An Approach to Mass-produce Si Nanomaterial Composite with High Energy Density in Li-ion Cells without Cycle Life Compromise

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Commercial Strength Built on Scientific Bedrock





- Founded in 2001
- Based in Palo Alto, CA
- Dominant platform of fundamental and applied nanotechnology IP
 - Exclusive University relationships
 - Currently 750+ patents & apps

- 10 Years of industrial development with leading global partners
- Entering into licensing agreements and scaling to high volume manufacturing
- On path to achieve >\$300M in annual within 5 years
 Anosys

Nanosys is the Leading Architected Materials Solution Company

Process-Ready Architected Material Solutions Moving from Lab to Loading Dock

Lighting Solutions

Optical components that improve color quality, efficiency and reduce cost of system for LED backlighting

Energy Storage

Cell components that increase storage density, capacity and reduce cost of system for Li-ion batteries





Industrial Revolution



Process innovation, once king



Materials Revolution





Value shifting to novel, tunable materials





High volume production process using battery graphite as direct substrate for Si nanowire growth

- Cost effective
- High Si utilization
- Improves dispersion within slurry and drop in process
- Si-C conductivity improvement
- Si Weight % is controllable, focusing on 500 ~ 1600 mAh/g
- High electrode loading, i.e. >1.5g/cc
- Good cycling performance, cycled >1000 times



SiNANOde: 500 ~ 1600 mAh/g









Nanosys SiNANOde vs. Si Particle/Porous Si

Nanosys Exploit Advantages & Defeat Potential Problems of Si Nano-materials

| Nanosys SiNANOde | Other Si Particle/Porous Si |
|--|--|
| Low A/V & Intact NW after cycling | High A/V; defects |
| Pack density similar to graphite | Pack density lower than graphite |
| Can be mass-produced with a competing cost & high Si utilization | The structured nanomaterials can do magic in the lab but they are difficult and expensive to commercialize |



- The nanowire has lower surface area/volume ratio, A/V, compared to the nano-particle or nano-porous powder with the same diameter.

- Reduction in particle diameter results in the A/V ratio much lower for nanowire vs. spherical particle, and hence the nanowires have lower surface reactivity and better cycle life.



SiNANOde™ vs Commercial Nanopowder

Full cells w/8% Si: Nanowires vs. nanopowders





Full Cell: SiNANOde vs. Graphite





- Full cells with a baseline cathode (LCO) & a SiNANOde exhibited ~350 cycles at ~76% capacity retention, which still showed much higher anode-specific capacity over graphite anode.



Normalized Capacity at High C-Rate





SiNANOde Full Cell Voltage Profile





- A typical slope-like charging voltage profile between 3.0 and 4.2V with a shoulder at 3.8~3.9V.

- During discharging a clear Si capacity plateau around 3.4~3.5V
- The full cells can be operated in a typical voltage range of 3 \sim 4.2V

Enhanced SiNANOde Capacity - ICE of >92% even for a SiNANOde with a

reversible capacity of ca. 1678mAh/g.



Full Cell Overall Electrodes Capacity Gain Capacity Gain



Overall cell electrodes capacity can be improved between 30% ~40% when used 900~1600mAh/g SiNANOde and >160mAh/g cathode.



>1000x Cycle Life, 80% retention in 18650 full cell

18650 Cell-1 Using Si composite



- The 18650 cell was build with 4.8mAh/cm² Si anode
- More than 1100 times at 0.5C discharge current.
- After 135, 400, 425, and 950 cycles the cell was checked at 0.1C showing that the capacity can be recovered at such current.

— Normalized Capacity



SEM Characterization of SiNANOde Post Cycling



Prior to cycling

10th cycle

~100th cycle

- SiNANOde material deforms to fill void areas in carbon anode material matrix
- SiNANOde material remains intact and fully functional after 100% DoD cycling



Integrates into Existing Battery Manufacturing Processes



Lithium-ion Manufacturing Process



SiNANOde Performance Summary



Excellent performance of SiNANOde material in partner full cells

- 1st cycle efficiency 93%
- High Specific and volumetric
 Capacity: 300~400 Wh/kg or
 700~800 Wh/L
- Controlled specific surface area and mitigated side reactions
- High and stable coulombic
 efficiency over cycles → better
 cycle life





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Questions?

For more information, visit: http://www.nanosysinc.com

