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Electrodeposition of Silicon Nanoparticles Using Ionic Liquid for Energy Storage Application

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Abstract : Silicon (Si) is a promising negative electrode material for lithium-ion batteries (LiBs) due to its low cost, non-toxicity, and a high theoretical capacity of 4200 $mAhg^{-1}$. The primary challenge of the application of Si-based LiBs is large volume expansion (~ 300%) during the charge-discharge process. Incorporation of graphene, carbon nanotubes (CNTs), morphological control, and nanoparticles was utilized as effective strategies to tackle volume expansion issues. However, molten salt methods can resolve the issue, but high-temperature requirement limits its application. For sustainable and practical approach, room temperature (RT) based methods are essentially required. Use of ionic liquids (ILs) for electrodeposition of Si nanostructures can possibly resolve the issue of temperature as well as greener media. In this work, electrodeposition of Si nanoparticles on gold substrate was successfully carried out in the presence of ILs media, 1-butyl-3-methylimidazolium-bis (trifluoromethyl sulfonyl) imide ($BMImTf_2N$) at room temperature. Cyclic voltammetry (CV) suggests the sequential reduction of Si^{4+} to Si^{2+} and then Si nanoparticles (SiNs). The structure and morphology of the electrodeposited SiNs were investigated by FE-SEM and observed interconnected Si nanoparticles of average particle size ∼100-200 nm. XRD and XPS data confirm the deposition of Si on Au (111). The first discharge-charge capacity of Si anode material has been found to be 1857 and 422 $mAhg^{-1}$, respectively, at current density 7.8 Ag^{-1}. The irreversible capacity of the first discharge-charge process can be attributed to the solid electrolyte interface (SEI) formation via electrolyte decomposition, and trapped Li^+ inserted into the inner pores of Si. Pulverization of SiNs results in the creation of a new active site, which facilitates the formation of new SEI in the subsequent cycles leading to fading in a specific capacity. After 20 cycles, charge-discharge profiles have been stabilized, and a reversible capacity of 150 $mAhg^{-1}$ is retained. Electrochemical impedance spectroscopy (EIS) data shows the decrease in Rct value from 94.7 to 47.6 kΩ after 50 cycles of charge-discharge, which demonstrates the improvements of the interfacial charge transfer kinetics. The decrease in the Warburg impedance after 50 cycles of charge-discharge measurements indicates facile diffusion in fragmented and smaller Si nanoparticles. In summary, Si nanoparticles deposited on gold substrate using ILs as media and characterized well with different analytical techniques. Synthesized material was successfully utilized for LiBs application, which is well supported by CV and EIS data.

Keywords : silicon nanoparticles, ionic liquid, electrodeposition, cyclic voltammetry, Li-ion battery
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