Massive replication of nanophotonic crystals using combined-nanoimprint-and-photolithography

K.-H. Choi [1,*] , J. W. Huh [2,*] , Y. Cui [1] , B.-K. Ju [2] , W. Hu[1], J.-B. Lee [1]

[1] *Department of Electrical Engineering, University of Texas at Dallas, TX 75083, USA*
[2] *Department of Electrical Engineering, Korea University, Seoul, 136-713, Korea*

[*] First co-author
Author to whom correspondence should be addressed; electronic mail: kxc046000@utdallas.edu

We report a method of fabrication for massive replication of nanophotonic crystals utilizing hybrid mask mold and combined-nanoimprint-and-photolithography. Photonic crystal is a periodic structure of dielectrics in which the flow of electromagnetic waves can be controlled. The device dimension is proportional to the wavelength. In the case of telecommunication wavelengths (e.g., 1.55μm), critical feature size of the photonic crystals is in submicron range. Such photonic crystals are typically fabricated by using either electron beam lithography or focused ion beam techniques. However, in order to demonstrate photonic crystal devices, micron scale waveguides and/or deflection blocks and other associated structures are needed. Such structures are typically fabricated by using conventional optical lithography. This typical two-step lithography increases fabrication complexity and lower the overall yield. In this work, we report a combined-nanoimprint-and-photolithography (CNP) using a quartz hybrid mask mold (HMM) for the fabrication of two-dimensional slab photonic crystals in which both nanoscale and micron scale features are formed in single step lithography process.

In order to fabricate a HMM (Fig. 1), 30 nm-thick Al layer was deposited on a quartz substrate, which was followed by a lift-off process for the formation of 100 nm-thick Cr alignment marks. Then another PMMA lift-off process for 20 nm-thick Cr layer was done by electron beam lithography. The Cr pattern was formed with a triangular array of submicron scale circular dots with 120nm diameter and 347nm pitch distance. The Cr layer works as a hard mask for dry etch of aluminum layer. Al was then used as a hard mask for etching of the quartz substrate. Approximately 300 nm-tall quartz rod array was formed by fluorine based dry etch. Finally, 100 nm-thick Cr pattern with micron scale features was formed by a lift-off process using S1813. The hybrid mask mold shows a dense array of nano scale rods for the nanoimprint and a surrounding micron scale Cr mask for the photolithography. The close-up images of a part of the array shows fairly uniform cone shaped rods. The rod's flat top diameter was measured to be approximately 110 nm while the bottom of the rod diameter was found out to be 347 nm (Fig. 2).

The sample fabrication (Fig. 3) was started with the deposition of 100 nm-thick SiO_2 on top of a Silicon-on-Insulator (SOI) substrate and followed by the deposition of 20 nm-thick Al layer on the SiO_2 layer. Then, approximately 230 nm-thick SU-8 2000.5 was spin-coated on the top of the Al layer. Prior to the CNP process, a self-assembled monolayer of 1H,1H,2H,2H-perfluorodecyltrichlorosilane (FDTS) was coated on top of the hybrid mask mold for easy detachment after the imprinting. The imprinting was carried out at 85°C with a pressure of 30 bar (3 MPa) for 10 minutes. Near the final stage of the imprinting process, the SU-8 resist was exposed by 365 nm UV light source through the HMM with an exposure dose of 100 mJ/cm^2. The mold was then detached and the sample was post-baked and developed. Next, the SU-8 layer was etched by an inductively coupled plasma etcher to open the Al surface with O_2 plasma. Then, Al layer was etched by the chlorine based dry etch process. The 100 nm-thick SiO_2 layer was then etched by the fluorine based dry etch. Finally, Si was etched by the chlorine based etch and residual SiO_2 was removed by wet etching. The process yielded fairly uniform 180 nm diameter air hole array in silicon which forms a 2D slab photonic crystal (Fig. 4).

This work demonstrates a method of fabrication for massive replication of 2D slab silicon photonic crystals with multi scale patterns. This novel mold-based process significantly simplifies the fabrication of massive number of multi-scale photonic crystals and this same technique can be utilized for the fabrication of other multi-scale devices such as metamaterials-based devices.

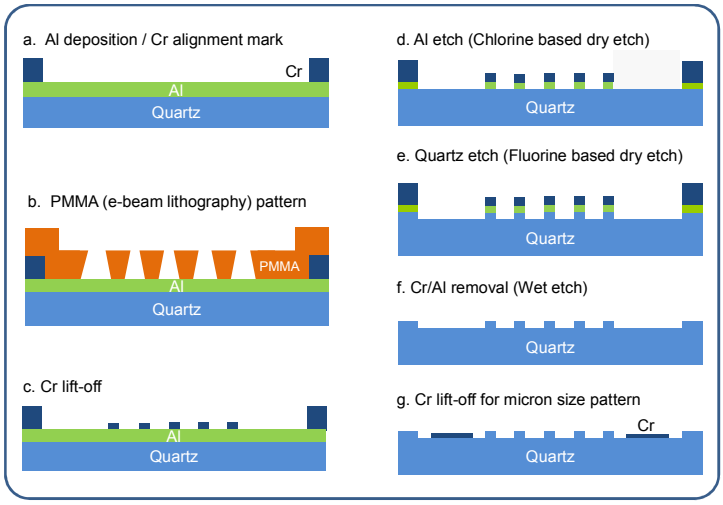

Fig. 1. Schematic diagrams of fabrication process of the hybrid mask mold.

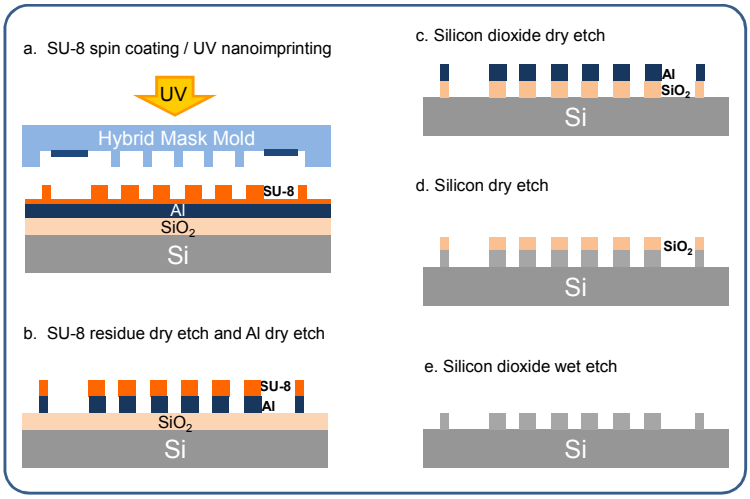

Fig. 3. Schematic diagrams of fabrication process of the 2D slab photonic crystal.

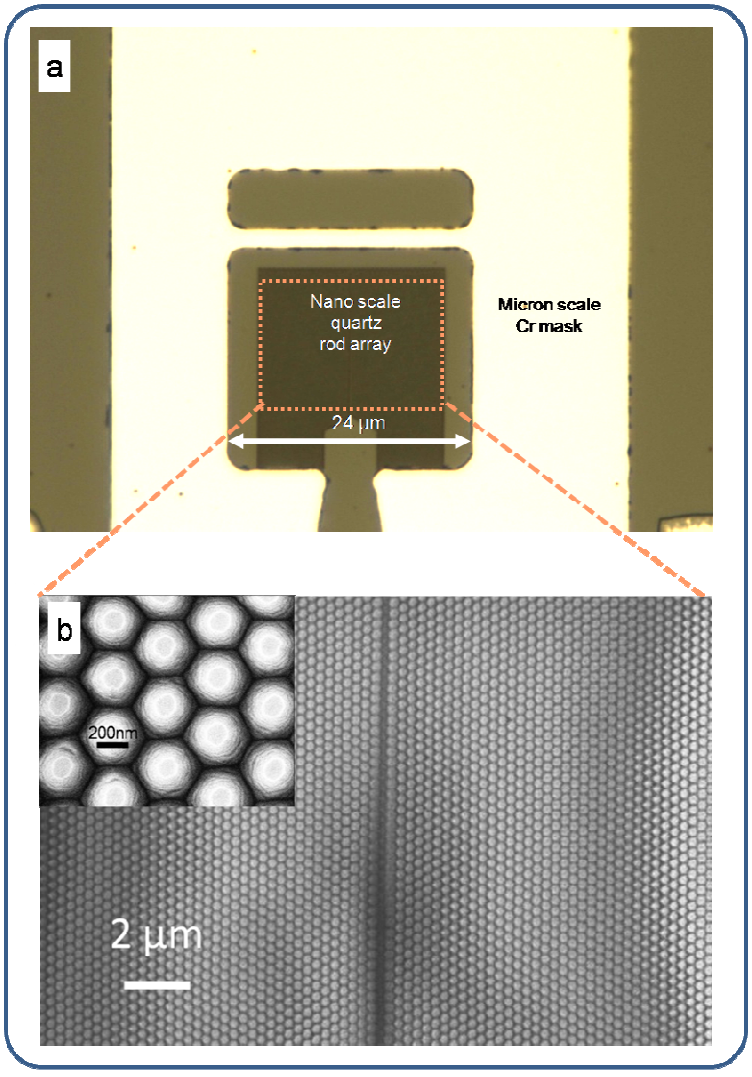

Fig. 2. (a) Optical image of the hybrid mask mold and (b) a SEM image of the nano rod array.

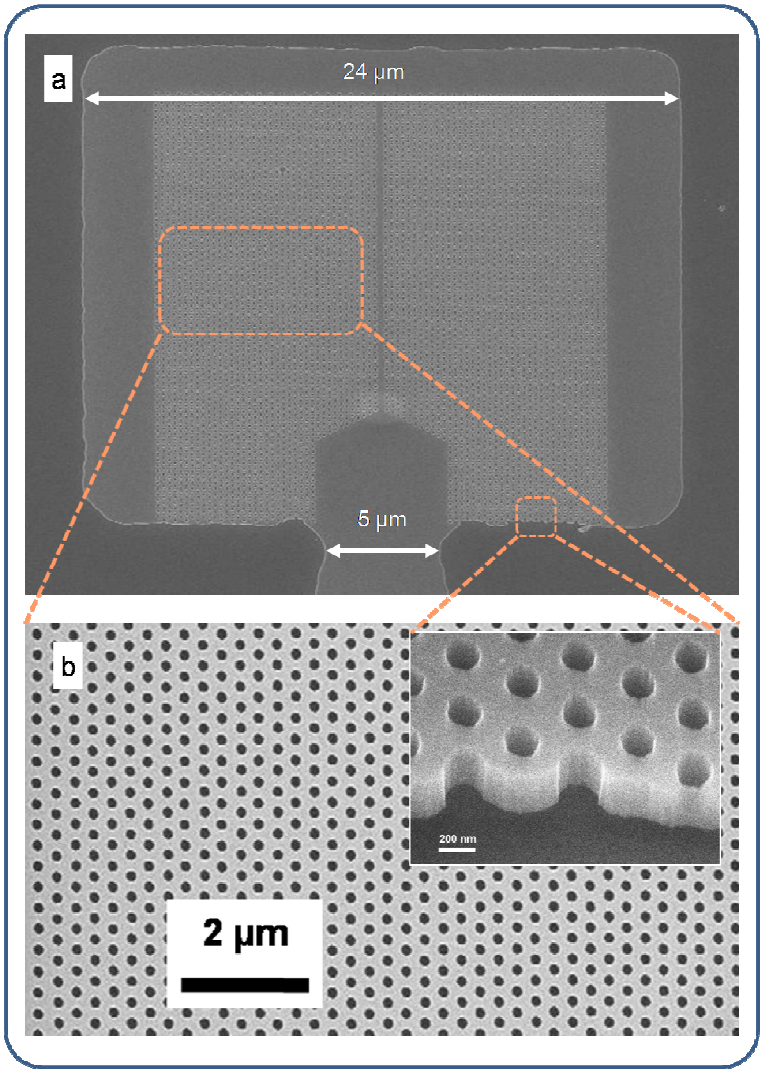

Fig. 4. SEM images of (a) the 2D slab photonic crystal and (b) the close-up images of the triangular air hole array with a top view and a 30º tilted view.