Design and Fabrication of High-Performance Electrodes for Li-ion Batteries Based on Sequential Multilayer Electroplating

Our study focuses on developing rationally designed and deterministically engineered structures to be used as electrodes in batteries with rapid charging capabilities. These high-power electrodes are achieved by the minimization of certain inherent resistances taking place during the transportation process of ionic and electronic species within the battery. For the realization of these electrodes, electrochemical as well as microfabrication techniques have been utilized. Diffusion-limited models have been adopted to concurrently optimize the liquid- and solid-state ion transport for high power capabilities by determining the optimum active material thickness as well as the inter-layer gap distance within the multilayer electrode. Robotically-assisted electroplating setup has been utilized to fabricate the modeled multilayer structures with alternating layers through a standard photoresist mold enabled by photolithography techniques. By adjusting the current density and electrodeposition time, structures composed of sub-micron-thick individual layers are realized whose total thicknesses reach up to several hundreds of microns. 100 pairs nickel (Ni) and copper (Cu) layers are electroplated from their respective plating baths in an alternating fashion under galvanostatic conditions. Following the fabrication of multilayer Ni/Cu structures of desired thickness, the first mold is stripped and a second photoresist molding process is carried out to electroplate Ni anchors on the specific regions of the multilayer structure. These Ni anchors serve as both supporting columns for the suspended structure and electrical connection between the Ni layers following the complete and selective removal of sacrificial Cu layers. The resulting Ni backbone structure exhibits a large electrode surface area, as well as serves a highly conductive current collector. To demonstrate the contribution of these architectures to the overall performance of the electrode, a conformal film of nickel-tin (NiSn) serving as the active material is electrodeposited onto the Ni backbone in the last step of the fabrication process. To ensure a conformal coating, pulse plating techniques are utilized. This conformal coating of the active material with sub-micron thickness provides a reduced diffusion and conduction path lengths for the ionic and electronic species, respectively, and hence, leads to high power capabilities. To confirm that, galvanostatic charge and discharge tests are conducted at rates up to 60 C (i.e., charging completely in 1 minute). The electrodes exhibit remarkable areal capacities of 2 mAh cm^{-2} and are able to deliver more than 50% of their 1 C capacities at rates as high as 60 C.