**Docket #:** S22-224

# Wavefront manipulation by electrically and fluidically tuned polymer metasurfaces

Active manipulation of light beams is required for a range of emerging optical technologies, including sensing, optical computing, virtual/augmented reality, dynamic holography, and computational imaging. Miniaturization of these optical components is key to facilitating their integration into a range of applications. Despite many advances, the size and weight of traditional macroscopic lenses and dynamic optical elements still take up significant space due to their use of classic optical elements. Therefore, it is highly desirable to reduce the size and weight of the dynamic optical components in such systems. Subwavelength control over the phase using ordered arrays of nanoantennae, or metasurfaces, could allow this goal to be achieved. Tunable metasurface lenses have been realized and typically use strain or thermal tuning of the entire metasurface or mechanical movement between metasurface lenses. Recent efforts have demonstrated impressive modulation of phase and color of pixel elements that could be individually actuated with high-speed microelectromechanical MEMs technology. However, these are challenging to fabricate and experience limitations in dynamic applications due to vibration instability.

Inventors at Stanford have created a hybrid polymer/metal tunable optical metasurface system, with operation in wavelength ranges from the visible to the infrared. It can reversibly tune the color and phase of reflected wavefronts through applications of stimuli, including applied voltage or application of suitable fluids to the surface of the metasurface. The tuning mechanism is non-volatile, involving changes in polymer thickness due to changes in thermodynamic equilibrium condition. . In the case of fluidic control, the fluid infiltrates into the polymer and causes a change in the swelling degree. In the case of electrochemical control, applied voltage leads to ion intercalation, modifying the swelling degree. Depending on the specific design chosen, this can result in a change of the reflected color from the metasurface, continuous tuning of the direction of the reflected beam, or on-off modulation between different diffraction orders. These ultra-thin devices can also be made with thicknesses of 500nm, much smaller than conventional optical elements that range from the millimeter to centimeter scale. Nanoscale optical elements, combined with rapid advances in electrical control systems, or microfluidic systems infrastructure, could enable the next generation of optical elements light control.

## Applications

- low power optical modulators, reconfigurable optical devices (including reconfigurable lensing and display), and sensing systems directly integrated into nano/microfluidic systems.
- Microfluidic systems and existing technologies
- any dynamically tunable focusing devices
- virtual/augmented reality devices
- wearable optical systems
- use in color display elements (such as Kindles)

## Advantages

- can be integrated with electrical control methods (including low voltage CMOS chips), and patterned to allow for discrete pixelated control
- can be integrated with existing microfluidics technology
- system can be made ultracompact and avoids the use of complex mechanics
- could be apply to flat, wavelength specific, dynamically tunable focusing devices, which require no power upon moving to a new focus state
- Response times of 100ms could be of benefit to high throughput systems
- Use of liquid and electrochemical tuning allows for reliable and durable operation without typical mechanical wear
- Can be directly integrated into microfluidic system for inline sensing of system parameters, including potentially concentrations of biomolecules (e.g. with modifications of the polymer)

## Publications

- Holsteen, A. L., Raza, S., Fan, P., Kik, P. G., & Brongersma, M. L. (2017). " Purcell effect for active tuning of light scattering from semiconductor optical antennas". Science, 358(6369), 1407-1410.
- Holsteen, A. L., Cihan, A. F., & Brongersma, M. L. (2019). " Temporal color mixing and dynamic beam shaping with silicon metasurfaces". Science, 365(6450), 257-260.
- Julian Karst et al., " Electrically switchable metallic polymer nanoantennas". Science374,612-616(2021).DOI:10.1126/science.abj3433

## Patents

- Published Application: WO2024015379

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