MEMS-ACTUATED METASURFACE ALVAREZ LENS

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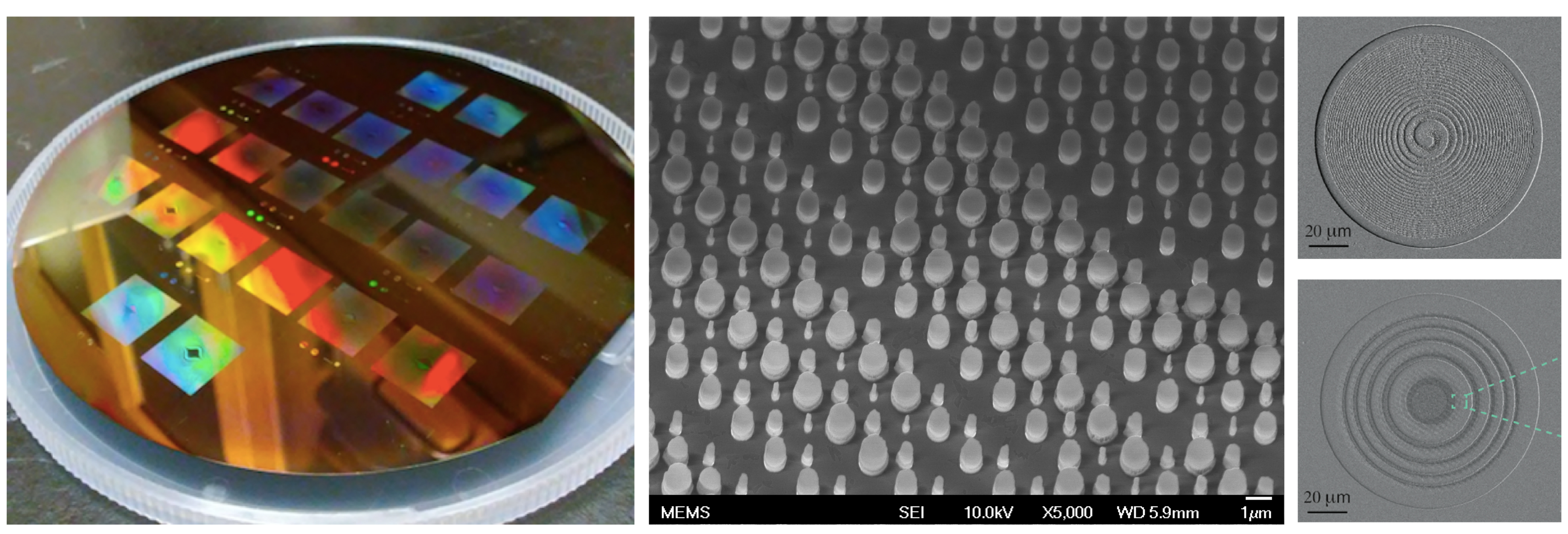
Objectives

- To design and demonstrate a miniature optical device with tunable focal length
  - modulated with high precision and speed
  - requiring low power consumption
  - CMOS-compatible fabrication process for mass production at low unit cost

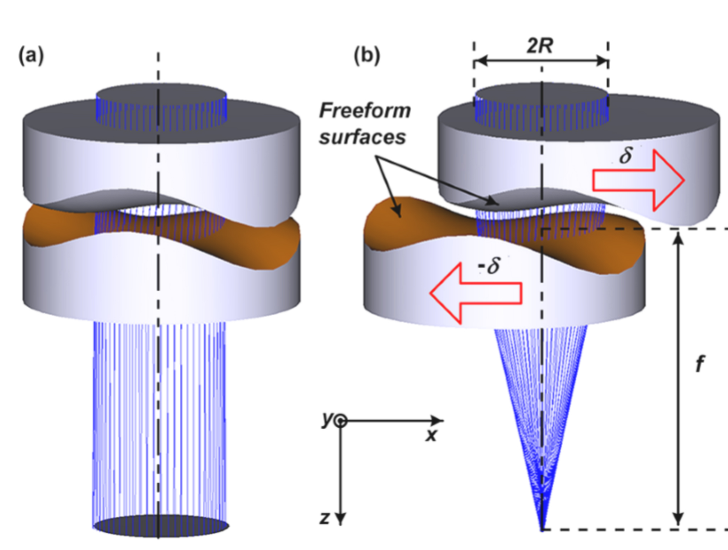
Metasurface Optics



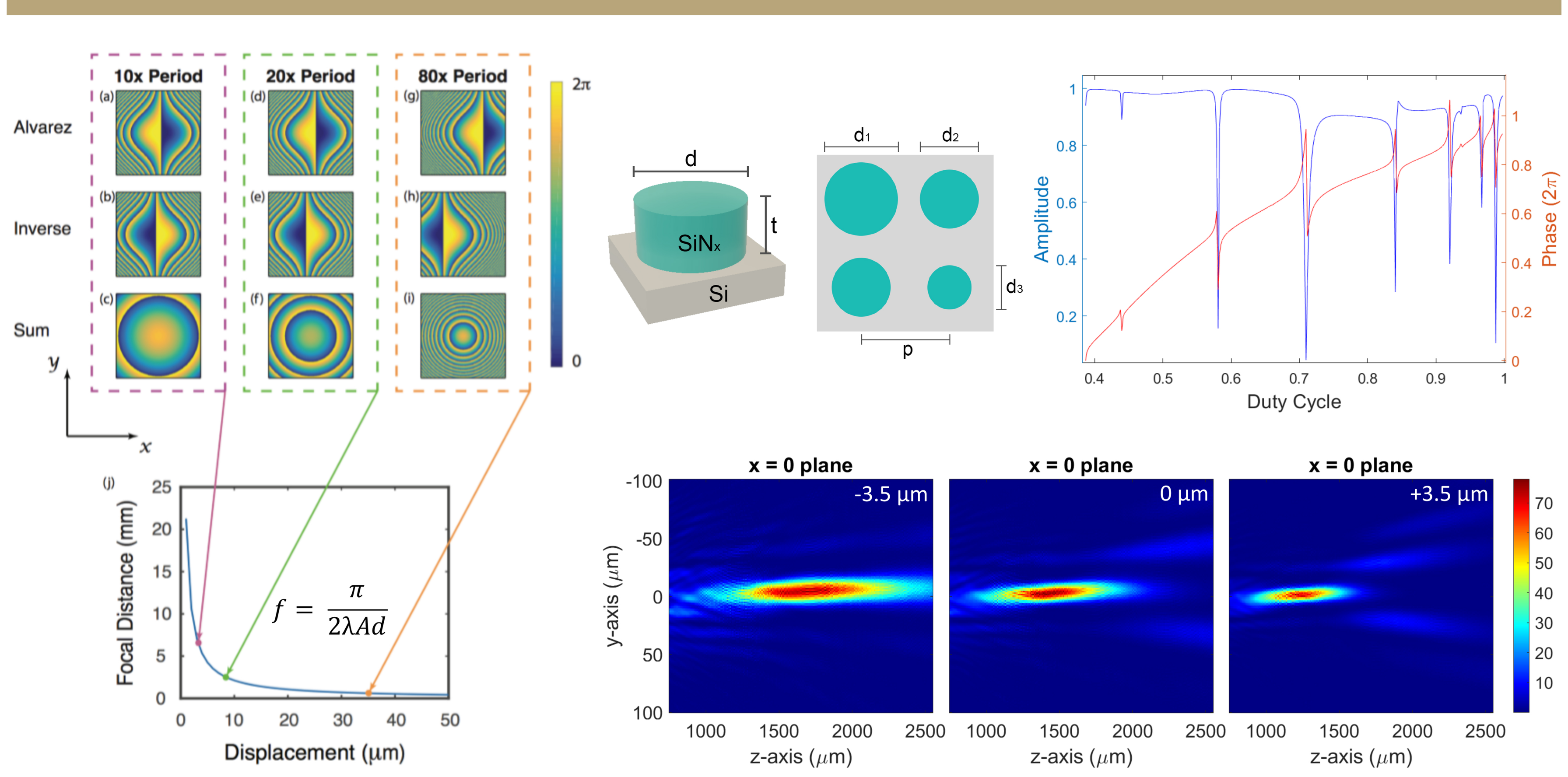
- Metasurfaces comprise 2D arrays of subwavelength scattering elements which can abruptly alter the properties of incident light
- By changing the scatterer geometries in a spatially varying manner, metasurfaces can change amplitude, phase, and polarization of the incident light accordingly
- The flat nature of metasurfaces and their subwavelength resolution enable highly compact optical systems with applications in planar cameras, near-eye visors, LIDAR, IoT sensors, and microscopy

Alvarez Lens

- A typical Alvarez lens contains a pair of optical elements with complementary surface profiles defined by cubic functions
- Optical power modulation is achieved by introducing a small relative lateral displacement
- Change in focal length is inversely proportional to the lateral displacement
- However, the bulky refractive optics in conventional Alvarez lenses are hard to fabricate and assemble – CMOS incompatible



Metasurface Alvarez Lens



- Alvarez metasurfaces with complementary cubic surface profiles:

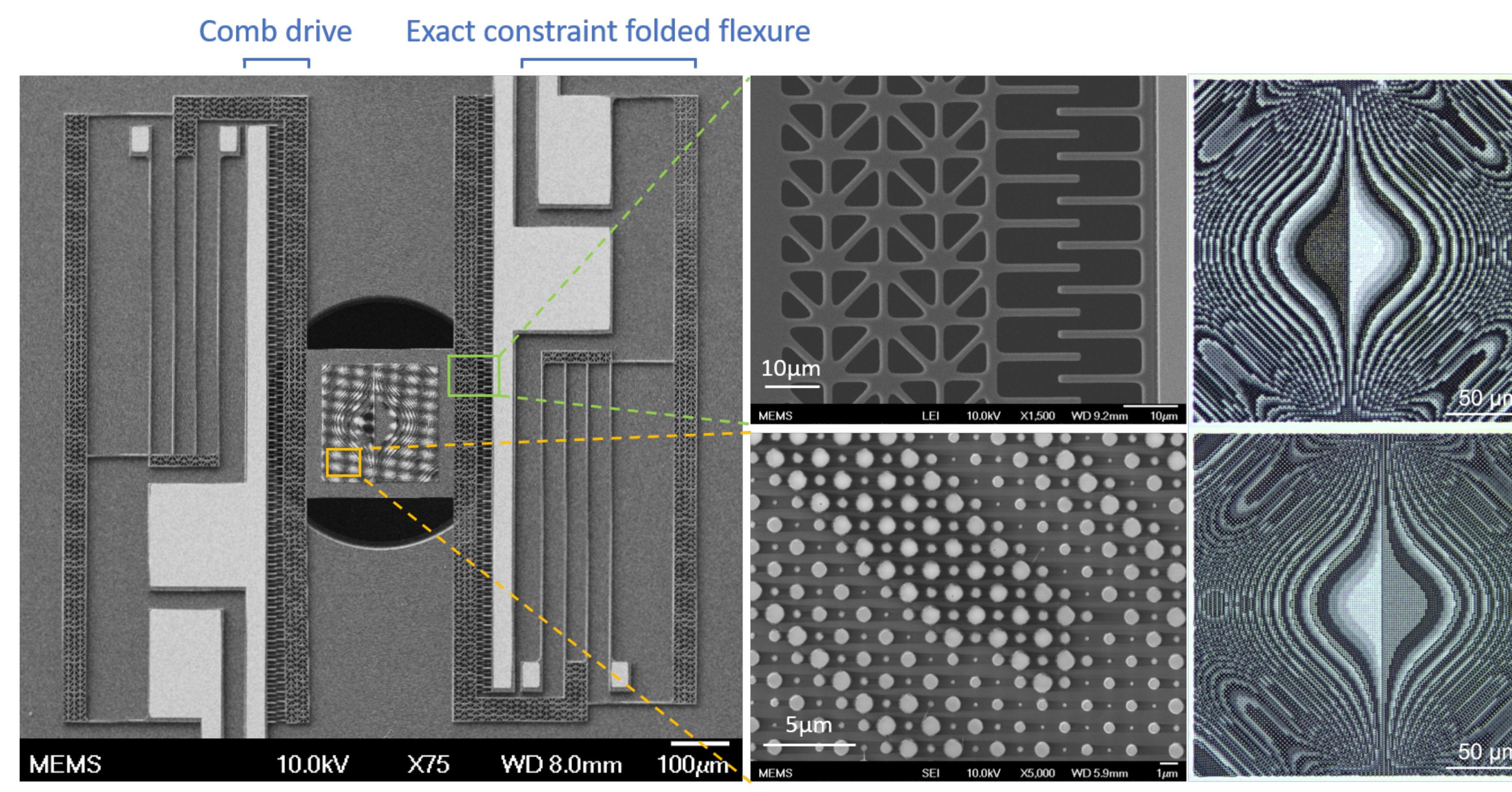
$$\varphi_{reg}(x,y) = -\varphi_{inv}(x,y) = A\left(\frac{1}{3}x^3 + xy^2\right)$$

- With symmetric lateral displacement, the two Alvarez metasurfaces in conjunction form a singlet metalens imparting a quadratic phase profile onto incident wavefront:

$$\varphi_{Alvarez}(x,y) = \varphi_{reg}(x+d,y) + \varphi_{inv}(x-d,y) = 2Ad(x^2+y^2) + \frac{2}{3}Ad^3$$

- A larger lateral offset gives rise to a more rapidly varying phase profile and a shorter focal length
- The phase profiles are discretized into 6 diameters for the SiN_x-on-Si cylindrical nanoposts, mapping the spatial phases of the Alvarez optics

MEMS-actuated Alvarez Metalens

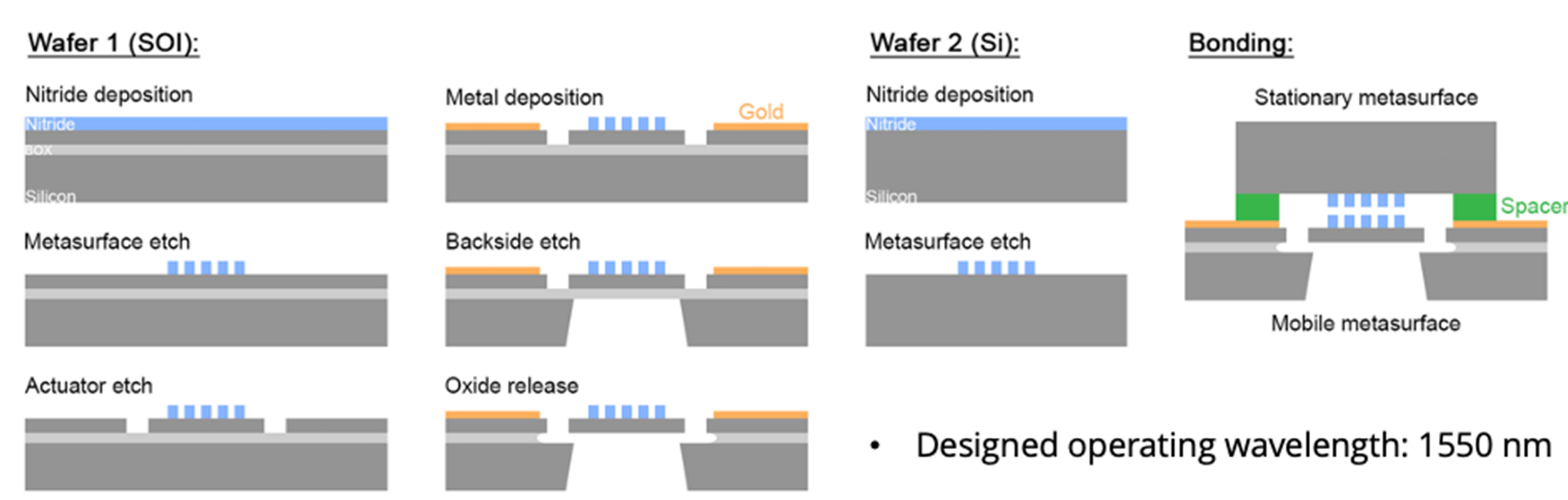


- In comb-drive actuators, the actuated displacement is linearly proportional to the electrostatic force, and quadratically dependent on the actuation voltage:

$$x(V) = \frac{F_{el}(V)}{k} = \frac{N\varepsilon h V^2}{kd}$$

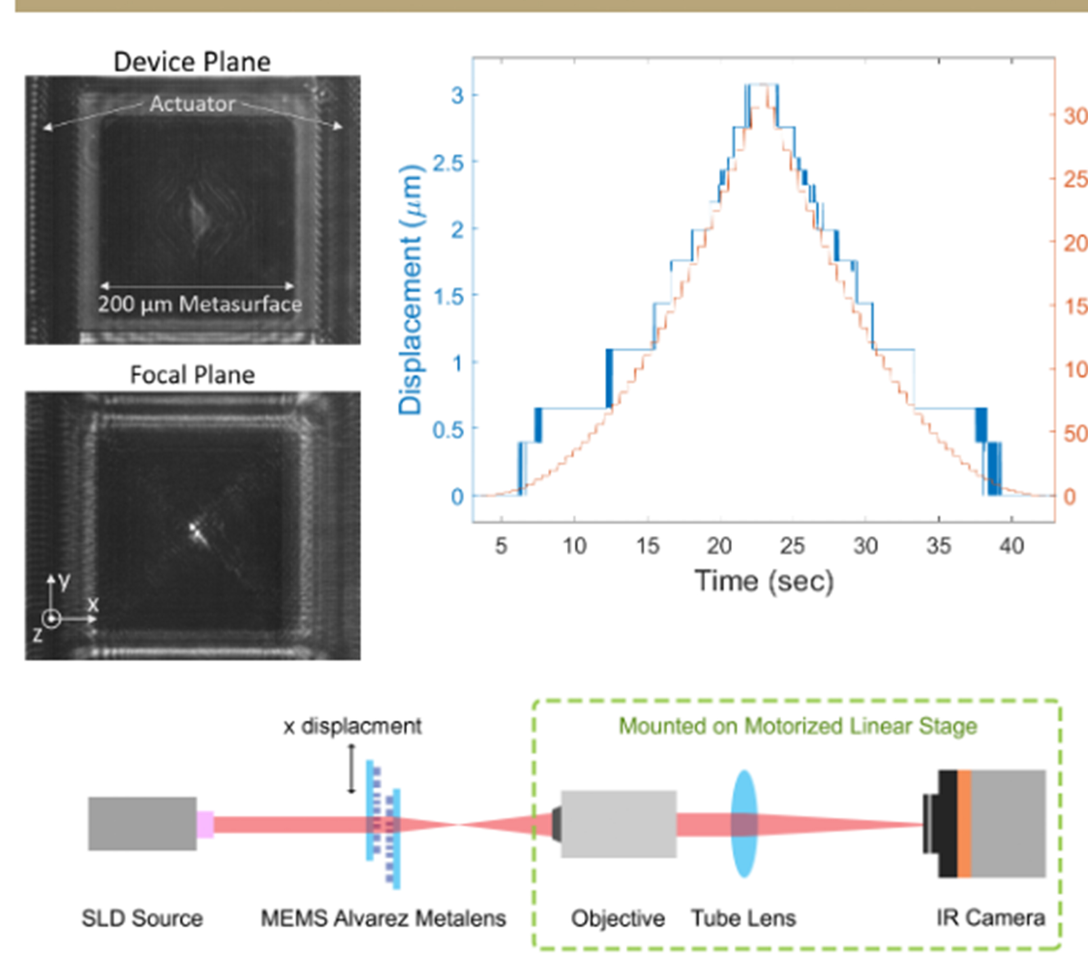
- High energy density, high controllability, fast switching speed and low power consumption

Device Fabrication

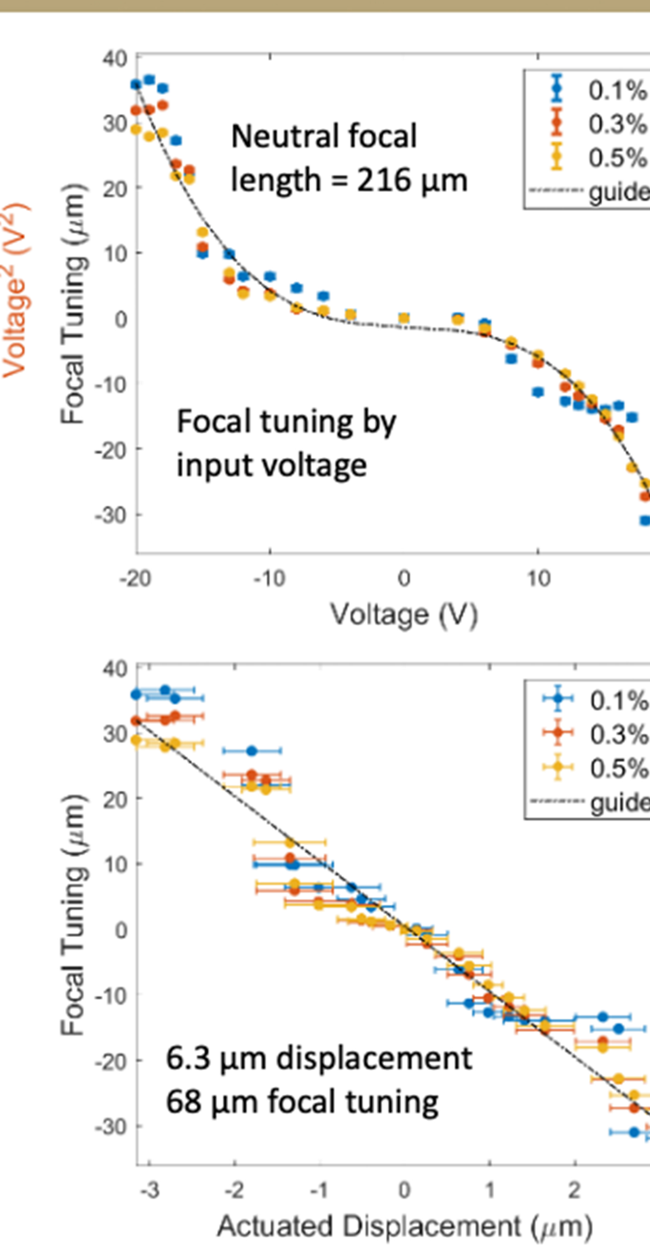


- Designed operating wavelength: 1550 nm

Tuning Performance



- Actuated displacement shows clear quadratic dependence on actuation voltage
- Alvarez metalens produces more than 10 times scaling between the actuated input (6.3 µm) and focal tuning output (68 µm)



Future Work

- Increase Alvarez metalens aperture size for higher focusing efficiency
- Design and demonstrate Alvarez metalens for imaging in the visible spectrum

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