Ultra-narrow Linewidth Symmetry-breaking Silicon Metasurface for Trace Biomolecules Sensing

Guohua Li[1], and Jingxuan Cai[1]

[1]*School of Biomedical Engineering, Sun-Yat Sen University, Guangzhou, China*

caijx27@mail.sysu.edu.cn

The silicon-based all-dielectric metasurface, based on the Mie scattering theory, improves the interaction between light and matter by enhancing the local electromagnetic field intensity of the metasurface. Compared with their metallic counterpart, the silicon-based dielectric metasurface has lower optical loss while retaining a stronger optical resonance response, resulting a narrower linewidth optical response. The optical response of the silicon-based metasurface is determined by many factors, such as period, shape, and thickness of silicon. Recent studies reveal that utilizing structural symmetry-breaking dielectric metasurfaces, an ultra-narrow linewidth (<1 nm) optical absorption (or transparency/reflection) will arise, which is induced by the quasi-BIC of the asymmetric structure.[1] Such unique property of symmetric-breaking dielectric metasurface makes it a promising candidate as a high quality factor (Q-factor) biosensor for highly-reliable detection of the tiny spectral shift of resonance caused by the attached trace biomolecules. Many efforts have been devoted to optimizing structural design for excellent optical responses, such as disk-bar structure and tilted silicon nanobars.[2, 3] However, resonances in most of the structures are strongly depends on the geometry of the dielectric nanostructures and requires costly high-precision nanofabrication techniques. Therefore, a symmetry-breaking dielectric metasurface with ultra-narrow linewidth optical response and robust nanofabrication is of importance to its real-life applications.

In this research, we propose a robust structural symmetry-breaking silicon metasurface with ultra-narrow transparency. **Figure 1** shows the dielectric metasurface fabrication process flow. Polycrystalline silicon is first deposited on a fused silica substrate by a low-pressure chemical vapor deposition (LPCVD) process. Then a thin layer of polymethylmethacrylate (PMMA) is spin coated on the substrate. A dual-trapezoidal nanostructure array is fabricated in PMMA through electron beam lithography (EBL). Thereafter, a thin-layer chromium is evaporated as a mask for the following reactive ion etching (RIE) process. Finally, dual-trapezoidal nanopatterns are transferred into silicon by RIE and complete the whole fabrication. **Figure 2a** shows the metaunit of the metasurface, which is composed of two centrosymmetric silicon trapezoids on the fused silica substrate. **Figure 2b-f** show the finite-difference time-domain (FDTD) simulation results. As shown in **Fig. 2b**, the FWHM of the resonance on the reflectance spectrum of the metasurface can be as narrow as 1.5 nm. The electric field are mainly concentrated on the waists of the trapezoids (**Fig. 2c**), thus results a relatively large detection depth for biomolecules. The refractometric sensitivity of the metasurface is 209.6 nm/RIU (**Fig. 2d**). Moreover, the FWHM and resonance suppression efficiency are not significantly influenced by the distance between trapezoids and fillet radius (**Fig. 2e, f**), indicating that the metasurface is robust against fabrication errors.

1. Tseng, M. L.; Jahani, Y.; Leitis, A.; Altug, H., Dielectric Metasurfaces Enabling Advanced Optical Biosensors. *ACS Photonics* **2020,** *8* (1), 47-60.

2. Yang, Y.; Wang, W.; Boulesbaa, A.; Kravchenko, II; Briggs, D. P.; Puretzky, A.; Geohegan, D.; Valentine, J., Nonlinear Fano-Resonant Dielectric Metasurfaces. *Nano Lett* **2015,** *15* (11), 7388-93.

3. Yesilkoy, F.; Arvelo, E. R.; Jahani, Y.; Liu, M.; Tittl, A.; Cevher, V.; Kivshar, Y.; Altug, H., Ultrasensitive hyperspectral imaging and biodetection enabled by dielectric metasurfaces. *Nature Photonics* **2019,** *13* (6), 390-396.

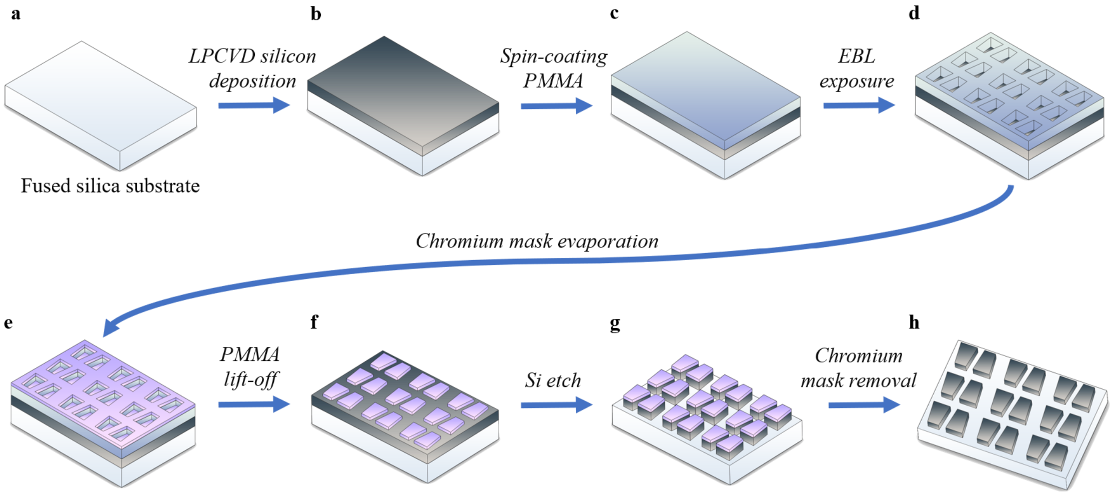

Figure 1. Silicon-based dielectric metasurface fabrication process flow.

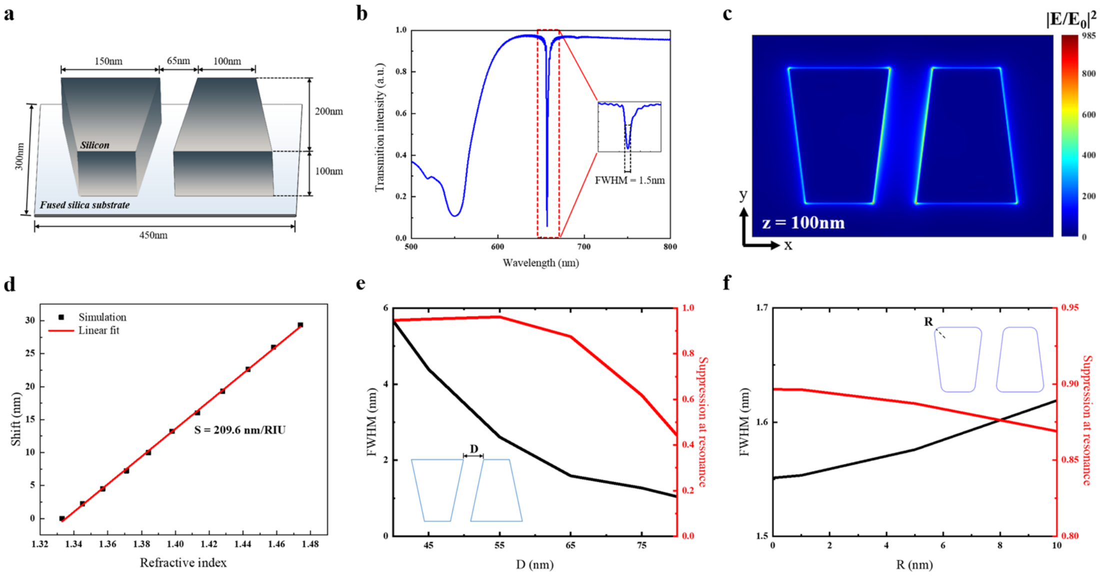

Figure 2. Metaunit and simulation of the dielectric metasurface. a, The metaunit diagram of the dielectric metasurface, composed of two trapezoids symmetrical about the center. **b-f**, FDTD simulation results, including (**b**) the transmittance spectrum, (**c**) the electric field distribution at the resonance wavelength (657 nm), (**d**) the refractometric sensitivity (n=1.333-1.474), and (**e, f**) the effect of the distance between trapezoids (D) and fillet radius (R) on FWHM and resonance suppression efficiency, respectively.