Fabrication of Multilayered Metasurfaces

Nicholas Riley[1], Hanyu Zheng[2] & Jason Valentine[3]

[1]Ira A. Fulton School of Engineering, Arizona State University, Mesa, AZ

[2]Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN

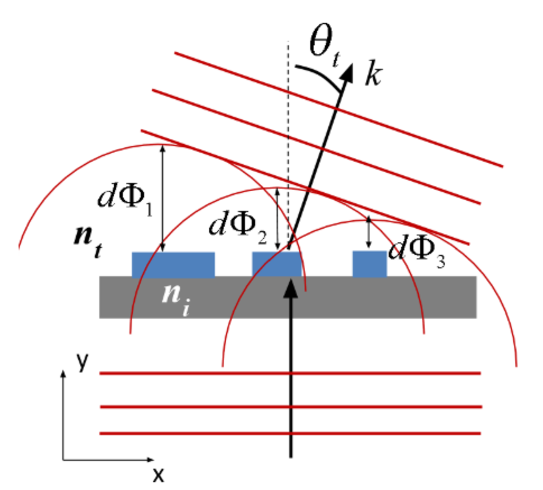
[3]Department of Mechanical Engineering, Vanderbilt University, Nashville, TN

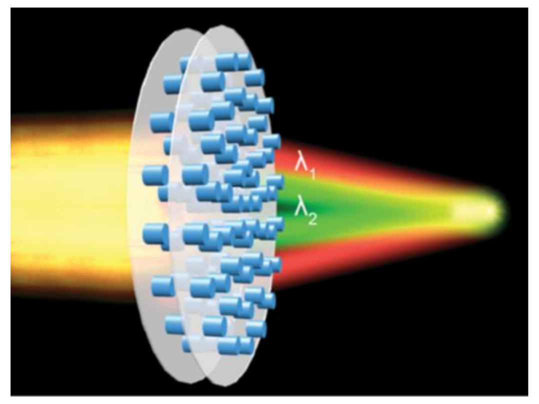
Introduction

•Metasurfaces are thin sheets of metamaterials, which are nanostructured devices that manipulate the wave front of light. Engineering the nanostructures of a material changes the way it interacts with light.

•Uses as beam deflectors, holograms, and lenses

•Compact imaging and optical systems (ex: augmented reality)





•Operates on resonant response of nanoantennas

•Silicon nanoposts act as waveguides

•Height, period, and radius determines transmission and phase variation

•Multiple metasurface layers work in tandem for multiwavelength operation

Top: Structure of nanoposts redirect resonant light that passes through it[1]

Bottom: Use of two metasurface layers to redirect two wavelengths to a single focal point[1]

Objective

Previous methods of fabricating metasurface doublets involve creating two layers then aligning them using a transfer stage as well as alignment marks imprinted on the layers. They are usually bonded using PDMS.

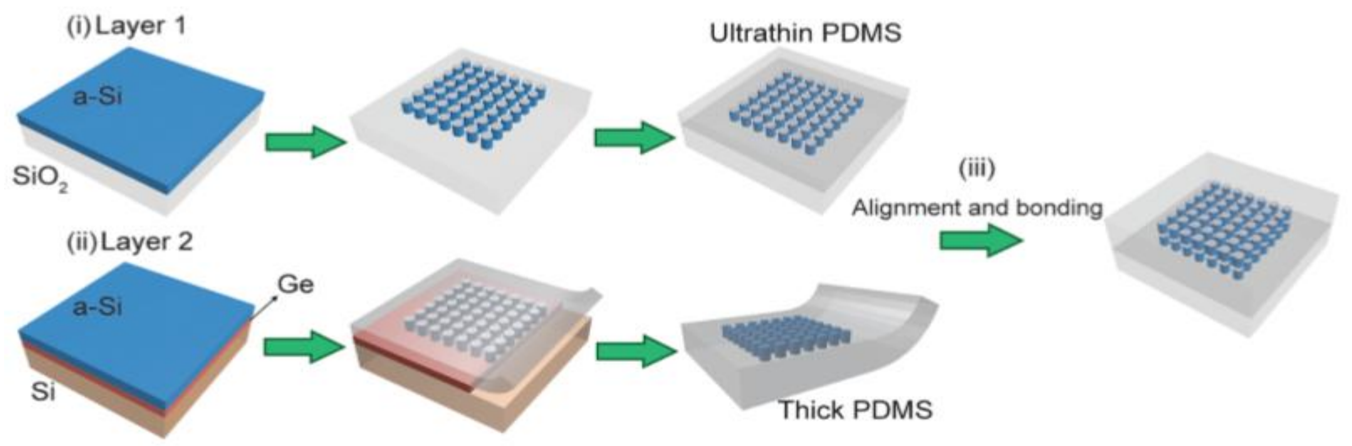
Goal: To achieve a higher precision of horizontal and vertical alignment of metasurface layers

How: By developing a more effective transfer method

Why: To decrease fabrication error and create better metasurface doublets.

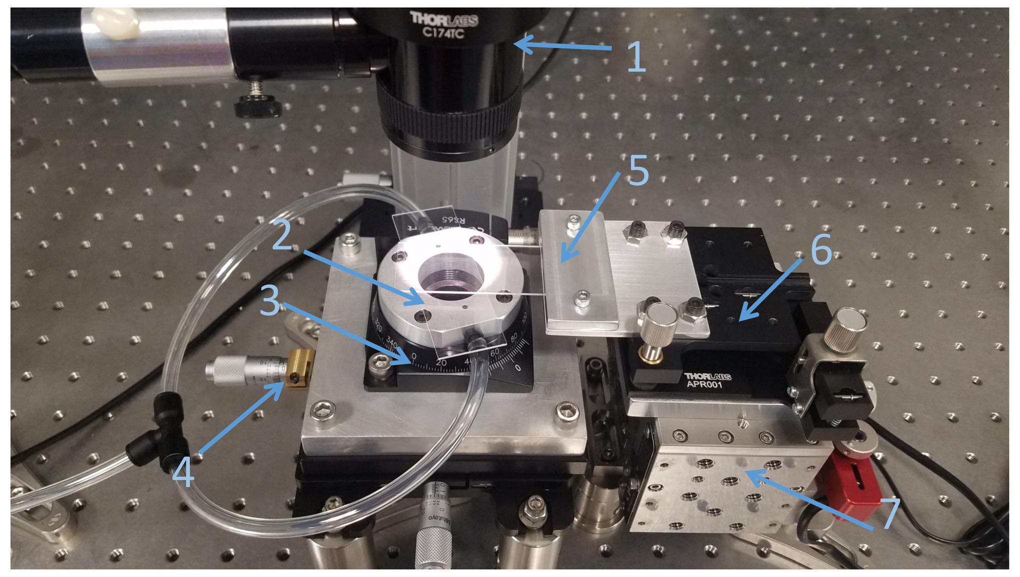
Fabrication of Metasurfaces

1. Amorphous Silicon wafer grown on SiO_2 using plasma-enhanced chemical vapor deposition
2. PMMA spin coated and used to etch patterns using e-beam lithography
3. Hard mask is deposited where the pattern is and PMMA is removed
4. Reactive ion etching leaves behind patterned Silicon nanoposts
5. PDMS is spin coated and cured to encapsulate nanoposts



Process of fabricating and bonding metasurface layers[1]

Alignment of Metasurface Layers



Picomotor Actuators allow for XYZ translation with 30 nm resolution

1. **Camera** w/ 12x zoom allows for viewing on monitor
2. **Vacuum chuck** holds bottom sample onto stage
3. **Rotation stage** can rotate bottom sample
4. **XY Stage** moves bottom sample to align with laser
5. **Slide chuck** holds top sample onto stage
6. **Tip/Tilt Stage** tilts top sample to be aligned parallel with bottom
7. **XYZ stage** moves top sample in 3-D to align

*Laser is reflected through transfer stage and samples

- Use cross pattern marks for coarse XY alignment
- Use Moiré fringe pattern for fine XY alignment
- Use Fabry-Pérot cavity for z alignment
- Spin coat NOA61 mixture at 1500 rpm for 1 µm onto bottom metasurface layer
- Return to alignment position
- Cure NOA61 mixture with 365 nm UV light

Alignment Methods

Fabry-Pérot Cavity

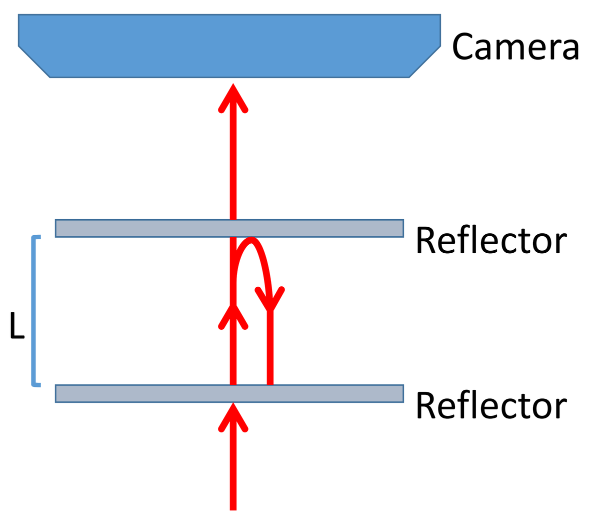
•At resonant frequency, light passes through the reflectors

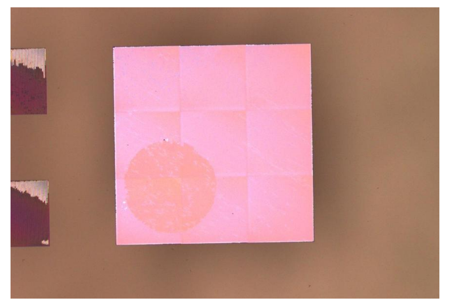
$$L = \frac{\lambda}{2} \times n$$

•At L (when n = 1, 2, 3 …), the cavity stores that light

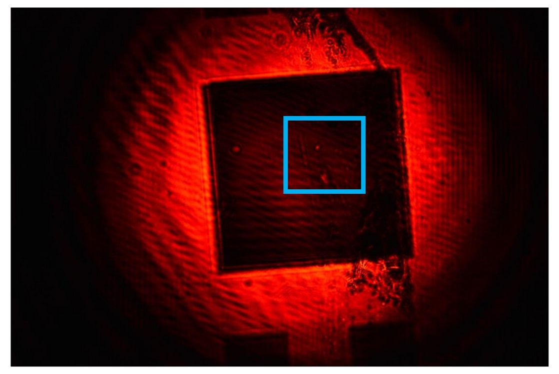
•Intensity of the light picked up by the camera can be used to determine distance between layers

•Alignment in Z direction

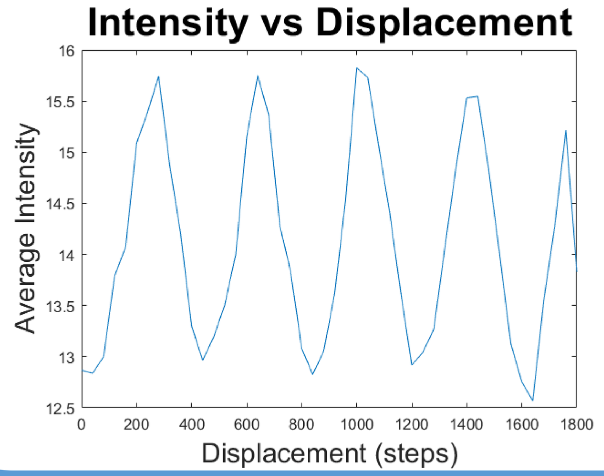




Silicon square on each sample layer used for Fabry-Pérot cavity



Intensity of beam observed by objective characterizes distance between layers



•Intensity peaks at λ/2

•Sinusoidal function characterizes intensity variation from relative distance between layers

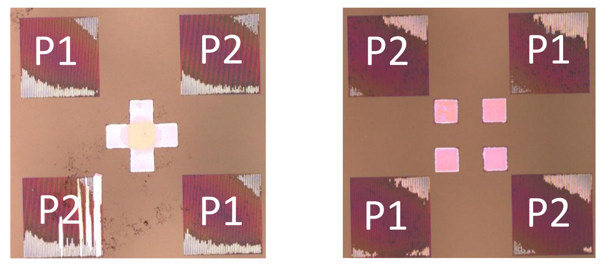
•Function can be used to determine relative distance

Alignment Marks

Cross Pattern

•"+" mark overlaid with inverse image

•Used for coarse XY and rotational alignment



Top Layer Bottom Layer

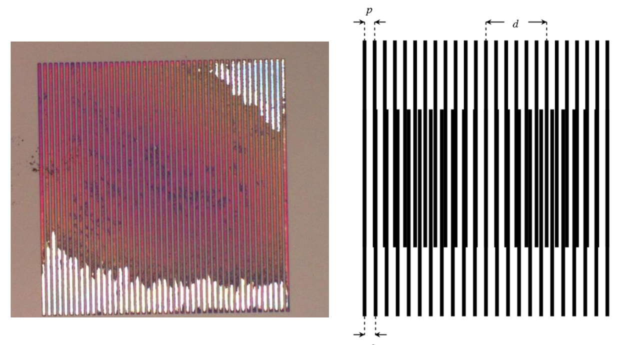
Moire Fringe Pattern

•Two grating w/ different periods overlaid

•Interference creates Moiré fringe

•Used to amplify effects of small adjustments

•Fine alignment in XY direction



Example of grating on sample

Fringe pattern from overlaid gratings

Conclusions

•Developed transfer stage with precise translation, rotation, and tilt capabilities

•Integrated laser alignment

•Usable with UV curable adhesive

•Fabricated alignment marks

•Fabry-Pérot cavity only determines relative distance

•Cantilever top mount not stable enough

Next Steps

•Use all alignment methods for one sample

•Lens array for z alignment

•Implement remote control of camera to increase stability

•Utilize live view software and MATLAB programming to measure intensity in real time

•Integrate closed-loop actuators for precise manipulation

References

[1] You Zhou, Ivan I. Kravchenko, Hao Wang, J. Ryan Nolen, Gong Gu, and Jason Valentine *Nano Letters* **2018** *18* (12), 7529-7537
DOI: 10.1021/acs.nanolett.8b03017

[2] Chengliang Di, Jiangping Zhu, Wei Yan, Song Hu, A modified alignment method based on four-quadrant-grating moiré for proximity lithography, Optik, 125(17) 2014.

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