Engineering Nanoscale Building Blocks for Macroscopic Functionality

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Our research group works to develop a fundamental understanding of how to program and process nanoscale building blocks into functional structures, and the structure-property relationships of the resulting nanostructured materials. We seek to develop new nano-materials and methods for **batteries**, **fuel cells**, and **printable electronics**. In this talk I will discuss our recent results overcoming critical challenges to create functional nanostructured materials. I will discuss our work on chemical engineering surfaces of nanoparticles to form conducting nano-dot solids: we have developed a novel surface modification method to link colloidal nanoparticles together through inorganic bridges. We show a method to completely remove bulky surfactant ligands from semiconducting nanocrystal films, and forming inter-particle connection with metal-sulfur groups. Next, I'll discuss our chemical and structural engineering of cobalt nanoparticles to create additive-free battery electrodes, made without polymeric binders or carbon black. We have found that electrophoretic deposition (EPD) of nanoparticles creates a strong electrical and mechanical bond for the batteries to perform at maximum capacity. This innovation increases the power density by reducing the overall volume. We have applied these techniques to make printable electronics. Using our surface treatment methods to link the nanoparticles, and the EPD method for deposition, we make copper sulfide films with high conductivity and high mobilities. We show that our nanoparticle films have conductivities that are on par with many bulk copper sulfide films (~75 $S \cdot cm^{-1}$), without the need for heat-treatments. Finally, I'll discuss our new structural characterization tool, where we have developed a microfabricated phonon spectrometer. Non-thermal distributions of phonons are locally excited and detected in silicon micro- and nanostructures by decay of quasiparticles injected into an adjacent superconducting tunnel junction. In our prototype phonon spectrometer we have demonstrated spatial resolution of 200 nm, a frequency resolution of ~20 GHz, and a frequency range from ~80 to ~800 GHz. Our results on Si nanosheets indicate that the Casimir limit is reached at much lower frequencies than previously believed. This means that surface scattering in nanostructures is a substantial impediment to phonon transport, causing a much larger decrease (4x) in thermal conductivity than had been thought.