Nanomaterials for Energy Storage

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Batteries & Supercapacitors

Today’s market of $25+Billion expected to grow to $1+Trillion by 2040

- Hybrid and Electrical Engines for Transportation
- Hybrid Engines for Energy Efficient Industrial Equipment
- Power Quality for National Grid
- Electric Planes & Drones
- Power Tools
- Department of Defense (DoD)
- Electronics
Operating Principle of Li-ion battery

- “Rocking-chair” or “shuttlelock” mechanism: Li ions shuttle between the anode and the cathode

- Higher capacity of the cathode or the anode will lead to higher capacity of a battery

- For high battery voltage, a cathode should maintain high potential vs. Li/Li$^+$ for the large range of Li concentrations, while an anode should maintain low potential vs. Li/Li$^+$ for the large range of Li concentrations
Materials for Li-ion batteries

Challenges with Conversion Electrode Materials

• Significant mass transport (slow kinetics) ☹
• Large volume changes & electrode swelling ☹
• Fractures of individual particles ☹
• Electrode disintegration & disconnection from current collectors ☹
• Continuous irreversible decomposition of electrolyte ☹
• Dissolution of active materials (cathodes) ☹
• Many others ☹

Nanotechnology is needed to overcome such challenges
Conversion-Type Cathodes: Li$_2$S and S

Hierarchical Li$_2$S-C Nanocomposites: Overcoming Dissolution

- Shells may protect dissolution of cathodes during cycling, but typically fail due to repeated volume changes.

- Hierarchical particles’ shelling for enhanced mechanical stability of volume-changing active materials.

- Significant reduction of the hoop stress within the outer shells achieved in hierarchical particles.


*Patent pending*
Hierarchical Li$_2$S-C Nanocomposite Preparation:

- Ideally would like to have a narrow distribution of Li$_2$S nanoparticles within conductive C matrix

- Conventional approach (formation of Li$_2$S nanoparticles and coating it with carbon) does not work: (1) nanoparticles tend to agglomerate in solutions; (2) solution-solvable organic carbon precursors dissolve Li$_2$S

- Our solution: employ (i) steric separation of freshly nucleated Li$_2$S particles, (ii) their self-assembling, (iii) polymer carbonization due to high MP of Li$_2$S

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Voltage V (vs. Li/Li$^{+}$) vs. Specific Capacity (mAh g$^{-1}$ Li$_2$S)

Specific Capacity (mAh g$^{-1}$) vs. Cycle Number

Hierarchical C-Li$_2$S-C in this work at C/5

LiI comprising electrolyte

Specific Capacity (mAh g$^{-1}$) vs. Cycle Number

Hierarchical C-Li$_2$S-C in this work at C/2

LiI comprising electrolyte

“True Conversion”-Type Cathodes: MFx

- Challenges with MFx:
  - Metal dissolution
  - Irreversible separation of LiF and M clusters

\[ x\text{Li}^+ + xe^- + MF_x \leftrightarrow x\text{LiF} + M \]

M – is a fluoride-forming element

- Volumetric capacity of most metal fluorides: up to \( \sim 2200 \text{ mAh/cc} \) – similar to that of S/Li_2S

- Due to higher V: higher energy density

“True Conversion”-Type Cathodes: MFx

- To prevent agglomerations of LiF and M clusters we confine MFx in carbon nanopores.

- Conductive carbon pore walls will additionally provide pathways for electron transport (so we don’t rely on interconnectivity of M clusters).
“True Conversion”-Type Cathodes: MF\textsubscript{x} with \textit{in-situ} formed protective shell

- The longest stability of MF\textsubscript{x} demonstrated thus far
- Extremely small (for this chemistry) hysteresis @ RT and 140 mAh/g (C/3) current density
- Unique MFx-electrolyte combination

Gu, W. et al., \textit{Advanced Funct Mater}, 2016
Silicon Anodes

Minimizing volume changes using nanocomposites (note: 300%+ volume increase in Si upon lithiation)

- Uniformity of the deposited Si nanoparticles
- No volume changes during Li insertion/extraction
- Compatibility with existing manufacturing technologies (drop-in replacement)
- High electrical & thermal conductivity

Patent pending


Project started in 2008
Silicon Anodes

- Small volume changes at the nanocomposite particle level

Before cycling After

Patent pending

Silicon Anodes

- SEI stabilization

Our proposal: porous core-shell structure.
Simplest Design – Single Pore

Si core

Georgia Tech Invention Disclosure, Jan 2008

Patent pending

G. Yushin et al., JACS, 2010
Where we are now?

- In 2011 formed Sila Nanotechnologies Inc., a Georgia Tech startup

- Sila is a Materials company that develops & manufactures breakthrough engineered materials for smaller, lighter, longer-lasting batteries.
  - Drop-in solution to existing battery manufacturing processes
  - Sila is backed by Tier I investors, Public Sector & Industry Partnerships

Credit: Sila Nanotechnologies, Inc., web: www.silanano.com; email: info@silanano.com
Market Opportunity

Wearables
- More features and elegant form factors, with improved battery life to drive mass adoption

Portable Electronics
- Add capabilities, reduce size, increase battery life

Drones
- Extended flight time and advanced on-board capabilities

Electric Vehicles
- Mass market EVs: sub-$40,000, 300+ mile range

Renewable Energy
- Enable integration of renewable energy sources at grid-scale

Credit: Sila Nanotechnologies, Inc., web: www.silanano.com; email: info@silanano.com
Sila Products Roadmap:
Double Energy Density of Li Batteries by 2022

- Micron-scale electrode powders
- Low volume changes @ very high capacity
- Complex nanostructured materials are produced in bulk reactors

Phase I: Anode Materials

2017: +20% (vs. 2015 state of the art Li ion batteries)
2018: +30%
2019: +40%

Phase II: Cathode Materials

2020: +60%
2021: +80%
2022: +100%

Phase III: Other Energy Storage Tech

Credit: Sila Nanotechnologies, Inc., web: www.silanano.com; email: info@silanano.com
Energy Storage Technologies: High Power & Ultra-Fast Charging Capabilities
**AC- Li$_4$Ti$_5$O$_{12}$ Nanocomposites for Ultra-Fast Charging: Aiming to Approach Energy Density of Batteries, while Retaining Power Density of Supercapacitors**

- Battery active materials (such as LTO) store ions in the bulk and thus offer much higher energy storage than supercapacitors.

- But… they suffer from low electrical conductivity and slower ion transport. As a result – the power performance is poor.

- Our approach: porous carbon-active material nanocomposites, where porous carbon provides high conductivity & porosity for rapid ion transport & LTO provides high capacity for Li ion storage.
AC- Li$_4$Ti$_5$O$_{12}$ Nanocomposites for Ultra-Fast Charging

- Uniform infiltration of LTO into 3 types of porous carbons: AC#1, AC#2, AC#3
- Similar distribution of micropores and small mesopores

Zhao, E. et al., *ACS Nano*, 2016
AC- Li$_4$Ti$_5$O$_{12}$ Nanocomposites for Ultra-Fast Charging

- AC#3-LTO composite have charge-discharge rates comparable to double-layer capacitors (seconds), while offering much higher specific and volumetric capacities

Zhao, E. et al., *ACS Nano*, 2016
Summary

➢ Nanocomposites may help to overcome challenges of conversion-type materials for ultra-high energy density Li-ion batteries

➢ Nanocomposites may also lead to dramatic increase in the charge or discharge rates of electrochemical energy storage technologies utilizing conventional intercalation-type materials

Thank you!

➢ GT patents have been licensed to Sila Nanotechnologies, Inc.,

➢ G. Yushin & Georgia Tech are stock holders in Sila Nanotechnologies, Inc.