Nanoscience for Energy Storage: Success and Future Opportunities

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Emerging electric transportation and large-scale stationary applications call for new materials, chemistries and architecture for low-cost, high energy, fast and safe operation of electricity storage. Nanoscience has afforded new ideas and tools to understand, design and test materials across multiple length scale from atom, nano to macro scale. Selected past successful examples will be highlighted. Future research opportunity will also be discussed.

The requirements on energy storage set by different applications will be analyzed. Relevant parameters including energy density, cycle life, calendar life, cost and safety will be introduced. Based on the applications, there might be different battery chemistries needed. The current lithium ion battery cells are based on graphite anodes and lithium metal oxides, which start to meet the performance limit particularly on energy denisty, calling for new materials chemistries. For anodes, silicon, lithium metal, phosphorus representing exciting choices of materials and can provide ~10x capacity compared to graphite. For cathodes, sulfur stands out as an exciting choice which also offers ~10x capacity compared to the existing lithium metal oxides. However, these new materials with very high charge storage capacities have challenging materials issues to be overcome. Nanoscience provides new solutions to these issues.

The most successful example is the nanostructured design for silicon anodes. Silicon has the issues of large volume change and instability of solid electrolyte interphase. The 11 generations of Si anode design will be discussed, including Si nanowires, core-shell nanowires, hollow Si particles, double-walled hollow structures, pomegranate-like Si structures, self-healing electrodes and graphene-caged Si. The successful commercialization story of Si anodes through my founded company Amprius Inc. will also be presented.

The nanoscience successes in battery materials are extended to Li metal anodes and sulfur cathodes. Li metal anodes have half-century old problems of dendrite formation, large interface chemical reactivity, infinite relative volume change. Sulfur has problems of soluble polysulfide species and insulating nature of sulfur and lithium sulfide. A variety of nanostructures have been designed to solve these problems with success.

Future opportunities of nanoscience for energy storage will also be discussed: 1) how to optimize high energy and high power at the same time; 2) How to increase cycle life and calendar life to meet with long-term needs of transportation and grid storage; 3) How to make battery safe ultimately; 4) How to reduce cost of batteries.