Materials for High Capacity Li- and Na-Based Batteries

Sayed Youssef Sayed Nagy
Department of Chemistry
University of Alberta

Humanity’s dependence on fossil fuels to meet ever-increasing energy demands puts civilization at risk due to climate change and concerns over global security. Feasible strategies for widespread integration of clean and sustainable energy (wind, wave, solar) have become urgent. However, the regional and very intermittent nature of these sustainable energy sources represents a significant challenge with respect to integration into large-scale electric grids. Thus, complementary cost-effective and efficient energy storage systems are needed to store off-peak energy and release the stored energy during peak hours. The state-of-the-art Li-ion batteries can reach a specific energy of ~250 Wh/kg, and thus, have had a profound impact on portable electronics and transportation. However, growing energy demands call for the development of new electrode materials with much higher capacities. This seminar describes two different families of high capacity batteries and illustrates the properties of employed nanostructured materials and challenges. The first is Si-based anodes for Li-ion batteries, in which silicon outperforms the native graphite electrode with one order of magnitude higher capacity (3600 mAh/g). The roadblock, however, is that Si undergoes a very large volume expansion, resulting in severe pulverization, and as we show, maybe related to the formation of crystalline-Li$_{3.75}$Si. Moreover, we show how a multilayer architecture of alternating carbon and silicon nanolayers suppresses the formation of the c-Li$_{3.75}$Si phase to a degree dependent upon the relative thicknesses of both the silicon and carbon layers. The second family of high capacity batteries is alkali metal-oxygen batteries, which also promise higher energy densities than the state-of-the-art Li-ion batteries. Sodium-oxygen batteries have been referred to as the battery of “cleaner chemistry”. Here we provide evidence that the reversibility of Na-O$_2$ batteries can be significantly influenced by the particle size (micrometer vs. nanometer) of NaO$_2$ formed upon discharge, and exposure time (reactivity) of NaO$_2$ to the electrolyte. Finally, we probe the underlying pathway of kinetics enhancement by transition metal nanoparticles in the Li$_2$O$_2$ oxidation, the discharge product in lithium-oxygen batteries. To summarize, I hope to convince you that electrochemical energy storage is a vibrant and exciting area of research that underpins the successful integration of renewables into a decarbonized economy.