Design of Optical Transformer for Nanohole Array – Theory and Simulation

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Abstract

- We aim to adapt methods and techniques Traditionally used in the microwave region of the electromagnetic spectrum for application at optical frequencies. Specifically, we will design and develop a transformer structure by employing mode matching and impedance matching techniques.
- Investigate the adaptation of methods from the microwave spectrum to optical frequencies, focusing on overcoming obstacles such as reduced wavelengths and heightened losses to enhance the efficiency of cutting-edge photonic systems.
- This design process will include both analytical calculations and numerical modeling, utilizing the finite difference time domain (FDTD) method. The primary objective is to enhance power transmission through nanohole arrays.

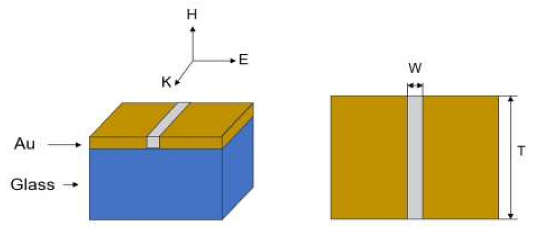
Introduction

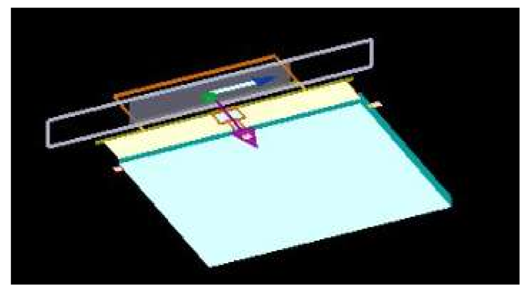
- Explore the extension of techniques from the microwave region to optical frequencies, addressing challenges like shorter wavelengths and increased losses to improve performance in advanced photonic systems.
- Develop a multi-layer transformer structure incorporating mode matching and impedance matching techniques, adapting microwave engineering principles to ensure efficient energy transfer and minimal reflection in optical systems, enhancing overall transmission efficiency.
- Combine analytical methods with numerical modeling, specifically using the finite difference time domain (FDTD) method to simulate electromagnetic behavior at optical wavelengths and optimize the design.
- Enhance power transmission through nanohole arrays for various applications such as increasing sensitivity in biosensing devices, enhancing optical filters' performance, and developing advanced photonic circuits for data transfer in telecommunications, refining the design to maximize light transmission while maintaining control over propagation characteristics.

Methods

Finite Difference Time Domain (FDTD) Simulation

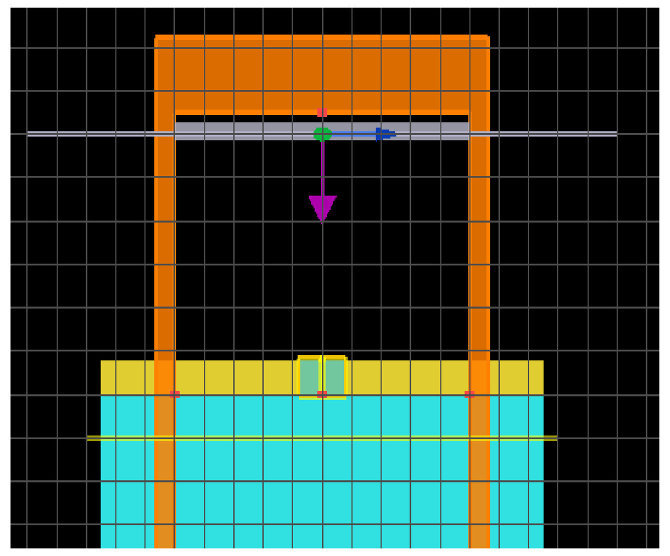
- Plane-wave source of 400-1400nm normal incident.
- Periodic boundary conditions in the X and Y directions to model nanohole array structure,
- Mesh size of 0.15nm.
- Nanohole structure ranging from width of 50nm to 150nm on a Au-(Johnson and Christy) segment on top of silica substrate (n =1.5).
- Creating two-layer structure consisting of two gold structure with different width and thickness of nanoholes to optimize the structure of minimum reflection coefficient.



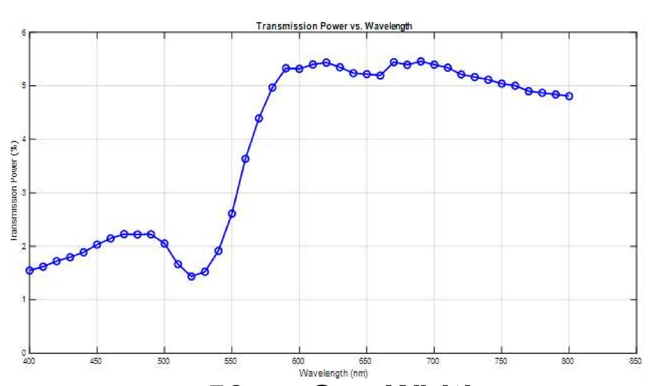


FDTD Simulation Results

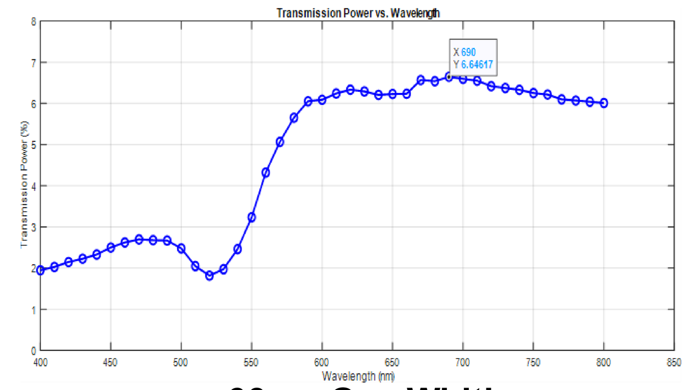
Single Layer System -:



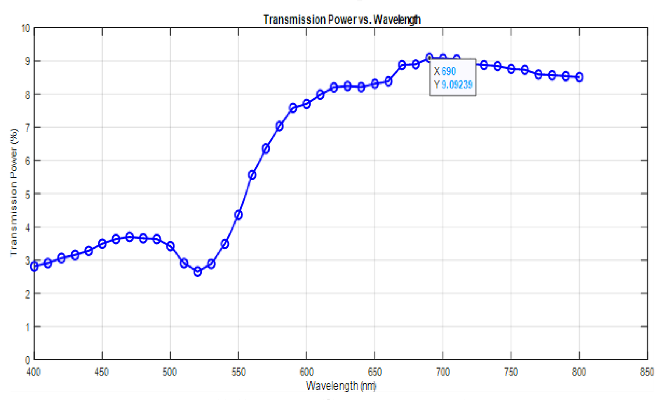
- For a single-layer transformer structure with a constant gold layer thickness of 100 nm, the power transfer efficiency is significantly low, ranging from 5% to 9%, depending on the gap width.
- As the gap size increases, the resonance wavelength also increases due to a decrease in the propagation constant.
- Further calculation suggested that to obtain the minimum reflective coefficient, the thickness of the hole must be modified according to the wavelength, effective refractive index



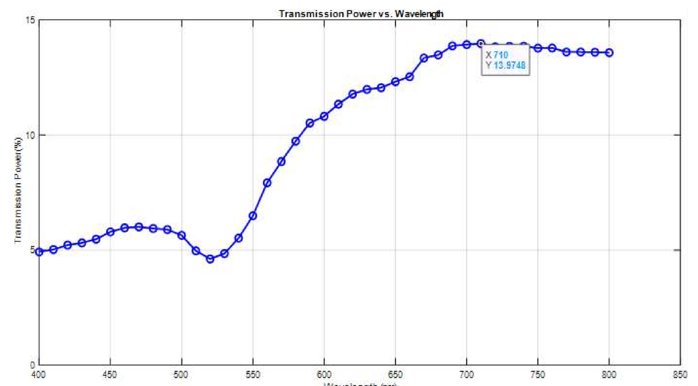
50nm Gap Width



60nm Gap Width

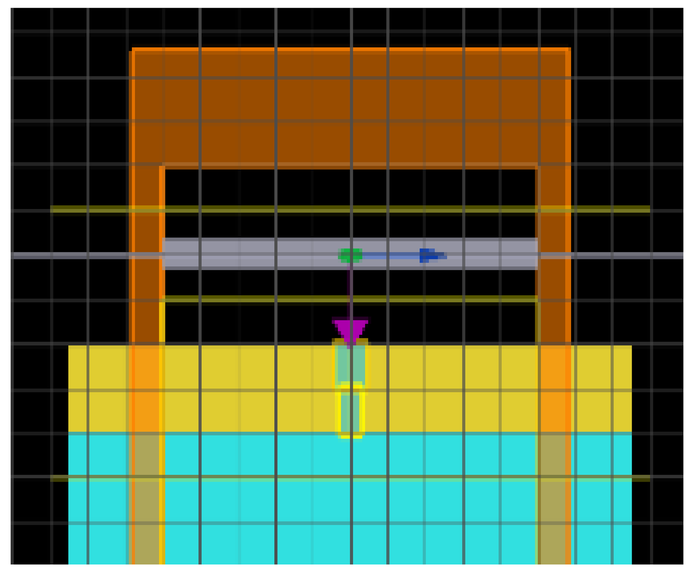


80nm Gap Width

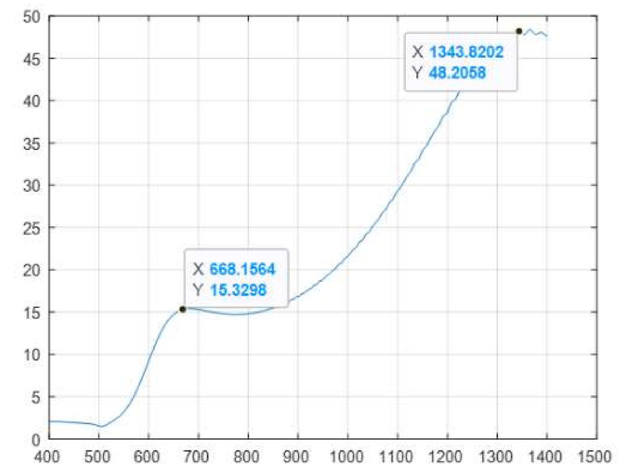


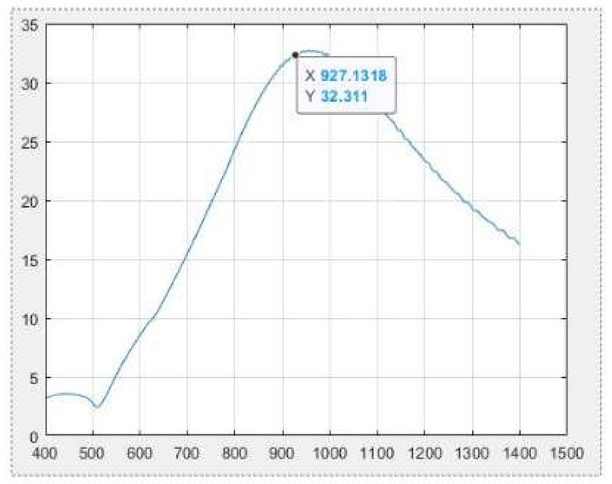
120nm Gap Width

Two Layer System -:



- Analysis of a two-layer transformer structure indicates that increasing the thickness of the gold layer enhances power transfer, achieving nearly 50% power transmission for specific combinations of hole thickness and width.
- However, the peak resonance occurs in the near-infrared (NIR) wavelength range, which extends beyond our desired bandwidth.
- Consequently, a more detailed analysis was conducted to identify peak resonances for two single-layer structures within the visible range. These resonances were then overlapped and constructively tuned to design a high resonance within the target wavelength.



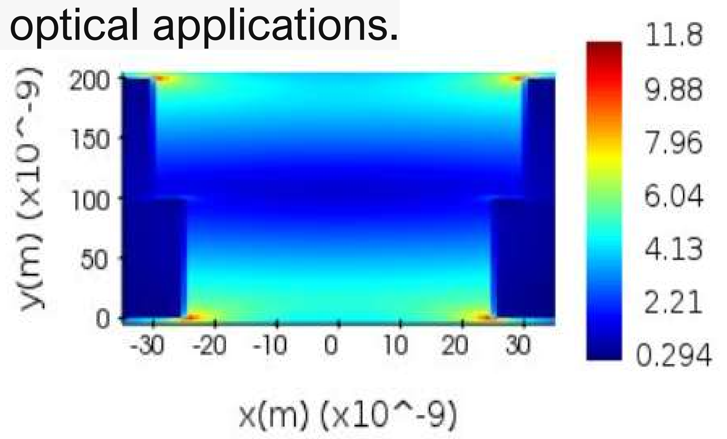


Power Transfer against Wavelength for Two-Layer Transformer Structure

Conclusion

- **Simulation results indicate promising power transfer for a two-segment transformer structure.** The findings suggest that achieving a minimum reflective coefficient for a Gold-Glass structure is possible by carefully selecting the appropriate thickness and width of the nanohole. This optimization is crucial for enhancing the efficiency and performance of the transformer.
- **Analysis of transmission plots and localized electric fields reveals that a thicker nanohole enhances power transmission.** However, this adjustment results in a shift of the resonance peak towards the near-infrared (NIR) range. This shift must be considered when designing the structure to ensure it meets the desired operational wavelength requirements.
- **By adjusting the propagation constant through changes in the width and thickness of the nanohole,** it is feasible to achieve power transfer resonance at visible range wavelengths. This manipulation allows for fine-tuning of the device's performance, enabling it to operate effectively within the visible spectrum, which is often critical for various optical applications.

E-Field at Resonance Wavelength of 810nm



Future Work

- **The transformer structure will be modified to a multiple-segment configuration to achieve optimal power transfer.** By increasing the number of segments, we gain additional parameters that can be fine-tuned to maximize efficiency. This approach allows for better matching between all segments, thereby enhancing overall performance.
- **The structure will be adjusted to shift the resonance wavelength from the near-infrared (NIR) to the visible light range.** Currently, significant power transfer is observed at wavelengths between 900nm and 1350nm. Through careful tuning, we aim to achieve similar efficiency at wavelengths below 800nm, thereby broadening the potential applications of the device.

Acknowledgments

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