# Inverse Design of DOE in 2D FDFD

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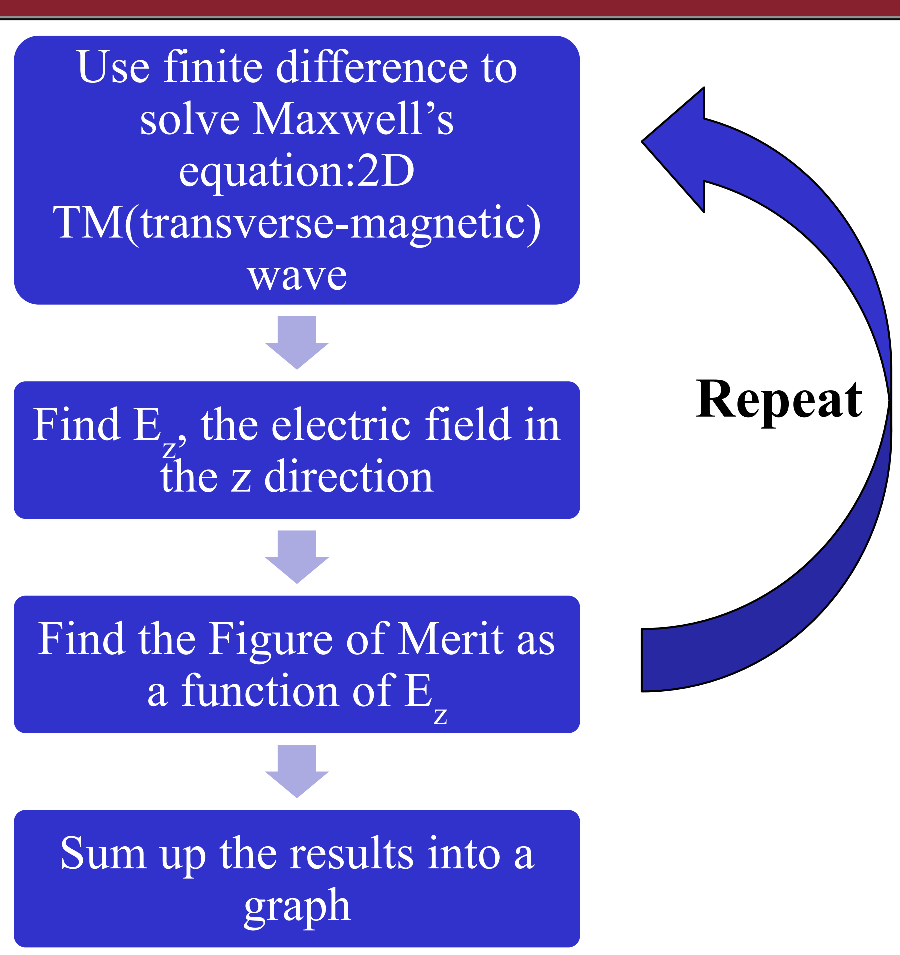
## Introduction

In Professor Hsu's research lab, we focus on using modern technologies to control interactions between light and matter in complex systems. Examples include exploring new paradigms for controlling light, overcoming and harnessing light scattering, retrieving information from photons, and much more. One of the current interests is developing computational imaging methods that can reconstruct volumetric 3D images inside an opaque scattering medium that typically cannot be seen through.

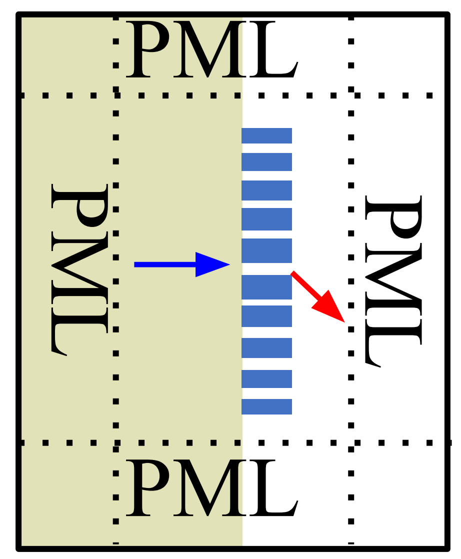
## Impact of Research

- Utilizing cutting edge fabrication and high performance simulations to manipulate light, to have deeper and finer resolution in imaging system. It can be widely used in medical and biomedical purpose, such as detecting the tumor behind human skin.

## Flow chart of optimization




## Methods and Results




By radiating a light beam(blue arrow) through the silicon oxide substrate(beige color) into the silicon nitride grating(blue squares), the light beam is scattered into multiple directions. Our goal is to alter the pillar width to end up with a light beam with the strongest transmittance at a specified angle(in this experiment, 10 degrees).

*Figure 1. Diffractive Optical Elements surrounded by Perfectly Matched Layer*

**FoM = $|t_{10°}| - |t_{0°}|$**, t = Transmission Coefficient

$\vec{w} = \vec{w}_{old} + \eta \frac{\nabla FoM}{|\nabla FoM|}$, η = Learning Rate

- Our goal is to find the position with maximized FoM.
- We measured the figure of merit for each of the first 300 iterations to produce this graph.
- As the graph suggests, we can see an increasing trend for the Figure of Merit.

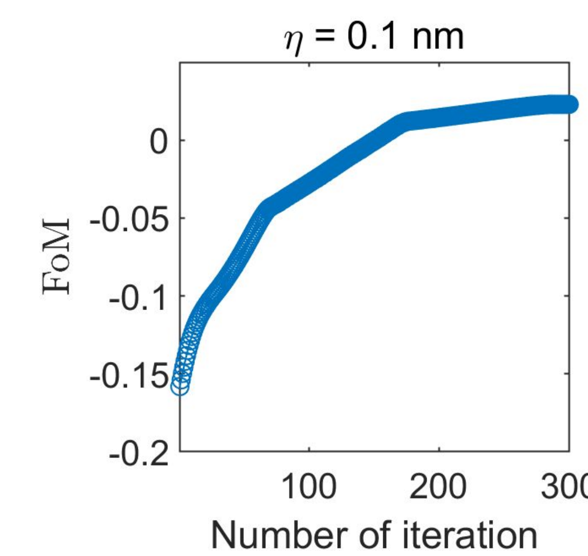
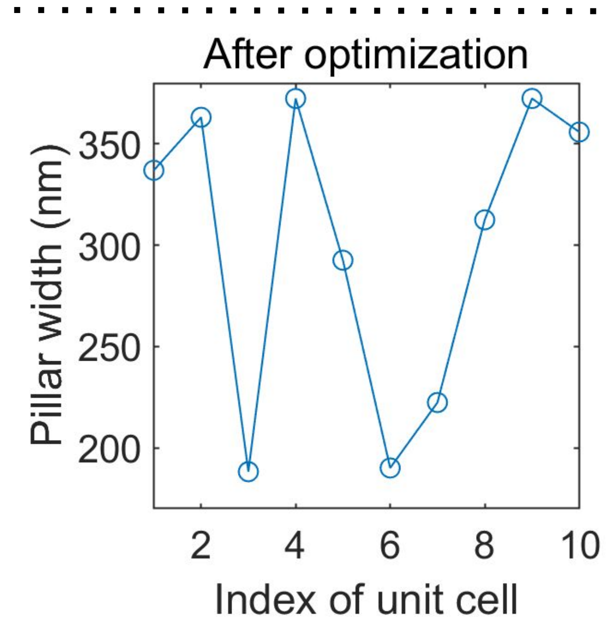



*Figure 2. Figure of Merit of the first 300 iterations*




**Conditions:**

1. Pillar height is 695 nanometers
2. Diameters vary from 170 to 374 nanometers

- We take the final iteration, since it has the maximum FoM.
- Then we measure the width of each individual pillar.

*Figure 3. Optimized width of the 10 pillars of the gradient*

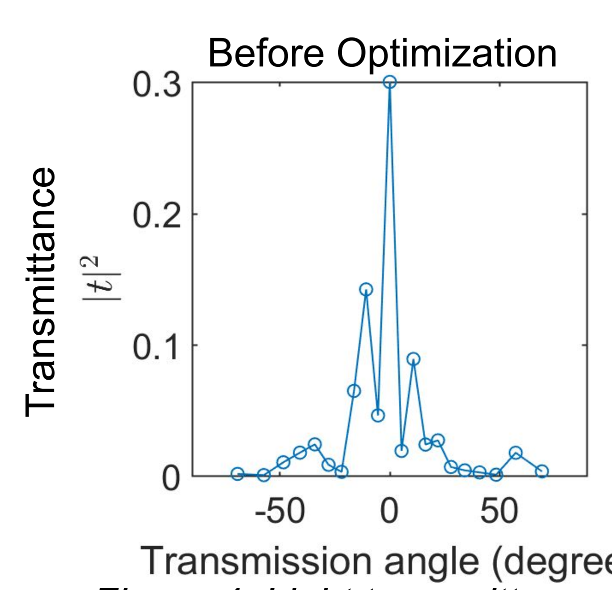



*Figure 4. Light transmittance v.s. transmission angle before optimization*

- The light beam initially projects normal(0 degrees) to the gradient.
- As a result of altering the pillar width, the light beam of strongest transmittance projects at an angle of -10 degrees.

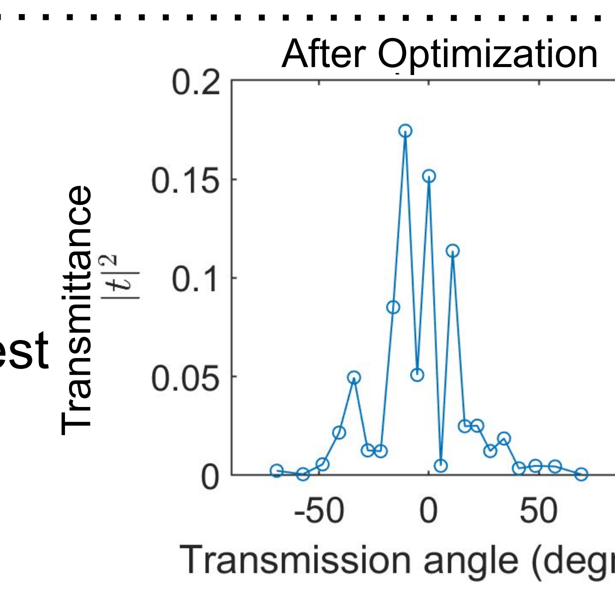



*Figure 5. Light transmittance v.s. transmission angle after optimization*

## Skills Learned

- Utilization of MATLAB
- Multivariable calculus
- Finite-Difference Method in
- Maxwell's Equations and wave equations
- Adjoint method
- Optimization methods, such as gradient descent(ascent) method and Monte Carlo method

## Advice for Future SHINE Students

My advice for future SHINE students would be don't be afraid to ask for guidance. When SHINE first starts, everyone will feel new to the environment and not sure what to do. As SHINE progresses, everything will connect like puzzle pieces. Asking for help not only clarifies the questions you have, but also helps you connect with your professor and mentor as well.

## Reference

[1] Lipsman Rosenberg Multivariable Calculus With MATLAB
[2] Zhi-Bin Fan,Zeng-Kai Shao,Ming-Yuan Xie,Xiao-Ning Pang,Wen-Sheng Ruan,Fu-Li Zhao,Yu-Jie Chen,Si-Yuan Yu,and Jian-Wen Dong, "Silicon Nitride Metalenses for Close-to-One Numerical Aperture and Wide-Angle Visible Imaging"

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