Nanofabrication of photonic crystal structures with complex geometries using ALD-enabled imprint lithography

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The ability to fabricate dense and complex geometries of nanostructures over large areas in the centimeter range is critical for a wide range of scientific and technological applications. In particular, the fabrication of photonic crystal (PhC) device structures of complex geometries at the nanoscale has multiple applications such as optical filters, optical wave-guiding, sensing and photovoltaics. The preferred fabrication technique of PhC structures is usually the electron beam lithography technique since it offers the flexibility of exposing complicated structures[1] or shapes at a very high-resolution. Nevertheless, this technique is not always cost-effective and involves complex process steps[2] including proximity effects issues that limit the turn-around fabrication time. In this work, the ALD-assisted nanoimprint technique is applied to fabricate dense PhC structures with sub-50 nm features over areas as large as 10 x 10 mm. In particular, sub-50 nm holes and pillars in the square and triangular lattice configurations have been fabricated using this approach. The authors have previously demonstrated feature size reduction[3, 4] by a factor of 2 to generate nanostructures in the sub-100 nm range, using the ALD-enabled nanoimprint technique. Silicon molds were fabricated using a Raith Voyager Electron beam lithography system with a beam current of 0.6 nA and dose of 100 $\mu C/cm^2$. The patterns on the molds consisted of periodic holes (250 nm pitch, 100 nm hole diameter) in square-lattice and triangular-lattice configurations, exposed over an area of 10 x 10 mm on a 100 nm thick ZEP 520A coated silicon chip. The exposed sample was developed before etching using an Oxford Instruments reactive ion etcher with a fluorine chemistry. The silicon molds, coated with an anti-release layer, were then used to thermally imprint the PhC patterns on a 90 nm thick imprint resist coated silicon chip (Nanonex 1006, imprint temperature, 130 °C, 200 psi, 2.5 min). Atomic layer deposition (Oxford Opal ALD) was then used to coat a 30 nm-thick layer of Al_2O_3 on the silicon molds (300 cycles at 0.1 nm/cycle). The conformal nature and the sub-nanometer deposition control[5] of the ALD technique ensure that the profile of the PhC structures is preserved. Figs. 1 (a) shows the fabricated PhC square-lattice silicon mold and Fig 1 (b) shows the same ALD coated silicon mold. In this work, a simple ALD coating step on the pre-fabricated imprint mold is used to 're-size' the nanostructures according to the device requirements. Figs. 2 (a) and (b) show the images of the imprint results of the ALD coated silicon molds. As demonstrated by these results, the feature sizes of the PhC structures have been reduced to about 50 nm (Fig. 2(b)) from the original 100 nm size and the imprint transfer of the PhC structures was successful over large areas.

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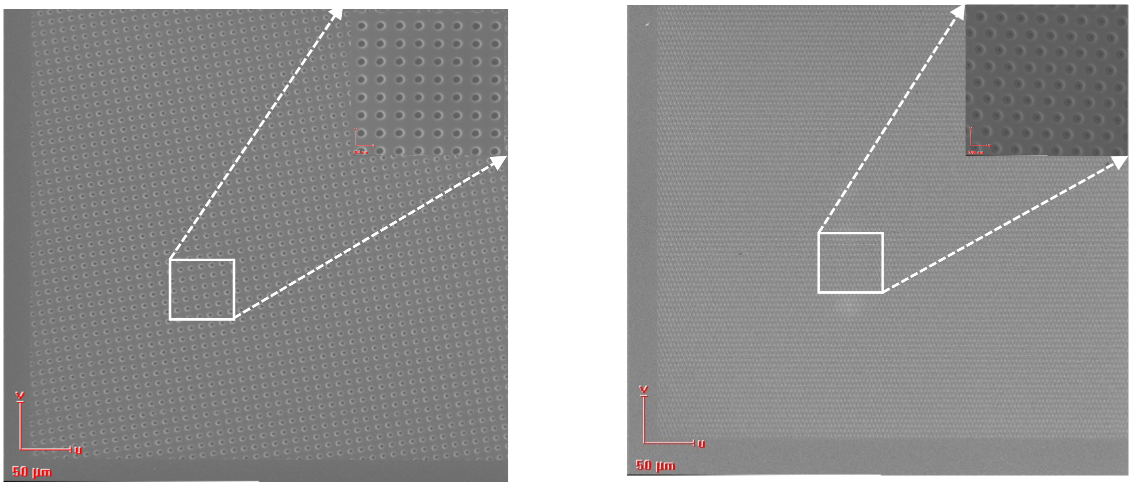
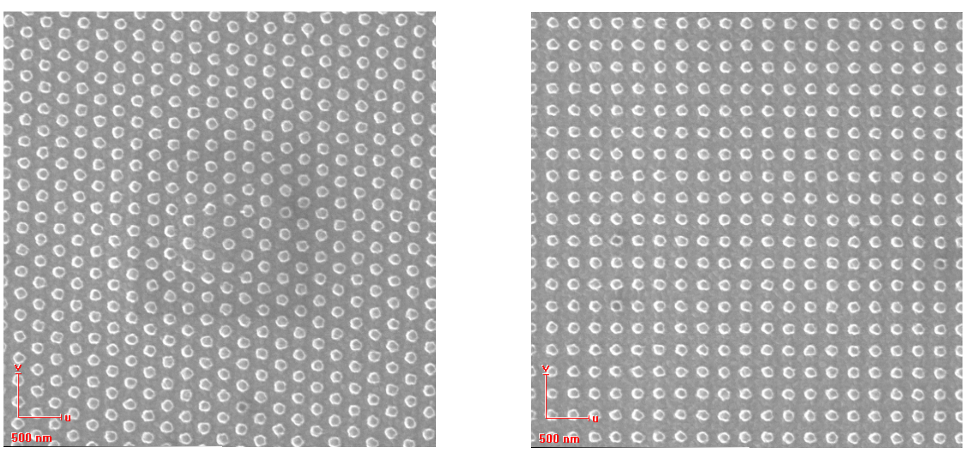


(a) (b)

Figure 1: scanning electron microscope micrographs (SEM): (a) silicon mold with square-lattice PhC holes (b) the ALD coated (30 nm-thick Al_2O_3) silicon mold



(a) (b)

Figure 2: SEM micrograph of the imprint transfer of ALD coated silicon molds (a) triangular lattice PhC pillars, (b) square lattice PhC pillars