Nanofabrication of Multifunctional Nanoscale Materials within Nanoporous Materials and on 2-D Substrates

CNF Project # I448-06
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Abstract:
Our research group is interested in developing novel nanostructured materials possessing multifunctional groups; these materials are created by combining “bottom-up” and “top-down” synthetic approaches such as electrodeposition, electroless deposition, chemical vapor deposition, self-assembly, sol-gel processing, wet-chemical synthesis, and reactive ion etching. The two or more functional groups or structures introduced into these materials have resulted in the material possessing two or more properties which allow them to perform either multiple applications or to increase the efficiency of the optical response and the magnetic and catalytic activities of the materials. By virtue of their multifunctional groups as well as structures at the nanoscale, these materials will find future applications in photovoltaics, nanoelectronics, and nanophotonics devices and for catalysis and biomedical applications.

Summary:
The design, synthesis and self-assembly of nanostructured materials are important steps leading to the development of novel miniaturized nanoscale devices for optical, electronics, photonics, sensing, biological or medical applications. To realize the tremendous potential of nanomaterials for diverse applications, we use various “bottom-up” approaches of wet-chemical synthesis and molecular self-assembly combined with “top-down” approaches of engineering nanomaterials to create novel nanoscale materials having multiple functional groups with well-defined nanoscale structures.

In one approach, we prepare nanoporous alumina substrates (0.2 µm diameter and 10 µm width) via electrochemical anodization of aluminum thin films [1] and we use the resulting nanoporous materials as hard-templates to produce silica and organosilica coated conductive metallic nanowires such as copper, silver and gold via electrodeposition.

To perform the electrodeposition in the nanochannels of these materials, we first deposit thin conductive layers of metals on one side of the substrate either via sputtering or thermal evaporation. We have successfully used aluminum sputtered and silver thermal evaporated nanoporous alumina substrates for our electrochemical deposition experiments. Results to date indicate that the Ag thermal evaporated substrates work better for copper electrodeposition inside the nanochannels of the alumina forming well-defined nanowire structures. We speculate this success is because the silver thermal deposition on the nanoporous alumina formed smooth conductive layers.

By changing the deposition times and deposition potentials, we have been able to collect free standing metal-silica (or metal-organosilica) core-shell nanowires. The silica or organosilica layer in these materials, which has low dielectric constant, provides an insulating layer to the metal and would be an important component when assembling these nanowires on solid devices for future nanoscale electronic components [1]. The nanowire materials we prepared before and after deposition are characterized by methods such as scanning electron microscopy, transmission electron microscopy, atomic force microscopy, UV-Vis-NIR spectroscopy and X-ray diffraction.

In other work, we prepare metal-thiolate precursors by reacting metal chlorides with alkanethiols and we spin-coat the resulting metal-thiolate precursors on noble metal nanopattared Si-wafers. By performing e-beam lithography on the metal-thiolates decorating the substrates, we form nanopatterns and write semiconductor metal-sulfide nanostructures on the substrates by using seeded mediated nanostructure formation. For instance, by depositing Zn-dodecanethiolate on gold nanoparticles containing Si-wafer substrate followed by e-beam writing, patterns of semiconducting ZnS nanoparticles or nanowires preferentially grow around the gold nanoparticles forming nanostructures. Electron beams are used to pattern structures of noble metals such as gold nanoparticles from gold-thiolate on solid substrates. We characterize the resulting substrates with UV-Vis-NIR, atomic force microscopy and scanning electron microscopy.

References:
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CNF Project # 1448-06
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Figure 1, left: Synthetic scheme of nanotube and nanowire deposition within the nanochannel pores of porous alumina “hard-template”. The arrows indicate nanotubes and nanowires that can be deposited within the nanoporous alumina via electroless deposition or electrodeposition, respectively.

Figure 2, below: Copper nanowires electrodeposited inside Ag-sputtered nanoporous alumina channels. This side-view image shows the copper nanowires as well as empty channels of the alumina nanochannels that are not yet filed. By controlling the deposition times and electrodeposition potential, we can grow metallic nanowires of various lengths.