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Harvard University
Guenette Group

LIDINE - 9/16/2021

Increasing photodetector light collection with

Metalenses

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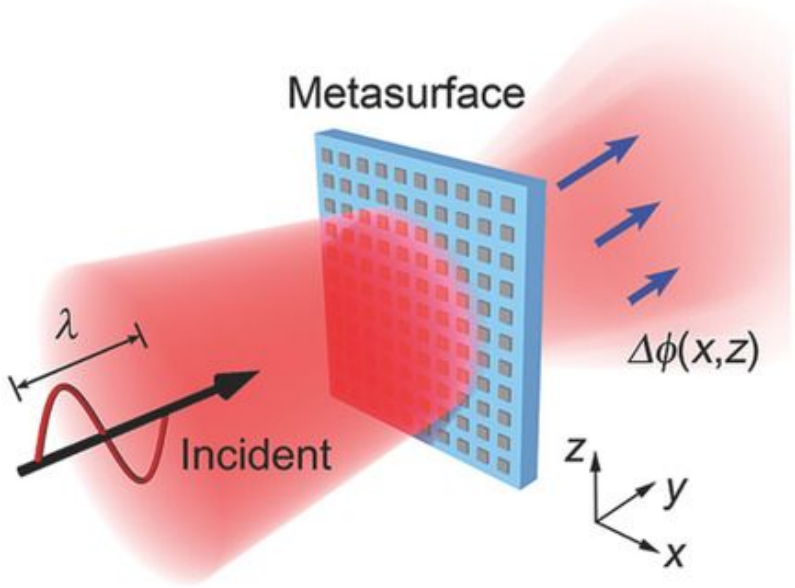
Outline

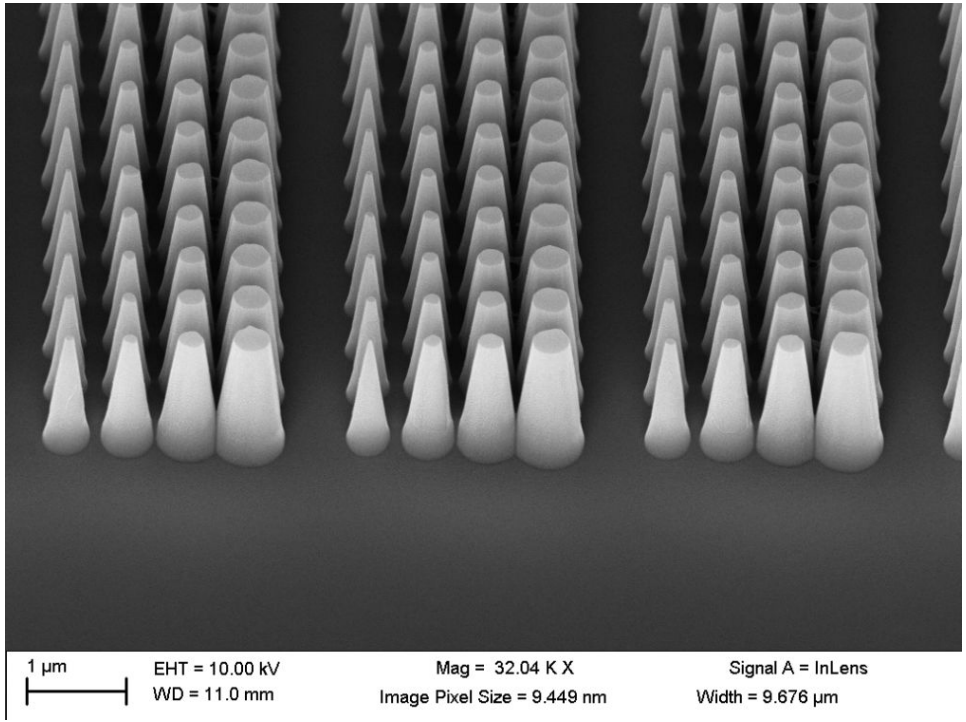
1. What are metalenses?
2. Metalens instrumentation concept
3. Current state of our research

What are metalenses?

A metalens is a type of metasurface

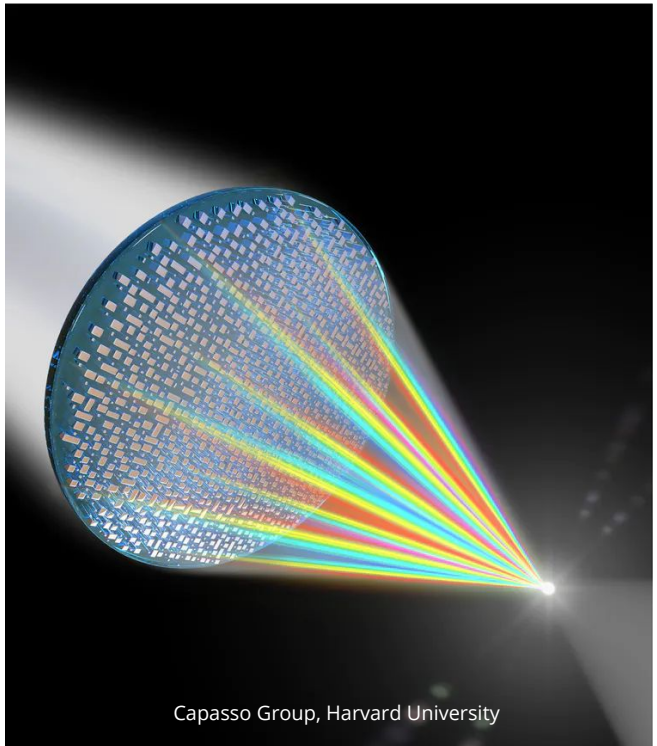


Kim, K.-H., Jung, G.-H., Lee, S.-J., Park, H.-G. and Park, Q.-H. (2016), Ultrathin Capacitive Metasurfaces for Strong Electric Response. Advanced Optical Materials, 4: 1501-1506. https://doi.org/10.1002/adom.201600146



What are metalenses?

Metalenses are designed to focus light, much like traditional lenses



Metalenses have seen some big developments in the last few years, with the Capasso Group at Harvard University at the forefront of that development.

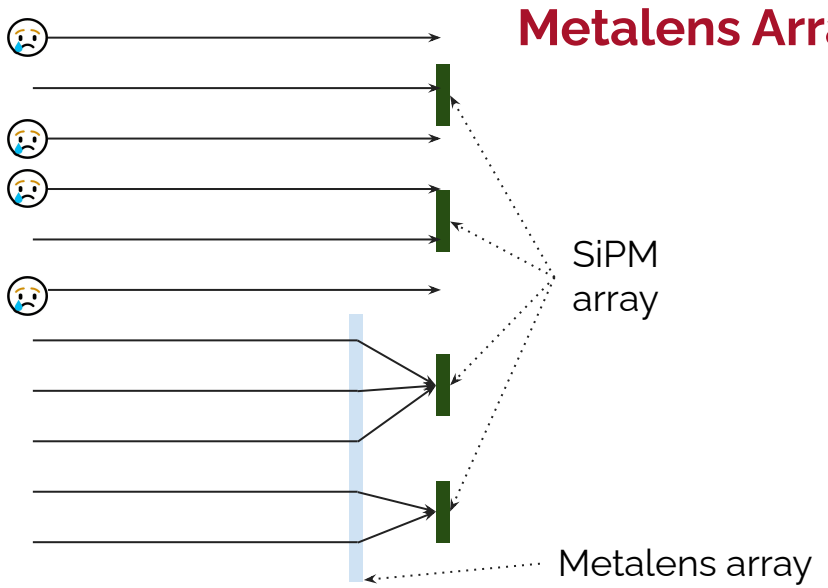
- (2016) M. Khorasaninejad et al., Metalenses at visible wavelengths: Diffraction-limited focusing and subwavelength resolution imaging. *Science* **352**, 1190–1194.

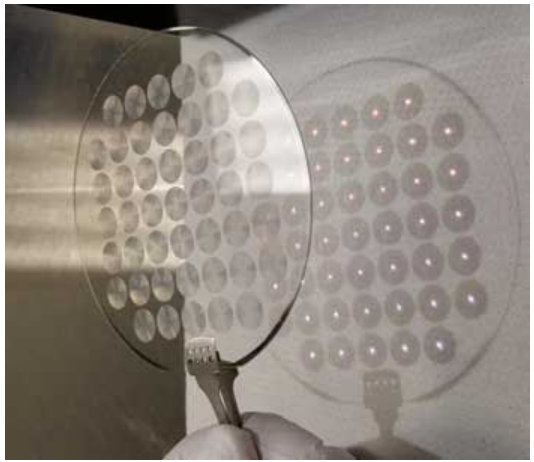
- (2018) Chen, W.T., Zhu, A.Y., Sanjeev, V. et al. A broadband achromatic metalens for focusing and imaging in the visible. *Nature Nanotech* **13**, 220–226

- (2021) Intel, 3M, and others announced a $10 million dollar investment to expand the capabilities of the Capasso laboratory to further the innovation and move toward large scale fabrication.

Metalens Instrumentation Concept

Some modern scintillation detectors feature sparse SiPM arrays to collect scintillation light, with coverage on the order of 1%. We propose a detector concept in which a plane of metalenses are placed in front of a sparse SiPM array in order to collect more scintillation light.

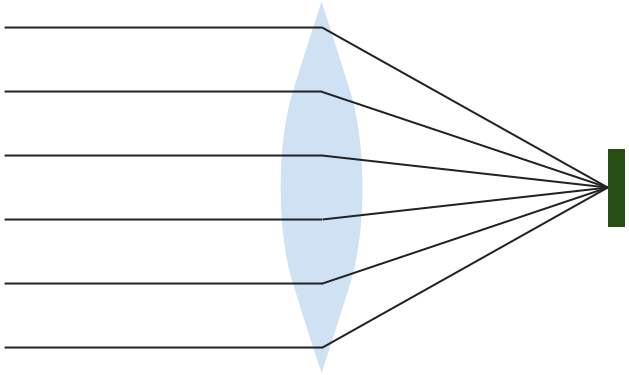




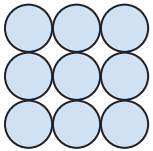
Capasso Group, Harvard University

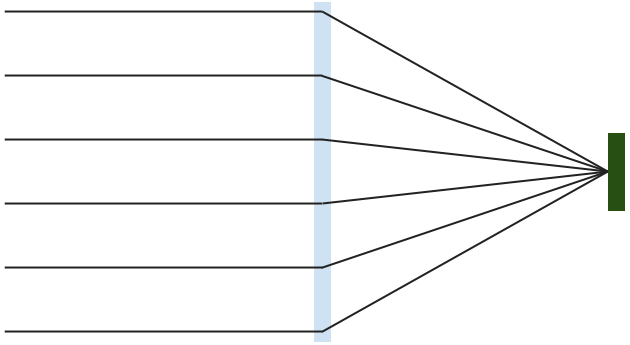
Importance to instrumentation

Traditional vs **Meta**

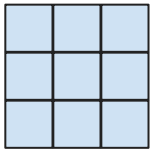


- Bulky
- Expensive
- Optical limitations



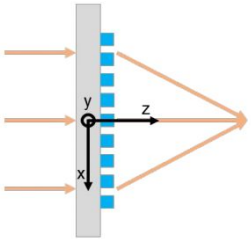


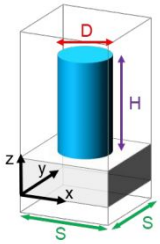
- Thin and lightweight
- Cheap, easy to mass-produce
- More flexible



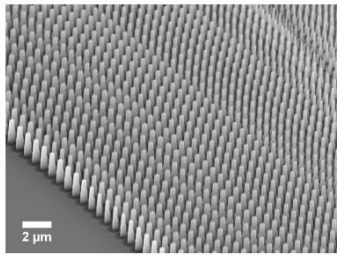
Past work

A.A. Loya Villalpando *et al* 2020 *JINST* 15 P11021

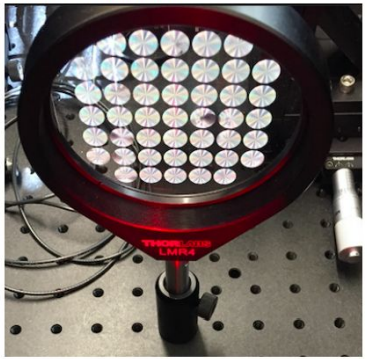




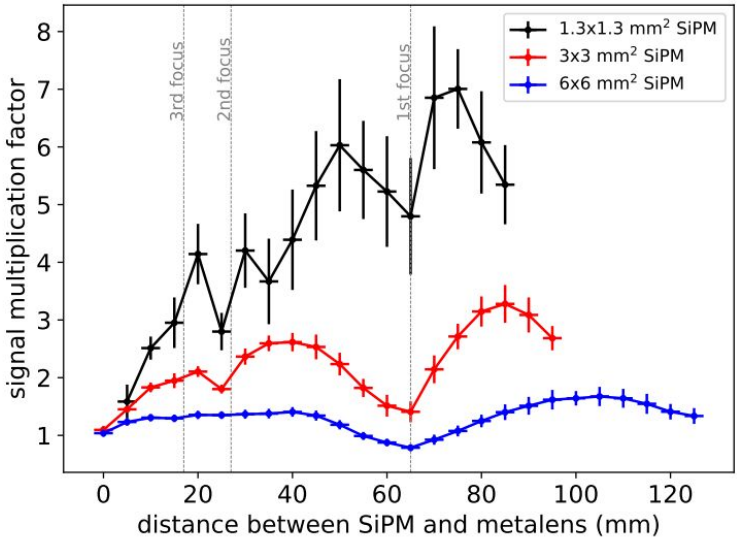
(a) Schematic representation of a metalens nanostructures.



(b) SEM image of our metalens nanostructures.

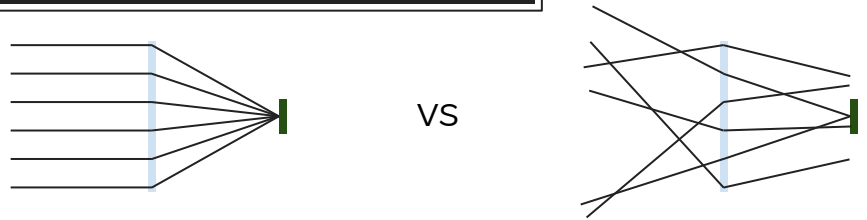


(c) Array of identically fabricated metalenses composed of the nanostructures in (b). Each metalens has a diameter of 10 mm and was designed at 630 nm with a numerical aperture of 0.1.



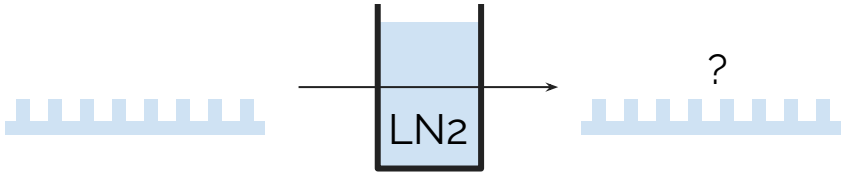
Current Work

Angular efficiency studies



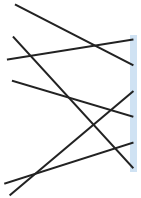
Submersion studies

Cryogenic temperature durability



VUV Metalenses

Angular Efficiency Studies



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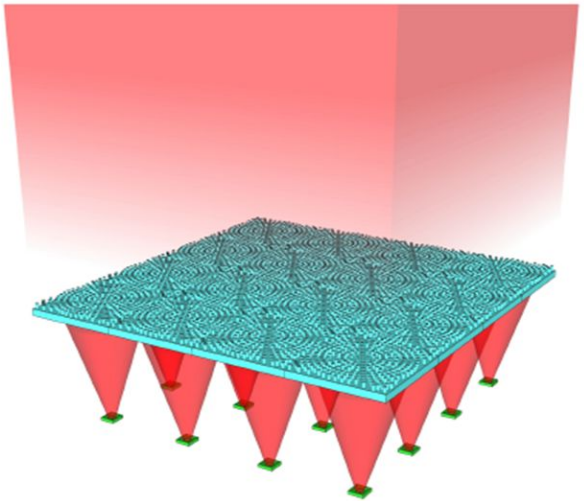
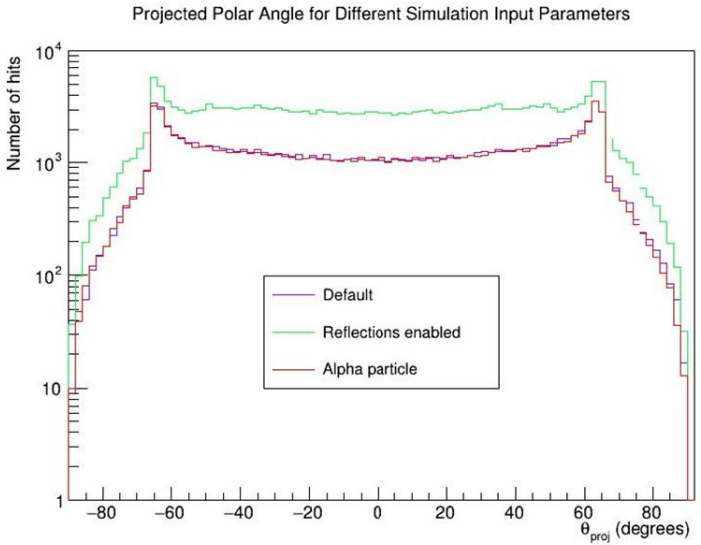
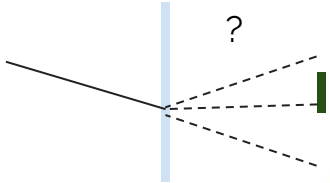
What kind of incident angles do we expect in a detector?
How does it depend on the detector geometry?



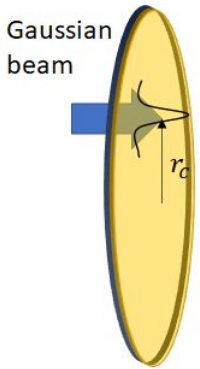


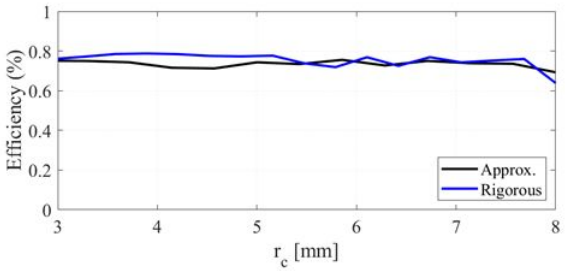
From Benjamin Lawrence-Sanderson (SULI intern, UT Austin)

Angular Efficiency Studies



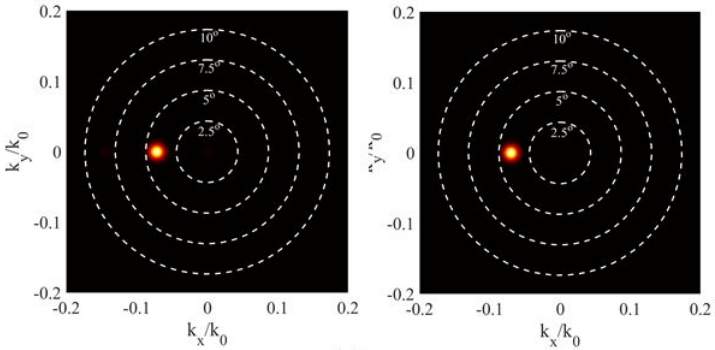
How efficient are metalenses at different angles?





Beam waist: 15 μm
Lens focal length: 6 cm
Diameter: 2.45 cm (NA=0.2)
Wavelength = 632 nm
SiO_2 based nanoposts

Rigorous (RCWA) Approximation



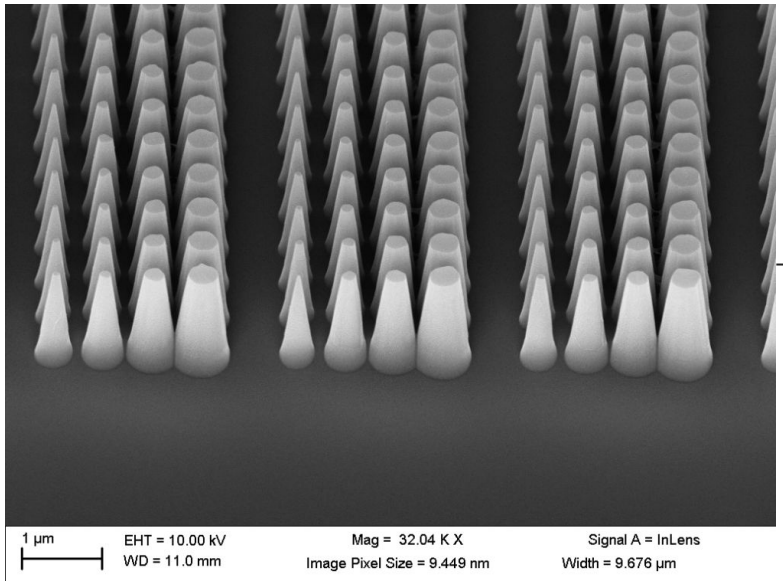
$r_c = 4.2mm$

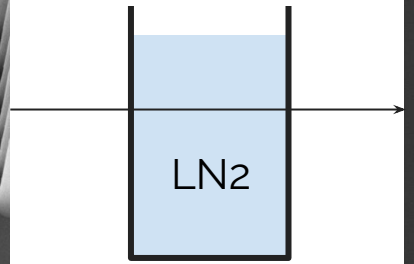
Computational time (for each r_c):
Rigorous: $\sim 32\ hours = 4\ (nodes) \times 8\ hours$ (cluster)
Approximation: $< 2\ min$ (personal computer)

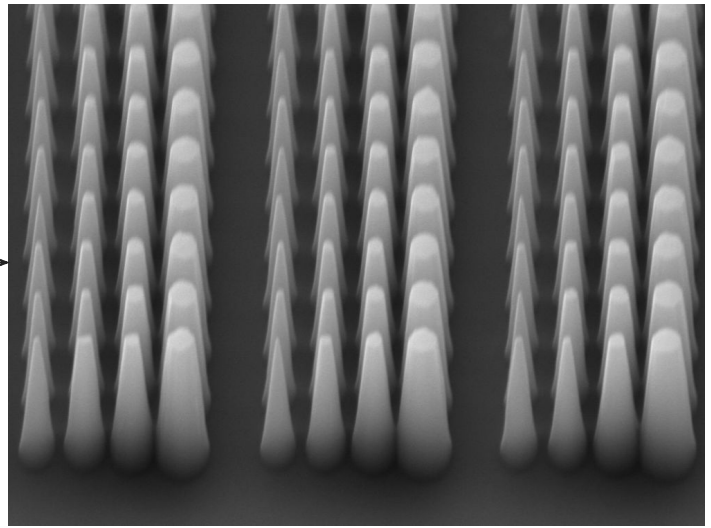
From Augusto Martinez Alves (Harvard)

Cryogenic Temperature Durability

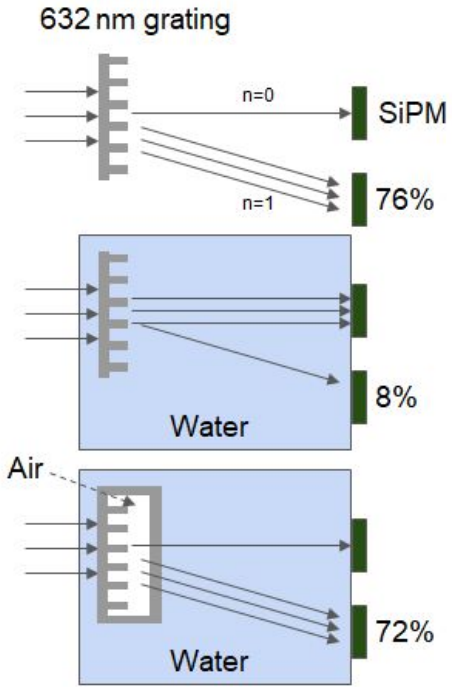
Nanopillars have proven durable under LN2 submersion

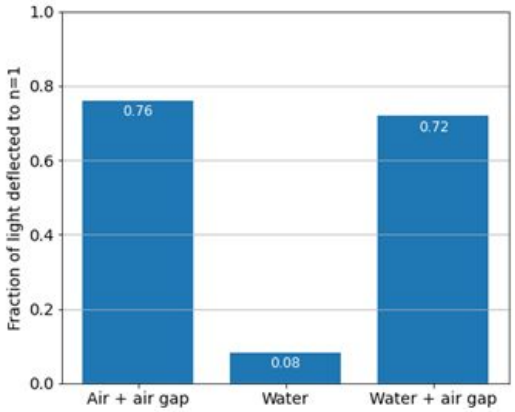






Submerged Metalenses





- The grating's performance was poor when submerged in fluid.
- Performance was recovered when an air gap was introduced surrounding the pillars.

Next Steps

- Develop metalenses for <200 nm.
- Confirm metalens simulations with experiment.
- Build a metalens and SiPM array and measure the increase in efficiency in a noble element test stand.

Questions