Novel Lithium Ion Anode Structures: Overview of New DOE BATT Anode Projects

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Project ID #: ES101

Overview of Anode Projects

PI/University/Institution	Year 1 Funding	Title of Project
Y. Gogotsi and M. Barsoum Drexel University	$245,000	New layered Nanolaminates for Use in Lithium Battery Anodes
Y. Cui Stanford University	$300,000	Wiring Up Silicon Nanostructures for High Performance Anodes
A. Dillon, NREL S.H. Lee; S. George Colorado University	$450,000	Atomic Layer Deposition (ALD) for Stabilization of Amorphous Silicon Anodes
D. Wang and M. A. Hickner Pennsylvania State University	$200,000	Synthesis and Characterization of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes
J-G Zhang and J. Liu Pacific Northwest National Laboratory	$300,000	Development of High Capacity Anode for Li-Ion Batteries
K. S. Chan and M. Miller Southwest Research Institute	$300,000	Synthesis and Characterization of Silicon Clathrates forAnode Applications in Lithium-Ion Batteries
S. Whittingham SUNY at Binghamton	$172,376	Metal-Based High Capacity Li-Ion Anodes
P.N. Kumta University of Pittsburgh	$220,500	Nanoscale Heterostructures and Thermoplastic Resin Binders: Novel Li-ion Anode System

New layered Nanolaminates for Use in Lithium Battery Anodes – Y. Gogotsi and M. Barsoum, Drexel University

- **Technical Objectives:** Replace graphite with a new material. Layered ternary carbides and nitrides known as MAX phases - may offer combined advantages of graphite and Si anodes with a higher capacity than graphite, lesser expansion, longer cycle life and, potentially, a lower cost than Si nanoparticles.

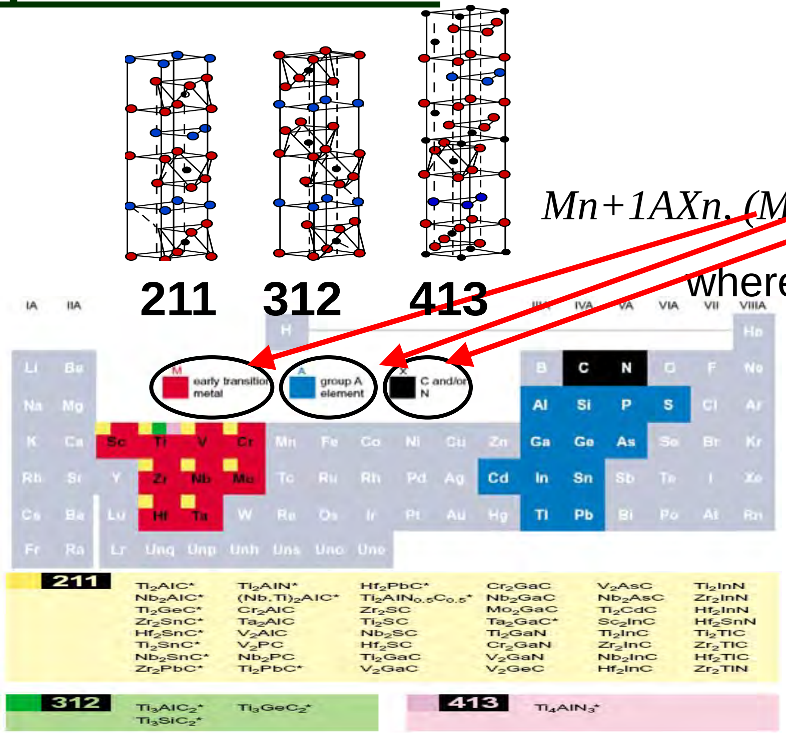
- **Barriers:** *Ability to reversibly insert Li into the MAX phases. Achieve first cycle irreversible loss and cycling efficiencies similar to graphite.*

Milestones – Year 1

Month/Year	Milestone
June-11	Complete theoretical investigation and conduct preliminary electrochemical screening of MAX phases. Demonstrate by modeling that MAX phases have a potential to surpass conventional carbon anodes
June-11	Produce porous anodes of MAX phase that require neither binder nor carbon black additives
September- 11	Achieve particle size reduction and exfoliation of MAX phases into graphene-like 2-D structure "MAXene"
December-11	Conduct a complete electrochemical characterization of MAX phases and demonstrate the effect of vacancies in the metal sublattice on lithium uptake by the anode.

Technical Approach-Overview

- **Technical Approach:** *Since at this time the relationship between capacity and MAX phase chemistry is unknown; a rapid screening of as many MAX phases as possible will be carried out to find out the most promising chemistry, by testing their performance in lithium ion batteries. This will be guided by ab initio calculations. Reducing particle size, selective etching of A element out from the MAX structure, and exfoliation of these layered structure also will be investigated to increase the Li+ uptake of these structure and improve the Faradaic efficiency.*

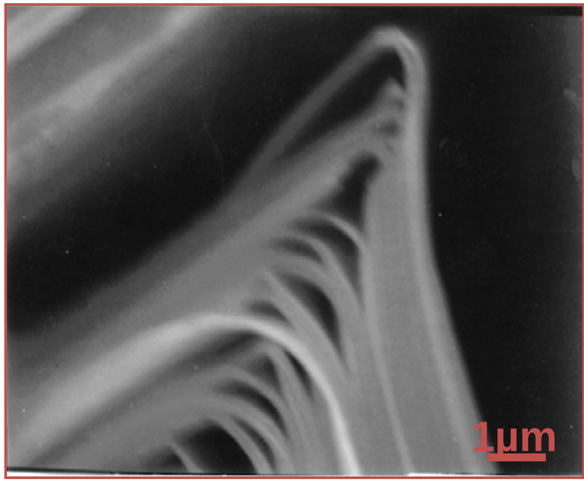


Mn+1AXn, (MAX);

where n = 1 to 3,

MAX phase: is a large family of **layered, hexagonal** carbides and nitrides – which today number **> 60** member.

- MAX phases combine the advantages of both metals and ceramics, like:
  - Electrically and thermally conductive
  - Machinable - Elastically rigid
  - Lightweight (density down to 4.11g/cc for Ti_2AlC)
  - Maintain their strength to high temperatures
  - Creep, fatigue and oxidation resistant

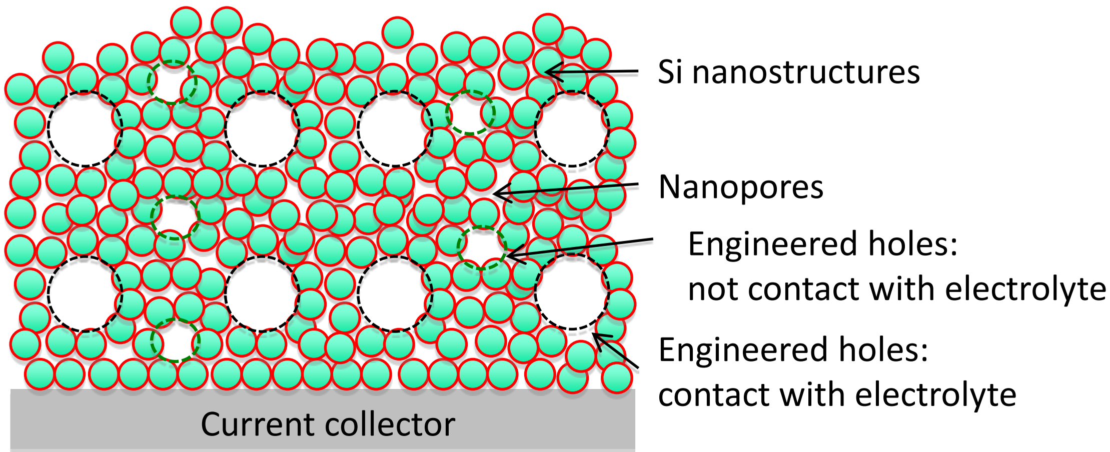


Mn+1AXn + yLi = Mn+1ALiyXn

Theoretical capacity of Ti_2AlC Assuming 2Li per mole of Ti_2AlC ~398 mAh/gm

Wiring Up Silicon Nanostructures for High Performance Anodes – Y. Cui; Stanford University

Technical Objective: Design high performance Si nanostructure anodes to fulfill the requirements of electric vehicles.



Barriers:

1. Engineering large scale systems
2. Translation of nanoscale architectures into practical batteries
3. Translation of the fundamental results to the engineered systems

Milestones for Year 1

1) Identify the method to connect Si nanoparticles electrically (Jun 15, 2011).
2) Find out the relationship of critical breaking size versus capacity for deep lithiation(Sep. 15, 2011).
3) Identify a method to produce porous Si electrodes (Sep. 15, 2011).
4) Obtain detailed information on the volume expansion and contraction of Si.

Technical Approach:

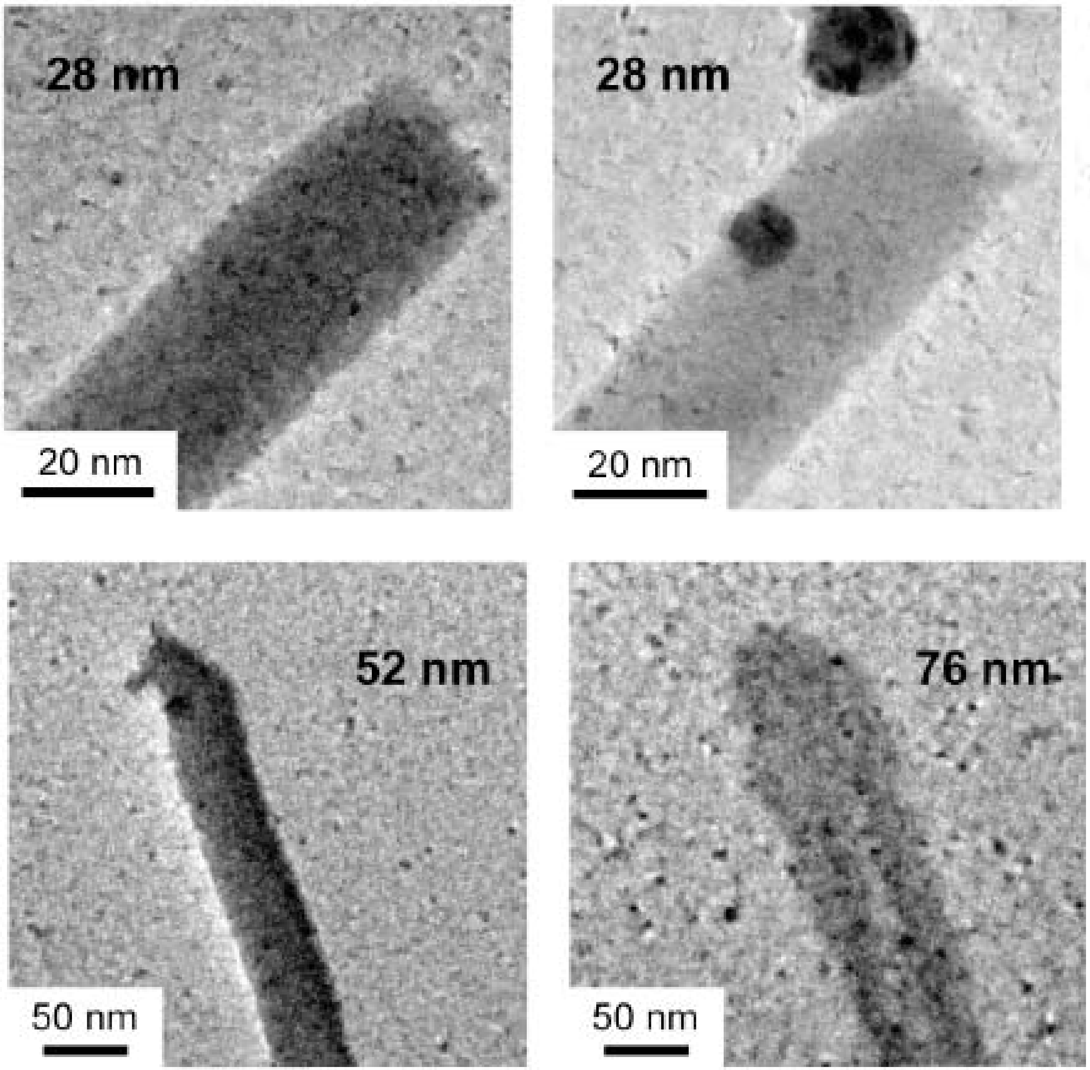
1) Use ex-situ and in-situ TEM to obtain the critical breaking size of Si particles versus capacity. They have to be small enough for the strain relaxation.
2) Rationally Design the pore space. The free space around Si particles is critical for volume expansion.
3) Design methods for electrical connection of Si particles to collectors.
4) Explore strategies to form stable solid electrolyte interphase (SEI).

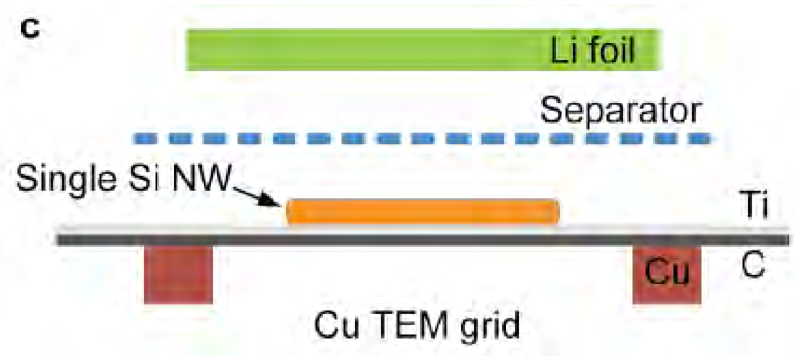
Technical Accomplishments

Volume change depends on the the size of Si.

Before and After one cycle

$$Si \xrightarrow{+Li} Li_xSi \xrightarrow{-Li} Si$$





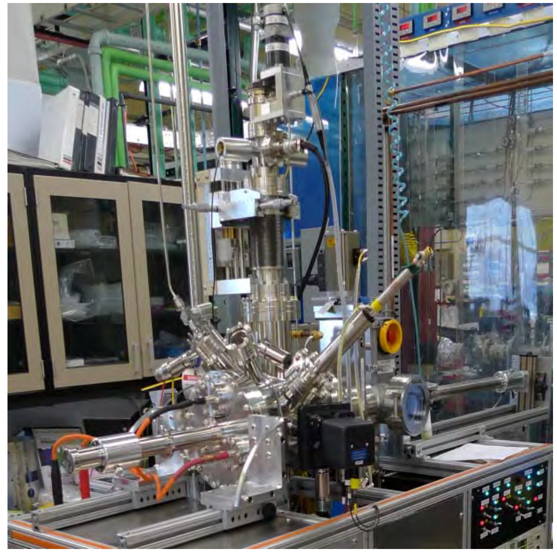
Structure correlation on the same single nanowires.

Atomic Layer Deposition (ALD) for Stabilization of Amorphous Silicon Anodes – PI: A. Dillon (NREL); Se-Hee Lee and S. George (U Colorado); Collaborations: Battaglia, Liu (LBL); Whittingham (SUNY-Binghamton); Payzant, Kirkham (ORNL); Harris (GM); Grey (SUNY-Stony Brook); Groner (ALD Nanosolutions

Barriers

- **Cost**: developing novel anodes from abundant, inexpensive materials (Si).
- **Capacity:** improvements in both gravimetric and volumetric capacities will be demonstrated for thick electrodes.
- **Rate capability:** Durable rate capability will be achieved through application of ALD coatings previously demonstrated for high volume expansion metal oxide materials.

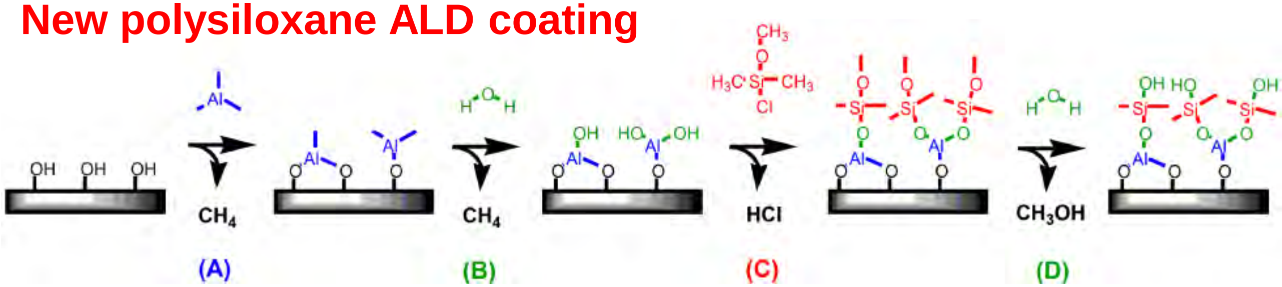
Technical Objectives and Approach



We will use HWCVD to fabricate thick electrodes of amorphous Si, and nano or polycrystalline Si as well as doped variations of the above (to improve electronic conductivity) at NREL.

New ALD chemistries (below) will enable durable high rate cycling. ALD is suitable for R2R processing that is being demonstrated at ALD, Nanosolutions (ALDN). ALD will initially be performed at CU with scale-up later demonstrated at ALDN. Build on previous demonstration of Al_2O_3 ALD to stabilize MoO_3 anodes., ~200% volume expansion.

New polysiloxane ALD coating



Low elastic modulus, similar to rubber!

<u>Milestones – Year 1</u>

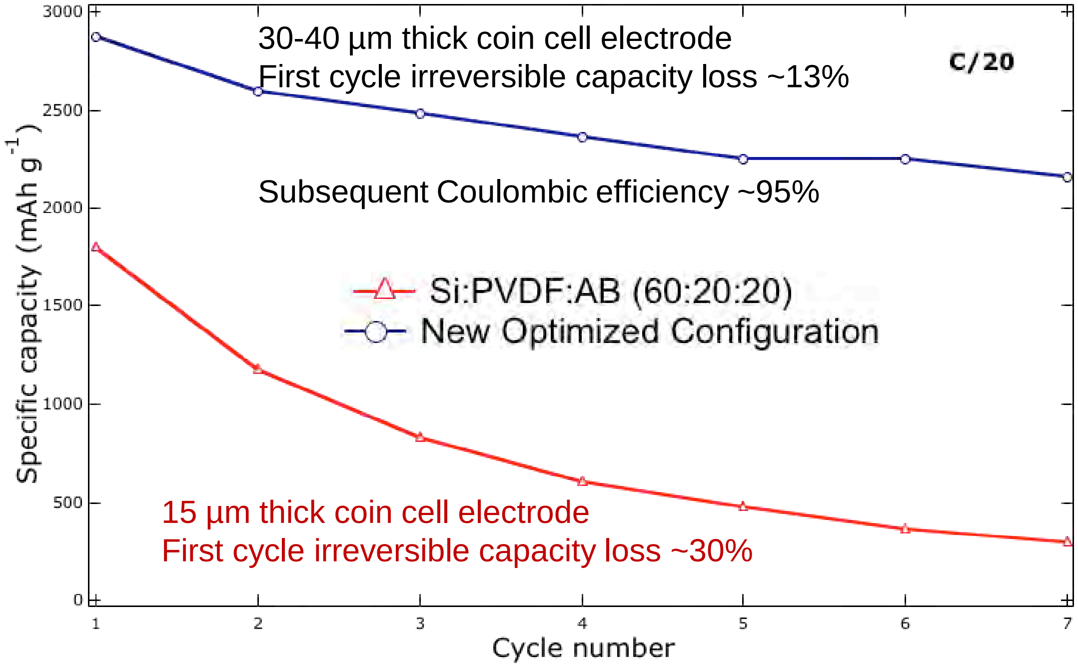
May 2011: Optimize HWCVD produced a-Si or nano-Si in conventional coin cell.

July 2011: Demonstrate an ALD coating for improved performance of Si anode.

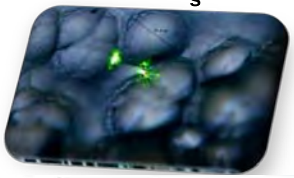
Sept. 2011: Optimize coated electrode and demonstrate durable cycling.

Primary FY11 goal is to improve Coulombic efficiency and cycling rate.

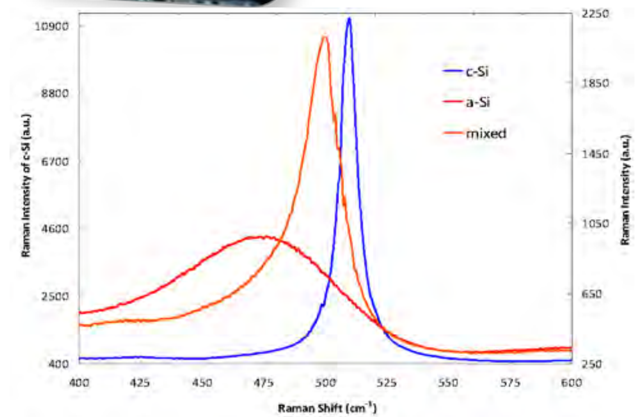
Technical Accomplishment: Progress towards achieving milestones



HIGH T_s

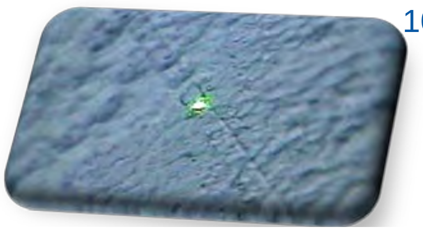


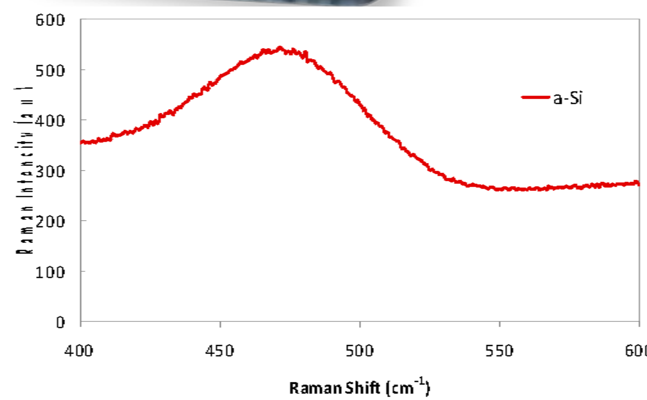
magnification of 100 x: crystals ~ 25 -35 µm



LOW T_s

magnification of 100 x





- Initially HWCVD scale-up resulted in mixed crystalline phases.
- HWCVD synthesis conditions were optimized to produce all a-Si powder ~60 mg /h produced with a small-scale single filament system. Multi-filament HWCVD systems are available at NREL.
- Small spot Raman reveals substrate temperature (T_s) is critical to avoid crystalline silicon (c-Si) island formation.

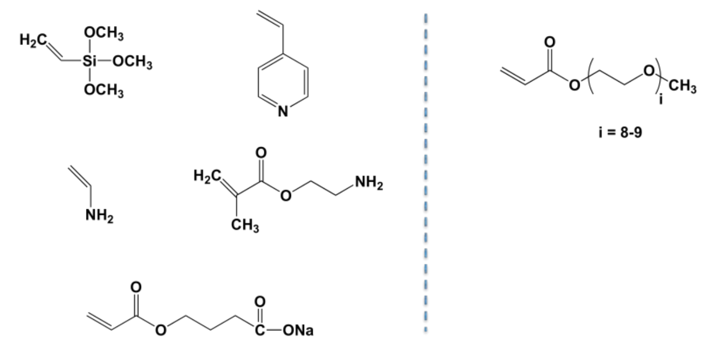
Synthesis and Characterization of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes – PI: D. Wang, M. Hickner, Pennsylvania State University; Collaborations: Zhang (PNNL); Kumta (UPitt); Liu (LBL)

Technical Objectives

Novel Block Copolymer Binders for the Nanocomposite Anodes

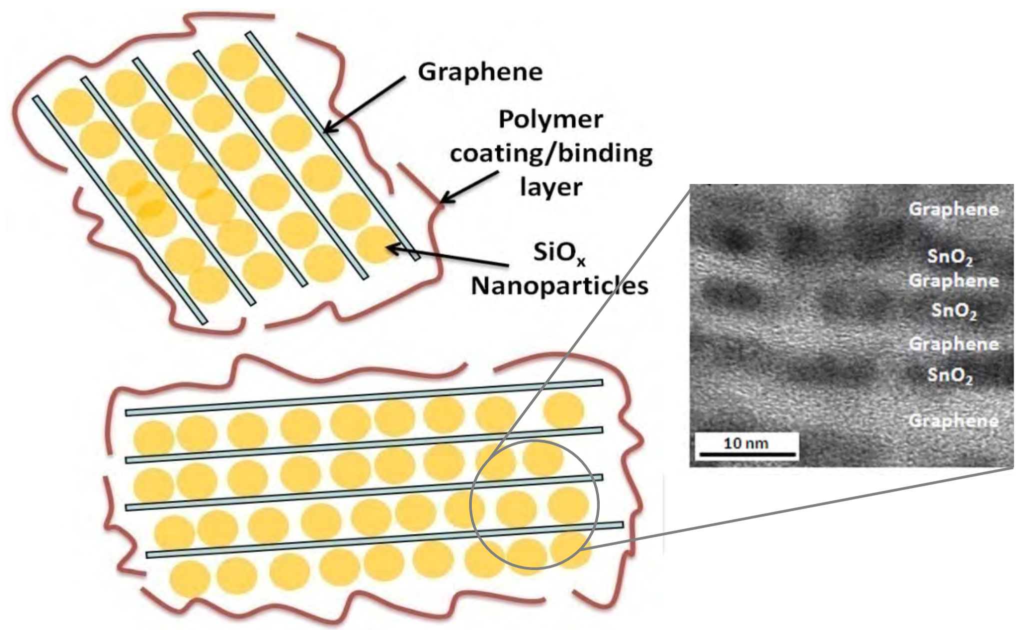
SiO_x anchoring block	Li conducting block	SiO_x anchoring block

SiO_x anchoring group example — Li conducting group example



To design and develop novel anodes based on layered-structured SiO_x nanocomposites in an attempt to:

- develop SiO_x-graphene nanocomposite anodes with specific capacity > 1,500 mAh/g and minimal 500 cycle capacity fade at 1C rates.
- understand the composition-structure-property-performance relationship for large-volume-change, high capacity anode materials in Li-ion batteries.



A Schematic of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes

Barriers

- Achievement of first cycle irreversible loss ~15%
- Achievement of coulombic efficiency >99.9%
- Ability of binder to binder to exceed performance of PVDF

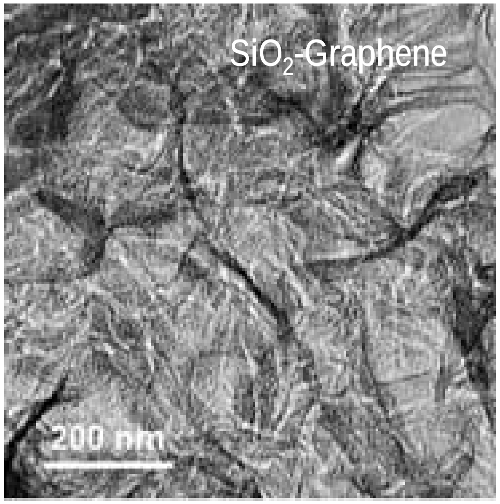
Milestones – Year 1

Month/Year	Milestones
06/2011	Milestone: 1. Prepare SiO_x nanoparticles with controlled particle size and demonstrate SiO_x-graphene hybrids with novel polymer binders. 2. Determine electrochemical properties of SiO_x nanoparticle, SiO_x-graphene hybrids and the polymer binders in lithium half cell.
12/2011	Milestone: 1. Completed synthesis of Si/graphene nanocomposites via a one-step process 2. Design and synthesize high MW binder and block copolymer binder; 3. Obtain 40% first cycle capacity as well as 90% coulombic efficiency cycle to cycle thereafter.

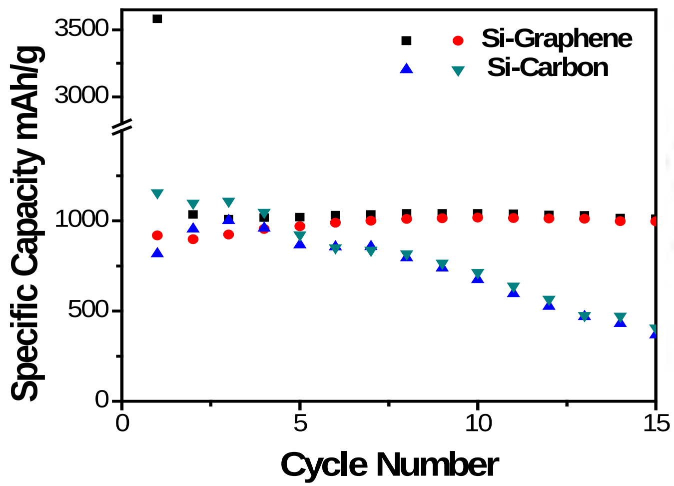
Technical Approaches

- **Synthesis of SiO_x Nanoparticles with Controlled Particles Sizes**
  - Solution reduction of $SiCl_4$ to form Si nanoparticles or Mg reduction of SiO_2
  - Surface coating of Si Nanoparticles into Si-SiO_x Nanoparticles
- **Synthesis and Functionalization of Graphene**
- **Self-assembly and Testing of SiO_x-Graphene Nanocomposites**
  - Functional group or surfactant mediated self-assembly of Si precursor/ SiO_x nanoparticles on graphene
- **Pre-lithiation of SiO_x-graphene Nanocomposites**
- **Synthesis of Polymer Binders**
- **Fabrication and Testing of Polymer-coated Nanocomposites**

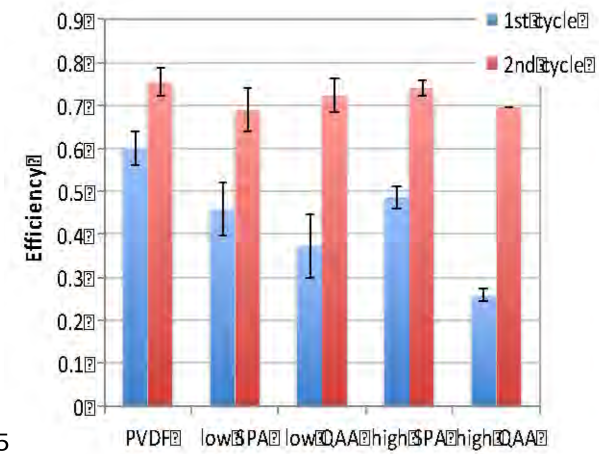
Technical Accomplishments



Si-Graphene



Polymer Binder for Si



- **Completed synthesis and functionalization of graphene**
  — *via* an oxidation-reduction wet-chemistry approach

- **Preliminary results of Silicon nanoparticles**
  — *via* solution reduction of $SiCl_4$ ($SiCl_4$ + Na-Naphathelene → Si + NaCl)

- **Performance measurements of binder-polymers**
  — Low MW sulfonate (SPA) or quaternary ammonium (QAA) terminated polymer binder was tested as Si nanoparticles binder.
  — The polymer with SPA unit was much better than that with the QAA unit.
  — Polymers with higher ion content showed better performance.

Development of High Capacity Anode for Li-Ion Batteries – PI: Ji-Guang Zhang and Jin Liu, PNNL; Collaborations: UPitt; Princeton; PSU; NDSU; Vorbeck, Inc.

Technical objectives

Develop high capacity, stable, low cost anodes with good rate capability to replace graphite in Li-ion batteries.

Barriers

- Achieving reduction in first cycle irreversible loss.
- Achieving coulombic efficiency higher than 99.9%.
- Achieving good rate capability.

Milestones – Year 1

- Identification of optimized carbon matrix/additives with reduced first cycle loss.
- Improvement of coulombic efficiency.
- Optimization of new conductive polymers as a binder for Si anode.

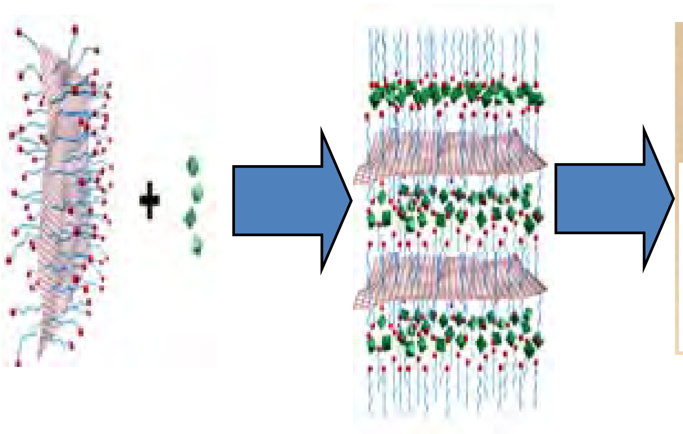
Technical Approaches

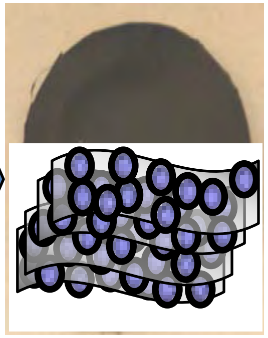
- Silicon with nano-porous structure and CVD-coated carbon to accommodate the volume variation of Si during cycling and to improve the electronic conductivity.
- Graphene-silicon nanocomposite to improve the electronic conductivity and mechanical stability.
- New carbon additives and binders.

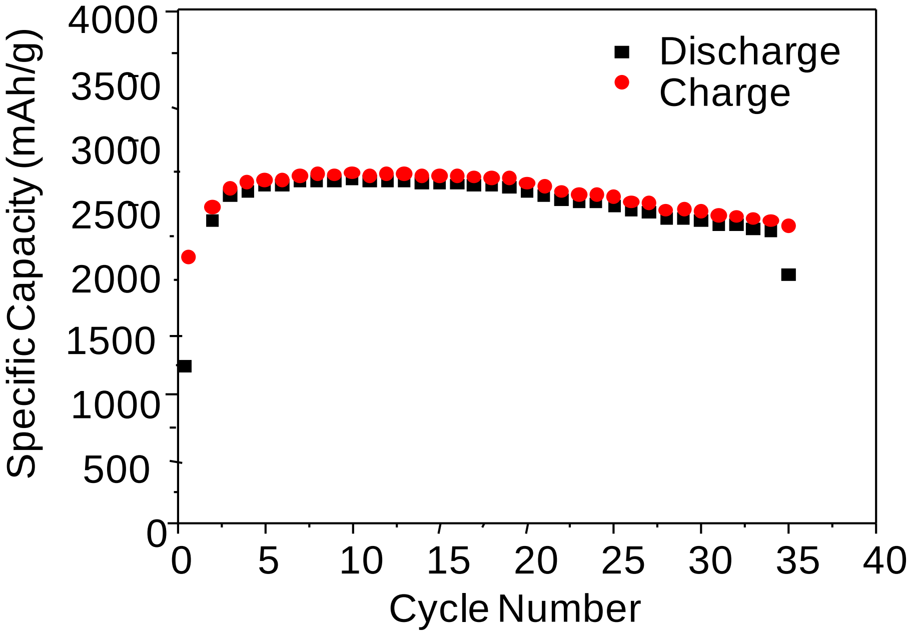
Technical Accomplishments:
Nano-structured Si Demonstrate Improved Cyclability

Self-assembly with graphene

Paper-like sample of Si-graphene Wt% of Si: 33%



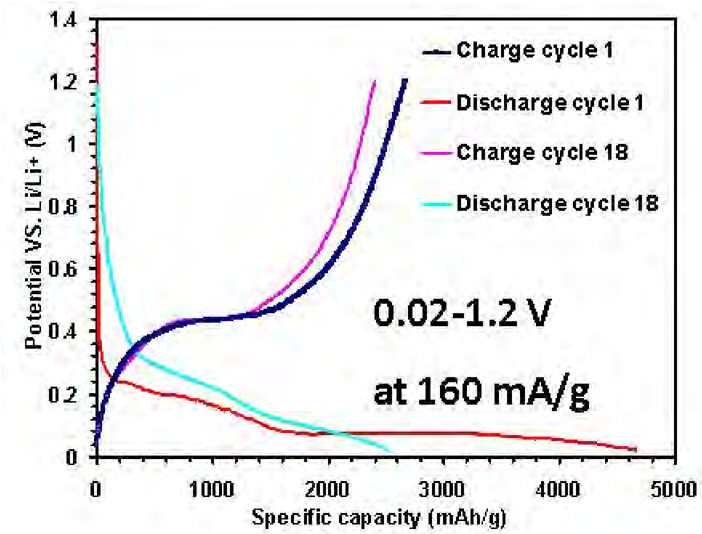




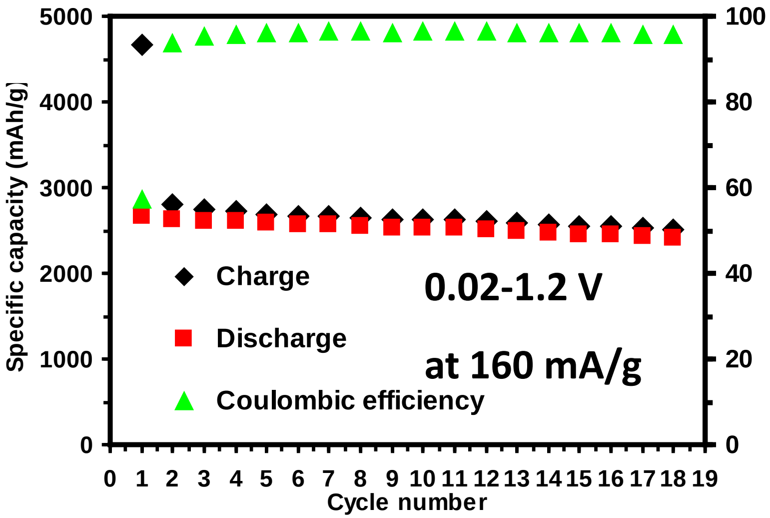
- Capacity based on Si and whole Si/graphene hybrid electrode are ~2300 and 800 mAh/g, respectively.
- Graphene sheets buffer the volume variation of Si during cycling leading to a high reversible capacity and cycling stability.

Technical Accomplishments:

Adjusting the Ratio of Graphene and Carbon in the Composite Anodes



Cycling ability of Si/graphene hybrid electrode. The capacity is calculated based on the whole weight of the electrode.



Cycling ability of Si/graphene hybrid electrode. The capacity is calculated based on the whole weight of the electrode.

The volume expansion and contraction of Si particles during cycling are effectively buffered by the graphene sheets.

Synthesis and Characterization of Silicon Clathrates for Anode Applications in Lithium-Ion Batteries – PI Kwai S. Chan and Michael A. Miller, Southwest Research Institute, San Antonio, TX

Technical Objectives

- Synthesize and characterize silicon clathrates (Si_{46}).
- Design Si_{46} anodes to exhibit small volume expansion, high specific energy density, while avoiding capacity fading.
- Improve the life and abuse tolerance of Li-ion batteries with Si_{46} anodes.

Goals

Specific Energy (W·h/kg)	Specific Power (W/kg)	Cycle-Life	Calendar Life (yr)
200 (EV)	316	1000	15
96 (PHEV)	316	3000 (40 mi equiv.)	15

Baseline Systems: Conoco Phillips CPG-8 Graphite/1 M $LiPF_6$+EC:DEC (1:2)/Toda High-energy layered (NMC)

Barriers

- Low specific energy
- Low specific power
- Short calendar and cycle lives

Milestones – Year 1

Prepare 1-2 gram quantities of Type I clathrates by one or both synthesis methods (6/30/2011).

Select one synthetic pathway (9/30/2011).

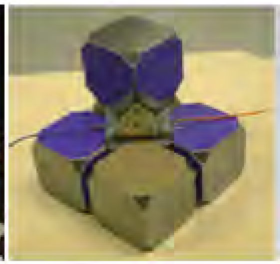
Identify possible reaction pathways (based on modeling results) for the formation of empty clathrates Si_{46}, Li_xSi_{46}, and $Li_{15}Si_4$ (9/30/2011).

Construct and evaluate an electrochemical half-cell device using silicon clathrate materials synthesized in Year 1 (12/30/2010).

Technical Approaches

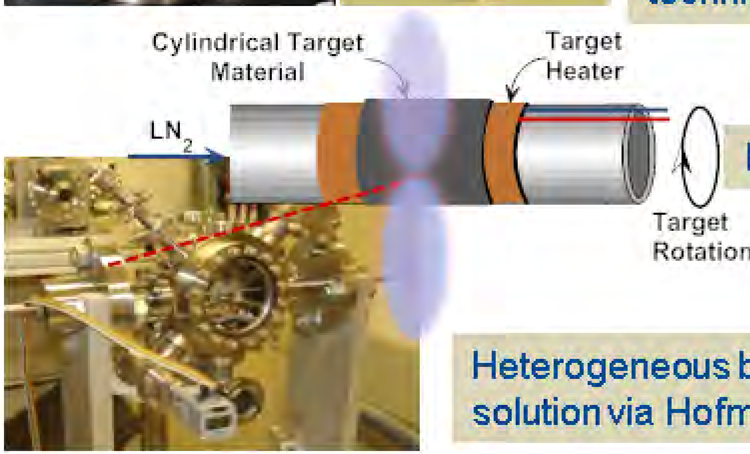
Approach

Experimental	*Theory*



Synthesis of Si_{46} via parallel paths:

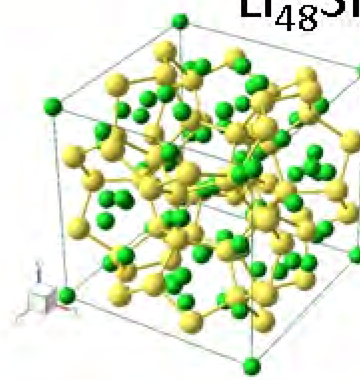
- High pressure and temperature multi-anvil techniques (high energy)



- Pulsed laser ablation
- Heterogeneous batch synthesis in solution via Hofmann-type reaction

First principles predictions of lithiation pathways, thermodynamic and kinetic constraints, transformation of allotropic states, and mechanical stability

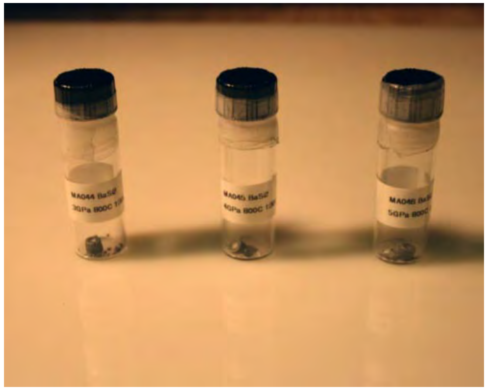
$Li_{48}Si_{46}$

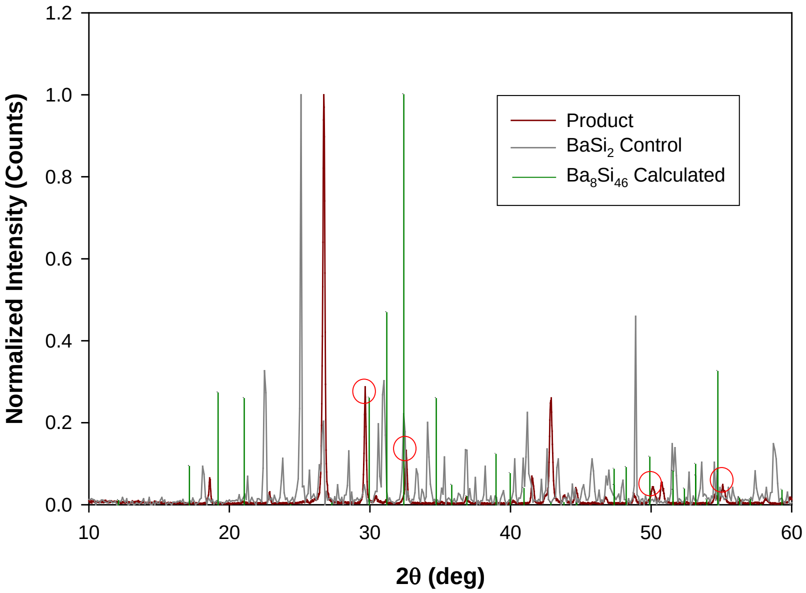


$$4[R'\text{-}CH_2\text{-}NR_3]^+ + Si_9^{4-} \longrightarrow 9Si_{46}^0 \text{ [Clathrate I]}$$

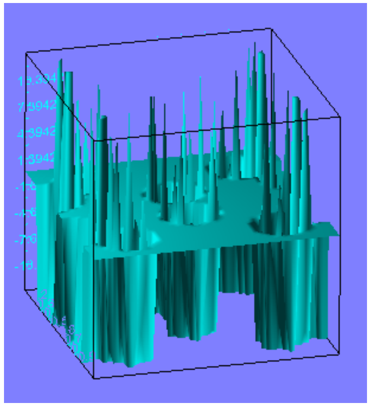
Technical Accomplishments

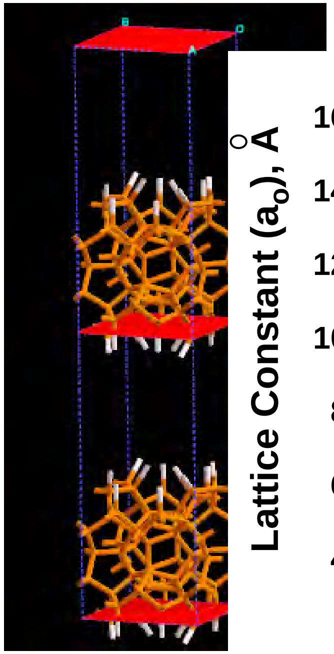
High Energy Synthesis of Ba_8Si_{46} Leading to Empty Clathrate Si_{46}



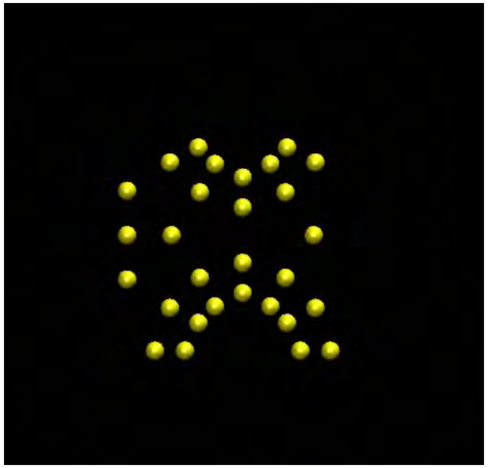


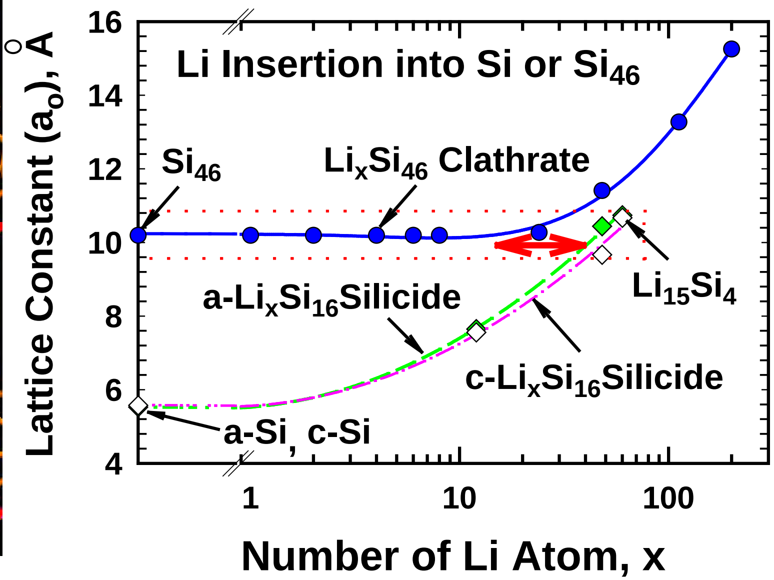
Prediction of Work Functions





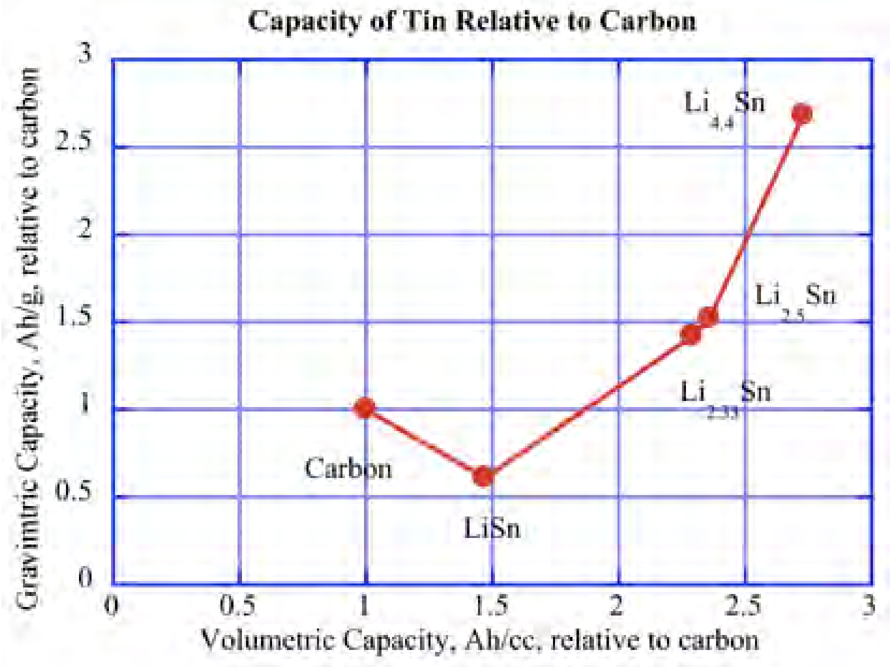
Lithiation Simulation





Metal-Based High Capacity Li-Ion Anodes - PI: M. Stanley Whittingham, SUNY at Binghamton; **Collaborations: National Labs: BNL; ANL; LBL; Industry: Primet; other University Anode**

- **Technical Objectives:**
  - Increase the volumetric capacity of the anode by a factor of two.
  - Use low cost materials and approaches
- **Barriers:**
  - Reduced first cycle irreversible loss
  - Higher coulombic efficiency
  - Long term cyclability
  - Rate capability



Milestones – Year 1

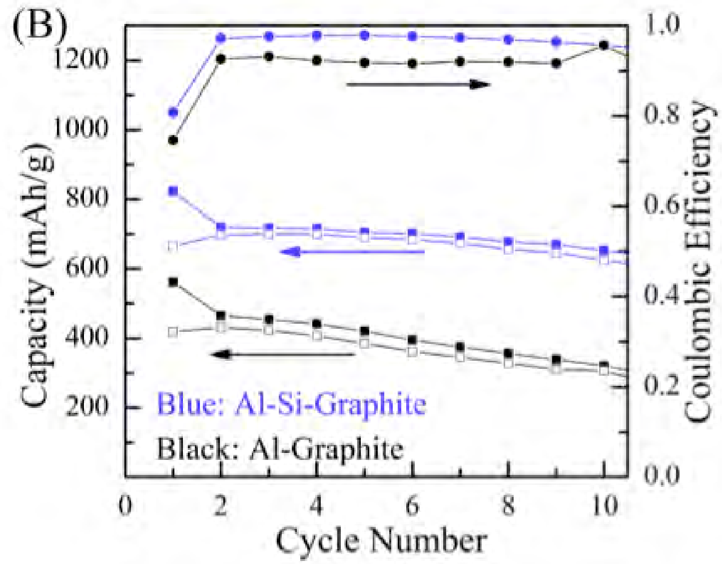
- Synthesize nano-size tin materials by at least two different methods.
  - One synthesis underway using only low cost materials.
- Characterize these materials and determine their electrochemical behavior.
  - Improved electrochemistry found on un-optimized material, as shown below.
- Initiate studies on nano-silicon materials. Synthesize by at least one method.
  - Will start in 3Q 2011.

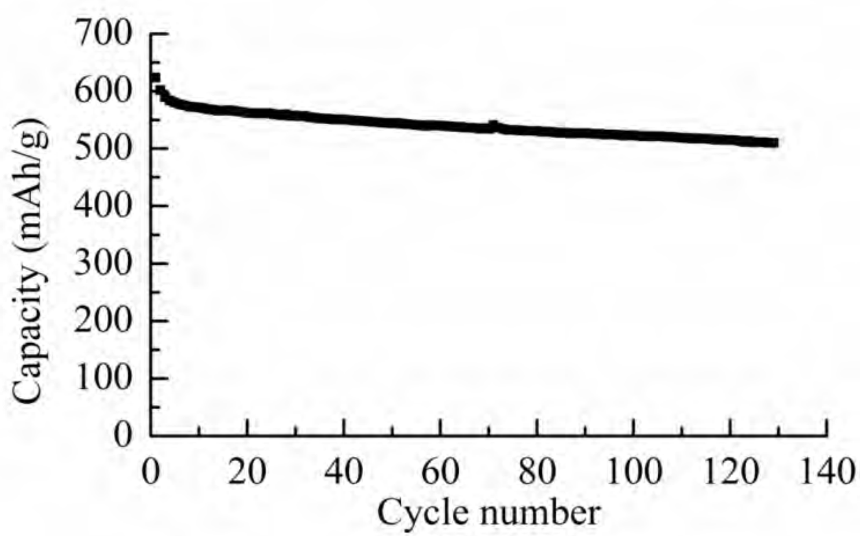
Technical Approaches

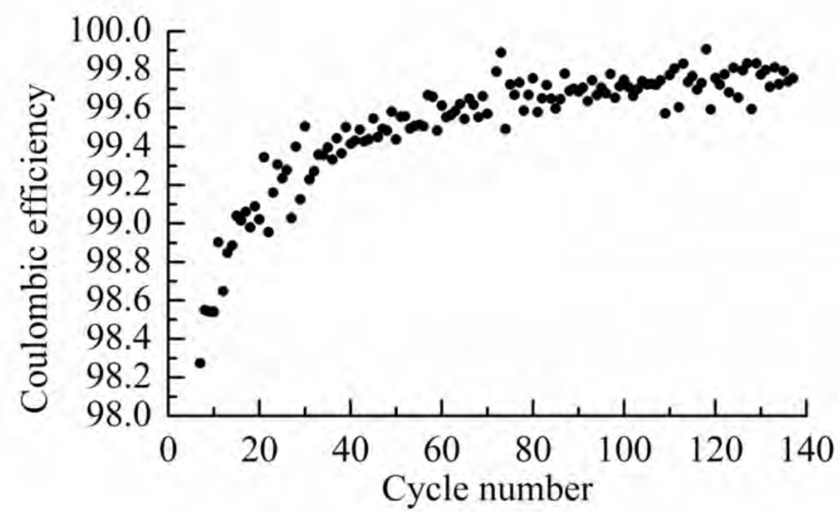
- Study modified tin initially
  - Safer than silicon
- 2 Li/Sn doubles capacity
- Find several simple synthesis methods
  - Nano-amorphous tin
  - Need low cost components
- Protect the nano-tin
  - From reaction with the electrolyte

Technical Accomplishments

- Our earlier work showed that going nano enabled capacity retention
  - Sn-Co-C
  - MnO_x
- Nano-size changes properties and improves electrochemistry:
  - Al dissolves silicon when nano-size (no solubility in bulk)
    - Increases capacity and capacity retention







Nanoscale Heterostructures and Thermoplastic Resin Binders: Novel Li-ion Anode System – PI Prashant N. Kumta, University of Pittsburgh; Collaborations: Ford; LBL; ORNL; NETL; PSU

Technical Objectives

• Alternative ***nanostructured anodes*** of higher gravimetric and volumetric energy density to graphite
• Similar or lower ***irreversible loss (~15%)*** compared to graphite
• Similar or better ***cyclability and calendar life*** to graphite
• Investigate ***nanostructured and amorphous Si*** based composite anodes
• Improve the specific capacity, energy density, rate capability, and cycle life of nano-structured and amorphous Si based anodes
• Identify high performance ***elastomeric binders***

Barriers

•***Low available*** *energy density*
•***Poor cyclability***
•***Large 1st cycle*** *irreversible loss*
•***Poor rate capability***
•***High coulombic*** *efficiency*
•*Improved binders to endure volume expansion related stresses in Si*

Milestones – Year 1

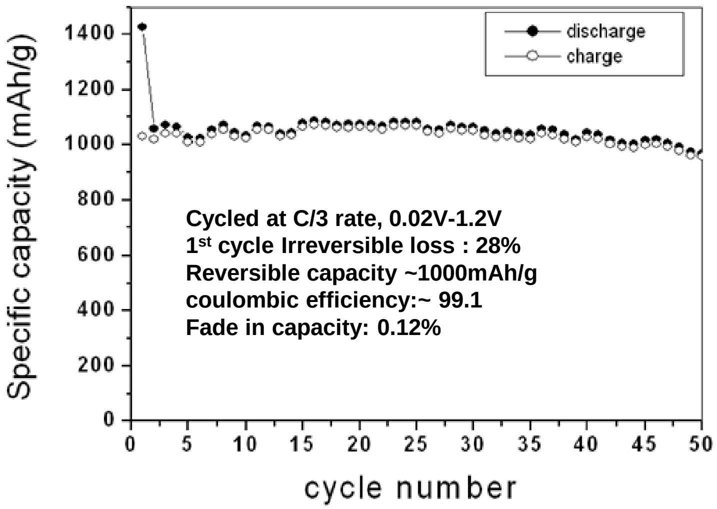
- **May 2011**: Synthesize nanostructured and amorphous Si based anode by cost effective method
- **August 2011**: Reduce ***irreversible loss < ~15%***
- **September 2011**: Improve the ***coulombic efficiency > 99.9%.***
- **January 2012**: Identify new binders and achieve stable ***reversible capacity (~1200mAh/g***) with low irreversible loss and high coulombic efficiency
- **March 2012**: Test best anode materials in a ***pouch cell configuration***

Technical Approaches

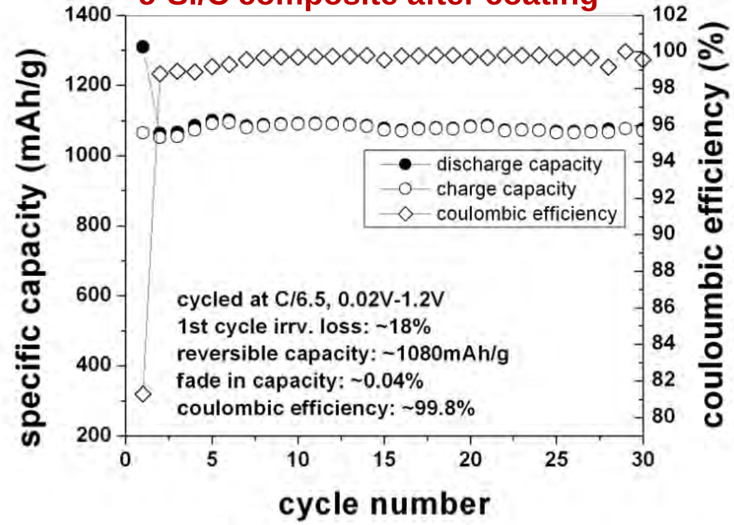
- Explore ***Si and carbon,*** and ***silicon, carbon, and boron*** based composite anode
- Explore ***novel low cost approaches*** to nanocrystalline and amorphous Si/C and Si/C/B composites
    - ***High energy mechanical milling***
    - ***Mechanochemical reduction***
    - ***Chemical vapor deposition and high throughput vapor phase reactions***
- Explore alloying elements to ***reduce 1st cycle irreversible loss and improve coulombic efficiency*** in subsequent cycles of Si/C
- Coating of Si/C composite with suitable element or compound
- Explore high strength, ductile ***elastomeric binders*** to bind the active materials
- Full cell and long cycling tests:
    - ***Coin cell and pouch cell*** configuration with suitable cathode

Technical Accomplishments

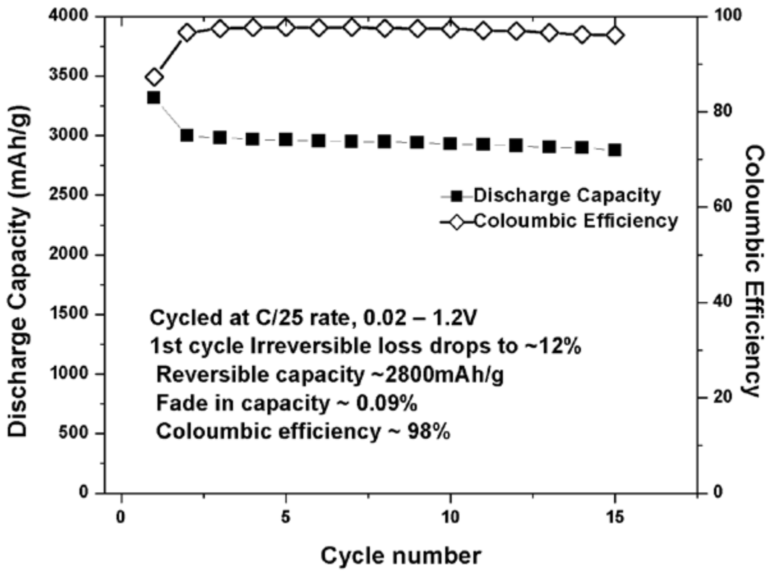
a-Si/C composite

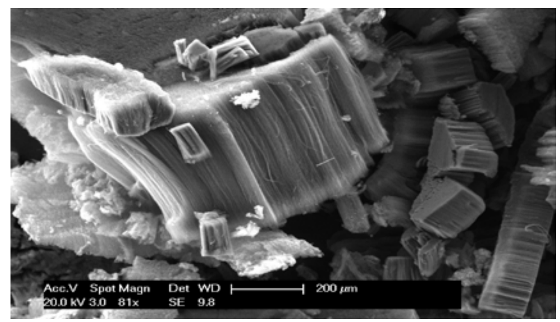


c-Si/C composite after coating

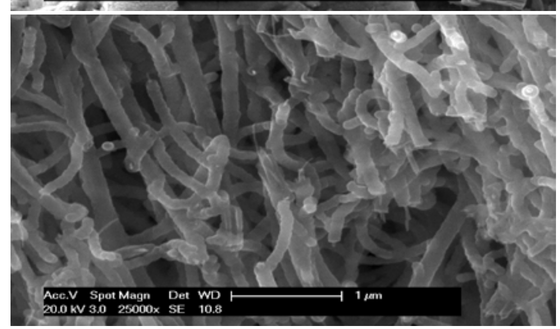


nc-Si/CNT heterostructures





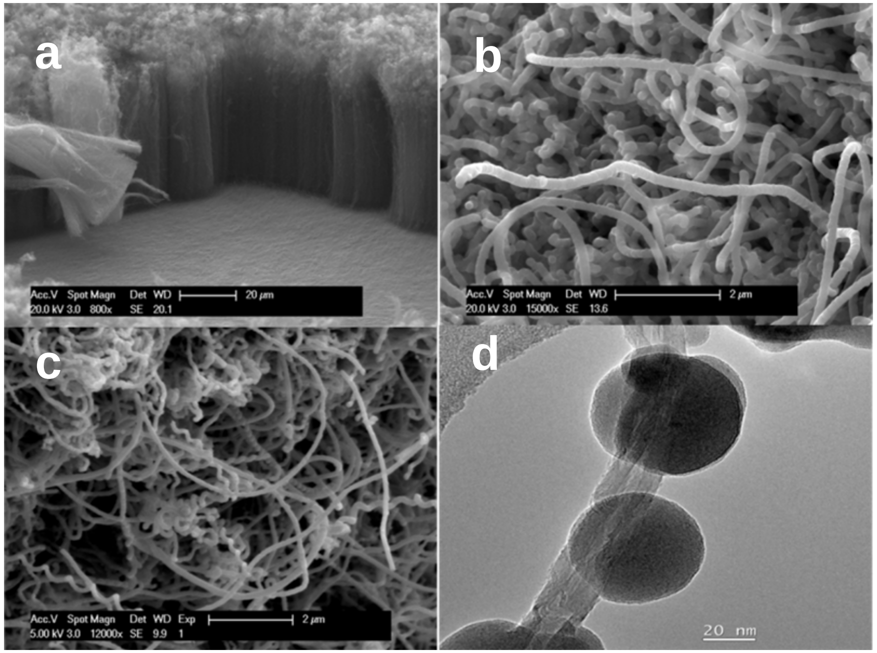
Vertically aligned CNTs



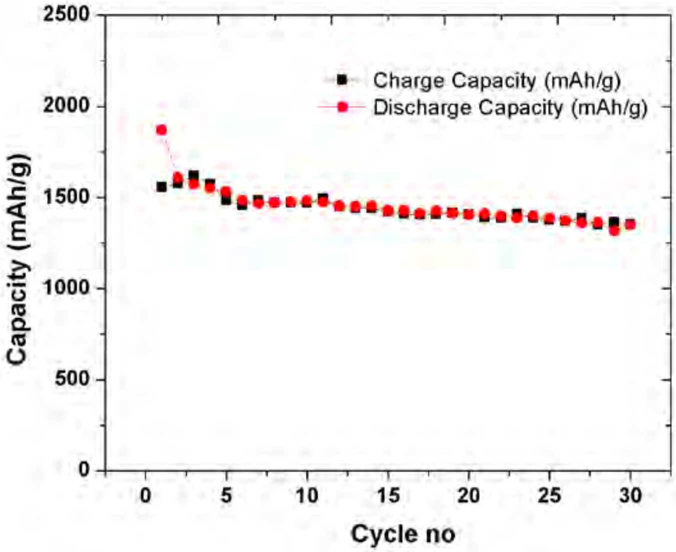
nc-Si coated CNTs

Technical Accomplishments

"*Binderless" Si/VACNT* nanostructured composite



SEM images of a) bare VACNTs, b) Si coated as film, c) Si coated as droplets on VACNTs, d) TEM image of Si droplets on VACNTs



Cycled at C/15
First cycle irreversible loss : 14%
Coulombic efficiency: ~99%
Fade in capacity: 0.4%
Reversible capacity: ~1400 mAh/g

Collaborations

Industry

- Ford Motor company (Kumta); General Motors (Dillon); Vorbeck, Inc. (Zhang); Primet (Whittingham)

National Laboratory:

- LBNL (Kumta, Wang, Dillon, Whittingham) *; BNL (Whittingham); ANL (Whittingham, Kumta)*; ORNL (Kumta, Dillon); PNNL (Wang)*;

University:

- Other Anode PIs

*Collaborators within the VT Program

Activities for next fiscal year

- **Project 1: New layered Nanolaminates for Use in Lithium Battery Anodes (Gogotsi)**
  - Complete theoretical investigation and produce porous MAX anodes phase.
  - Generate graphene-like 2-D structure "MAXene" .
- **Project 2: Wiring Up Silicon Nanostructures for High Performance Anodes (Cui)**
  - Connect Si nanoparticles electrically and produce porous Si electrodes with improved performance.
- **Project 3: Atomic Layer Deposition (ALD) for Stabilization of Amorphous Silicon Anodes (Dillon)**
  - Optimize HWCVD process to synthesize a-Si or nano-Si and demonstrate ALD coating for improved capacity and stability.
- **Project 4: Synthesis and Characterization of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes (Wang)**
  - Prepare SiO_x nanoparticles and SiO_x-graphene hybrids with novel polymer binders exhibiting improved performance.
- **Project 5: Development of High Capacity Anode for Li-Ion Batteries (Zhang)**
  - Identify optimized carbon matrix/additives and new conductive polymer binders exhibiting improved performance.
- **Project 6: Synthesis and Characterization of Silicon Clathrates for Anode Applications in Lithium-Ion Batteries (Kwai)**
  - Prepare Type I clathrates (Si_{46}, Li_xSi_{46}, and $Li_{15}Si_4$) and demonstrate electrochemical performance.
- **Project 7: Metal-Based High Capacity Li-Ion Anodes (Whittingham)**
  - Synthesize nano-size tin materials of tin and Si, and characterize their electrochemical behavior.
- **Project 8: Nanoscale Heterostructures and Thermoplastic Resin Binders: Novel Li-ion Anode System (Kumta)**
  - Synthesize nanostructured and amorphous Si based anode by cost effective methods and identify new binders to achieve stable ***reversible capacity (~1200mAh/g***) with low irreversible loss and high coulombic efficiency in full cell configurations.

Summary

- 8 **anode projects** initiated, 6 of which are new.
- New exciting concepts on Si clathrates, wiring up nanostructures, integrating graphene; and generation of amorphous silicon (a-Si) and nanocrystalline silicon (nc-Si) heterostructures have been initiated.
  - Initial results on nanoscale architectures and amorphous Si as well as heterostructures and composites appear very promising.
  - New ideas on interface modifications and coating modifications have promising affect on reducing first cycle irreversible loss and improving coulombic efficiency of *a*-Si and *nc*-Si.
  - Li inserted MAX and empty Si containing clathrate structures have been proposed.
- Two new projects on generation of novel elastomeric binders have been created.
  - Initial results indicate improvements compared to PVDF.
- Approaches to generate large scale quantities of high performance amorphous Si (*a*-Si) and nanocrystalline Si (*nc*-Si) indicate promising electrochemical response.
  - Initial results of HWCVD to generate *a*-Si, SiO_x-Graphene, Si/graphene composites indicate high capacity ~1000-2500 mAh/g.
  - Results on MCR and CVD derived composites indicate capacities in the 1000 mAh/g – 2800 mAh/g range.
  - low irreversible loss (~5-18%) have been achieved.
  - Excellent coulombic efficiency (~99.9%) has been attained.
  - Binderless concept of VASCNT exhibiting capacities ~1400-2000 mAh/g.

Back up Technical Slides

Atomic Layer Deposition (ALD) for Stabilization of Amorphous Silicon Anodes
NREL and University of Colorado, Boulder (CU) / Joint Award

Timeline

- Oct. 1, 2010
- Sept. 30, 2011

– First Quarter Milestone, **Complete**

– Preliminary results show next milestone is on track.

- **Full award ~ 6% complete**

Budget

- Total project funding

FY11: $450K

FY12: $470K

FY13: $500K

FY14: $500K

P.I.: Anne Dillon, NREL

Co-P.I's: Se-Hee Lee and Steven George, CU

Barriers

– Cost: developing novel anodes from abundant, inexpensive materials (Si)

– Capacity: improvements in both gravimetric and volumetric capacities will be demonstrated for thick electrodes

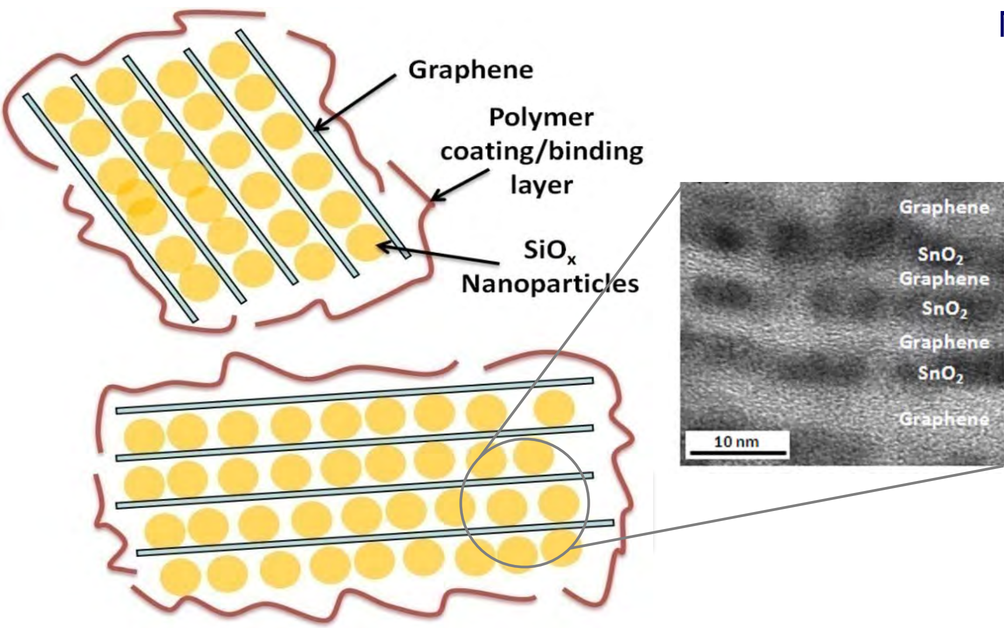
– Rate capability: Durable rate capability will be achieved through application of ALD coatings previously demonstrated for high volume expansion metal oxide materials.

FY10 Partners

- V. Battaglia and Gao Liu , LBL
- M.M. Thackeray and S-H. Kang, ANL
- M.S. Whittingham, SUNY-Binghamton
- E.A. Payzant and M.J. Kirkham, ORNL
- S. Harris, GM
- C. Grey, SUNY-Stony Brook
- M. Groner, ALD Nanosultions

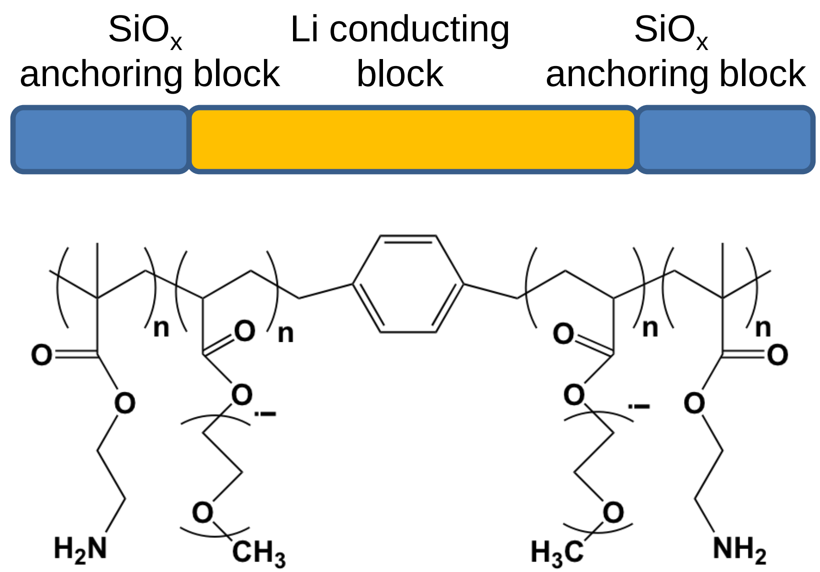
Synthesis and Characterization of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes

Donghai Wang and Mike A. Hickner, The Pennsylvania State University



A Scheme of Polymer-Coated Layered SiO_x-Graphene Nanocomposite Anodes

Novel Block Copolymer Binders for the Nanocomposite Anodes



Budgets

- Total project funding: DOE - $ 800K
- Funding received in FY10: $ 200 K
- Funding for FY11: $ 200 K

Collaborations

- Pacific Northwest National Laboratory (Jason Zhang)
- University of Pittsburg (Prashant Kumta)
- LBNL (Gao Liu)

Metal-Based High Capacity Li-Ion Anodes

PI: M. Stanley Whittingham,
SUNY at Binghamton, Binghamton, NY 13902

Timeline

- Project start: 01/01/2011
- Project end: 12/31/2014

Budget

- Total project funding
  - DOE $724,626
- Funding for FY11
  - DOE $172,376 (this CY11)

Partners

- National Laboratories
  - Brookhaven
  - Argonne
  - Lawrence Berkeley
- Local Industry
  - Primet
- Academia
  - Other Anode Partners

Nanoscale Heterostructures and Thermoplastic Resin Binders: Novel Li-ion Anode System

PI: Prashant N. Kumta, Swanson School of Engineering, University of Pittsburgh

- **Timeline**
  - Start: January 1, 2011
  - Finish: December 31, 2014
- **Budget**
  - Funding for FY11
    - $220,500K
- **Barrier**
  - *Low available energy density*
  - *Poor cyclability*
  - *Large 1st cycle irreversible loss*
  - *Poor rate capability*
  - *High coulombic efficiency*

- **Partners/Collaborators/Students**
  - ***Industries***
    - Ford Motor Company
  - ***National Laboratory***
    - Dr. Robert Kostecki, LBNL
    - Dr. Vincent Battaglia, LBNL
    - Dr. Jagjit Nanda, ORNL
    - Dr. Mani Manivannan, NETL
  - ***Faculty/Students***
    - Dr. Spandan Maiti, University of Pittsburgh
    - Dr. Monikanchan Datta, Univ. of Pittsburgh
    - Rigved Epur, Univ. of Pittsburgh

Nanoscale Heterostructures and Thermoplastic Resin Binders: Novel Li-ion Anode System – PI Prashant N. Kumta, University of Pittsburgh; Collaborations: Ford; LBL; ORNL; NETL; PSU

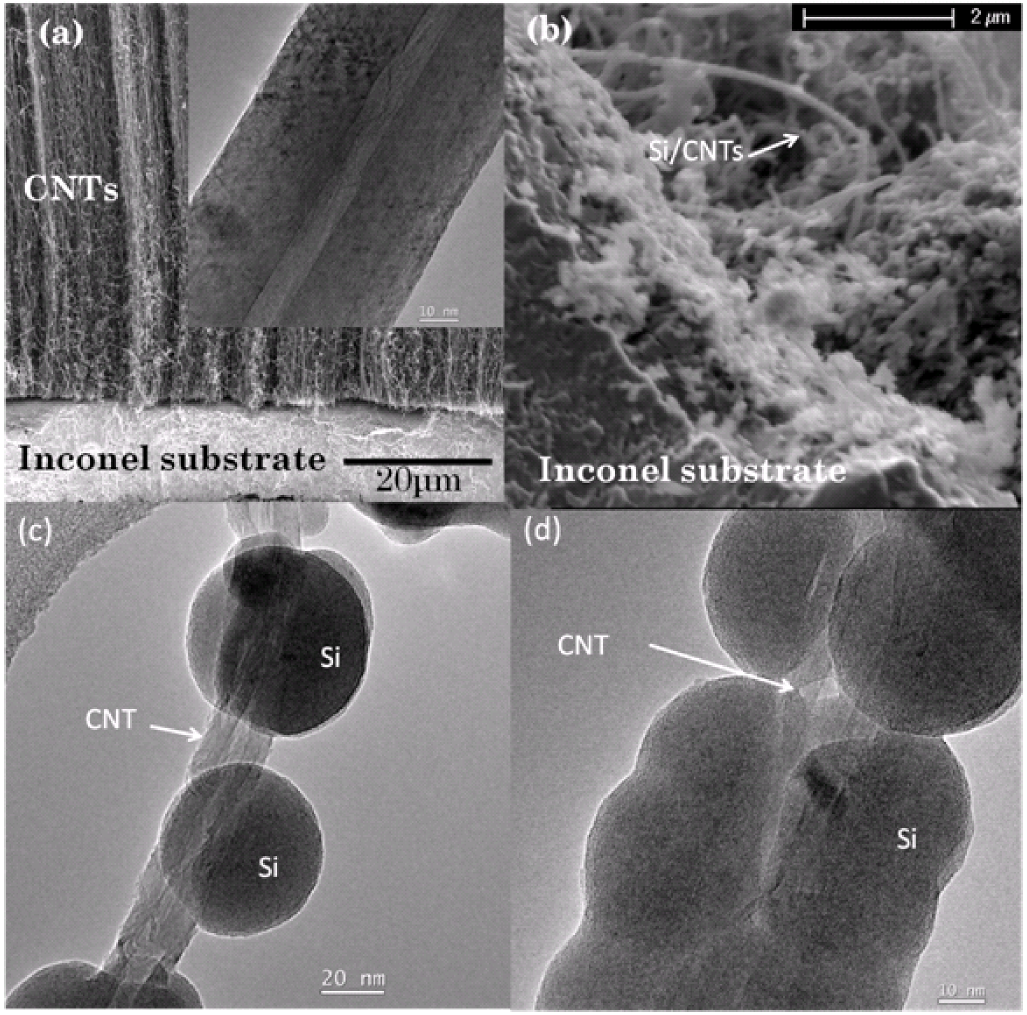


Figure: (a) SEM image of MWNTs on Inconel disc. Insert image showing the HR-TEM image of a nanotube. **(b**) SEM image of the MWNTs on Inconel disck after silicon deposition **(c)** and **(d**) HR-TEM images of a single carbon nanotube covered with multiple silicon nanoclusters at defined spacing, and with continuous coating of silicon layer after different deposition times.

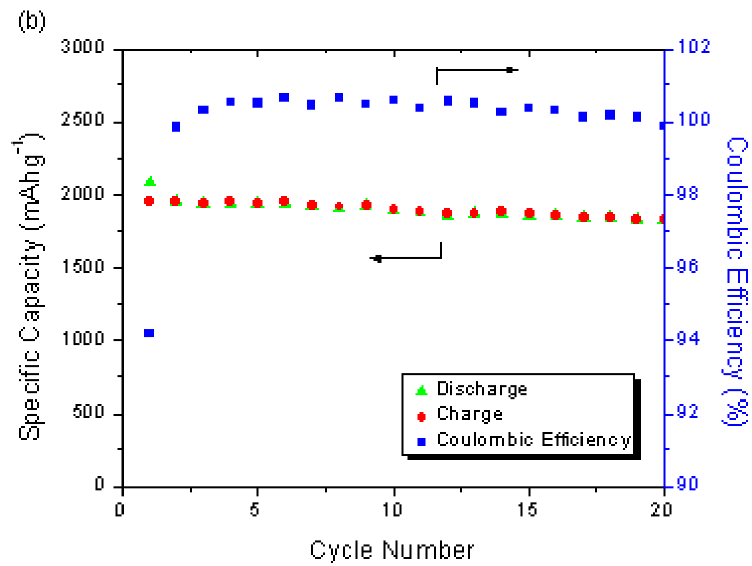


Figure : (b) Curve of discharge/charge capacity and coulombic efficiency of the cell over 30 cycles.