Gradient-Index Nanolattices Using Multilayer Processing

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Antireflection structures have been widely researched and various methods have been proposed to reduce the Fresnel reflection losses from the mismatch of the optical index on the interface of two different materials [1-2]. One solution is placing a layer with gradual-vary optical index to bridge the index discontinuity on the boundary. Previous studies have shown that by building a layer of tapered nanostructure [3] or a gradient-index (GRIN) multilayer stack,[4] a more continuous boundary can be achieved to reduce the transmission energy loss. In our previous work, multiple layers of periodic nanostructures have been successfully built in a single stacking, and the material properties of each layer can be controlled individually.[5] Here, we demonstrate the results of this technique and its potential application as an antireflection medium.

The processes of the proposed fabrication approach are illustrated in Figure 1(a). The periodic nanostructure is first patterned by phase-shift lithography process in which a monolayer of hexagonal-close-packing nanospheres is employed as the near-field phase mask. A thin shell of oxide layer is then deposit onto the nanostructures by the atomic layer deposition (ALD) to protect the underlying structures. Further photoresist patterning and ALD processes can be used to build multiple nanolattice layers on the existing pattern, and free-standing thin-shell structures can be made after removing the photoresist by high temperature. The geometry and material of each layer can be controlled by the lithography and ALD parameters, allowing great control over the effective refractive index to create a GRIN medium.

Initial fabrication results are shown in Figure 1(b), where 5 layers of nanolattice thin shells are fabricated. The EDX image shows the material and geometry of each layer can be fabricated individually. In this case, the layers are made by zinc oxide, aluminum oxide, zinc oxide, titanium oxide, zinc oxide, respectively. Using this method, a multiple layers of nanolattice thin-shell stacking with gradient index is built on a silicon substrate to create the GRIN medium. The ALD thickness conditions for each layer from bottom to top are 40 nm and 25 nm of titanium oxide, and 15 nm and 10 nm of aluminum oxide, and the corresponding optical index are 1.69, 1.40, 1.21 and 1.08, respectively. Initial characterization shows that this GRIN suppresses 60% to 90% of the specular reflectance under the incident condition between 4 to 70 degree. Figure 2(a) and (b) show the TE and TM specular reflectance for 633 nm laser. In both cases, the specular reflectance reduces as the layer number of nanolattices increases. The proposed GRIN nanolattice material also demonstrates effective antireflection property of <6% reflection between 400 nm to 2400 nm wavelength. More optical properties as the diffuse reflectance and the numerical model of the stacking structures will be further explored and presented. This novel technology shows a breakthrough in the ability to control the lattice geometry and material of complex multilayer nanolattices.

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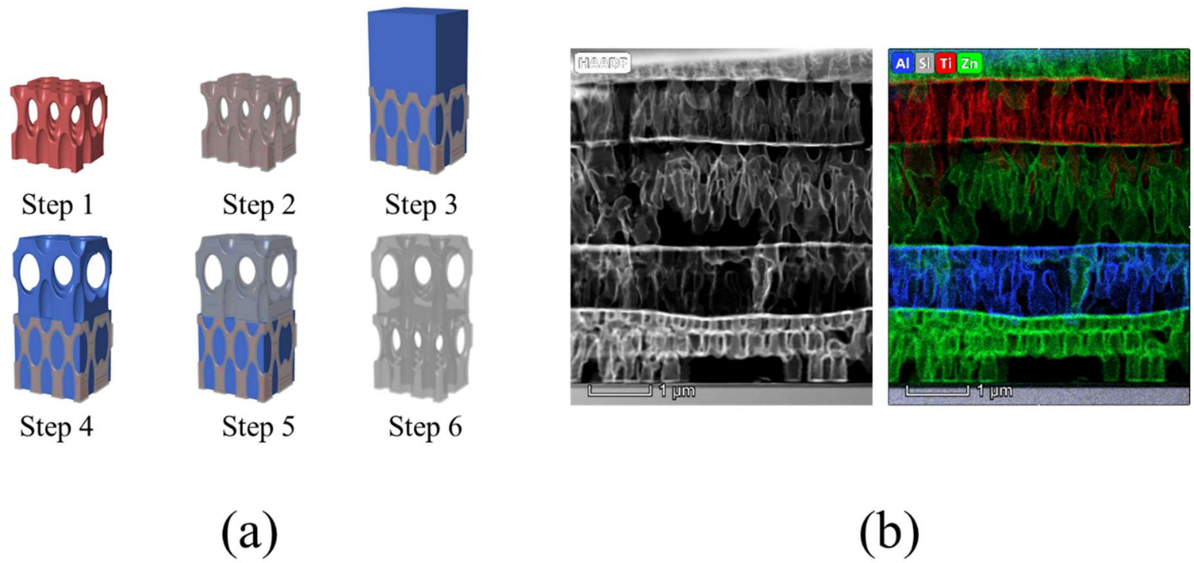

Figure 1. Fabrication processes and the result of the multiple layers nanolattice stacking (a) manufacturing process (b) TEM image and the EDX of a zinc oxide, aluminum oxide, titanium oxide nanolattice hybrid stacking.

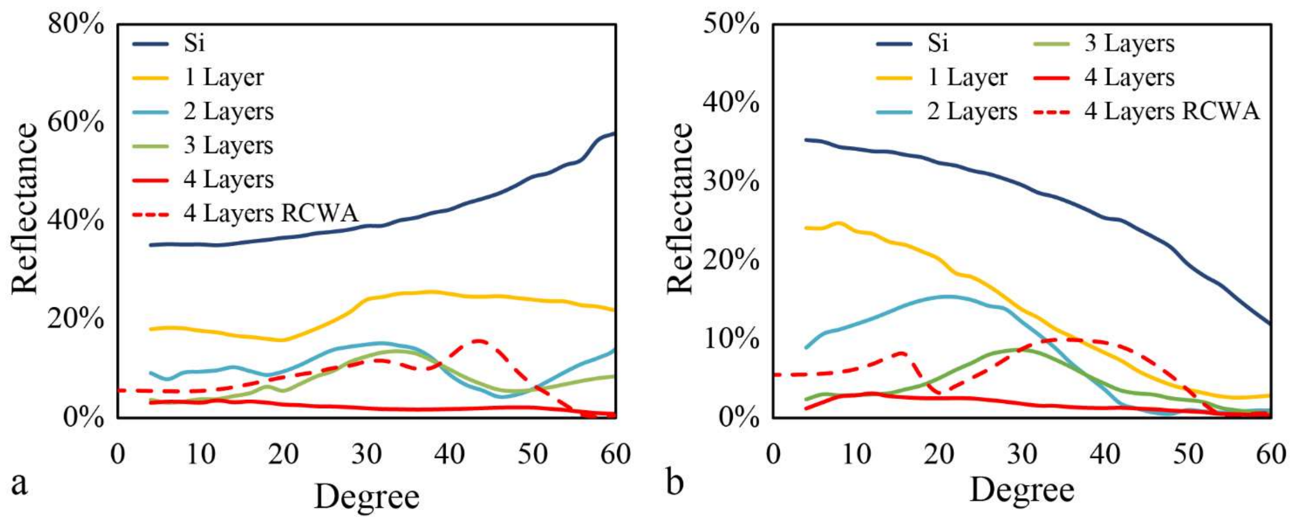

Figure 2. Specular reflectance of the multiple layers process. (a) specular reflectance for 633 nm TE incidence (b) specular reflectance for 633 nm TM incidence.

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