Fabrication of Waveguides on Porous Nanolattice Films for Low-Index Photonic Integration

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Integrated photonics and waveguides are central to emerging VR/AR display architectures because they guide and manipulate light within the compact multilayer stacks. The most important factor for improving waveguide performance is maximizing the refractive-index contrast which enhances light trapping, overall transmission efficiency, and field of view.[1] However, conventional low-index materials used in integrated photonic devices are predominantly polymer-based and are typically limited to refractive indices near 1.3. Air-gap approaches can reduce the index to 1 but suffer from poor mechanical stability and reduce device durability.[2] This motivated the development of a mechanically robust, ultra-low index layer that can be integrated directly beneath or within waveguides to improve optical confinement without sacrificing the device's structural and mechanical integrity. Periodic porous nanolattice films address this materials gap by combining near air refractive indices with engineered stiffness. The ordered periodic geometry helps suppress optical scattering relative to randomly porous media.[3–5] At the same time, periodic cellular architectures can retain high stiffness at low density with demonstrated modulus in the GPa regime.[6] Building on prior demonstrations that planar films can be integrated with nanolattice layers to enable waveguide architectures, this research develops a fabrication process to integrate porous nanolattice materials into photonic waveguides. The objectives are to optimize transmission efficiency, investigate defect modes and corresponding mitigation strategies and characterize the coupled optical and mechanical response of the fabricated devices.

In this work, we developed a fabrication route to form planar waveguides on nanolattice films by combining colloidal 3D lithography, atomic layer deposition, and multilayer integration. The main objective is to create a photonic device architecture in which a 3D nanolattice serves as a mechanically robust, low index underlayer enabling systematic measurement of waveguide transmission loss. In Fig. 1, a silicon wafer is patterned with a close packed monolayer of 0.7 μm polystyrene nanosphere on ~800 nm resist (PFI-88) then exposed at 325 nm to form the nanolattice template. After development, Al_2O_3 is deposited by ALD. The nanolattice is planarized with a resist overcoat followed by deposition of SiO_2 and SU-8. Then SU-8 is photopatterned, the stack is etched in CF_4 and O_2 plasma is used to remove PFI-88 to yield a freestanding waveguide supported on the porous nanolattice film.

The initial fabrication results (Fig. 2) show that the patterned SiO_2/SU-8 waveguide stack can be released while remaining mechanically supported on the porous nanolattice film. Achieving this required overcoming two main challenges. First, the high-quality colloidal lithography nanolattice regions were spatially limited, making it hard to align SU-8 photopatterning to the largest, uniform porous areas without nonuniformity or defects. Second, the release step required tight etch control to reach the nanolattice interface and enable O_2 plasma undercutting to remove the planarization layer and residual resist without over-etching or damaging the nanolattice. We will discuss the process modifications that improved targeting of uniform nanolattice regions and etch reliability and how the resulting waveguide on nanolattice platform enables optical loss and mode confinement measurements.

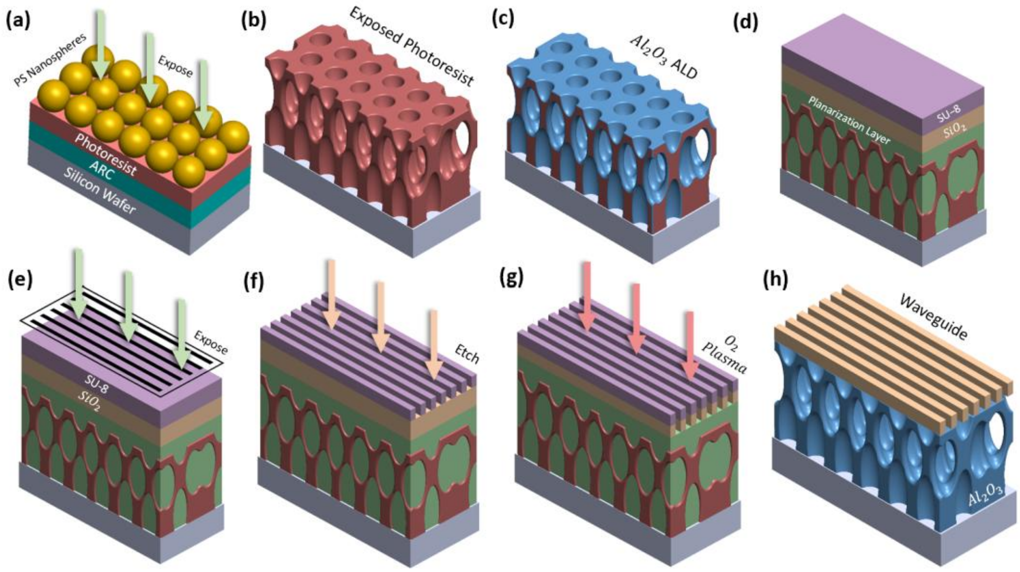

Figure 1. Fabrication process of the nanolattice structure (a) colloidal lithography (b) exposed photoresist 3D nanostructures (c) ALD (d) planarization and deposit of SiO_2 and SU-8 (e) photomask exposure (f) dry etch (g) O_2 plasma to remove resist (h) final waveguide on nanolattice.

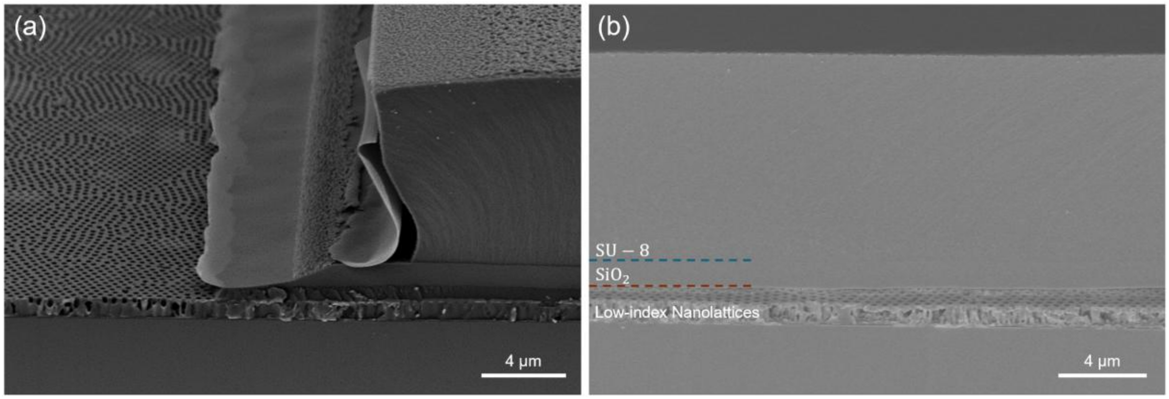

Figure 2. Cross-section SEM images of SiO_2 and SU-8 layer on nanolattices showing (a) the edge of the waveguide and (b) middle of the waveguide on top of low-index nanolattices.

Reference

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