Design and Fabricate Robust Nanocavities

CNF Project Number: 3261-25
Principal Investigator(s): Wei Bao
User(s): Wei Li, Yilin Meng

Affiliation(s): Department of Materials Science and Engineering, Rensselaer Polytechnic Institute

Primary Source(s) of Research Funding: Army Research Office

Contact: baow2@rpi.edu, liw24@rpi.edu, mengy5@rpi.edu

Primary CNF Tools Used: Heidelberg MLA 150 Maskless Aligner

Summary of Research:

To realize tunable mid-infrared nanophotonic platforms with strong light–matter interaction, we are fabricating arrays of gold disks as the foundational step toward constructing epsilon-near-zero (ENZ) plasmonic nanocavities. As illustrated in Fig. 1a and 1b [Nat. Photonics 15, 125–130 (2021)], such nanocavities enable significant optical resonance and ultra-strong coupling with phonons. Gold is chosen as the cavity material due to its low intrinsic loss and chemical stability in the infrared range.

At Cornell CNF, we first spin-coated a UV photoresist and employed photolithography to define the gold disk array patterns. The primary lithography tool used was the Heidelberg MLA 150 Maskless Aligner. Subsequent processing was carried out at RPI, where we deposited a 3 nm titanium (Ti) adhesion layer followed by 100 nm gold (Au) using electron-beam evaporation. A standard lift-off process was then applied to form the final gold disk array. Characterization at RPI confirmed the fabrication results of the designed structures, as shown in Fig. 2a. The fabricated array features a periodicity of 4.77 µm and disk diameters of 1.76 µm. To evaluate the optical performance of the fabricated nanocavity structure, we conducted transmission measurements of the bare gold disk array. The resulting spectrum (Fig. 2b) demonstrates an optical resonance, showing that our lithography created the intended plasmonic modes. However, the observed quality factor of the resonance remained low, suggesting the presence of optical loss. Further investigation using scanning electron microscopy (SEM), as shown in Fig. 2c, revealed prominent lift-off wings around the edge of each disk, which, we believe, are responsible for the elevated loss.

To address this issue, our next fabrication iteration will adopt a bilayer resist strategy to promote clean undercut profiles and facilitate lift-off process.

Conclusions and Future Steps:

The plasmonic disk array has been successfully fabricated, but the observed optical modes exhibit high loss, likely due to lift-off artifacts. Moving forward, we plan to use ASML PAS 5500/300C DUV Wafer Stepper and Heidelberg MLA 150 Maskless Aligner to optimize our fabrication. With high-quality plasmonic resonance mode achieved, we will coat the structure with ENZ materials to investigate cavity–matter coupling and explore optical control of material excitations.

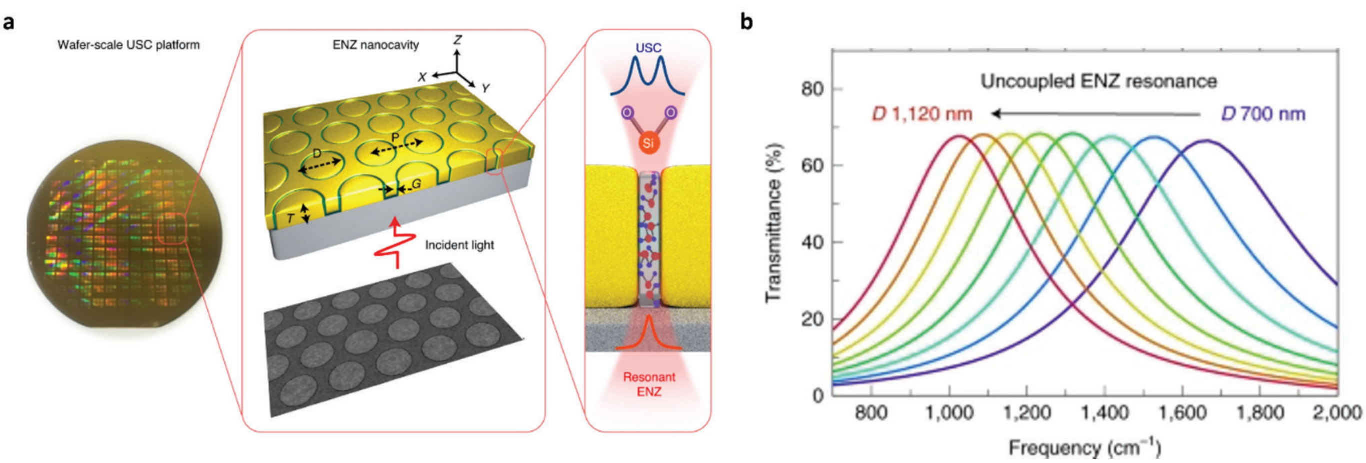

Figure 1: (a) Schematic of ENZ nanocavity and illustration of SiO2 phonons interacting with the nanocavity mode. (b) Transmission resonances of ENZ nanocavity with different aperture diameters. Image reproduced from Nat. Photonics 15, 125–130 (2021).

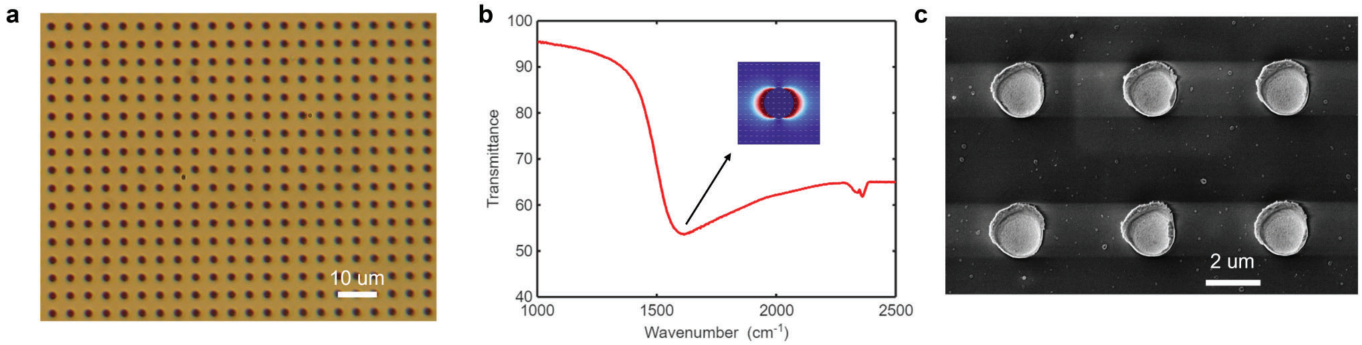

Figure 2: (a) Optical image of the fabricated gold disk array with a designed periodicity of 4.77 µm and disk diameters of 1.76 µm. (b) Measured transmission spectrum of the array, showing a resonance dip. The inset displays a simulated electric field profile of the resonance mode, indicating the dipolar resonance around the gold disk. (c) Scanning electron microscopy image reveals the presence of lift-off wings surrounding each gold disk.