Structured Carbon Nanotube/Silicon Nanoparticle Anode Architecture for High Performance Lithium-Ion Batteries

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Abstract

Silicon is emerging as a very attractive anode material for lithium ion batteries due to its low discharge potential, natural abundance, and high theoretical capacity of 4200 mAh/g, more than ten times that of graphite (372 mAh/g). This high charge capacity is the result of silicon’s ability to incorporate 4.4 lithium atoms per silicon atom, however, this property also leads to a 300-400% volume expansion during charging, which can cause pulverization of the silicon material and loss of electrical contact between the silicon and current collecting substrate. The architecture of the anode must therefore be able to adapt to this volume increase. Here we present a low cost, high rate, and scalable process for constructing silicon anodes using directed assembly techniques to create a layered carbon nanotube and silicon nanoparticle structure. This layered architecture increases the surface area available for electrochemical reactions, and also provides a conductive path to the current collecting substrate.

Applications

- Guided Missiles
- Microelectronics
- Implantable Devices
- Satellites
- Remote Sensors
- NEMS/NEMS Devices

Method

Directed Assembly of Carbon Nanotubes and Silicon Nanoparticles

- Copper foil serves as current collecting substrate
- Surface treatment removes oxides and increases wettability of surface
- Carbon nanotubes (CNTs) assembled on copper substrate
- Silicon nanoparticles assembled on top of carbon nanotubes

Multi-Layer Anode Structure

- Last two steps repeated until desired number of layers is achieved
- Silicon particles are sandwiched between two layers of CNTs, such that each particle can make contact with CNT network
- Top CNT layer connects to lower CNT layer, providing a conducting path to current collector
- Average particle size is 20-30 nm

Results

Directed Assembly of First Layer

- Silicon anode in uncharged and charged states
- Shows extreme volume expansion, which can cause loss of electrical contact

Comparison to Graphite Anode

- Silicon and Graphite Anodes (2013)

Conclusions

- Achieved uniform assembly of CNTs and silicon nanoparticles on copper substrate
- Layered electrodes show great advantage over standard fabrication electrodes in regard to capacity, and power and energy density
- Capacity fade remains an issue

Path Forward

- Investigate and correct cause of poor capacity retention
- Testing of multi-layer silicon anodes

References & Acknowledgements


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