Multilayer Stacking of 3D Periodic Nanostructures Assisted by Atomic Layer Deposition

I-Te Chen[1],* Dennis T. Lee[2], Gregory Parsons[2] and Chih-Hao Chang[1]

[1]Department of Mechanical and Aerospace Engineering, North Carolina State University
[2]Department of Chemical and Biomolecular Engineering, North Carolina State University
Raleigh, NC 27695, USA

Periodic three-dimensional (3D) nanostructures process unique physical properties due to their nanoscale features, and have different applications in photonics, acoustics and mechanics [1-2]. Therefore, a number of 3D nanolithography techniques, such as multiple beams interference lithography [1] and phase-shift lithography using near-field phase mask [2] or colloidal particles [3,4] are employed. However, the thickness of structures fabricated using these approaches are restricted to the light absorption of the resist material, and is typically less than 10 μm. Moreover, the structure parameters (period, feature size, duty cycle, etc.) cannot be readily changed from layer to layer, making patterning of nanostructures with depth-varying properties challenging.

In this work, we investigate a novel approach to stack multiple layers of 3D periodic nanostructures in consecutive steps. This method employs a thin ceramic layer fabricated by atomic layer deposition (ALD) as the protection shell of the underlying layer, which allows the further processing of additional photoresist patterning. The proposed fabrication method is illustrated in Figure 1, where the initial patterned structure is coated by a conformal oxide film using ALD. Another layer of photoresist is then coated without damaging or dissolving the existing structure, allowing a second lithography step to pattern a new structure above the original one. This method can be repeated to stack 3D layers and fabricate thicker structures, with the possibility of changing the exposure parameters between each step. A finial ALD should be deposited after entire processes and then the photoresist will be removed by evaporating with high temperature in an oven. By this method, we can integrate different structures in a single stacking with different parameters.

Initial results are shown in the scanning electronic micrograph (SEM) image on Fig 2., which shows the stacking patterning process. Fig 2(a) demonstrates the second layer photoresist has been patterned with 500 nm colloidal particles above an underlying layer with ALD shell protection. The ALD thin film prevent the first layer pattern from dissolving during the second coating step, and the following photoresist could also fill and protect the empty space of the bottom. Fig 2(b) and (c) show the 10 nm-thick ALD nanolattice after removing the photoresist by thermal treatment. Here the period of the bottom layer period of both cases are 350 nm, but the top layer is designed to be (b) 390 nm and (c) 500 nm, respectively. This process can also be employed to manufacture flat thin film above a rough surface, Fig 2(d) shows an additional photoresist deposition is employed after the ALD process and followed by an aluminum layer deposition on the second photoresist layer, after removing the photoresist template, the remaining ALD 3D nanolattice is covered by a flat metal layer and shows better reflectivity than direct deposition. We will also present unique material properties and processes flexibility of the proposed stacking structure. The investigated process is a convenient integration of additive and subtractive manufacturing with wide applications to enhance the existing technology.

* ichen5@ncsu.edu

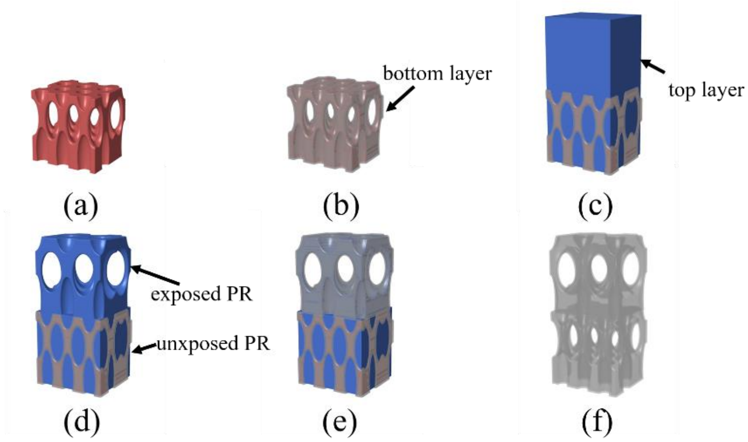

Figure 1. Manufacture of multiple layers processes (a) original 3D structure on the substrate, (b) 1st ALD coating, (c) deposit the material of 2nd layer, (d) pattern 2nd layer, (e) 2nd ALD coating, (f) remove photoresist.

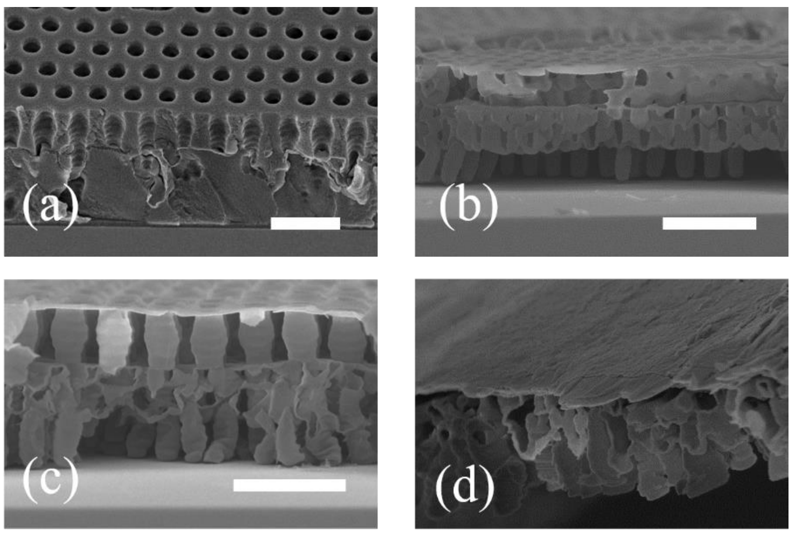

Figure 2. SEM of fabricated preliminary results. (a) Patterned second layer of photoresist on ALD-coated first layer. Stacked ALD nanolattices with 350 nm period at bottom and (b) 390 nm and (c) 350 nm period top layer, respectively. (d) Smooth aluminum layer on a rough ALD nanolattice.

References:

[1] *J.-H. Jang et al., Adv. Funct. Mater., 2007. 17,3027-3041.*
[2] *S. Jeon et al., PNAS, 2004, 101, 12428-12433.*
[3] *C.-H. Chang et. al., Nano Letters, 2011, 11, 2533-2537.*
[4] X. A. Zhang, *et. al., ACS Nano, 2013, 7(7), 6212-6218.*