Electrode Architectures for Enhanced Lithium Ion Battery Performance
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Abstract
Increasing prevalence of portable electronic devices and growing concern over the consumption of fossil fuels has led to a growing demand for more efficient energy storage options. Lithium ion chemistry has grown to dominate the battery market, but still requires improvement to meet the increasing need for smaller, cheaper, better performing batteries. The use of nanomaterials has garnered much attention in recent years as a potential way of improving battery performance while decreasing the size. However, new problems are introduced with these materials such as low packing density and high reactivity with the electrolyte. This research focuses on the development of an electrode architecture using nanomaterials which will decrease lithium ion transport distance while enhancing electrical conductivity within the cell. The proposed architecture consists of a stacked, 2D structure composed of layers of carbon nanotubes and active material particles, and can be applied to both the anode and the cathode. The process also has the advantage of low cost because it can be performed under normal laboratory conditions (e.g. temperature and pressures) and easily adapted to a commercial scale.

Background

\[ \text{Power} = \frac{\text{Voltage}^2}{\text{Internal Resistance}} \]

\[ R_l = R_e + R_{diffusion} + R_{geo} + R_{ct} \]
- Electronic resistance
- Solution resistance (electrolyte)
- Ionic Resistance
- Charge Transfer Resistance

Multi-Layer Electrode Architecture:
- Nano-sized active material particles provide short ion diffusion lengths, higher surface area, and novel ion storage mechanisms, reducing the ionic and charge transfer resistances
- Carbon nanotube layers further enhance the surface area without significantly increasing volume and provide a conductive network through the bulk material, reducing the ionic and electronic resistances
- Fabrication process is low-cost, fast, and easily scalable for commercialization

Method
Directed Assembly of Carbon Nanotubes and Active Material Nanoparticles
- Copper or aluminum foil serves as current collecting substrate
- Surface treatment removes oxides and increases wettability of surface
- Carbon nanotubes (CNTs) assembled on copper substrate
- Active material nanoparticles assembled on top of carbon nanotubes
- Multi-Layer Electrode Structure
  - Last two steps repeated until desired number of layers is achieved

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

Results
Cathode
- Rate capability is much higher for multi-layer electrodes: similar performance is observed between the 24 mg loading multi-layer cell and the 8 mg loading standard cell, indicating that we can achieve similar performance at 3x loading

Anode
- Cells show improved capacity over standard fabrication, but capacity fades rapidly due to repeated expansion and contraction of silicon particles
- Multi-layer electrodes show significantly higher power and energy than standard fabrication, cells and graphite cells

Conclusions
- Lithium manganese oxide cathode: Multi-layer architecture improves capacity, rate capability, power density, and energy density: loading can be increased by 3-4x times over a standard cell and still see equivalent performance
- Silicon anode: Multi-layer architecture improves capacity, power density, and energy density, however capacity retention is low due to degradation of silicon over time

Future Directions:
- New applications for cathode: flexible batteries, large structural batteries (sprayed on inside of vehicle or aircraft walls, etc.)
- Capacity retention of silicon will need to be improved before it can be useful in a full cell

References & Acknowledgements

-Li, C. and T. Poizot, Electrochemistry Communications, 2011.