Optical Properties of "Air-Like" Ordered 3D Thin-Shell Nanolattice Materials

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The refractive indices of naturally occurring materials are limited, and there exists an index gap between air and available solid materials. With many photonics and electronics applications, there has been considerable effort in creating artificial porous materials with optical and dielectric properties similar to air while simultaneously being mechanically robust [1,2]. However, the precise control of pore sizes and arrangements is difficult due to randomness of existing fabrication processes. In previous work, we reported initial demonstration of three-dimensional periodic structures that can be used as a sacrificial template to fabricate nanolattice materials with low index, improved mechanical stability, and reduced optical scattering [3]. Here, we report the fabrication details and in-depth optical characterization of these materials.

The fabrication process for the proposed structure is shown in Figure 1, where a 3D periodic polymer template is generated using colloidal 3D nanolithography. Then a conformal coating (ZnO, Al_2O_3, etc.) is formed using atomic layer deposition (ALD), and the thickness can be controlled with atomic scale precision. The polymer template is removed by a combination of thermal treatment, solvent dissolution and plasma treatment, leaving hollow nanolattice materials. A precise computational model of the 3D template was developed using finite element time domain (FDTD) simulation and a binary resist model. The fabricated periodic hollow nanolattice materials made of 6.0 nm Al_2O_3 shells are shown in Figure 2(a)-(c). The index dispersion relationships of the porous films with different shell thicknesses are determined by spectroscopic ellipsometry, as shown in Figure 2(d). The lowest refractive index is 1.025 for Al_2O_3, and the refractive index can be tuned up to about 1.3 using ZnO to fill the natural refractive index gap. Along with the high precision and control provided by the atomic layer deposition, a systematic investigation of index design factors is possible.

Beyond the initial broadband index measurements, the material anisotropy and its application in waveguide will be studied. Since the nanolattice geometry has directional symmetry and possesses material anisotropy, the refractive indices in different directions are expected to vary. Initial measurements are plotted in Figure 2(e), where refractive indices are measured from 30˚ to 75˚ for the sample with 9.2 nm Al_2O_3 shells. A slight anisotropy is observed, which is also dependent on wavelength. Furthermore, the integration of nanolattice materials is under investigation by determining the critical angle of the nanostructured glass coating. We will present more details on the effect of different design parameters on the resultant refractive index, such as nanolattice geometry and constituent materials. We will also characterize the scattering properties of these films, since low haze is a critical requirement for high-quality optical films.

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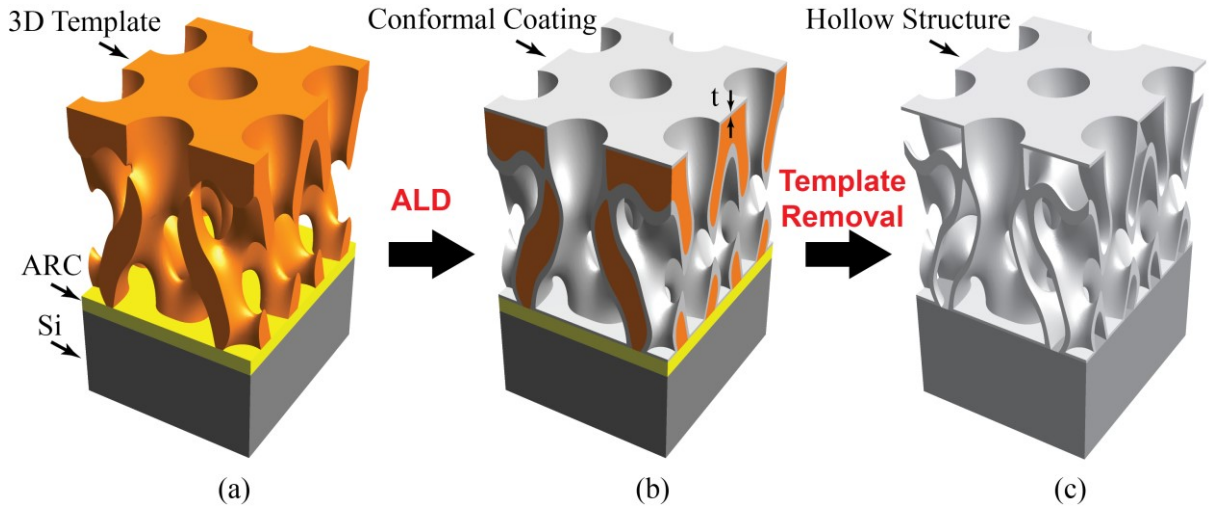

Figure 1. Fabrication process of low-index materials. (a) A 3D periodic polymer template is generated by 3D nanolithography. (b) A conformal coating with thickness *t* is formed by atomic layer deposition. (c) 3D polymer template is removed, leaving behind periodic 3D hollow structures with low effective refractive index.

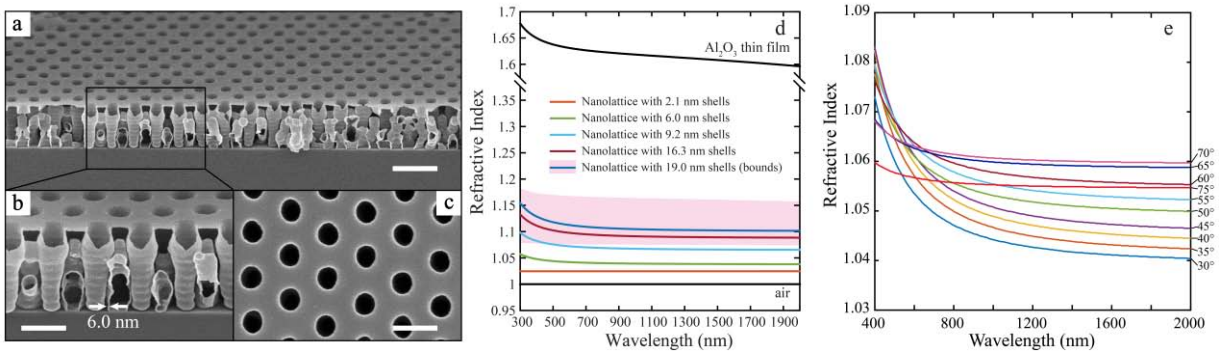

Figure 2. (a)-(c) Scanning electron micrographs of the fabricated Al_2O_3 nanolattices with shell thickness of 6.0 nm. Scale bars are 1 μm in (a) and 500 nm in (b) and (c). (d) Dispersion relationships for Al_2O_3 nanolattice materials, compared with dense Al_2O_3 thin film and air. (e) Anisotropy behavior of nanolattice materials from angles of 30˚ to 75˚.

References:

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