Lithium-Based Rechargeable Batteries

By: Gurpreet Singh, Ph.D.

The department of defense (DoD) consumes approximately 125 million barrels of petroleum and 30 million megawatt-hours of electricity annually. [1] The dependence on fossil fuel for power generation, and high human and monetary costs associated with fuel transportation to frontlines, is considered a strategic risk. [2] In 2011 alone, forward military bases in Afghanistan consumed as much as 200,000 gallons of fuel every day with air dropped fuel costing as much as $400 per gallon. [3] Clearly, better ways to deliver electricity to frontline war fighters are needed. Recent reports have recommended usage of alternative energy sources and efficient rechargeable energy storage devices as a risk lowering strategy. [4] Lithium-based rechargeable batteries are being studied intensively because of their relatively long cycle-life, high capacity and easy integration with renewable energy sources.

One parameter in defining battery performance is the choice of lithium host or the anode material. Atomically thin flakes of transition metal dichalcogenides (TMDs) such as molybdenum disulfide (MoS₂) are potential high capacity lithium host materials. Their high surface area and unique conversion-type reaction with lithium ions offers two to three times more “charge” storage than traditional graphite. [5,6] Despite this, TMDs electrodes are beset by (a) detrimental reaction with the organic electrolyte and rapid capacity fading; [7] (b) relatively low stability in air and moisture; [8] and (c) lack of knowledge related to cost-effective, large-scale production of single layer flakes for commercial applications. [9] Dr. Gurpreet Singh’s team at Kansas State University is determined to address these challenges so that practical applications of these remarkable 2-D materials can be realized.

Singh and his team have not only discovered new techniques to exfoliate layered TMD crystals into large quantities of few-layer thick flakes [10,11] but also demonstrated improvements in chemical stability of the exfoliated flakes against organic electrolyte in a Li-ion cell. Published in Nature’s Scientific Reports journal, [12] thin flakes of MoS₂ were chemically wrapped with liquid polymer (polysilazane) which upon heating resulted in formation of silicon carbonitride-wrapped molybdenum disulfide sheets or SiCN-wrapped MoS₂. This is the first time that SiCN has been utilized as a protection for dissolution of MoS₂ sheets into the organic electrolyte of a Li-ion cell. Traditionally, SiCN and B-doped SiCN have been utilized for parts that require operation at ultra-high temperatures. [13] Singh’s team observed that electrodes composed solely of exfoliated MoS₂ sheets stored almost twice the amount of lithium ions — or charge — than bulk MoS₂ crystals reported in previous studies. Unfortunately, however, this high Li-capacity of MoS₂ sheets was not retained, the cell capacity dropped to approximately 1/4th the initial value in just five cycles. This kind of behavior is similar to a more advanced Lithium-Sulfur type of battery, which uses sulfur as one of its electrodes; sulfur is notoriously famous for forming polysulfides that dissolve in the electrolyte of the battery, leading to capacity fading. The capacity drop observed in exfoliated MoS₂ sheets is also due to loss of sulfur into the organic electrolyte. Whereas SiCN-wrapped MoS₂ sheets showed stable cycling of lithium-ions irrespective of whether the battery electrode was prepared on copper foil-traditional method or as a self-supporting flexible paper as in bendable batteries. The team also conducted post-mortem analysis of the electrodes by dissembling the cells and observing them under the electron microscope, which provided direct evidence of protection of MoS₂ by SiCN against reaction with the organic electrolyte.

In the future, Singh intends to test the ability of SiCN/MoS₂ and other TMDs electrodes to store charge over hundreds of cycles.
About the Author:
Dr. Gurpreet Singh has a PhD in Mechanical Engineering from the University of Colorado at Boulder. He has been on the faculty in the Department of Mechanical and Nuclear engineering at Kansas State since Fall 2009. He has been on the Editorial Board of Nature-Scientific Reports journal since May 2013.

References: