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3D Composite Structures for Storing, Generating, and Harvesting Photons and Electrons

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Abstract – Through self and directed assembly, often in conjunction with optically based patterning approaches, we have formed three-dimensional inorganic and organic structures with unique optical and electronic properties with characteristic length scales ranging from a few nm to a few microns. Our efforts have focused on 3D photonic crystals, formed either through colloidal self-assembly or multibeam laser interference, optically definable inorganic materials, unique nanostructures that can be formed using colloidal crystals as templates as well as the properties of these structures for battery, solar energy, sensing, and optoelectronic applications.

Three-dimensional micro- and nanofabricated structures have numerous applications in photonics, microfluidics, energy storage, tissue engineering, drug delivery, chemical detection, and data storage. Many serial techniques exist for micro- and nanofabrication, including layer-by-layer photolithographic approaches, nanotransfer printing, microstereolithography, multiphoton polymerization, and ink-based direct-write assembly, but high cost and slow patterning speeds make scale-up difficult. Self-assembly techniques provide rapid routes to form large-area micro- and nanostructures, but they suffer from poor control over defect density and limited flexibility in the types of structures that can be fabricated [1]. For some applications, such as electrochemical energy storage, the inherent low defect density may not be an issue. However, for applications which require very exquisite structure, interference lithography, which relies on the interference of multiple coherent beams of light, is a popular choice due to the potential to fabricate nearly defect-free 1D, 2D, and 3D periodic microstructures over large areas using one or more parallel exposures [2]. By tuning the number of laser beams and their relative orientation, intensity, and polarization, interference lithography offers great flexibility in the periodic lattices and structural motifs that can be formed.

Through self-assembly of polymeric and oxide based colloidal particles, followed by materials deposition and etching strategies, we have formed both Ni metal hydride and lithium ion battery electrodes which enable high efficiency ultrafast discharge kinetics. Figure 1 gives the procedure for fabricating the 3D macroporous nickel electrode starting from a self-assembled polystyrene colloidal crystal and finishing with a Ni-$Ni(OH)_2$ composite structure and the discharge performance of this structure at different discharge rates.

For optical applications, large area, defect free structures are of the greatest interest. Over the past few years, we have created a series of organic [2] and inorganic [3] multidimensional photonic crystal structures via interference lithography(Figure 2), and developed procedures to convert them into high refractive index photonic band gap materials containing features such as waveguides, optical emitters, and optical cavities.

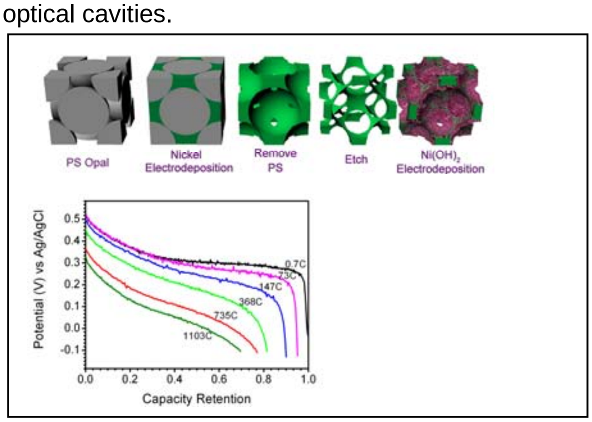

Figure 1: Top, fabrication process for forming the battery electrode. Bottom, discharge characteristics as a function of discharge rate (1C = 1 hour discharge).

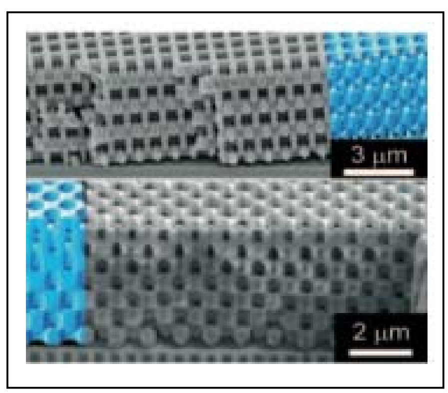

Figure 2: Inorganic 3D photonic crystal created via interference lithography.

References

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