

Low Power Structural Color Tuning in a-Si Dielectric Metasurface via Li ion insertion

Elena Kovalik¹, Janna Eaves-Rathert², Cary L. Pint³, Jason G. Valentine²

1. Interdisciplinary Materials Science Program, Vanderbilt University, Nashville, TN 37235

2. Department of Mechanical Engineering, Vanderbilt University, Nashville, TN 37235

3. Department of Mechanical Engineering, Iowa State University of Science and Technology, Ames, IA 50011

E-mail: elena.r.kovalik@vanderbilt.edu

Optical metamaterials allow for wavefront manipulation through the precise geometry of subwavelength scatterers. The incorporation of active materials into these structures enhances functionality by tuning wavefront response with an applied stimulus. However, next-generation device architectures require active elements that are readily available, can be applied at optical frequencies, and consume minimal power. Electrochemical control of a dynamic metamaterial uses the exchange of ions in a redox reaction to reversibly control a device's optical response using relatively low power. This method is particularly advantageous in the optical frequencies, as the charge compensation within the lattice mitigates Debye screening.

Silicon, whose high index makes it a popular material for dielectric metasurfaces, has recently been investigated as an energy storage material due to its high capacity for lithium ions¹. Significantly, silicon has been reported to expand volumetrically up to 300% at full lithium capacity². As metasurfaces are extremely sensitive to scatterer geometry, the lithium-silicon alloying reaction offers a way to precisely tune metasurface response with low power and full reversibility. Previously, the volume expansion and associated lattice strain were utilized in a reconfigurable architected metamaterial³ and incorporated into a dynamic fabry-perot coloration film⁴. However, using the silicon-lithium alloy volume expansion has to date never been examined as a method of electrically controlling the geometry of subwavelength resonators.

Here, we employ Li-ion insertion into amorphous silicon Fabry-Perot films and metasurfaces, utilizing both change in refractive index and accompanying lattice expansion as tuning mechanisms. With the application of only 0.2 V vs. Li/Li⁺, we show reversible color change for the thin film structure. We then pattern the thin film into a metasurface and demonstrate reversible color bleaching and restoration in individual structural-color pixels at voltages much less than those required for electrochromic oxides or electrical biasing. These devices show dynamic coloration ability well-suited for novel applications demanding low power consumption and high-resolution.

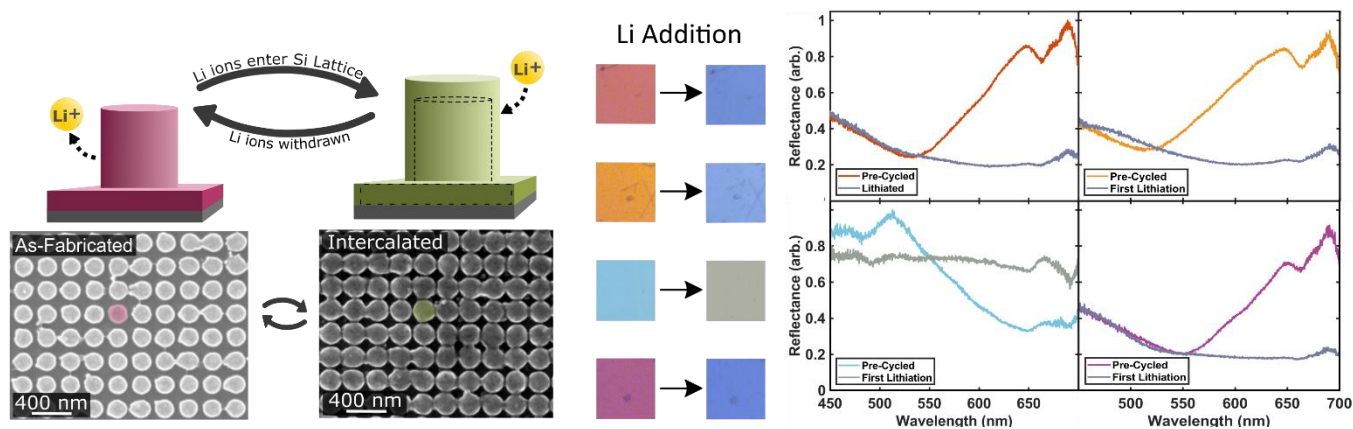


Fig. 1 (Left) Schematic showing Si resonators expanding with Li-ion insertion with SEM images of alloyed resonators. (Right) spectral measurements and images showing full color bleaching

References

- [1] Obrovac, M., Chevrier, V. L. 2014. *Chem. Rev.* 114. 11444-11494.
- [2] Beaulieu, L. Eberman, K., Turner, R. et. al. 2001 *Electrochem Solid-state Lett.* 4. A137-A140.
- [3] Xia, X., Afshar, A., Yang, H. et. al. 2019. *Nature.* 573. 205-212.
- [4] Bao, Y., Han, Y., Yang, L. et. al. 2019. *Adv. Fun. Mat.* 29. 1806383.