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2016 Material Science Series

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Accelerating Breakthrough Discoveries
www.wildcatdiscovery.com

Chemistry of Hello: Lithium Ion Batteries
Challenges and Opportunities for Personal Electronics Applications

Dee Strand, Wildcat Discovery Technologies
The Dreaded

My battery won’t even last a day.

Talk fast, my phone’s dying!

OH NO... I forgot to charge my phone!

The battery on those new phones aren’t very good.

The battery doesn’t last very long anymore...

Today’s Agenda

- How does the lithium ion battery work?
- Why won’t my battery last all day?
- Why has my battery performance decreased in my old phone?
- Why isn’t my new phone much better than my old phone?
- Can I put in a better battery?
- How do we fix the problem?
How does a lithium ion battery work?

A passivation (Solid Electrolyte Interphase or SEI) layer is required on the anode

- Carbonate electrolytes are not stable at the anode potentials (close to 0 V vs. Li)
- Formed during first few cycles in situ


Terminology/Units

- **Charge** (on an e⁻ or a Li⁺): unit of Coulombs
- **Current** – measure of charge passing a point per unit time: unit of Amperes (or Amps)
- **Amp-hour** (Ah) – measure of charge passing at steady current in 1 hour
- **Capacity** – amount of “charge” per unit weight or volume
  - For a material: unit of Ah/kg or mAh/g
- **Cathode capacity**
  - How much Li⁺ can it provide to move back and forth?
- **Anode capacity**
  - How much Li⁺ can it hold or accommodate from the cathode?
- **C-rate**
  - Full charge or discharge of a cell in a particular amount of time
    - 1 C = 1 hour
    - 10 C = 1/10 hour
    - C/10 = 10 hours
Terminology/Units

- **Energy** = area under discharge curve
  - $= V \times \text{mAh/g}$
  - $= \text{Wh/kg}$

- **How can we increase cell energy?**
  - Increase capacity (x-axis)
  - Increase voltage (y-axis)

Why doesn’t my battery last all day?

- How much energy can I store in the space that I have?

**Current Collectors:**
- Goal is to make as thin and light as practically possible

**Separator:**
- Goal is to make as thin as practically possible

**Cathode:**
- More Li$^+$ per unit volume
- Higher voltage
- Increased density
- Thicker electrodes
- *Goal is to pack more cathode into the battery volume*

**Anode:**
- More Li$^+$ per unit volume
- Lower voltage
- Increased density
- Thicker electrodes
- *Goal is to use less of the battery volume for anode*
Why doesn’t my battery last all day?

- How much energy can I store in the space that I have?

Audience Survey Question

**Why doesn’t my cell phone battery last all day?**

- It’s difficult to make thick, dense electrodes work well
- We need cathode materials that contain more lithium
- We need anode materials that can hold more lithium
- Cell phone apps expand to use available battery capacity
Why has my battery performance decreased in my old phone?

- Loss of lithium due to reaction of electrolyte with active material
- Continuous formation of SEI results in gradual loss of lithium to move back and forth

Why has my battery performance decreased in my new phone?

- Plenty of lithium, but becomes more difficult to move it
- Impedance rise in the cell due to SEI formation or other problem
What might make my phone last longer?

- Don’t leave it in a hot car in Arizona
- Don’t charge the phone outside in Michigan in the winter
- Keep your battery charged about 50%
- Don’t drop your phone

Why isn’t my new phone much better than my old phone?

- Your new phone most certainly has a **better battery** in it than your old phone
  - Higher capacity
  - Higher voltage

- But **WHAT ELSE** does it have?
  - Bigger display
  - Brighter display
  - More processors
  - You use it differently....

Phone features expand to exploit battery improvements
Can I put in a better battery?

- Need to be careful here
- Battery management systems (BMS) are very sophisticated
  - Prevent overcharge, undercharge
  - Control charging rates
  - Monitor state of charge and battery health
  - Etc.
- The BMS and the battery are a “matched set”
- Not all batteries are equal
  - Even if the specifications are the same

How do we fix the problem?

- Inorganic Chemistry
  - Cathode materials with more accessible lithium
  - Example: High Ni layered oxides

LiMO₂ → Li₁₋ₓMO₂ ⟷ LiM₂O₄-type spinel ⟷ M₂O₄-type spinel ⟷ MO rock salt

\[
\text{Li}_{0.33}\text{Ni}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2
\]

Seong-Min et al., Chem. Mater. 2013, 25, 337-351
How do we fix the problem?

- Inorganic chemistry, formulation science
  - Anode materials with high lithium capacity and low volumetric changes
  - Example: Si based anodes

![Graphite Anode and Conventional Cathode comparison](image)

- Organic chemistry
  - Electrolytes that are stable on active materials
  - Example: SEI formation on anode

![Electrolyte and SEI formation images](image)
Wildcat’s Value Proposition

- Wildcat uses unique high throughput technology to accelerate battery R&D for others
- Projects include new or improved cathodes, anodes, electrolytes, and binders
- Wildcat’s value proposition is to accelerate time to market for new cell technologies and to reduce R&D costs

High Throughput Research: Value Proposition

High Throughput = High Success Probability

**Cathode**
- Base Composition
- Crystal Structure
- Dopants
- Coatings
- Particle Size & Distribution
- Surface Functionality
- Slurry
- Binder
- Drying Process
- Linear Carbonate
- Active Material Pair
- Formation Process

**Anode**
- Slurry
- Linear Carbonate
- Active Material Pair
- Formation Process

**Coating**
- Conductive Additive
- Thickness
- Cyclic Carbonate
- Capacity Match
- Voltage Range

**Particle**
- Additive Ratio
- Density
- Co-Solvents
- Electrolyte Quantity
- C-Rate

**Additives**
- AM:Binder Ratio
- Mixing Method
- Pressing Process
- Additives
- Pulse Protocols

**Separator**
- Particle Size & Distribution
- Current Collector
- Electrolyte
- Separator Properties
- Temperature

**Electrolyte**
- Electrolyte Quantity
- Active Material Pair
- Electrolyte
- Assembly
- Testing
“What is a TR50 company? It is a business whose innovations force other businesses to alter their strategic course.”

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