# Design of Hierarchical Three-Dimensional Porous Nanostructures using Template-Directed Colloidal Assembly

Jonathan E. Elek*, Xu A. Zhang, Zhiyuan Xu, and Chih-Hao Chang
*Dept. of Mechanical and Aerospace Engineering, North Carolina State University*
*Raleigh, NC 27695, USA*

Many hierarchical 3D micro/nanostructures with useful material properties for various organisms have been observed in nature, common examples of which are the wetting properties of the lotus leaf[1] and the Namib Desert beetle[2]. These observations have led to efforts to improve upon the hierarchy observed in nature in a lab setting, where the parameters of a designed bio-inspired surface can be engineered for specific applications[3-7]. In these applications of hierarchical structure, the micro/nanoscale geometries are critical in the structure and device performance and should be independently designed.

In this work, we demonstrate the independent design of the micro and nanoscale geometries for hierarchical nanostructures using template-directed colloidal lithography. In this approach, as illustrated in Figure 1, the periodic array of particles functions as a phase mask for optical lithography, recording 3D intensity patterns in the photoresist[8]. Building upon our previous proof-of-concept demonstration, in this work we seek to establish the relationship of the microchannel and nanostructure lattice parameters as a function of template geometry, particle size, and incident light wavelength. The goal is to independently design and control the channel and 3D nanostructure geometry in a single integrated fabrication approach.

Initial demonstrations of the length scale effects are illustrated in Figure 2, where colloidal particles in the 1D template with channel width of 2, 3, and 4μm result in different porous structures. These initial experiments indicate that larger template width results in high defects during particle assembly, which can be readily detected in the fabricated structures. Figure 3 shows preliminary results comparing the geometry of the periodic nanostructure using 500 and 390nm particles exposed to UV light with $\lambda = 325\text{nm}$. The fabricated structures have axial periods of 1800nm and 1016nm, respectively, which can be predicted using the Talbot effect. Note that for an initial photoresist thickness of $t\sim1.5\mu\text{m}$, one full Talbot period is not recorded with an array of 500nm particles at this exposure wavelength. Continuing work will use exposure wavelengths of 325, 365, and 405 nm with particles of varying sizes to demonstrate the specific design of lattice parameters of the resulting 3D structures. We will examine the micro and nanoscale geometry using analytical models and finite-difference time-domain (FDTD) modeling. The model is then compared to experimental results to demonstrate the ability to engineer the porous 3D structures according to application needs.

*jeelek@ncsu.edu

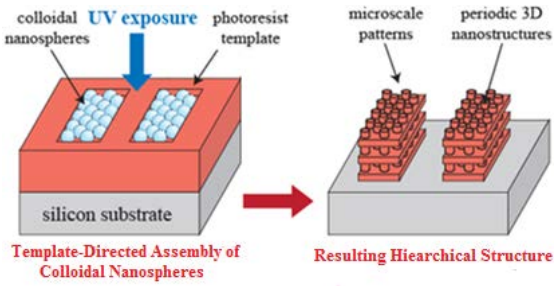
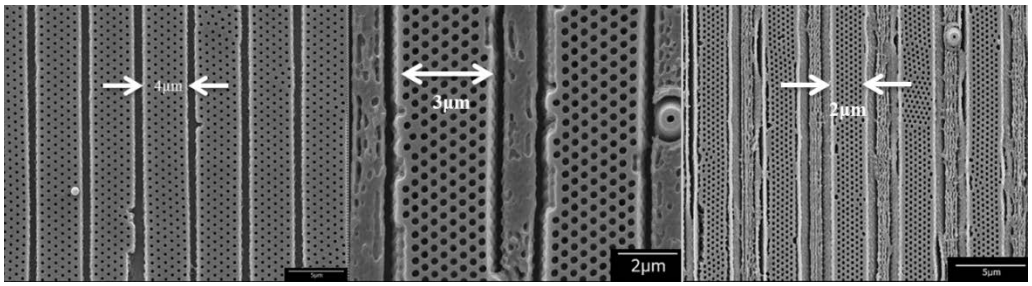
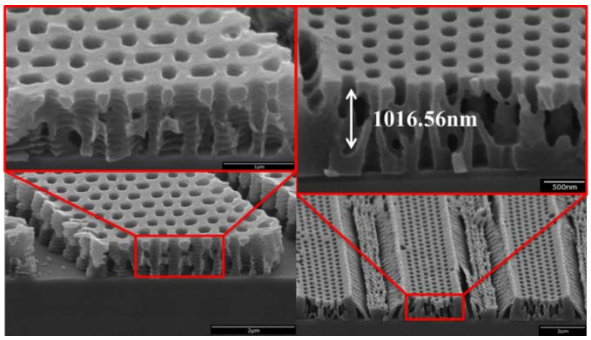



*Figure 1* Fabrication of hierarchical 3D nanostructures.




(a) (b) (c)

*Figure 2* SEM image of top view of structures fabricated by template-directed self-assembly of colloidal particles in (a) 4 µm, (b) 3 µm, and (c) 2 µm width channels. Underexposure of (b) and (c) leads to residual photoresist in the interstitial region




(a) (b)

*Figure 3* Cross section of structures using (a) 500nm and (b) 390nm particles.

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[1]H. G. Andrews *et. al.*, *Langmuir* 2011, *27*, 3798-3802.
[2]W.J. Hamilton *et. al.*, **Nature** Vol. 262, July 22 1976.
[3]K.-C. Park *et. al.*, *ACS Nano* 2012, Vol. 6, No. 5 3789-3799.
[4]B. White *et. al.*, *Applied Surface Science* 284 (2013) 826-836.
[5]C. Dorrer *et. al.*, *Langmuir* **2008,** *24*, 6154-6158.
[6]R.P. Garrod *et. al.*, *Langmuir* **2007,** *23*, 689-693.
[7]L. Zhai *et. al.*, *Nano Lett.*, Vol. 6, No. 6, **2006**.
[8]J. Elek, X.A. Zhang, and C.-H. Chang *57th EIPBN*, Nashville, TN, May 30, 2013.