Thin Film Batteries & Integration

presented by

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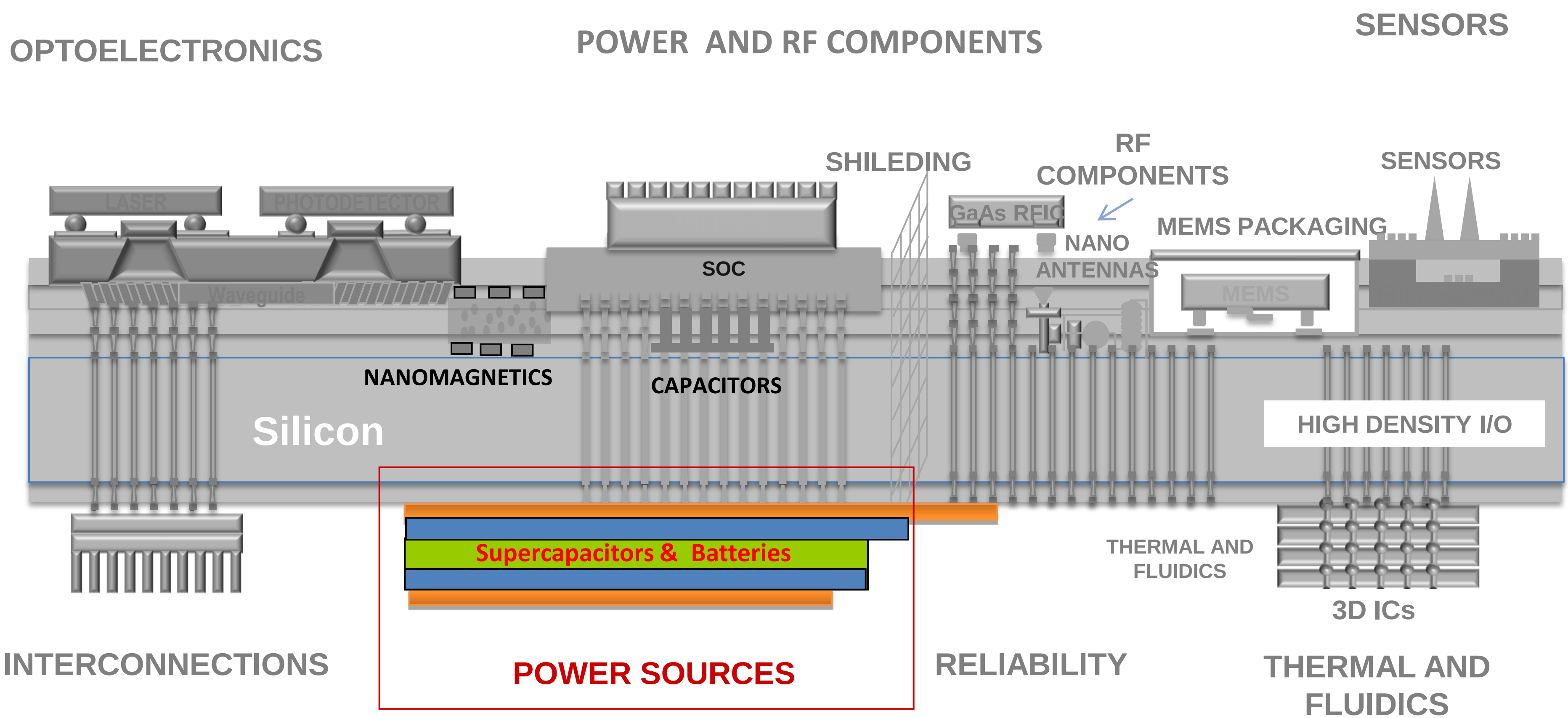
1. Research Focus



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New Materials for Energy Storage & Conversion

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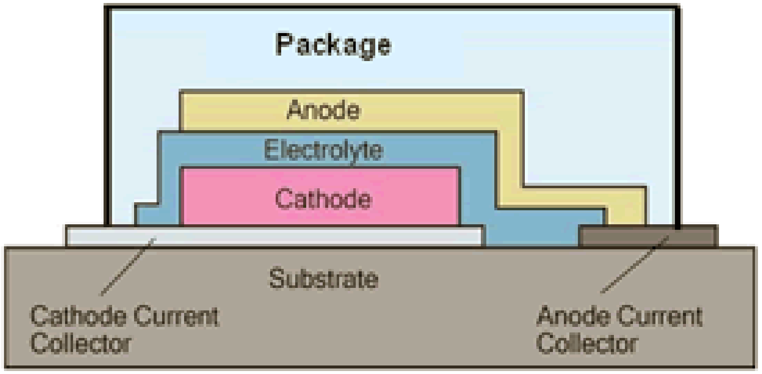
2. Overview of thin-film batteries

1 Unique features of thin-film batteries

- Unlike conventional batteries, thin-film batteries can be deposited directly onto chips or chip packages in any shape or size.
- All solid state construction (common electrolyte: solid lithium phosphorus oxynitride, LIPON)
- Can be operated at high and low temperatures: conventional batteries containing organic liquid electrolytes cannot survive such temperatures.
- Safer under all operating conditions.
- Excellent choice for non-volatile memory, smart cards, wireless sensors, RFID tags, and implantable medical devices.

2. Overview of thin-film batteries

2 Structure of thin-film batteries

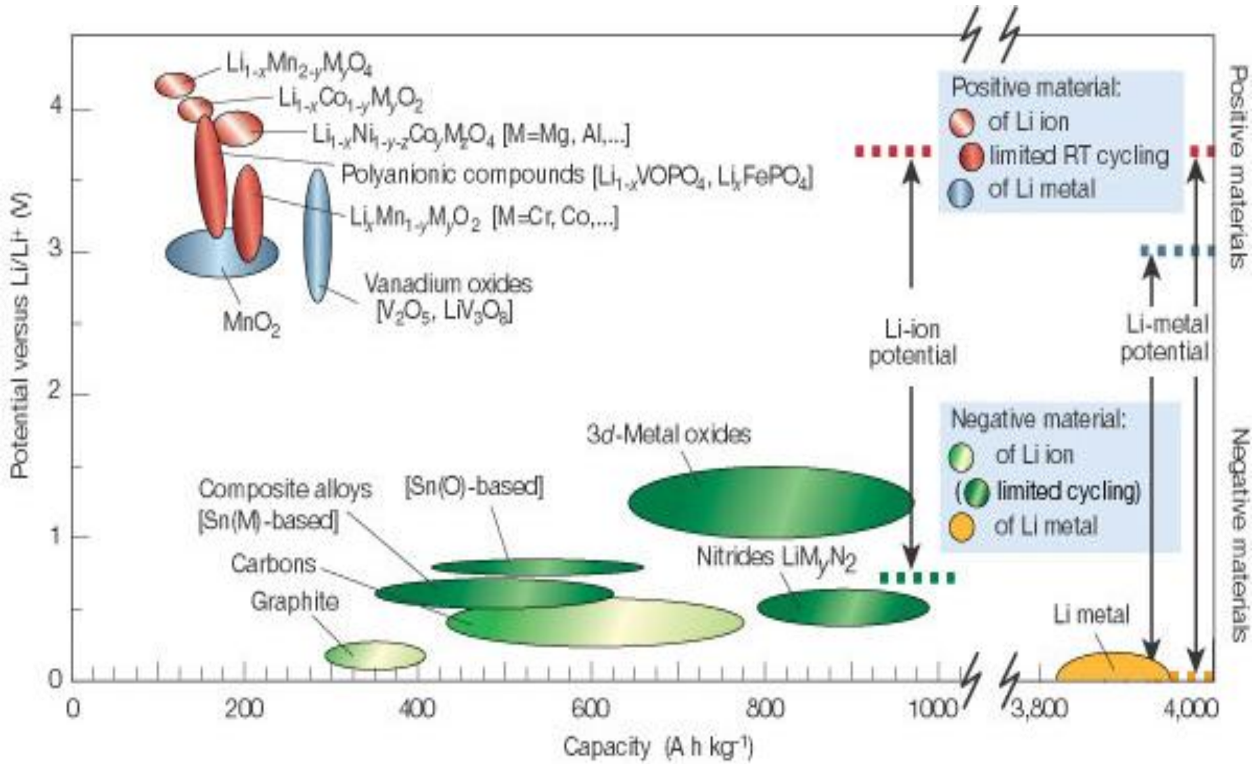


Schematic layout of a thin-film battery
(Courtesy: Oak Ridge Micro-Energy, INC.)

- The different layers are deposited by sputtering or evaporation methods which are commonly used in the semiconductor industries.
- The deposited battery stack from current collector to anode is less than 5 um thick.
- Other costs-effective techniques such as sol-gel process can be applied.

2. Overview of thin-film batteries

3 Candidate electrode materials for thin-film batteries

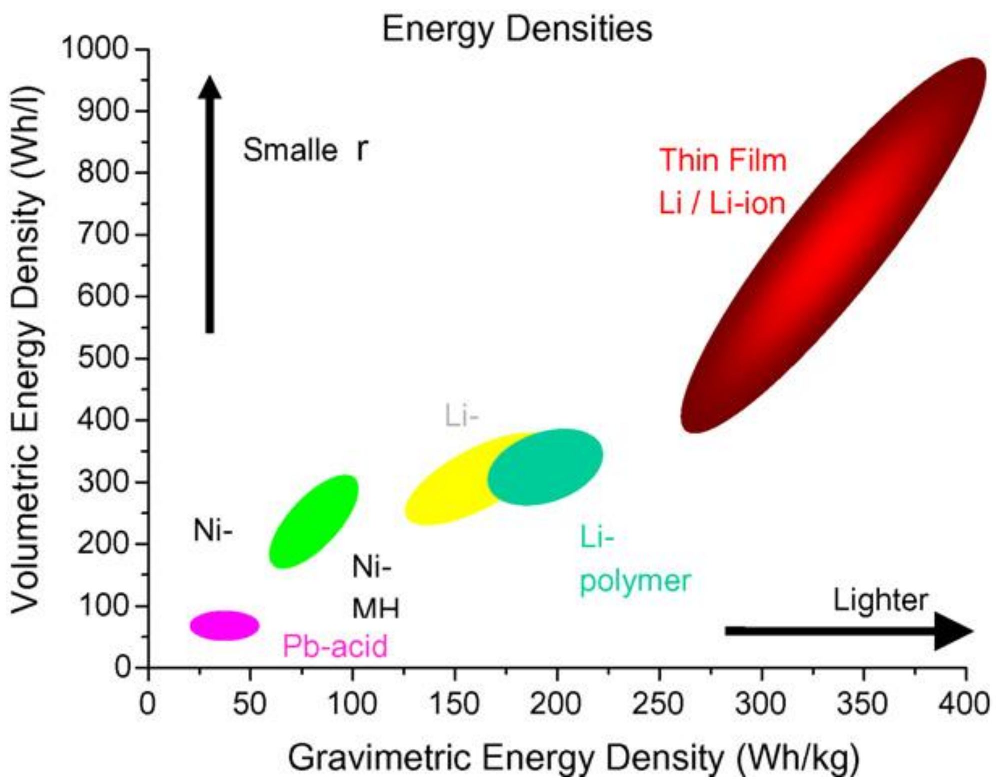


Candidate electrode materials are essentially same as in conventional lithium batteries. Currently, lithium metal is deposited in the vacuum as anode, but other safer materials (such as $Li_4Ti_5O_{12}$) can be also used.

J.-M.Tarascon, ***Nature***, 414, 2001

2. Overview of thin-film batteries

4 Prospects of thin-film batteries



State-of-the-Art

Among various existing technologies, thin-film lithium batteries are considered as one of the most competitive power sources in terms of volumetric energy density and gravimetric energy density.

A. Patil et al., ***Materials Research Bulletin***, 43, 2008

3. TPC Focus and Targets

	State-of-the-Art	*Proposed Research Objectives*
Capacity	• ~0.15 mAh/cm^2 ($T = 25^oC$)	• ~0.3 mAh/cm^2 ($T = 25^oC$)
Energy Density	• ~0.3 mWh/cm^2 ($T = 25^oC$)	• ~0.6 mWh/cm^2 ($T = 25^oC$)
Power Density	• ~20 mW/cm^2 ($T = 25^oC$)	• ~40 mW/cm^2 ($T = 25^oC$)

* Based on electrode thickness: ~1um

4. Thin-film Batteries - Challenges

- **Material challenges:**
  - Requires novel low temperature solid **electrolyte**: $>10^{-5}$ S/cm at 25 ^{o}C: conductivity of LIPON ~ 2.3×10^{-6} S/cm at 25^{o}C.
  - Requires new **electrode** materials having larger capacity and better rate capability.

- **Integration challenges:**
  - The use of moisture- and oxygen- sensitive lithium metal complicates the cell assembly and the integration.
  - Needs the fabrication process compatible with substrates and other process (such as soldering).

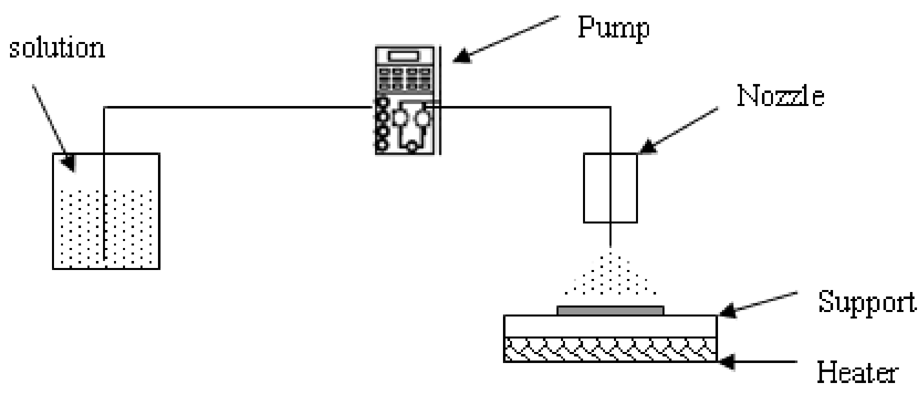
- **Manufacturing challenges:**
  - Rational design of 3D porous electrodes.

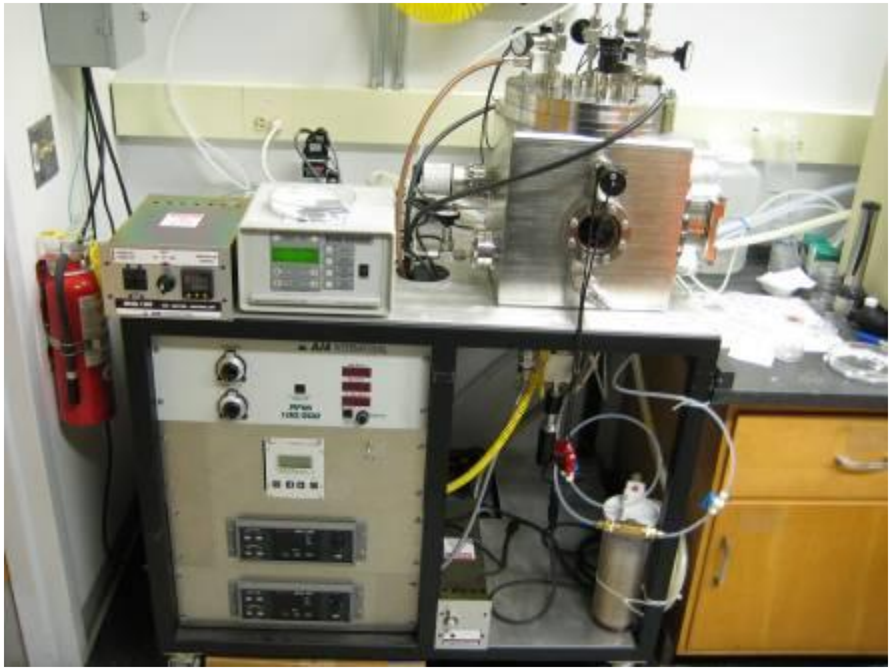
5. Proposed research

- Development of **novel materials** for **electrolyte** and **electrodes** for high performance thin-film batteries;
- **Cost-effective** and integration-compatible **fabrication process** of functional thin-films;
- **Innovative architecture** for high performance thin-film batteries;
- New *in situ* techniques for characterization of electrode processes;
- Multi-scale modeling of ionic and electronic transport processes in bulk, at surfaces, and across interfaces.

6. Research capabilities

1 Synthesis of novel materials for lithium batteries





<Aerosol-assisted CVD>

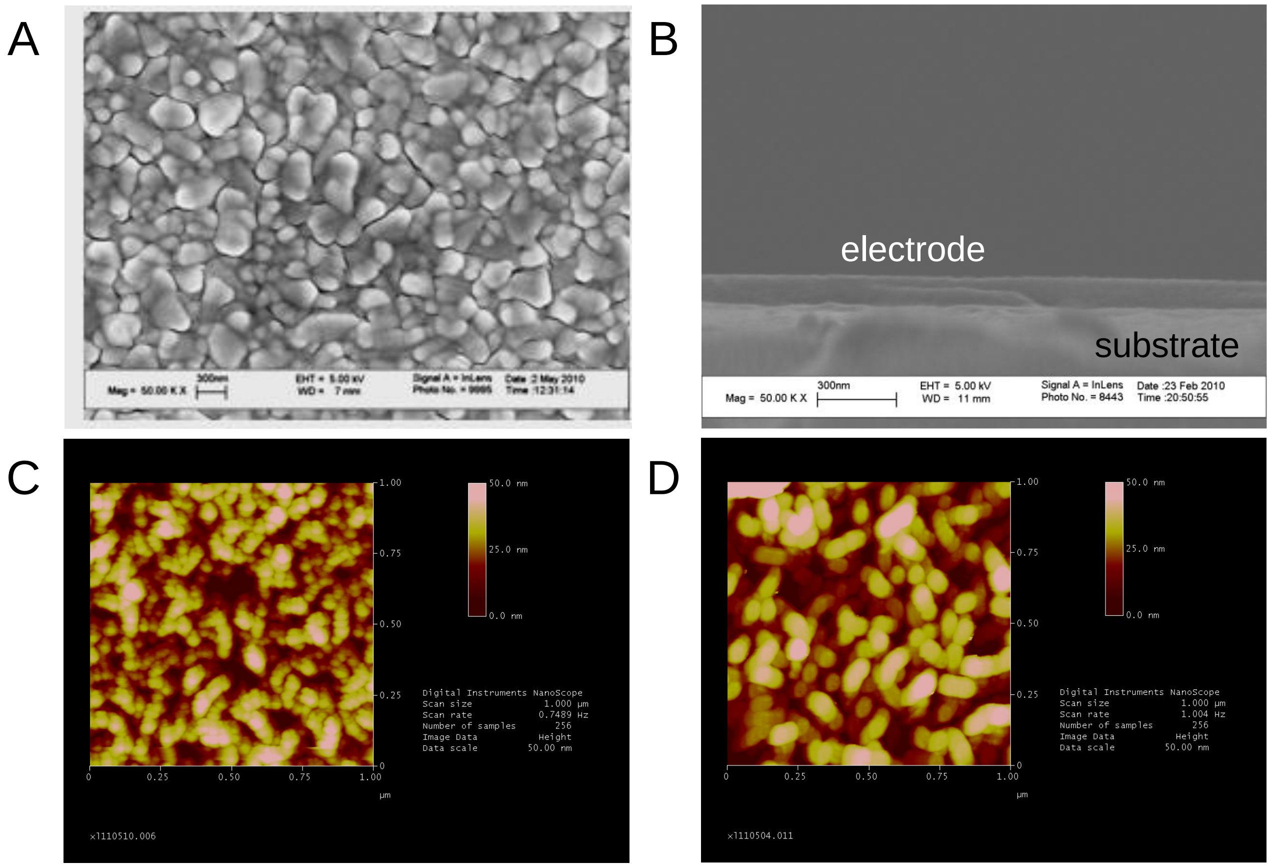
- Preparation of porous electrodes
- Preparation of thin-film electrodes

<DC/RF Magnetron Sputter>

- Preparation of thin film batteries

6. Research capabilities

1 Synthesis of novel materials for lithium batteries (continued)



SEM (A and B) and **AFM** (C and D) images of electrodes having different morphology and porosity

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6. Research capabilities

2 Fabrication and Characterization of Cells and Components

<Glove box filled with purified argon gas>

- Charge/Discharge behavior
- Rate capability
- Galvanostatic cycling test

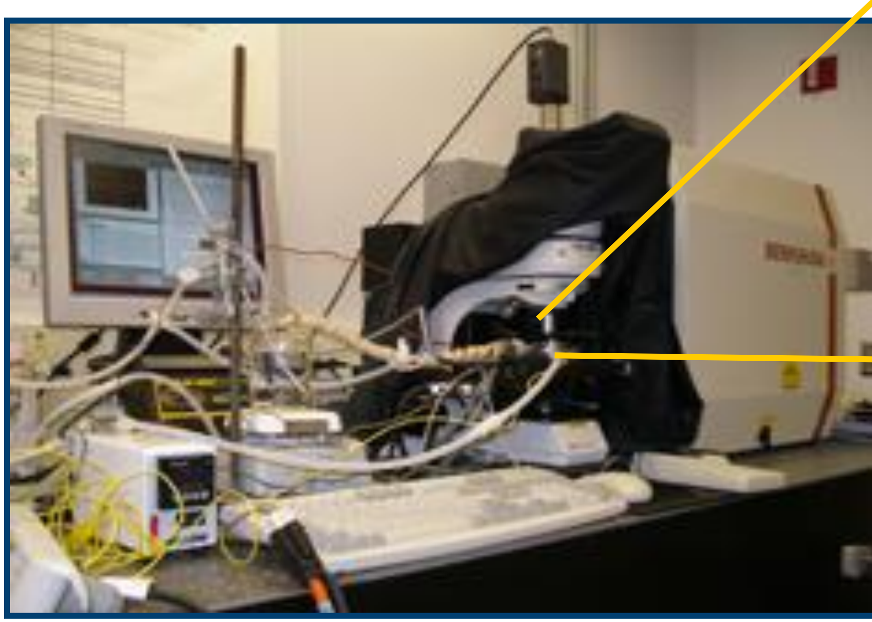
<Multi-channel battery test systems>

<Potentiostat/Galvanostat + Frequency Response Analyzer>

- Electrochemical Impedance Spectroscopy
- Cyclic Voltammetry/Linear Sweep Voltammetry
- Chronoamperometry/Chronopotentiometry

6. Research capabilities

3 *In situ* characterization

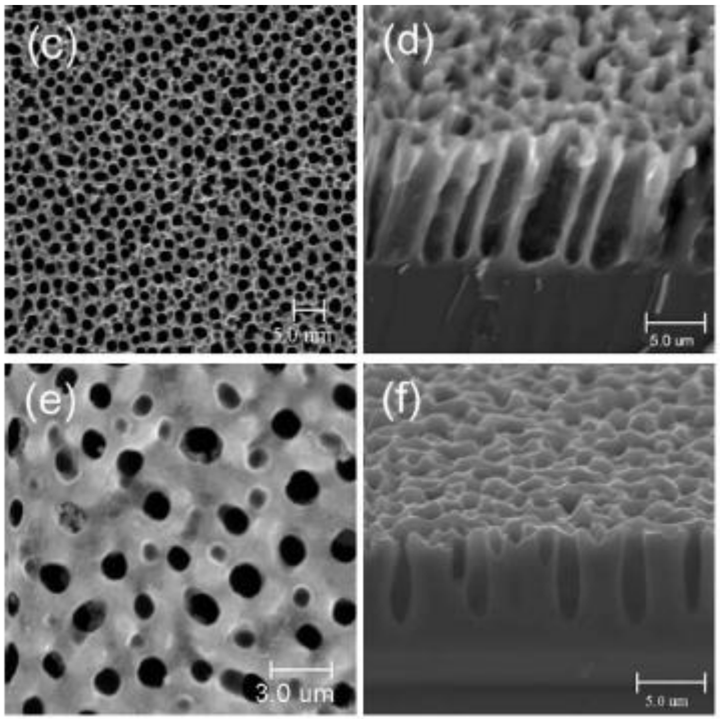


In situ Raman chamber

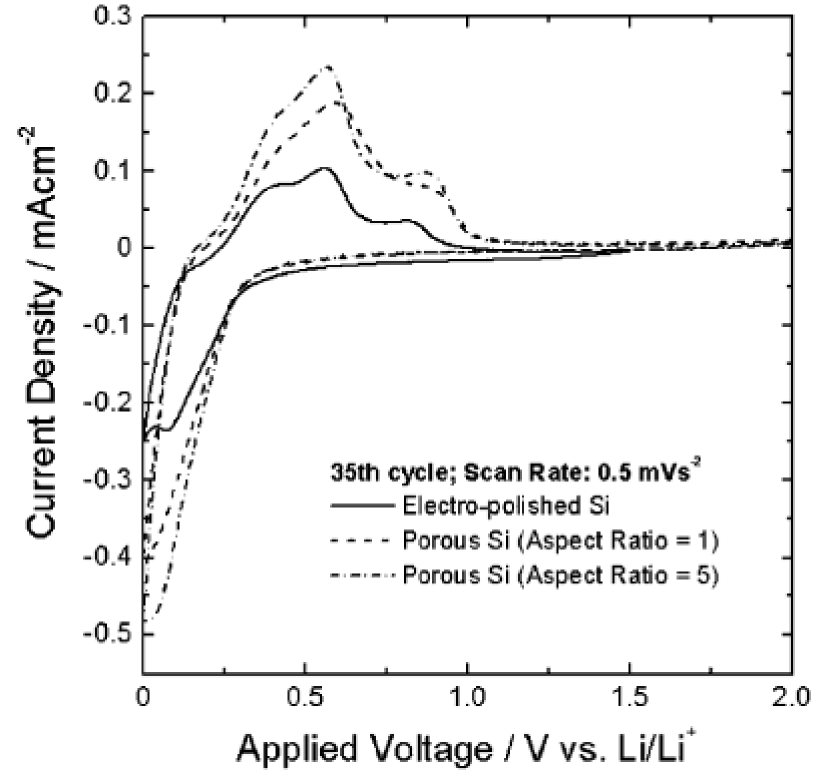
- X-Y-Z motorized stage moves in 0.02mm increments
- Spectra can be collected from 1 mm diameter spot

7. Previous works done by Liu group

1 Porous silicon negative electrodes for rechargeable lithium batteries



Images of Porous Si etched by different condition



Porous silicon anode was created by electrochemical etching process. The capability of lithium storage improved with the increasing channel depth. Also, the specific capacity increased with the degree of pre-activation at the expense of cycling stability.

H-C. Shin et al, ***Journal of Power Source***, 139, 2005

7. Previous works done by Liu group

2 Three-Dimensional Porous Copper-Tin Alloy Anode for Li Batteries

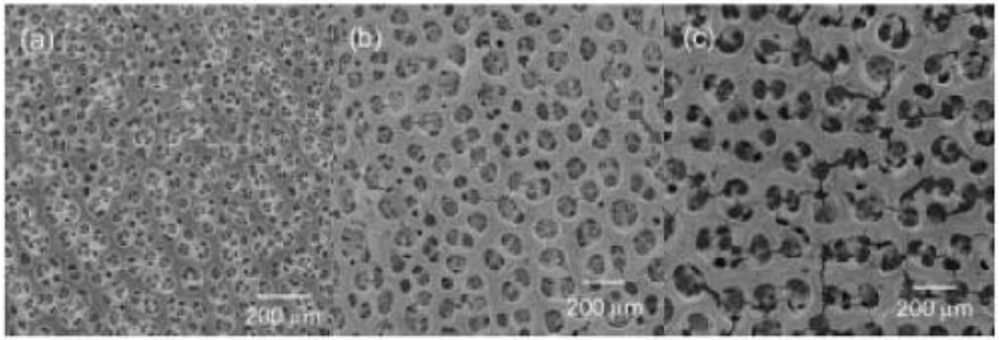


Figure 1. Typical SEM images of porous Cu–Sn alloys created by an electrochemical deposition process for different periods of time: a) 5 s, b) 10 s, and c) 20 s.

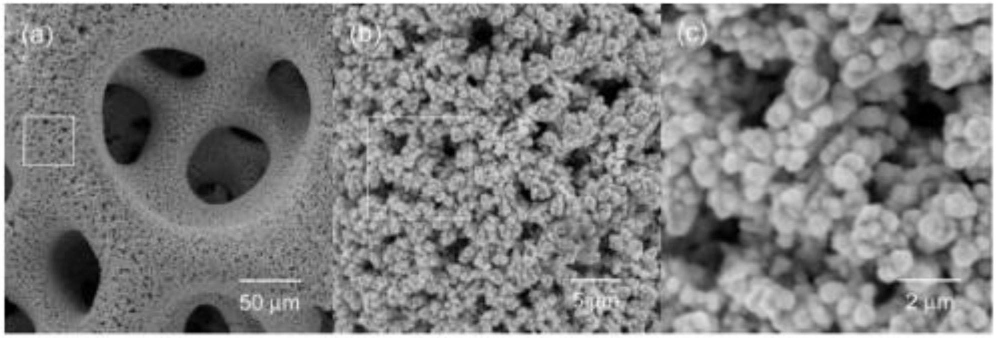
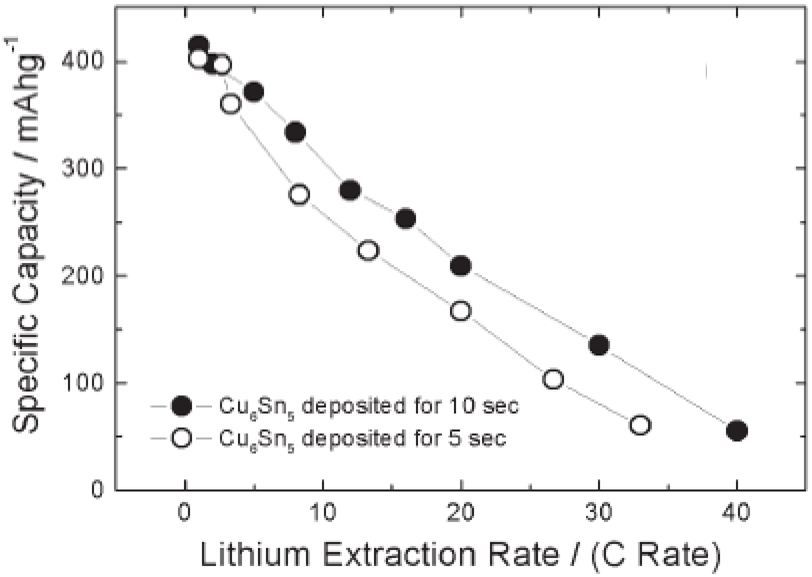


Figure 2. 3D foam structure of a porous Cu–Sn alloy sample (created for 10 s) at different magnification showing that a) the large pores formed due to evolution of H_2 from the substrate, b) the detailed microstructure of the walls, and c) the small pores within the walls formed by the evolution of H_2 from the deposited Cu–Sn particles.



3-D foam structure of Cu_6Sn_5 alloy was successfully created by electrochemical deposition process. Although the cycling stability needs to be improved further, excellent rate capability opens up new possibility of 3-D porous nanostructure.

H-C. Shin et al., ***Advanced Functional Materials***, 15, 2005

TPC Workshop

MAY 25, 2011

Thank you for attending.