Demonstration of unified metalens workflow through design and manufacture of example eye-tracking meta-optic

Contact:
Daniel Bacon-Brown
dbaconbrown@moxtek.com

Daniel Bacon-Brown[1], Thibault Leportier[2], Brad Williams[1], Matthew George[1], Sanjay Gangadhara[2], Dylan McGuire[2]

1) Moxtek, Inc. 2) Ansys, Inc.

Motivation

There is currently no standard workflow for designing and fabricating an optical system incorporating metasurfaces. Optical system designers, metalens designers, and metalens manufacturers are often in different organizations and communication difficulties between these groups can slow development.

Moxtek and Ansys demonstrated an integrated solution for the design and manufacture of metalenses.

- Metalenses can be designed within existing workflows, without special metalens expertise.
- Meta-atom layout incorporates by default the best-practices of metalens manufacturer, and the design is suitable for volume manufacture
- End user can be confident that any design will perform to expectation.

Here, we show results of the initial tests of such a workflow.

Optical Design

Design criteria for demonstration optic

Target: metalens for eye-tracker.

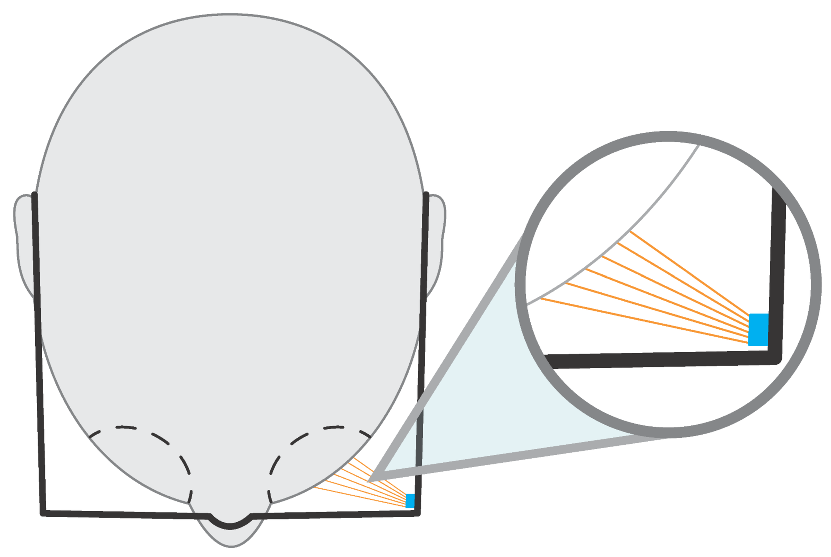
- Visible wavelength metalens optimized for 633nm.
- Suitable for Moxtek's high volume manufacturing process.
- Uses Moxtek's established metalens geometries, whose performance has been previously verified.
- Performs off-axis imaging. Image plane is austere, asymmetric surface, which allows flexibility for placement of optical components.
- Field of view reaches 43° from normal.
- Uses an off-the-shelf camera.
- Incorporates Moxtek optical bandpass filter at 633nm wavelength.

Design methodology

Design was done in Zemax, using the new metalens simulation and design methods.

1) Create meta-atom library using Lumerical RCWA for the target wavelengths based on Moxtek's best-practices.
2) Define target geometry and free parameters in Zemax.
3) Perform ray-tracing optics simulations implementing the Windowed Fourier Transform method.[1]
   As the ray impinges on the metalens, a 'window' of the metalens in the vicinity of the intersection is taken. The far-field of the window is calculated and used to determine the trajectory of the transmitted rays.
4) Repeat simulations , optimizing the phase profile for best focus and distortion.
5) Use meta-atom library to convert phase profile to a meta-atom array.
6) Export optimized layout as a GDS to be sent to e-beam lithography.

a)



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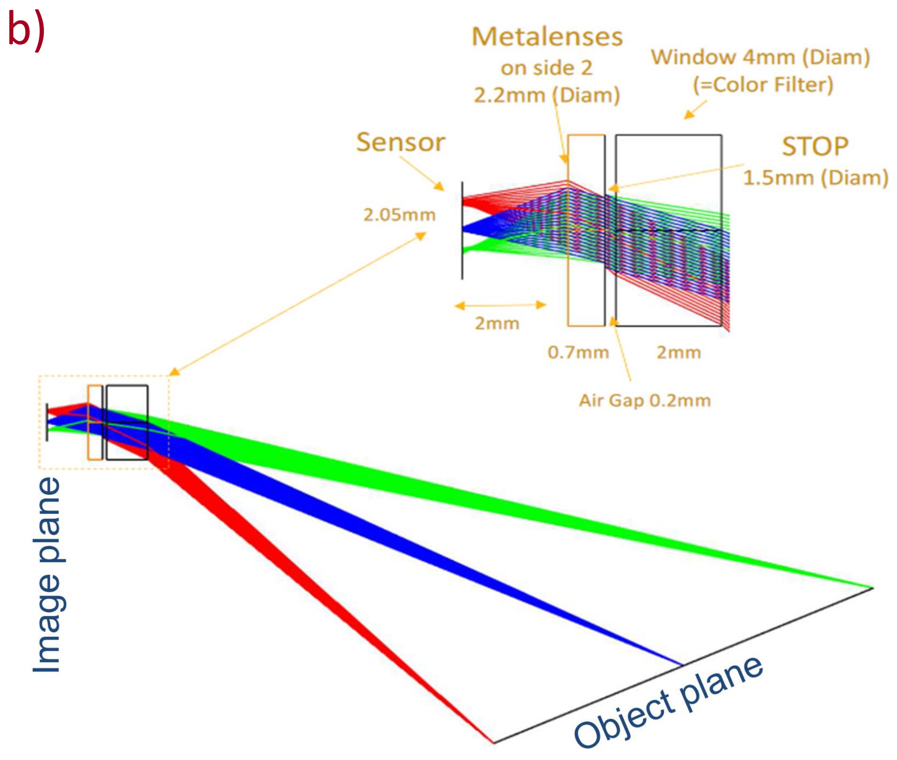
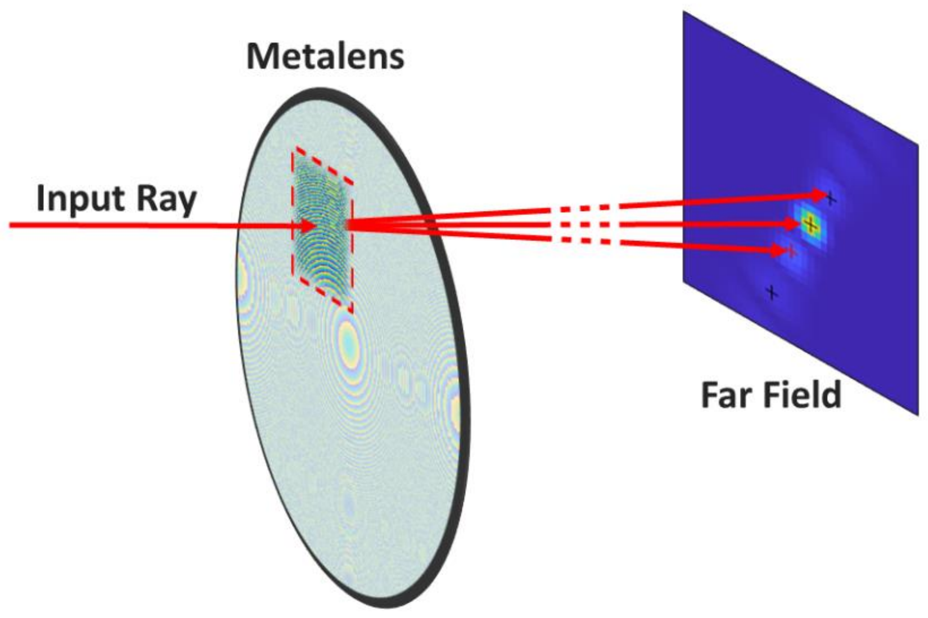
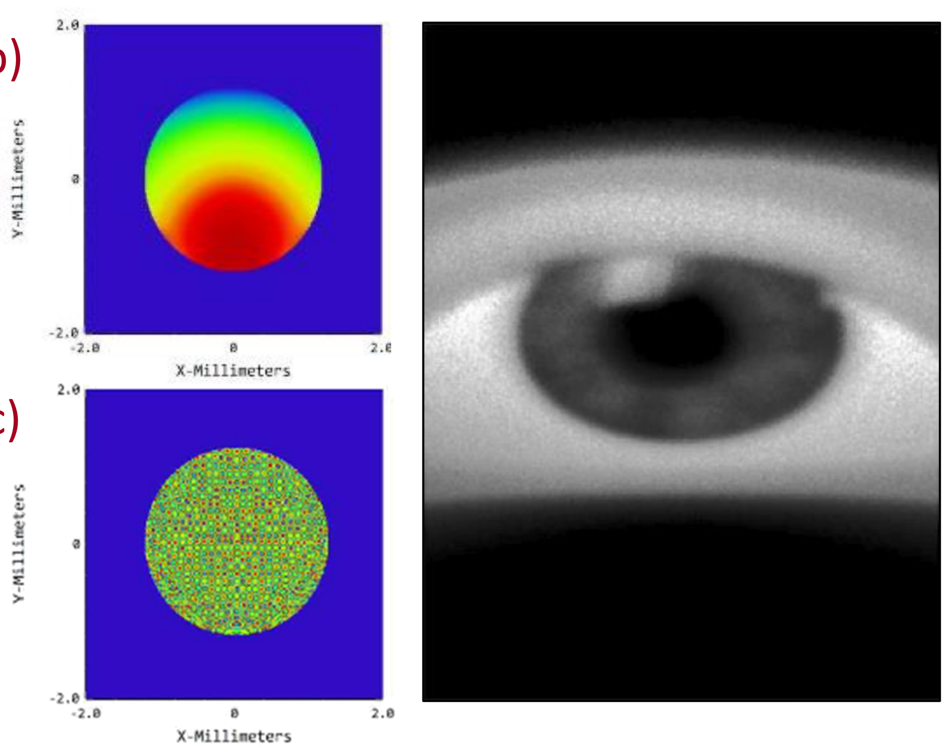


Design of eye-tracker optical system. a) Target design of off-axis eye-tracker. b) Optimized ray-trace of **off-axis** imaging system optimized to image the target object plane.

a)



b) c)



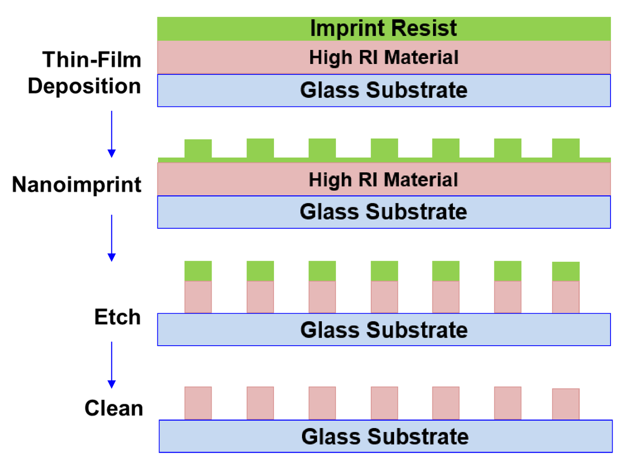
Design of eye-tracker optical system. a) Cartoon of the Windowed Fourier Transform method applied to metalens design. b) Unwrapped phase profile of optimized metalens. c) 2π-wrapped phase profile of optimized metalens. d) Simulation of image formed on camera sensor.

Metalens Manufacture

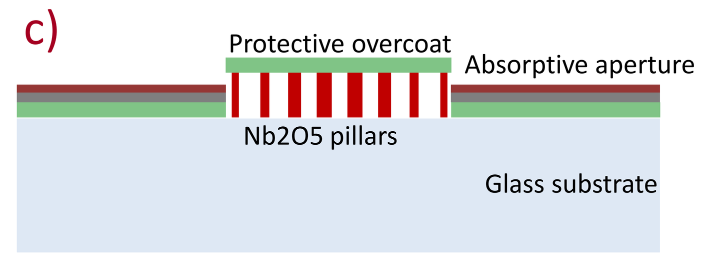
a)

1. Design Review
2. Build Master (shuttle or production)
3. Verify Master (SEM/AFM)
4. Make Stamps
5. Produce Prototypes
6. Verify Prototypes (SEM/AFM)
7. Cut, Measure, Inspect parts
8. Package and Ship
9. Customer Verification
10. Repeat as needed (Design Cycles)

b)



c)



Procedure for metalens production. a) Outline of steps taken in standard metalens production process. b) Diagram of steps to produce metalens pillars from pattern. c) Structure of the double-sided metalens.

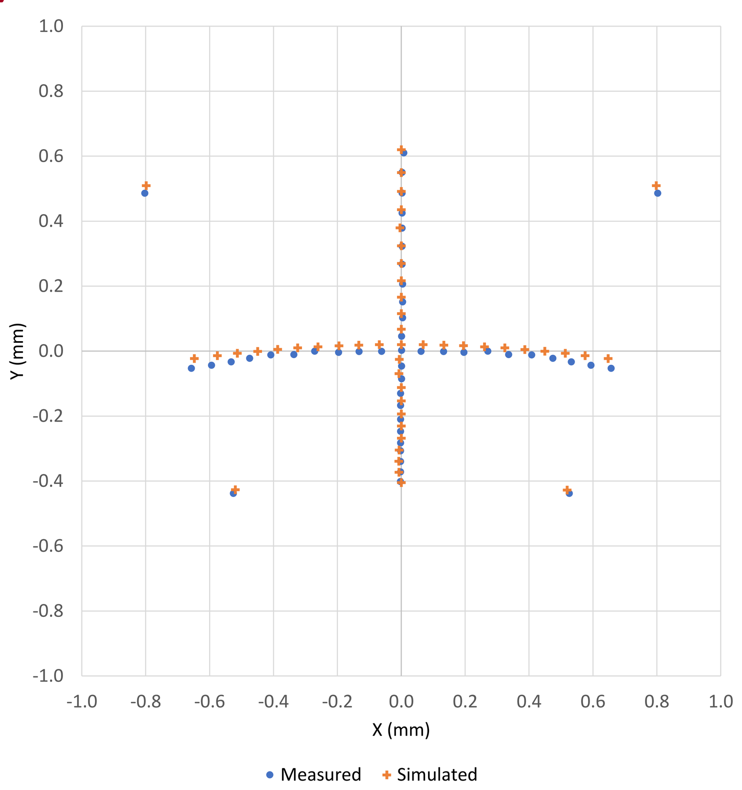
The metalens was fabricated in a 'print-and-etch' process to produce Nb_2O_5 pillars (n≈2.3) with an aspect ratio of up to 14:1.

The process starts with an imprint master fabricated by writing a single lens via e-beam lithography (EBL).[2] This single pattern is replicated many times by nano-imprint lithography (NIL) onto an 8" glass wafer with 1100nm thick NB_2O_5. A dry etching process is used to etch into a hard-mask and then Nb2O5 film. A wet etch is used to remove the remaining resist and hard-mask layers, leaving the Nb2O5 pillars. An overcoat is deposited on the pillars, protecting the pillars while leaving an air gap between them to keep the high index contrast. An absorptive aperture was deposited by sputtering two opaque and absorptive layers, and conventional lithography and etching was used to clear the areas above the lenses. In the case of the double-sided metalens, the wafer was flipped over and the process was repeated.

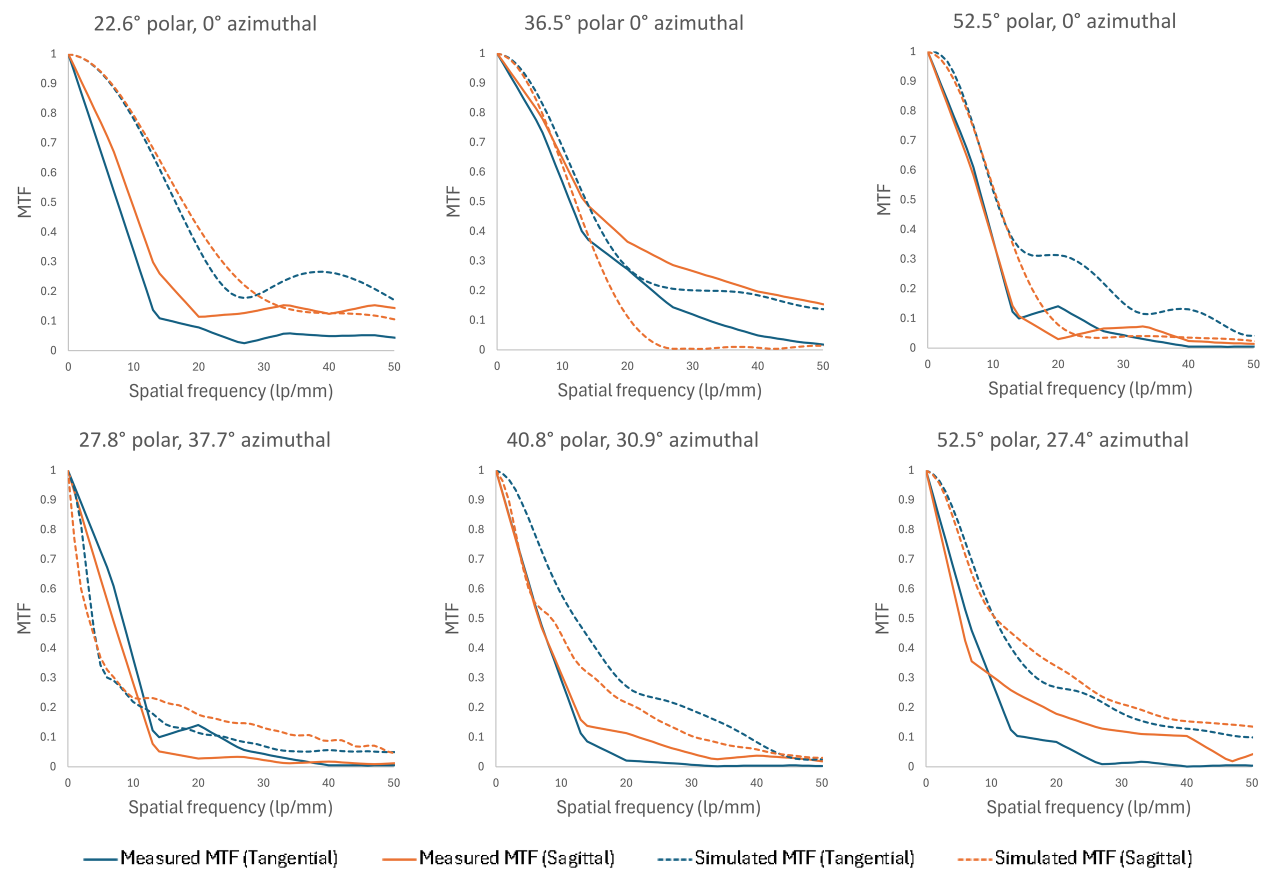
Metalens Metrology

Metalens characterized in infinite-finite imaging setup (Trioptics ImageMaster HR) measuring MTF and power on camera sensor. The simulations for these plots were performed assuming collimated incident light in order to properly compare with metrology data. Absolute efficiency is defined as image brightness relative to the brightness of a conventional lens when correcting for transmission. Six points were chosen for comparison with MTF, corresponding to the center as well as the unique corners, and midpoints of the edge of the object plane (3 points are duplicates). The final performance check was performed by mounting the metalens on the camera module and imaging the user's eye in approximately the target configuration.

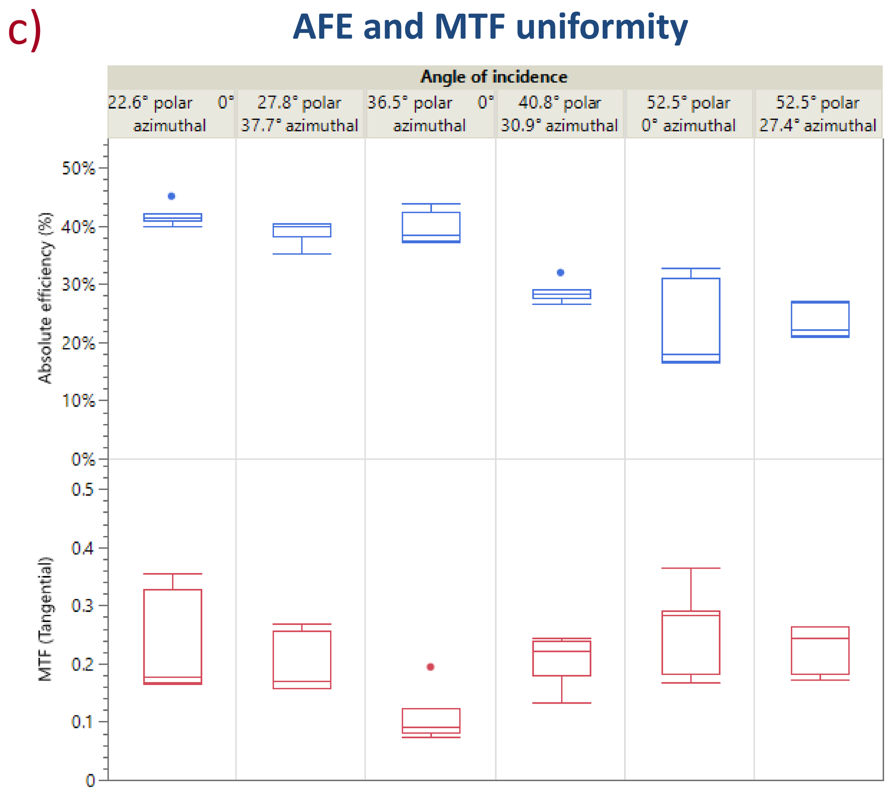
a) **Simulated and measured lens footprint**



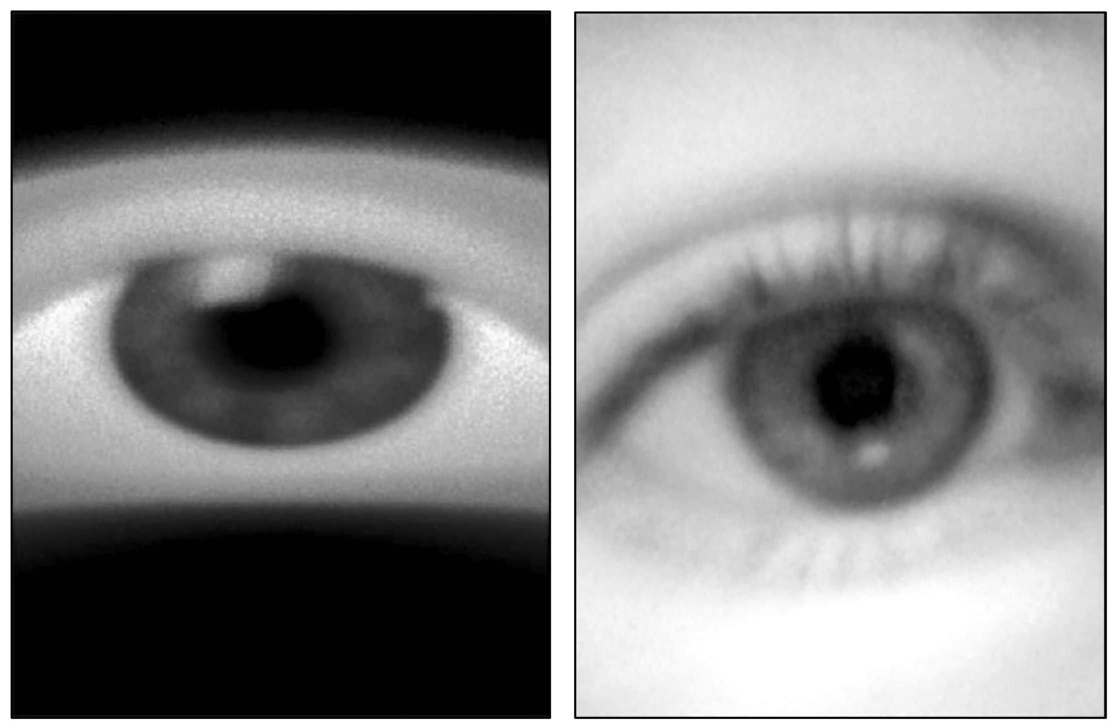
b) **Matching simulated and measured MTF at different field positions**



c) **AFE and MTF uniformity**



d) **Simulated** **Measured**



Performance of fabricated metalens. a) Plot of the simulated and experimental 'footprint' of the metalens. b) Simulated and experimental MTF curves for collimated light at angles of incidence corresponding to the center and midpoints of the target object plane. c) Absolute focusing efficiency and tangential MTF uniformity data for 5 measured lenses. d) Simulated and matching experimental image of a human eye.

See our companion talk:

Novel workflow for metalens optical system design, simulation, and manufacture.

29 January 2025 • 3:10 PM - 3:40 PM - Moscone Center, Room 313 (Level 3 South)

Visit Moxtek at booth **3533** and Ansys at booth **1455**

References:

[1] Ziwei Zhu, et al, "Metalens enhanced ray optics: an end-to-end wave-ray co-optimization framework," Opt. Express 31, 26054-26068 (2023). https://doi.org/10.1364/OE.496608

[2] Brad Williams, et al. "Metalenses for visible wavelengths: NIL volume manufacturing," Proceedings Volume 12432, High Contrast Metastructures XII; 1243209 (2023) https://doi.org/10.1117/12.2649026