Formation of Hierarchical Nanoparticle Patterns with Colloidal Lithography and Two-Step Self-Assembly

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Nanoparticle films containing multiple length scales have broad application to electronics, photonics, bio- and chemical sensors, and catalysis. Lithographically defined approaches to the formation of patterned nanoparticle patterns, both with the lithographic step before the particle deposition (templated self-assembly), and with the lithographic step following the deposition of a blanket nanoparticle film, have been demonstrated. Self-assembly is a very convenient process to generate nanoparticle films and colloidal crystals. Here, we demonstrate the use of colloidal lithography (CL) to define hierarchically patterned nanoparticle films.

First, we employed a two-step self-assembly to form first an underlying film of small spherical particles (SiO_2) followed by an overlayer(s) of larger spheres (polystyrene) of a different composition. Using reactive ion etching (RIE), the densely packed patterns defined by the overlayer colloidal particles are transferred into the bottom nanoparticle film. Finally, the top layer is selectively removed to form the patterned nanoparticle film (Fig. 1).

This approach is applicable to both silica and polystyrene nanoparticles. Hexagonal patterns of nanoparticle film were easily fabricated with a monolayer of large spheres using this approach (Figure 2). Furthermore, the shape and diameter of nanoparticle film discs depend on the etching duration while the periodic aspect of the initial layer is preserved during the etching process. The process is quite flexible with variations in size and packing of both particle layers, and quite inexpensive since it does not involve any top-down lithographic step. In addition, more types of patterns can be realized by varying the number of large particle layers, the crystal orientation and the RIE conditions in CL defined nanoparticle film. This approach offers a novel and simple method for fabrication of patterned nanoparticle films useful for material growth, biosensors, and catalysis as well as serving as a building block for further fabrication.

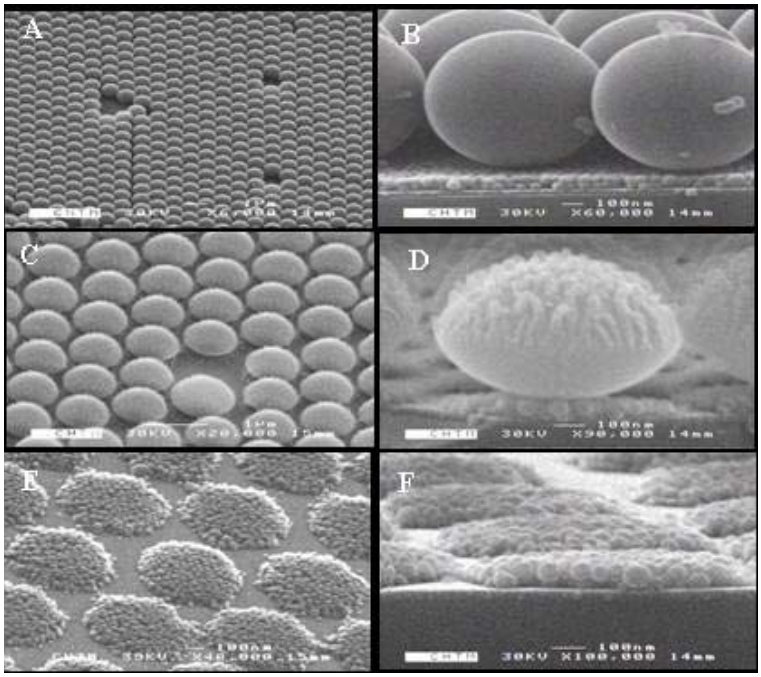

Fig. 1. SEM images of a colloidal monolayer of 1000-nm PS spheres atop a 50-nm silica nanoparticle film: (A)-(B) two-step self-assembly, (C-D) after 6-min RIE, (E-F) after removal of PS spheres.

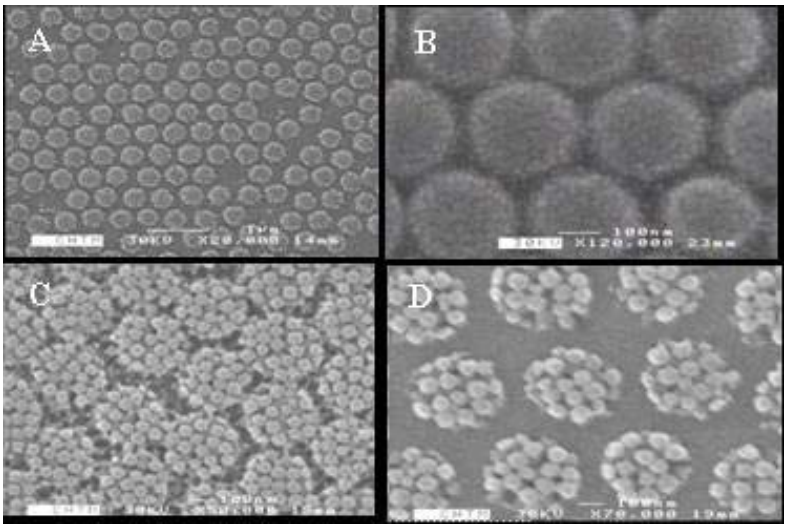

Fig. 2. SEM images showing the flexibility of this approach: (A) 50-nm silica particle patterns using 500-nm PS spheres in top layer; (B) 15-nm silica particle using 290-nm PS spheres in top layer; (C)-(D) 100-nm PS particle patterns using 520-nm silica spheres in top layer after O_2 RIE and after O_2/CHF_3 RIE, respectively.