MM-SCALE FOCAL LENGTH TUNING IN MEMS-INTEGRATED META-OPTICS

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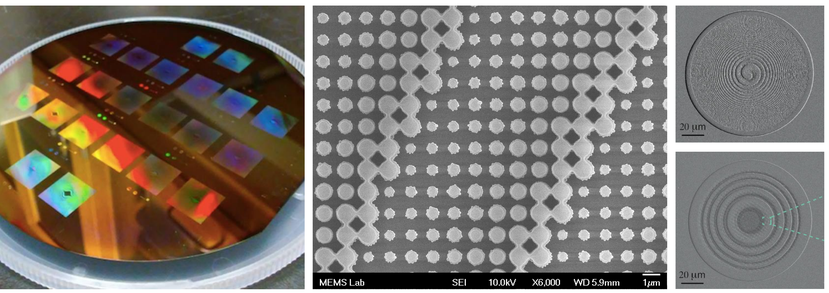
Objectives

- To design and demonstrate a miniature focus-tunable optical device that is
  - modulated with high precision and speed
  - requiring low power consumption
  - CMOS-compatible for electronics integration and mass production at low unit cost

Meta-optics



- Meta-optics 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, meta-optics can change amplitude, phase, and polarization of the incident light accordingly
- The flat nature and subwavelength resolution enable highly compact optical systems 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:

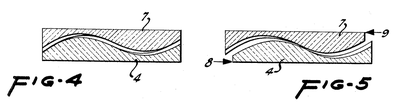
$$\varphi_{reg}(x,y) = -\varphi_{inv}(x,y) = A\left(\frac{1}{3}x^3 + xy^2\right)$$

- Optical power modulation is achieved by introducing a small relative lateral displacement between the optics
- In conjunction they form a singlet lens imparting a quadratic phase profile onto the incident wavefront:

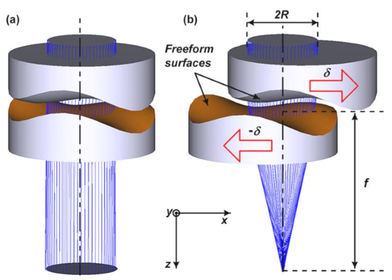
$$\varphi_{Alvarez}(x,y) = \varphi_{reg}(x+d,y) + \varphi_{inv}(x-d,y)$$
$$= 2Ad(x^2+y^2) + \frac{2}{3}Ad^3$$

- Change in focal length is inversely proportional to the lateral displacement:

$$f = \frac{\pi}{2\lambda Ad}$$

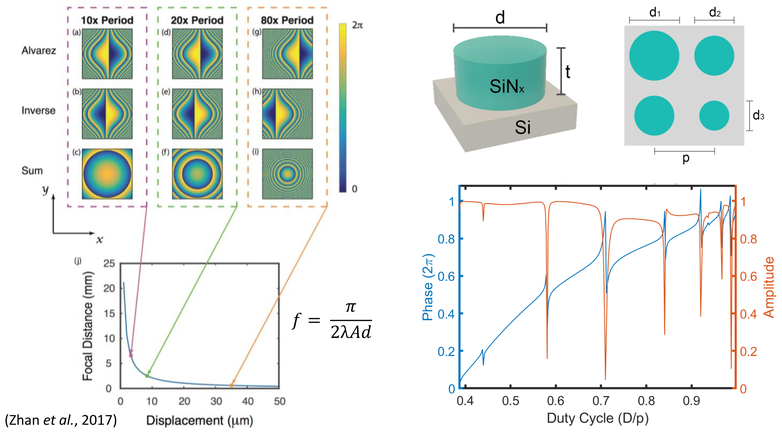


(Alvarez, 1964)



(Zou *et al.*, 2015)

Meta-optic Alvarez Lens

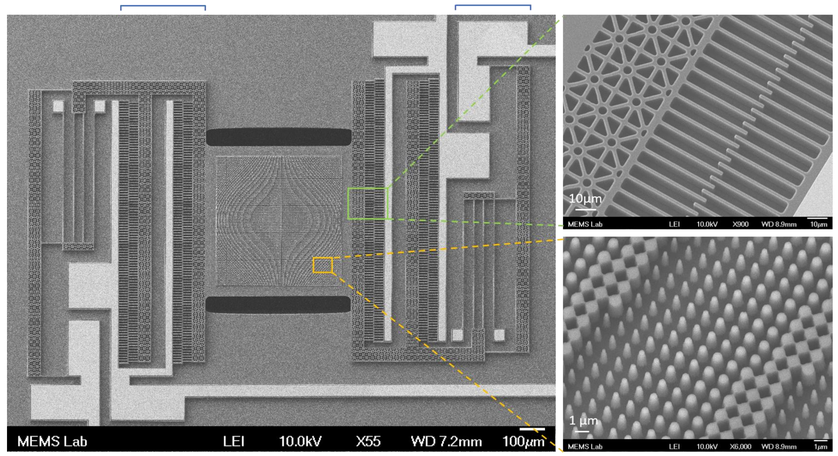


$$f = \frac{\pi}{2\lambda Ad}$$

(Zhan *et al.*, 2017)

- The cubic Alvarez phase profiles are discretized into six diameters for the SiN_x-on-Si cylindrical nanoposts to construct the planar Alvarez meta-optics
- A larger lateral offset produces a steeper phase profile and a shorter focal length

MEMS-integrated Alvarez Metalens

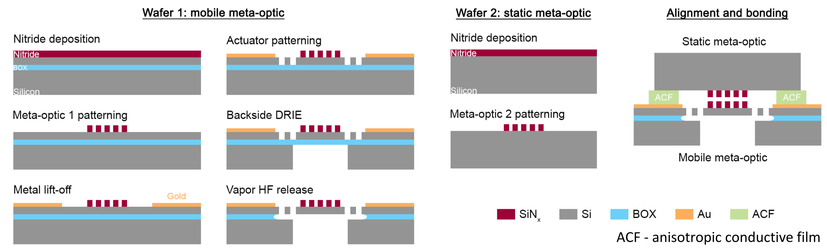


- In comb-drive actuators, the actuated displacement is linearly proportional to the electrostatic force, and quadratically dependent on the actuation voltage:

$$\Delta d(V) = \frac{F_{el}(V)}{k_{sp}} = \frac{N\varepsilon hV^2}{k_{sp}d_{sep}}$$

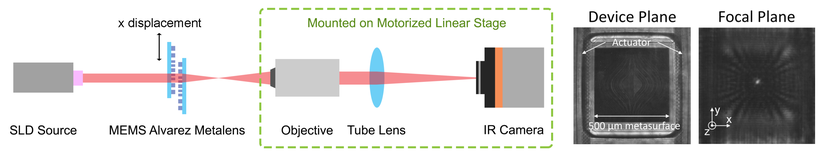
- High energy density, high controllability, fast switching and low power consumption

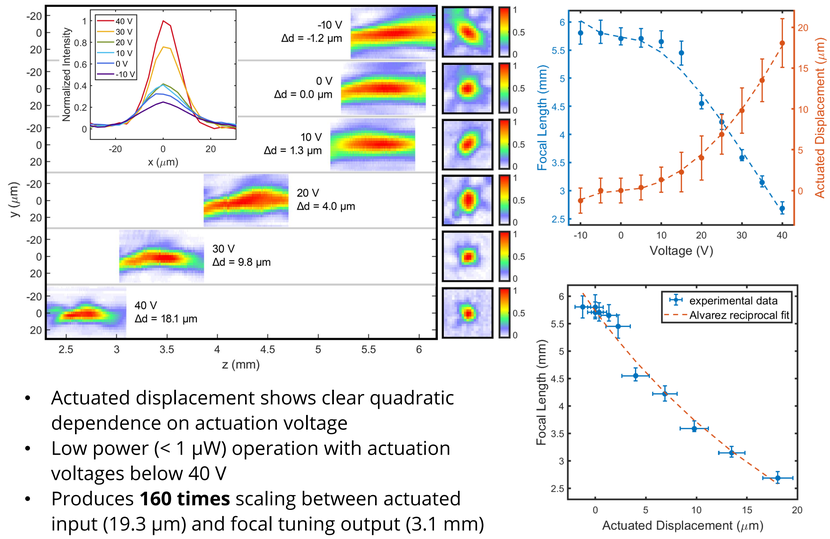
Device Fabrication



- SiN_x-on-Si meta-optics for optimal operation in the near-IR spectrum (1550 nm)

Tuning Performance





- Actuated displacement shows clear quadratic dependence on actuation voltage
- Low power (< 1 μW) operation with actuation voltages below 40 V
- Produces **160 times** scaling between actuated input (19.3 μm) and focal tuning output (3.1 mm)

Future Work

- Improve device performance tolerance to fabrication discrepancies
- Design and demonstrate Alvarez metalens for imaging in the visible spectrum

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