Carbon-Coated SiO2 for Li-Ion Batteries

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Li-ion battery technology is at the core of the imminent massive vehicle electrification due to the forecast growth penetration rate of electrified vehicles. In this cutting-edge Li-ion battery technology, silicon seems to be the most promising candidate for next-generation Li-ion battery technology due to its high theoretical capacity of 4200 mAh·g−1 (compared to 372 mAh·g−1 for graphite). Shifting to silicon as an anode material has the potential to deliver higher energy density for the batteries. The anode of a Li-ion battery should operate at low potentials and offer high specific energy capacity and density.

lithium-ion batteries anode silica carbon coating spray-coating

1. Overview

Porous silica-based materials are a promising alternative to graphite anodes for Li-ion batteries due to their high theoretical capacity, low discharge potential similar to pure silicon, superior cycling stability compared to silicon, abundance, and environmental friendliness. However, several challenges prevent the practical application of silica anodes, such as low coulombic efficiency and irreversible capacity losses during cycling. The main strategy to tackle the challenges of silica as an anode material has been developed to prepare carbon-coated SiO_2 composites by carbonization in argon atmosphere. A facile and eco-friendly method of preparing carbon-coated SiO_2 composites using sucrose is reported herein. The carbon-coated SiO_2 composites were characterized using X-ray diffraction, X-ray photoelectron spectroscopy, thermogravimetry, transmission and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy, cyclic voltammetry, and charge–discharge cycling. A C/SiO_2-0.085 M calendered electrode displays the best cycling stability, capacity of 714.3 mAh·g^{-1}, and coulombic efficiency as well as the lowest charge transfer resistance over 200 cycles without electrode degradation. The electrochemical performance improvement could be attributed to the positive effect of the carbon thin layer that can effectively diminish interfacial impedance.

2. Li-ion Battery Technology

Li-ion battery technology is at the core of the imminent massive vehicle electrification due to the forecast growth penetration rate of electrified vehicles [1]. In this cutting-edge Li-ion battery technology, silicon seems to be the most promising candidate for next-generation Li-ion battery technology due to its high theoretical capacity of 4200 mAh·g^{-1} (compared to 372 mAh·g^{-1} for graphite) [2][3]. Shifting to silicon as an anode material has the potential to deliver higher energy density for the batteries. The anode of a Li-ion battery should operate at low potentials and offer high specific energy capacity and density. However, several drastic challenges prevent the practical application of silicon anodes such as its huge (300%) volume change upon full lithiation, which causes the solid electrolyte interface (SEI) rupture or particle pulverization, leading to loss of electrical contact, fast reversible capacity loss, and low coulombic efficiency [2][4][5][6][7][8][9][10][11][12][13][14][15]. In recent years, research interest toward SiO_2-based materials as a promising new alternative to graphite has been significantly increased due to the high theoretical capacity and low discharge potential similar to pure silicon. Research groups all over the world studied intensively how to tackle the drawback of low coulombic efficiency and irreversible capacity losses during cycling [16][17][18][19][20][21][22][23]. A main strategy to overcome the challenges of silica as an anode material has been to use carbon as a conductive matrix material. Carbon coating provides an effective solution to the above issue, improving the cycling stability by buffering the volume expansion of the silica particles [24][25][26][27][28][29][30]. Therefore, it is desirable to design a sustainable and eco-friendly preparation route for C/SiO_2 composites. Different complex preparation routes and sacrificial templates of carbon-coated porous silica composites were also reported as an anode for Li-ion batteries [31][32][33].

3. Conclusions

Carbon-coated SiO_2 composites were prepared through a facile and eco-friendly method, involving the carbonization of a sucrose–silica precursor at 900 °C. The effect of the starting sucrose concentration on the properties of the resulting materials was investigated in the 0.04–0.085 M range. All samples consist of carbon-coated silica nanoparticles. The carbon content increases with increasing precursor concentration. XPS analyses showed the presence of predominately sp^2 hybridized carbon, with minor sp^3 C and C-O species, while high-resolution TEM analyses have evidenced the presence of graphitized and fullerenic carbon nanofilms on the surface of the silica nanoparticles.

Both calendered and uncalendered electrodes were prepared with the synthesized composites. Cyclic voltammetry measurements show that reversible lithiation and delithiation occurs for both types of electrodes. The discharge capacity of the calendered electrodes increases with increasing initial sucrose concentration at all C rates. The charge transfer resistance is inversely proportional to the initial precursor concentration while also being lower for the calendered electrodes. The transfer resistance is lower after 200 charging–discharging cycles in all cases.

The C/SiO_2-0.085 M calendered electrode exhibits the best charging–discharging cycling stability after 200 cycles. No significant electrode degradation could be noticed. SEM-EDAX analyses on this electrode after 200 cycles show good structural stability and the absence of cracks, as well as the preservation of a homogenous distribution of carbon and silica.

The C/SiO_2-0.085 M material exhibits the best capacity of 714.3 $mAh \cdot g^{-1}$, coulombic efficiency near 100%, and the lowest charge transfer resistance, after 200 cycles, which can be attributed to the carbon-coated layer that effectively buffers the volume expansion of silica during the Li-ion insertion/extraction process. This material is a promising anode for high capacity and stability Li-ion batteries, which can be obtained through a facile and green method that does not use corrosive acids or solvents.

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