Flow Programmed Mesoscale Assembly of Nanoengineered Materials and Net Shape Components

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We have reduced to practice a bottom-up mesoscale assembly tool capable of integrating highly dissimilar materials and producing features with critical dimensions in the submicron range. This system enables nanometer-scale precision synthesis of millimeter-scale materials and parts in a simple, low-cost system.

We perform this synthesis by computer-controlled electrophoretic deposition in a miniature aqueous deposition cell interfaced to computer-controlled automated fluidics. Nanoparticle solutions are available in a wide and ever-growing variety of material compositions, morphologies, and surface chemistry states. We introduce mixtures of various precursor solutions into the deposition cell, and deposit nm- to µm-scale layers by the pulsed-field electrophoretic deposition of particles onto substrates. We use post-deposition sintering to achieve densification of these films.

The high degree of control and wide range of heterogeneous materials made accessible by this approach brings powerful, low-cost capabilities to the fabrication of density- and composition-varying layers. The highly conformal nature of the deposition allows the fabrication of near-net shape high precision parts. The lack of need for vacuum conditions allows high-speed and low-cost nanomaterial synthesis in a simple benchtop system.

The system is available for follow-on work to capitalize on the broader capabilities it makes accessible, including the programmed synthesis of parts incorporating dissimilar and custom materials, the *in-situ* fabrication of hemispherical and other net-shape parts, and ultimately the electronically-controlled biochemically templated nanoscale self-assembly of nanostructured composite and functional materials.

Project Goals

The goals of this project were to: 1) produce a powerful and flexible prototype system for mesoscale assembly, ready to be leveraged for future work; 2) demonstrate the synthesis of porous polymer layers with defined, varying density profiles, via the computer-controlled electrophoretic deposition of submicron polystyrene spheres; and 3) convert an existing Brownian dynamics simulation code for this application.

Relevance to LLNL Mission

The proposed project is a seed effort for a new, integrated, mutually supporting, and dynamic multi-project portfolio in novel nanomaterial synthesis capabilities for mesoscale manufacturing. This portfolio is directed to LLNL application areas in target materials and structures, sensor materials, and biodetection devices. The short-term payoff is the creation of new nanoscale target structures. The proposed technology is ideal for combining novel nanomaterial components such as engineered nanoparticles, carbon nanotubes, and others into complex materials and structures.

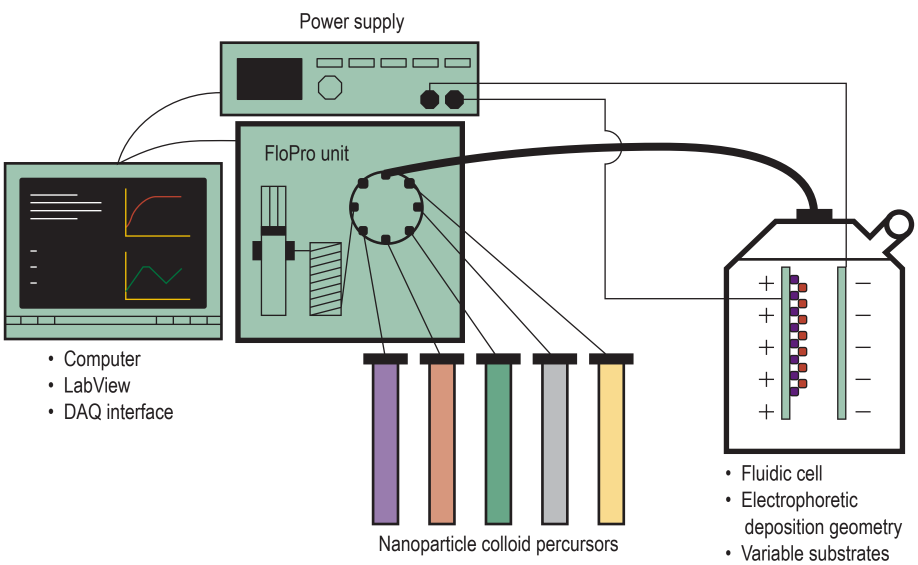

Figure 1. Schematic of the mesoscale assembly system. A FloPro unit provides automated valving and pumping to move particle solutions through the deposition cell. The power supply provides either constant voltage or constant current across the particle-laden fluid. The fluidics and the power supply are controlled via Labview software for full automation.

FY2007 Accomplishments and Results

We have accomplished the overall goal of this project by delivering the automated mesoscale assembly system. Specific results and accomplishments include the following.

1. Instrumentation (Figs. 1 and 2): Built a prototype system by combining a mini FloPro system (Global FIA) for automated control of the sample solutions, LabView-based control architecture, and a custom built miniature electrophoretic deposition cell.
2. Process testing and reduction to practice: Carried out a series of parametric tests to quantify and optimize the aqueous electrophoretic deposition process to allow predictive control; tested multiple electrode materials, particle materials, solution properties, and applied electric field.
3. Film synthesis: Demonstrated the deposition of thick (> 50 µm) films of polystyrene particles using particles of a single diameter; also demonstrated stacked film layers as shown in Fig. 3.
4. Density-gradient materials. Produced a two-layer film with a base layer of 200-µm polystyrene particles and 80-nm gold particles (Figs. 4 and 5).

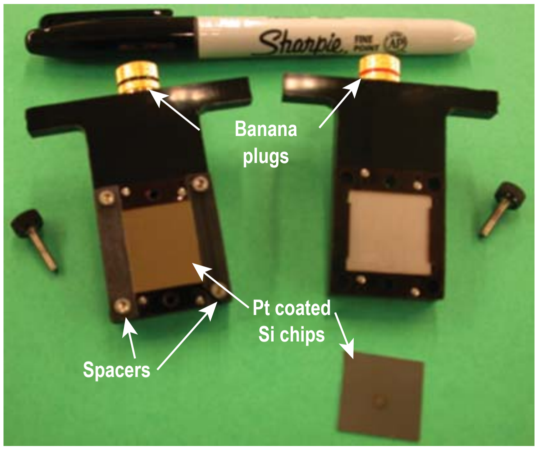

Figure 2. Exploded view of the electrophoretic deposition cell. The cell holds the platinum coated electrodes at a fixed distance to maintain a uniform and constant electric field. Depending on their charge, the particles are deposited onto either the cathode or the anode.

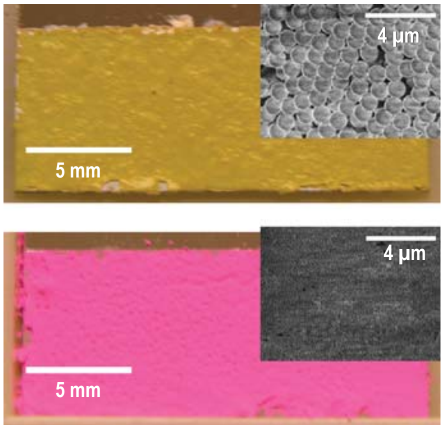

Figure 3. Examples of particle films of single particle types. Top: 1-µm-diameter yellow-green polystyrene particles deposited approximately 150 µm thick. Bottom: 200-nm-diameter red polystyrene particles deposited approximately 60 µm thick. Insets show SEM images of the top surface of the respective films.

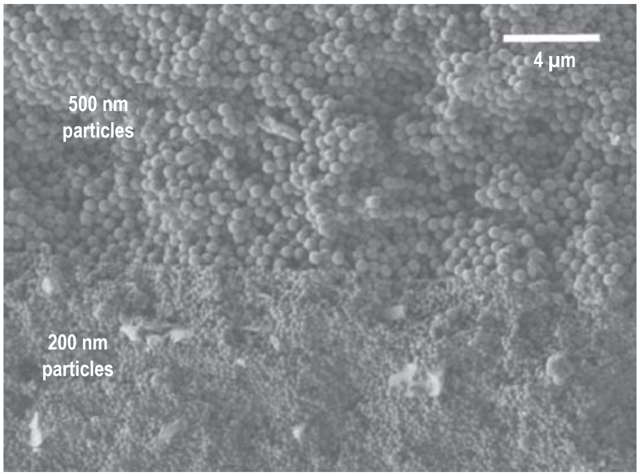

Figure 4. SEM cross-section of a two-layer particle film. The bottom layer is approximately 60 µm thick and comprised of 200-nm-diameter polystyrene particles. The top layer is approximately 15 µm thick and comprised of 500-nm-diameter polystyrene particles.

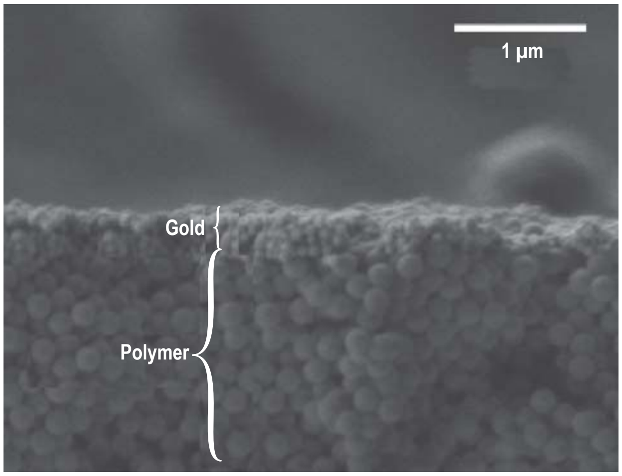

Figure 5. SEM cross-section of a two-layer particle film. The bottom layer is approximately 17 µm thick and comprised of 200-nm-diameter polystyrene particles. The top layer is approximately 300 nm thick and comprised of 80-nm-diameter gold particles.