Improving Porous Si Anode Properties by Atomic Layer Deposition (ALD) high-k Oxide Passivation For High Energy Density Storage Applications

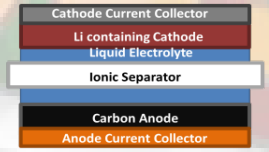
Michael Lim, Bongmook Lee, and Veena Misra

Department of Electrical and Computer Engineering, North Carolina State University, Raleigh NC

Goal of this study:

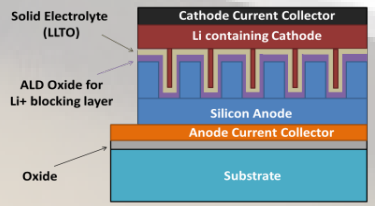
Design and fabricate high energy and high power density hybrid energy storage device for ASSIST platform

Current Battery Technology



- Liquid electrolyte is a safety concern when exposed to moisture
- Anode material has a low specific energy density ~372 mAh g^{-1}
- Low power rate

Our Approach in ASSIST



3-Dimensional All Solid State Nanobatteries with Atomic Layer Deposition (ALD) Technique

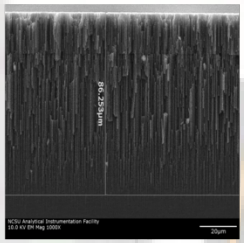
- All solid design
- Enhanced surface area to volume ratio
- Anode has high specific energy density ~4200 $mAhg^{-1}$

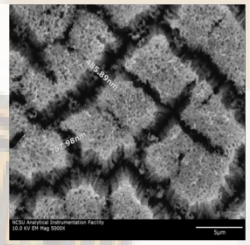
- **Advantages of ALD**
  - Conformal coverage
  - Complex structures may be used
    - Ensure mechanical and electrical stability at all interfaces
  - Safer packaging (no liquid/gel)
    - No need for separator to prevent electrode shorting
  - Precise thickness control

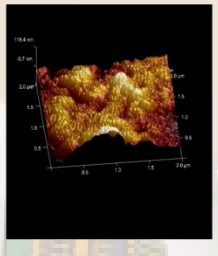
- **Technology Impact**
  - All ALD based 3D SS energy storage will be a good candidate for high density energy storage device
  - It provides safe and stable operation (b/c there is no liquid electrolyte)

Porous Silicon Formation

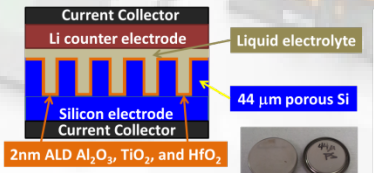
- $HF:H_2O_2:Ethanol:H_2O$ $(9:1:4:11)$
- $i \cong 20mA$, t=10 min to 30min
- Porous layer depth ≅44 μm to 86μm
- Porosity ~ 20% ~ 60%
- Depth and porosity controlled by current and etching time



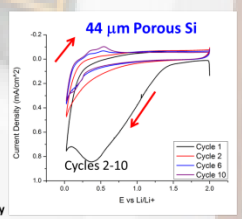


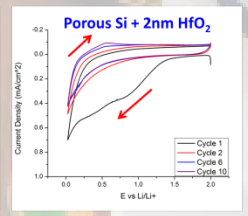


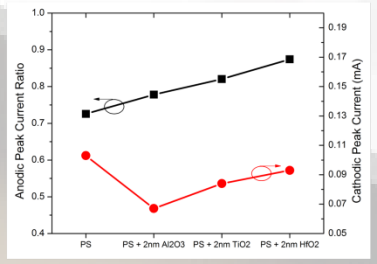
Structure and Cycling Characteristics



Assembled Coin cell battery







- Solid Electrolyte Interface formation from ~0.4V-1.4V
- Lithiation peaks ~0.4V - 0.5V cause Si amorphization, volumetric expansion, cracking

- Porous Si with ALD dielectrics demonstrate reduce lithiation peak i.e. less Si amorphization
- HfO_2 demonstrates highest capacity retention

NSF Nanosystems Engineering Research Center for
Advanced Self-Powered Systems for Integrated Sensors and Technologies (ASSIST)
EEC 1160483