Three-Dimensional Periodic Nanolattices with Precisely Controlled Refractive Index

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The recent developments in the field of light field and AR/VR displays have resulted from a competitive development in the industries towards emergence of new technologies to improve user experience [1-3]. The use of gradient index (GRIN) optics, meta surfaces and Bragg reflectors can be constructed to achieve more efficient manipulation of light. In these elements an important parameter of consideration is the refractive index mismatch involving low and high refractive indices. One method to achieve low-index material is to create porous nanolattice materials using 3D lithography and atomic layer deposition (ALD), which has demonstrated effective index as low as 1.025 [4,5]. However, in prior work less attention has been paid to how well the index can be tuned. The ability to precisely control the refractive index plays a critical role in the design of nanophotonic elements.

In this research we examine the precise control of refractive indices in 3D nanolattice material using nanolithography and ALD. This approach employees colloidal phase lithography to create a photoresist 3D template for ALD, which can be used to create a highly porous free-standing nanolattice. By controlling the unit-cell geometry by designing the exposure and the thickness of the ALD process, the effective index of the nanolattice film can be precisely controlled. The fabricated nanostructures were characterized using spectroscopic ellipsometry, demonstrating an index resolution of 4×10^{-4} for the proposed process. This opens a gamut of opportunities in index control and enable better performance in nanophotonic elements used in displays and other integrated devices [6].

Initial fabrication results are shown in Figure 1, where SEM images of the nanolattice patterned using 500 nm nanospheres and 21.5 nm ALD is shown. The samples used had aluminium oxide thickness values ranging from 215 to 225 ALD cycles, which results in a free-standing film that is nominally 20 nm in thickness. Cauchy model was employed in the ellipsometry with both isotropic and anisotropic models being used. An additional thin layer of SiO_2 was incorporated to capture the native oxidation of bare poly-silicon wafer. The measured refractive indices at 632 nm, nanolattice height, and MSE for various cycles of ALD using spectroscopic ellipsometry using the isotropic Cauchy model is shown in Table 1. Here data from 70 degrees incident angle and wavelengths between 400 and 1600 nm were used for the fitting. Here it can be observed that the index values vary between 1.0830 and 1.0912 for the difference of 10 ALD layers, and thereby indicating an index control of 0.0004 is achievable for a single cycle of ALD. We also observed that the measured height of the nanolattice film was in the range of 217 to 245 nm, whereas the desired values are from 310 to 325 nm. This reduction in thickness can be attributed to the reduction in height due to sagging of the structures during the annealing and can be prevented by reducing the ramp up rate of temperature. The measured index vs the ALD layer is plotted in Figure 2. Here it is observed that the slope gradually reduces with the increase in number of cycles, indicating that the effect of Al_2O_3 saturates after certain thickness in effective refractive index. We plan to present the detailed fabrication results of nanolattices with different unit cell geometry, processing challenges, and additional information on the optical characterization.

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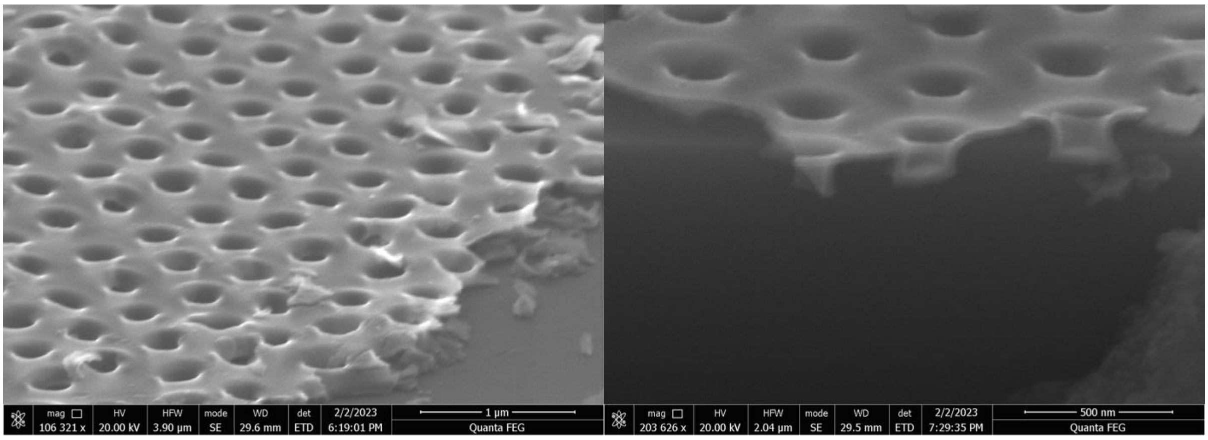

Figure 1. (a) Top-view and (b) cross-section SEM images of nanolattices fabricated with 500 nm diameter nanospheres and 21.5 nm of Al_2O_3 ALD films.

Number of Cycles	Thickness (nm)	MSE	Effective Ref. Index
215	235.582	23.09	1.08303
218	217.934	17.58	1.08712
220	235.239	20.89	1.08887
222	242.962	23.47	1.09065
225	244.369	21.33	1.09120

Table 1. Tabulated ALD cycles, measured refractive index, height, and MSE fitting error for the fabricated nanolattice samples.

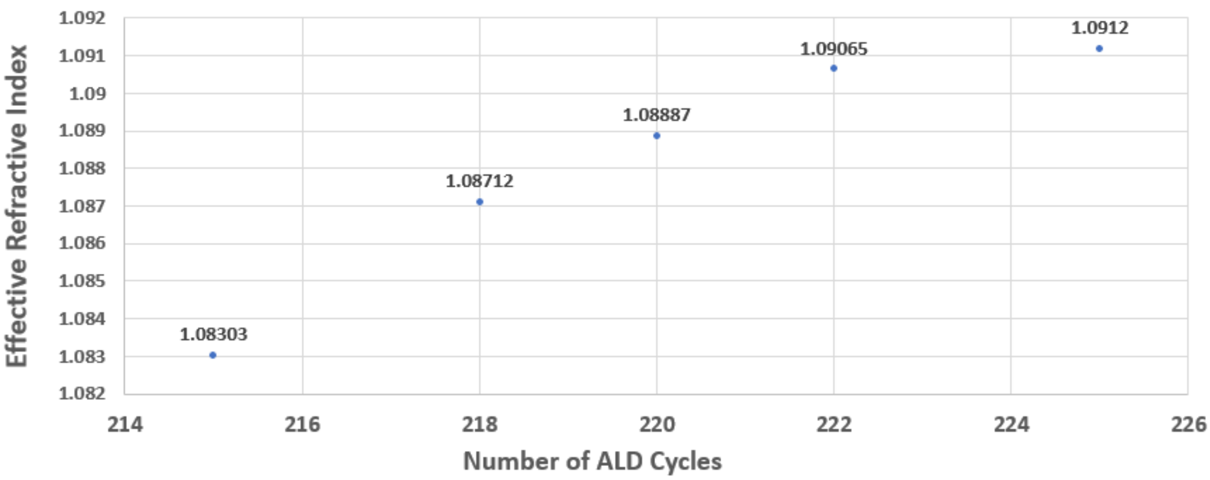

Figure 2. Measured refractive index for nanolattice with corresponding number of cycles of ALD layers using spectroscopic ellipsometry.

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