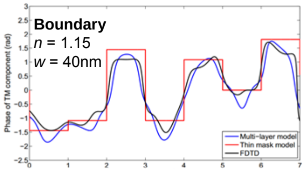
1D Multi-layer Modeling



3 scalar diffraction simulations needed per layer (glass, air and boundary material) **Capable of scaling to mm^2 area design**

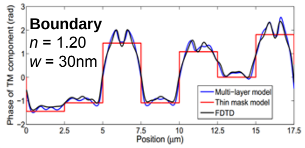
Divide the texture into layers of equal height:

- Use scalar diffraction approximation to propagate the electric field through each layer
- Simulate the hypothetical boundary material with varying index of refraction and width to model edge effects



Mean thin mask error: 0.301 rad

Mean new model error: 0.247 rad



Mean thin mask error: 0.253 rad

Mean new model error: 0.114 rad

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Future Goals

- Refine the new model to work at subwavelength features
- Include the effects of polarization leakage in the multi-layer model
- Apply our method at oblique incidences
- Apply our methods to 2D pixels

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