

Prospects in Battery Energy Storage Over the Next Decade

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The global electrochemical energy storage market ranging from electric vehicles to physical grid storage demands the development of key enabling technologies for high-energy long-life rechargeable batteries. I will describe the current state of the art and upcoming innovative approaches for the next decade on the design and synthesis of nanostructured materials towards enhanced reversible capacity; superior rate performance and cycling stability; superior gravimetric capacitance; and enhanced energy and power densities.

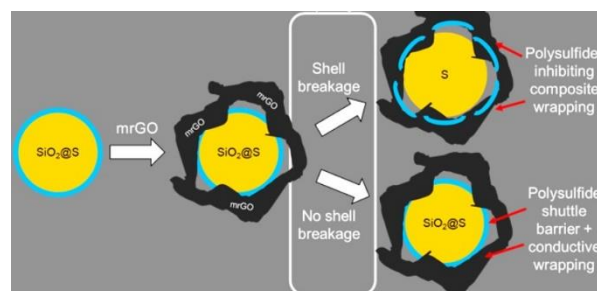
Silicon (Si) has been proven to be a very promising anode material due to its highest known theoretical capacity value of 3572mAh/g corresponding to the formation of $\text{Li}_{15}\text{Si}_4$ phase under ambient temperatures. Significant academic and industrial efforts have been made on the synthesis of silicon materials and novel binder systems to mitigate the volume expansion problems. Synthesis of monodisperse Si and C nanocomposite spheres via a facile magnesiothermic reduction with subsequent CVD process has been demonstrated. The monodisperse and high symmetrical nature of the composite spheres allow a homogeneous stress-strain distribution within the structure during charge and discharge cycles. Anode half cells based on MSNSs demonstrate an ultra high reversible capacity of 3207mAh/g along with enhanced cycling stability, improved ICE and rate performance.

Our recent work introduced a scalable industrial mature route to transform polyethylene terephthalate (PET) plastic waste into a superporous activated carbon material for rechargeable LIBs. Carbon-silicon composite anodes were derived by eletrospinning of PET dissolved precursors, pyrolysis under controlled pressure and temperature, and impregnation with silicon nanoparticles (SiNPs) into a superporous connected architecture network. Impregnation with silicon nanoparticles (SiNPs) into a superporous connected architecture network to produce a material with relatively high specific capacity of 201.31 mAh/g at a C/5 rate is demonstrated. Furthermore, half cells based on waste glass Si-C anodes exhibited nearly 1700 mAh/g after 300 cycles at C/2. The theoretical capacity of Li-S cathodes is 1675 mAh/g, and sulfur offers a relatively low-cost battery due to relatively high abundance.

I will describe our work on facile wet synthesis of SiO_2 -coated sulfur particles (SCSPs) as potential Li-S battery cathodes. SiO_2 has the inherent ability to surface-adsorb polysulfide species that are soluble in the electrolyte, which deters the loss of electrochemically active sulfur over numerous cycles. Our sulfur cathodes demonstrated superior cycling stability when coupled with mildly reduced graphene oxide (mrGO) as an additive, improving the capacity retention after 50 cycles from

440.8 mAh/g without mrGO to 763.2 mAh/g with mrGO. To further mitigate with the shuttle effect, the sulfur electrodes are coated with TiO_2 thin films, which provides a favorable solid-electrolyte interphase layer owing to the LiPs adsorption properties of TiO_2 layer and the confinement of the LiPs inside the cathode region.

I will describe more recent efforts on solid state batteries in the remainder of my talk. Especially the need for electrical vehicle storage and fast charging requirements necessitate the development of all solid state batteries (ASSLIBs). With the conductivity values reaching above $10^{-2} \text{ S cm}^{-1}$ level, solid state electrolytes can compete with the widely commercialized liquid organic electrolytes. Compared with traditional liquid lithium-ion batteries, the manufacturing cost gains an advantage by eliminating the electrolyte injection process; however, the large-scale production of the oxide-based ASSLIBs is critically hindered by its raw material cost and high-temperature ($>1000^\circ\text{C}$) sintering cost, leading to an estimated overall manufacturing cost of around 180 \$ kW/h. Besides, the insufficient mechanical stability of oxides SSE as the thickness diminished below 100 μm resulted in another manufacturing challenge. In general, ASSLIB, composed of lithium metal anode and sulfide SSE, is a cost-effective option for next-generation EV and consumer electronics batteries, especially considering the reduced cell size and safety measurements in practical applications while maintaining or surpassing current LIBs energy density. However, barriers such as interfacial degradation and high total resistance impede ASSLIBs from marching into industrial-scale productions. The overall cell resistance is mainly contributed by ion diffusion in SSEs and electrodes and interfacial resistances. With the guidance toward fast ionic charge transfer and stable interface, mitigation approaches are being adopted, including wetting, polishing, and removing impurity phases are a strategy to decrease the interfacial resistance.



Ozkan received his Ph.D. degree in Materials Science and Engineering at Stanford University. He made pioneering advancements in the fields of Li-ion batteries and supercapacitors; nanoelectronics; 2D materials including graphene and dichalcogenides and nanopatterning for beyond CMOS. He is a Member of the National Academy of Inventors, a Fellow of the Materials Research Society, and received a number of awards including the William Johnson International Founders Award, and the TUBITAK Presidential Scientific Achievement Award. Ozkan was elected a Meeting Chair for the Fall 2021 MRS Meeting in Boston, MA. Presenting author: Cengiz S. Ozkan, e-mail: cozkan@engr.ucr.edu, tel: +1 (858) 361-2750