Improved Stability and Electrochemical Characteristics of Highly Porous Coral-Like Si Nanoparticles with Carbon Coating

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Lithium-ion batteries (LIBs) are the most popular energy storage media for applications ranging from portable electronic devices to electric vehicles (EVs). The most representative commercial anode material for LIBs is graphite. However, unfortunately, its low theoretical capacity (372 mAh g^{-1}) and rate capability is not sufficient to be used in emerging applications, such as EVs and large-scale energy storage systems (ESS). Silicon is a promising anode material for LIBs due to its large theoretical capacity (3600 mAh g^{-1} for $Li_{15}S_4$), low working potential (0.3 V vs. Li/Li^+), abundant resource, low cost, low toxicity, high safety, and environmental compatibility. However, Si based anodes in LIBs have several drawbacks. During alloying with Li, Si exhibits volume expansion of >300%, leading to the pulverization of the active materials and resultant capacity fading. Si anode also has low intrinsic electrical conductivity compared with graphite. In addition, the solid electrolyte interface (SEI) layer is not stable when Si is exposed to organic electrolytes, leading to the consumption of electrolyte and low Coulombic efficiency. Recently, researches have used coatings on Si particles for forming a buffer layer to mitigate the volume expansion of Si anodes. Further, there have been many studies on improvement in conductivity by increasing contact area with electrolytes by making nano-sized or porous structure.

Synthesis of Si nanostructures have generally needed high-temperature chemical vapor deposition or complex chemical reactions. Recently, we have reported an ultra-simple Mg-thermal-reduction method for the production of mass-scalable coral-like Si powders with a high surface area (38 m^2/g), broad pore-size distribution (2–200 nm), and 3-dimensionally (3D)-interconnected Si structures. It is noticeable that this simple Mg-reduction process can be used in ambient air.

Further, in the present work, we prepared a coral-like nano-porous Si@C composites through a facile sol-gel route with various amounts of carbon originated from Glucose precursor. The morphology and crystal structure of the synthesized Si@C composites were analyzed by XRD, FE-SEM, TEM, Raman spectroscopy, and BET analysis. Furthermore, electrochemical characteristics of coral-like Si@C electrodes was investigated through electrochemical impedance spectroscopy (EIS), cyclic voltammetry, and charge-discharge test. The Si@C electrode exhibited a long cycling stability, good rate capability, and high specific capacity. In particular, starting of electrode degradation was remarkably delayed to >50 cycles. This superior performance of the electrode is attributed to the improvement in electrical conductivity, Li-ion accessibility, and the suppression of volume expansion due to porous nano-sized Si and carbon coating.