Large area nanofabrication of dense sub-50 nm structures using ALD-enabled nanoimprint lithography

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The ability to fabricate nanostructures over large areas in the centimeter range in a cost-effective fashion is critical for a wide range of scientific and technological applications, ranging from optical devices, sensors, solar cells to bio-medical devices. However, large area nanofabrication often involves complex and costly processes. The authors have previously demonstrated feature size reduction[1] by a factor of 2 to generate nanostructures in the sub-100 nm range, using the nanoimprint technique[2], assisted with Atomic layer deposition (ALD). This approach avoids the need to fabricate nanometer scale features using electron beam lithography (EBL) since the latter technique requires extensive process development although a faster spot-EBL echnique[3] may be used for certain grating structures. In this work, the ALD-enabled Nanoimprint technique is applied to fabricate dense sub-50 nm gratings over areas as large as 10 x 10 mm. A silicon mold was 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 pattern consisted of periodic gratings (200 nm pitch, 100 nm wide lines) exposed over an area of 10 x 10 mm on a 100 nm thick ZEP 520A coated silicon chip. The exposed sample was developed and then etched using an Oxford Instruments reactive ion etcher using fluorine chemistry. The mold was then coated with an anti-release layer by the chemical vapor deposition technique, which is a critical step to prevent the imprint mask resist from sticking to the mold. The silicon mold was then used to thermally imprint the grating pattern 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 mold (300 cycles at 0.1 nm/cycle). The conformal nature and the sub-nanometer control[4] of the ALD technique ensure that the grating profile is preserved. Figs. 1 (a) and (b) show the fabricated silicon mold and the ALD coated silicon mold. There have been previous reports[5,6] on the application of area-selective ALD technique as a viable nanopatterning technique, which however, includes an electron-beam induced deposition step that can result in a complex process flow. In this work, the additional of a simple ALD coating step on the pre-fabricated imprint mold is used to 're-size' the nanostructures according to the device requirement. The ALD coated silicon mold was coated with an anti-release layer. Figs. 3 and 4 below show the images of (a) the ALD coated silicon mold (b) Atomic force microscopy (AFM) scans of the imprint results of the ALD coated silicon mold. As demonstrated by these results, the gaps between the gratings have been reduced to 50 nm or less (Fig. 2(b)) from the original 100 nm size and the imprint transfer of the gratings was successful over large areas.

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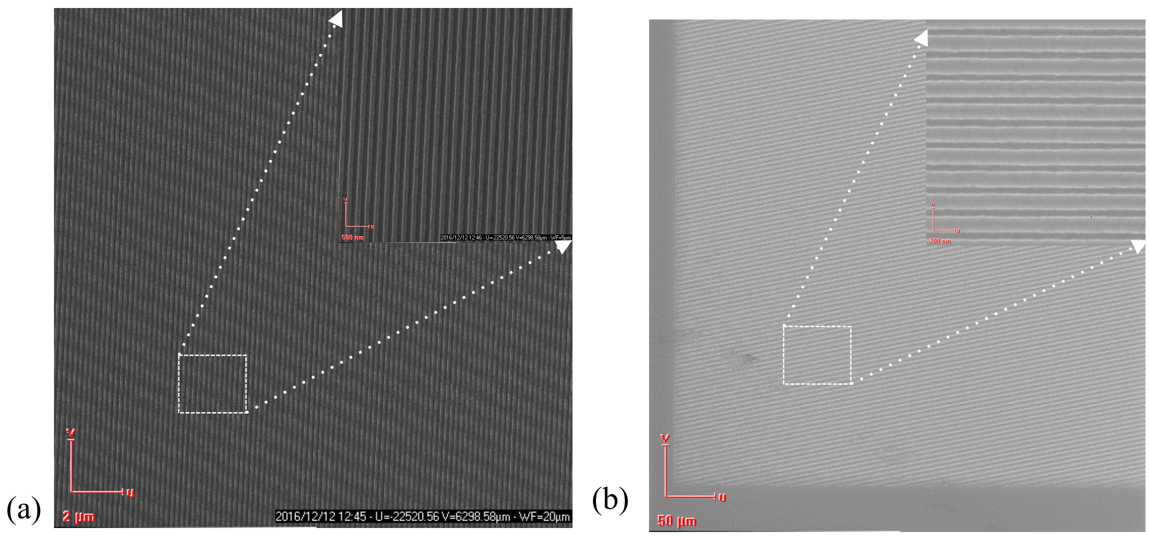

Figure 1: scanning electron microscope micrographs: (a) silicon mold with grating nanostructures, (b) ALD coated (30 nm-thick Al_2O_3) silicon mold

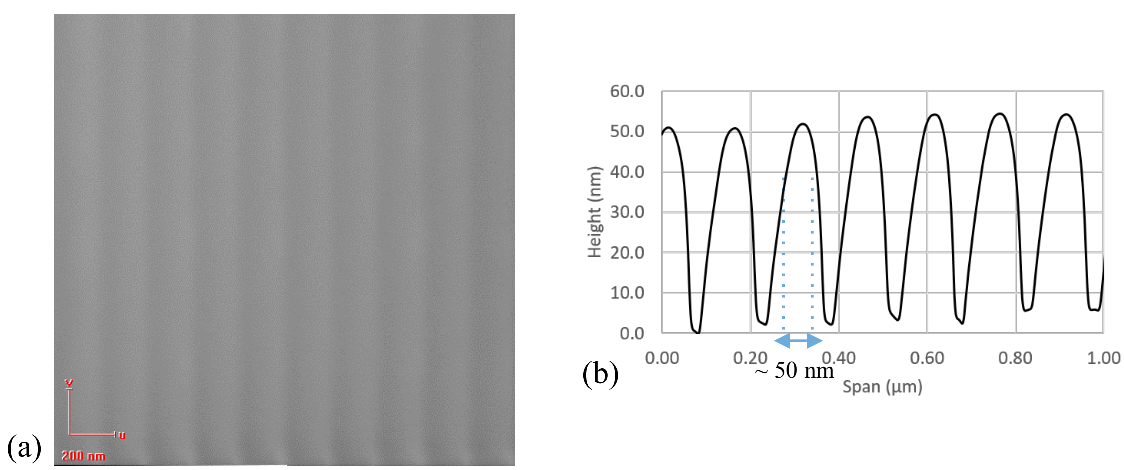

Figure 2: (a) scanning electron microscope micrograph of the imprint transfer of ALD coated silicon mold, (b) AFM scan of the imprint transfer of ALD coated silicon mold