Design, Fabrication and Characterization of Broadband Multilayer Nanolattices

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Nanophotonics and its applications in display and AR/VR technologies have been an ever-increasing field of research interest over the past couple of decades **[1]**. A crucial component of nanophotonic elements is Bragg reflector, which requires understanding of material parameters, notably the refractive index, pivotal in optimizing light-material interaction. Factors such as the absorption coefficients, dispersion properties, apart from the geometric factors such as lattice height, volume fraction, influence the optical and mechanical properties of these elements **[2,3]**. Nanolattices with ultra-high porosity and ultra-low refractive index finds applications in efficient Bragg reflectors. The prior work from our research groups, and the presentation from EIPBN 2024 demonstrated the utilization of low-index lattices to improve the efficiency of Bragg reflectors.**[2, EIPBN 2024].**

This investigation focuses on design, fabrication and characterization of six-stack 3D nanolattices with spatially varying geometries. Two geometric combinations of alternating index pairs are utilized to achieve the near-100% reflectance. These lattices are characterized for their optical performance using spectrophotometry to achieve 100% reflectance at target wavelengths. These multilayer lattices can be utilized to confine light into the structures at design wavelengths, which could potentially behave as better Bragg reflector. The optical behavior over the spectrum of these multilayer nanolattice structures are simulated using Rigorous Coupled-Wave Analysis (RCWA). This approach enables new opportunities in reflective optics and enhances the performance of nanophotonic components in displays and other integrated devices **[4].**

The fabrication of a six-stacks of alternating high-low index lattice pairs involves the combination of precise fabrication techniques such as lithography, atomic layer deposition (ALD) and electron beam evaporation, for which the schematic and SEM image is illustrated in Figure 1. A resist layer with a height of 90 nm and 140 nm for the first three layers and the subsequent layers respectively is used to obtain different thickness of the lattice **[5].** The lattices are patterned using a 3D lithography process using hexagonally close-packed nanospheres as the phase mask. Subsequently, ALD is employed to conformally coat the patterned sample with 213 cycles of Al_2O_3, yielding a total lattice thickness of 19.3 nm. A resist layer is applied over the porous lattice to planarize the surface to improve structural stability to the subsequent layers stacked. On top of the planarized layer, a high-index solid layer of TiO_2 is deposited using EBE to a thickness of 120 nm and 180 nm for the first three layers and subsequent layers respectively. This series of processes are repeated to fabricate six layers. Finally, the resist is removed from the lattice structure via thermal desorption, completing the fabrication process.

Reflectance measurements were conducted using the UV-Vis-NIR spectrophotometer as shown in figure 2. The observations indicated that the peak reflectance of 94.6% was achieved with >90% for broadband wavelengths between 400 nm and 1600 nm. A reflectance dip between 450 nm to 625 nm is observed owed to the destructive interference. However, the difficulty in fabricating multiple stacks and associated structural collapse results in the limitation of these nanolattice structures. The modelling of these lattices was also performed, using RCWA simulations wherein the reflectivity across spectrum is obtained for given geometries and refractive indices of periodic lattices. It can be noted that the experimental and simulated optical properties match closely well, thereby yielding great control over light manipulation at broadband wavelengths. The simulation of the 90/120, 140/180 and six-stack combination is shown in figure 2 as solid lines. These different geometric parameters for alternating pairs of lattices superimpose the spectrum over which destructive interference occurs, thereby increasing the bandwidth of peak reflectance.

We intend to present comprehensive results on the fabrication of nanolattices featuring varied unit cell geometries, highlighting the challenges encountered during processing and providing detailed insights into spectrophotometry characterization. A complete broadband reflector can be achieved by overcoming the destructive interference dip which in turn can be achieved by adding subsequent layers over the top of the existing six stack.

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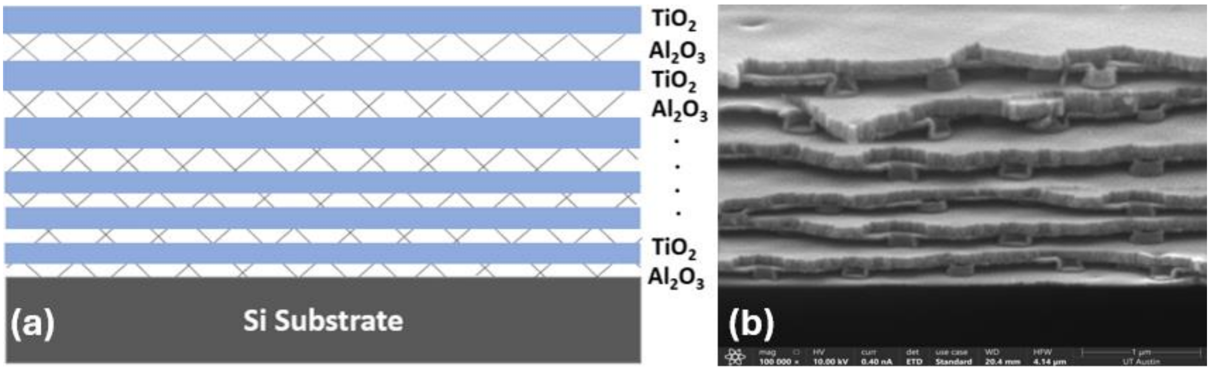

Figure 1. (a) Cross section schematic (b) SEM image of a six-stack lattice with 90nm/120nm of Al_2O_3 /TiO_2 (3 stacks) and 140nm/180nm of Al_2O_3 /TiO_2 (3 stacks).

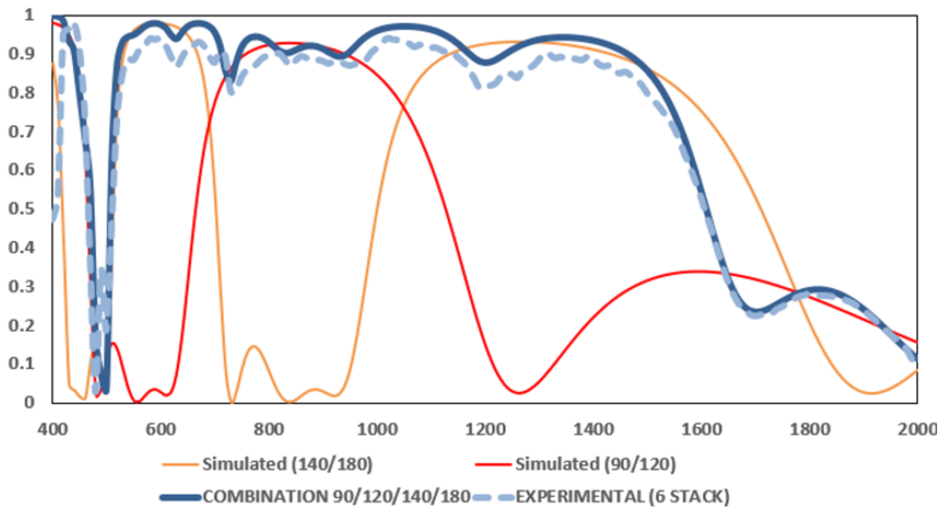

Figure 2. RCWA simulations of multilayer lattices consisting of near 100% reflectance over spectrum for a six-stack lattice with a combination of 90/120 (3 stacks) and 140/180 (3 stacks). The spectrophotometer data matches the modified design TMM.

References:

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