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Towards Scalable Synthesis of High Energy, High Power, Long Cycle Life Silicon Anodes for Li-ion Batteries at Low Cost

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Abstract

Silicon as a promising anode material for next-generation Li-ion batteries (LIBs) has attracted tremendous attention and investigation due to its extremely high specific capacity (3,579 mAh/g for $Li_{15}Si_4$), low lithium-alloying voltage (0.22 V vs. Li/Li^+), and abundant amount on earth. However, practical applications of Si are impeded by its low intrinsic electrical conductivity of Si (~10^{-6} S cm^{-1}) and huge volume expansion (> 300%) during lithiation. To address these challenges, nanoscale Si has been utilized to minimize volume expansion per particle during lithiation and to circumvent its low conductivity by connecting nano-Si to a conductive network. However, the use of Si nanoparticles is not only expensive, but also not sufficient for performance because the repeated volume expansion and shrinkage during charge/discharge result in repeated SEI layer fracture and formation that consume Li ions and deteriorate the electrolyte. Embedding engineered void space inside nano-Si particles in conjunction with a conductive shell can provide a solution to all the key technical problems faced by Si anodes. This presentation highlights a novel synthesis method that starts with commercially low cost, micron-sized Si powder and uses industry-scale high-energy ball milling with environmentally benign NaOH solution to create engineered void space inside the nanostructured Si core encapsulated by a conductive carbon shell. The Si micro-reactor particles derived from this novel manufacturing method not only are low cost (only one third of graphite anodes on the energy base, $/kWh), but also exhibit unusual electrochemical properties with specific capacities of 1,300 mAh/g Si at the current density of 1 A/g Si and 780 mAh/g at 8 A/g Si, ultrafast charging/discharging capability (6 min to the full capacity at 8 A/g Si), and long cycle life (1,000 cycles). The high-performance Si micro-reactor anode material produced via this facile and industrially scalable manufacturing method at low cost will pave the way for widespread acceptance of electric vehicles (EVs) by consumers, making EVs more affordable and society greener and sustainable.

Keywords: Silicon anode; Li-ion batteries; high capacity; high power; long cycle life.

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Biography of Presenting Author

Leon L. Shaw is Rowe Family Endowed Chair Professor in Sustainable Energy and Professor of Materials Science and Engineering at Illinois Institute of Technology, United States. Dr. Shaw has extensive experience in nanomaterials synthesis and processing for applications in hydrogen storage, Li-ion batteries, Na-ion batteries, redox flow batteries, and structural materials. His publications have been cited more than 10,000 times with h-index of 53 and i10-index of 178 (according to Google Scholar). His seminal contributions to nanomaterials synthesis and energy storage have been featured by many magazines and U.S. National Science Foundation highlights. His accomplishments are recognized worldwide with multiple awards including Energy Award in 2018 given by IAAM, many keynote presentations in national and international conferences Dr. Shaw is a Member of EU Academy of Sciences, a Fellow of ASM International, a Fellow of the World Academy of Materials and Manufacturing Engineering, and a Member of the Connecticut Academy of Science and Engineering.

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