

Si alloy material for next Generation Li ion batteries

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Dr. Petra Stegmaier

Electronics Materials Solutions Division

Since 1902

- Subsidiaries in 71 countries
- Sales in nearly 200 countries
- ~90,000 employees
- International sales \$20.1B (63% of company total)
- 200+ factories
- Sales: \$31.8B
- Net income: \$5.0B
- R&D investment: \$1.8B
- 55,000+ products
- 100,000 patents



Solutions for Li ion Cells & Batteries

Thermal Conductive Materials

Non-flammable liquid coolant / Novec



Vibration Dampening Materials



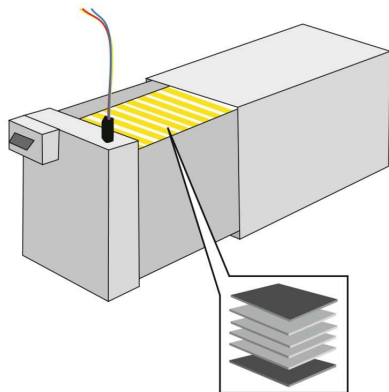
EMI Solutions



Bonding Solutions



Electrical Insulation Tapes



Flame Retardant insulation papers



Non-flammable liquid coolant

Silicon alloy anode powders

Electrolyte salts and additives

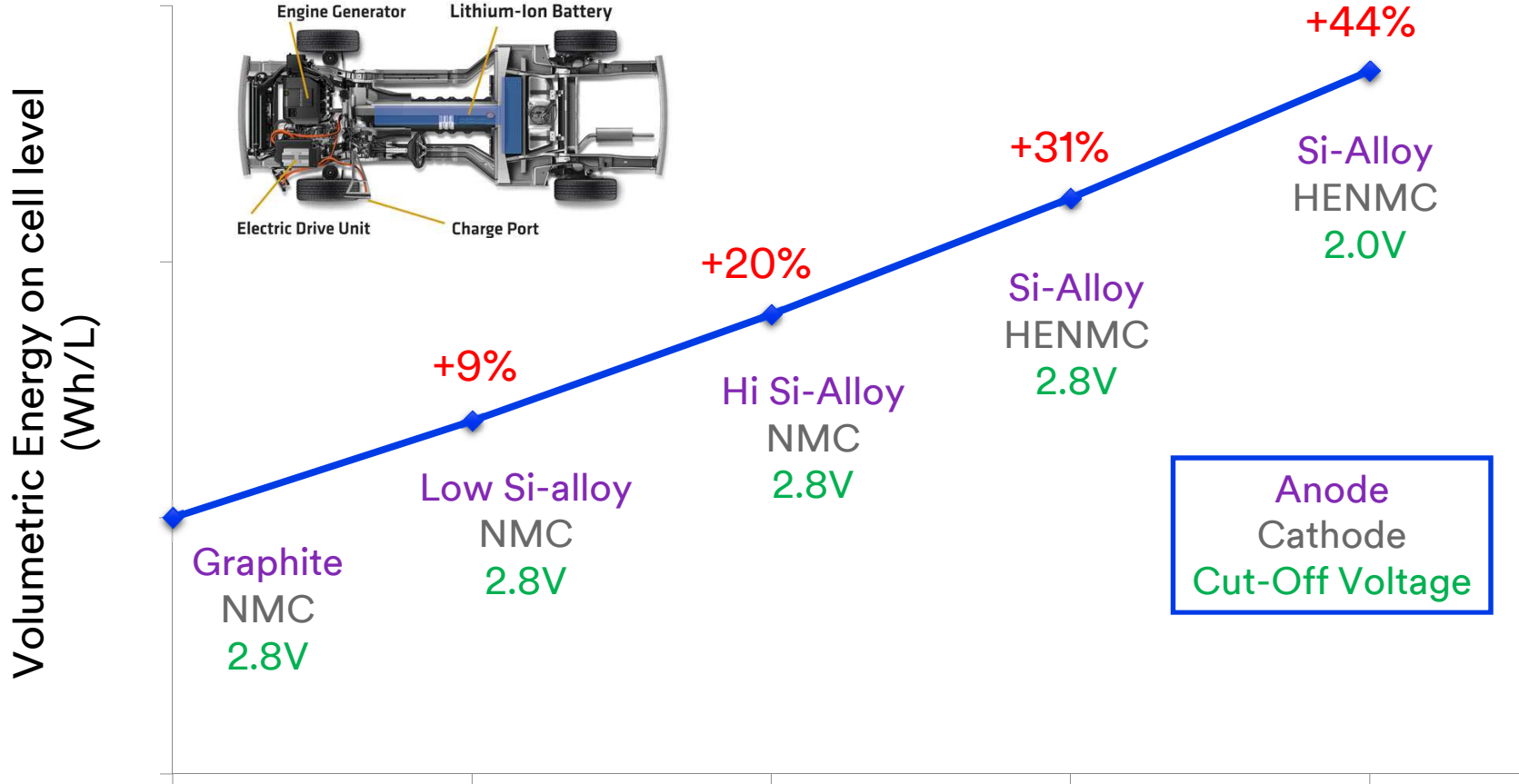
NMC cathode technology

Nano-carbon coated Al current collector

Acrylate and Fluoropolymer binders



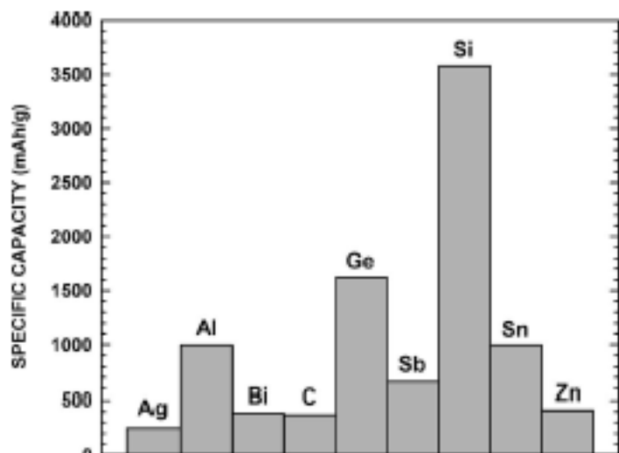
Battery Materials Roadmap



Anode Materials – General Considerations

Pros

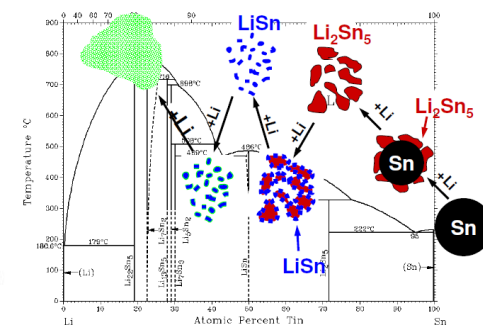
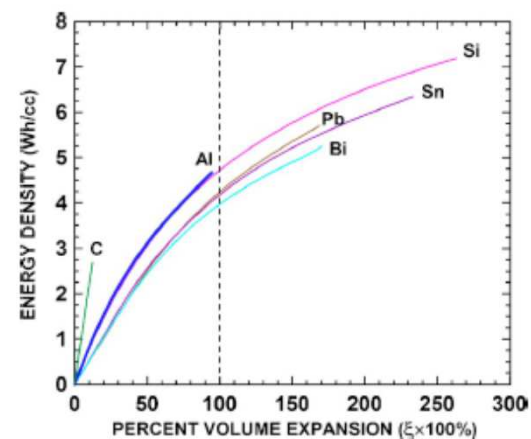
- High theoretical capacity (3579 mAh/g)



- Rather low working potential (0.4 V vs. Li)
- Abundant on the Earth's Crust

Contras

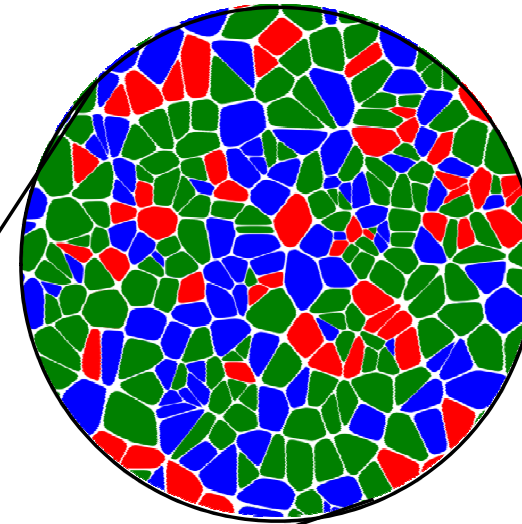
- High irreversible capacity loss at first cycle
- Slow Li diffusion: $D_{Li} 10^{-13}/10^{-14} \text{ cm}^2\text{s}^{-1}$
(D_{Li} in graphite = $10^{-8}/10^{-10} \text{ cm}^2\text{s}^{-1}$)
- Volume expansion during cycling



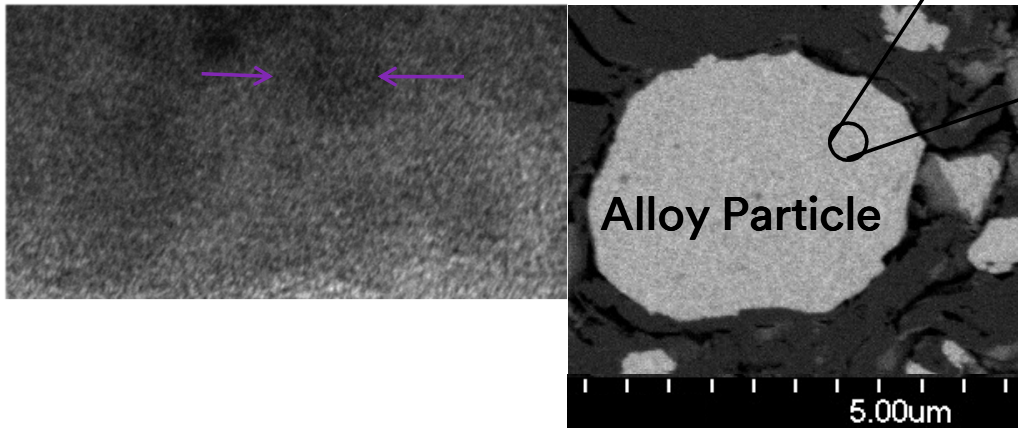
- Phase change → Pulverization

3M Si-Alloy Anode Material – Design Strategy

- Maximize volumetric capacity
- Inexpensive raw materials
- Binders and cells can only withstand up to ~100% expansion
- Nanostructured particles maximize cycle life
- Low surface area



■ active
■ inactive

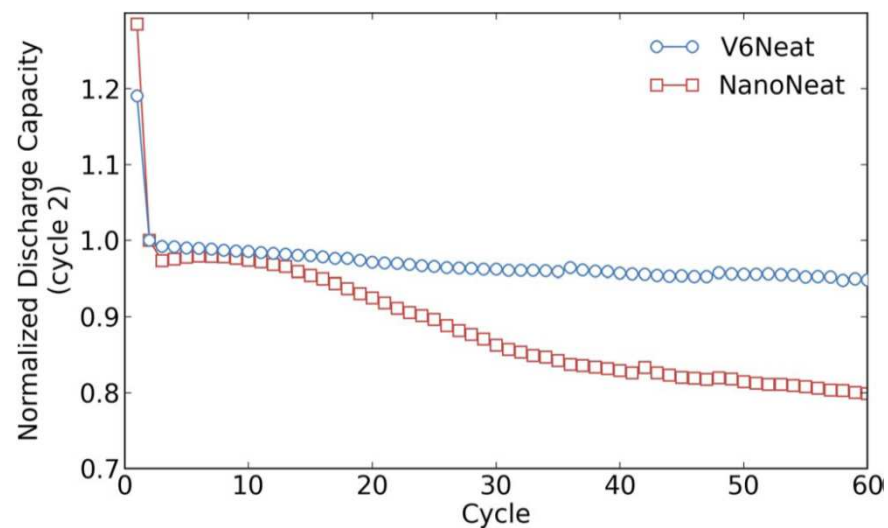
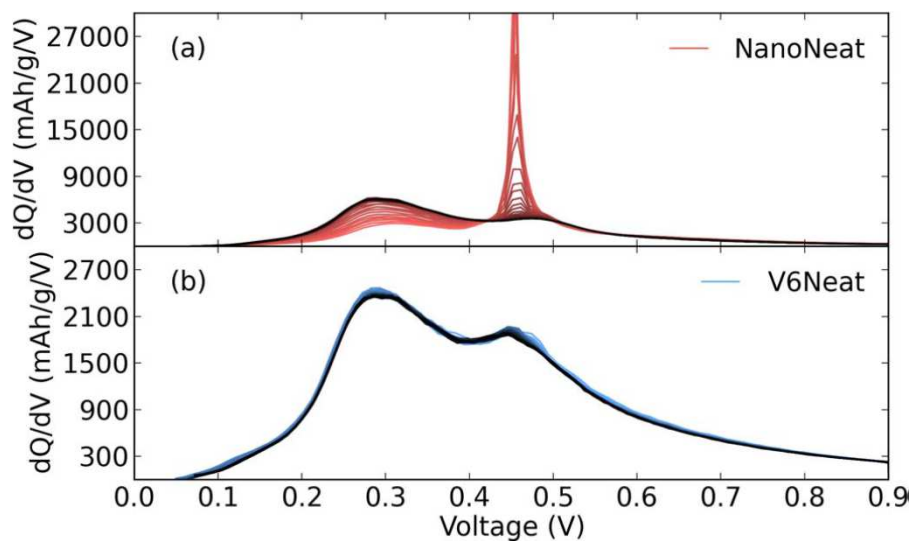


3M alloy

- Nano-Si in inactive matrix
- Active/inactive domains < 15nm
- High first cycle efficiency
- Remains amorphous on cycling
- Minimizes surface area
- Dilutes volume expansion
- Scalable alloying process

Comparison 3M-Alloy vs Nano-Si – Neat Electrodes

Half cell

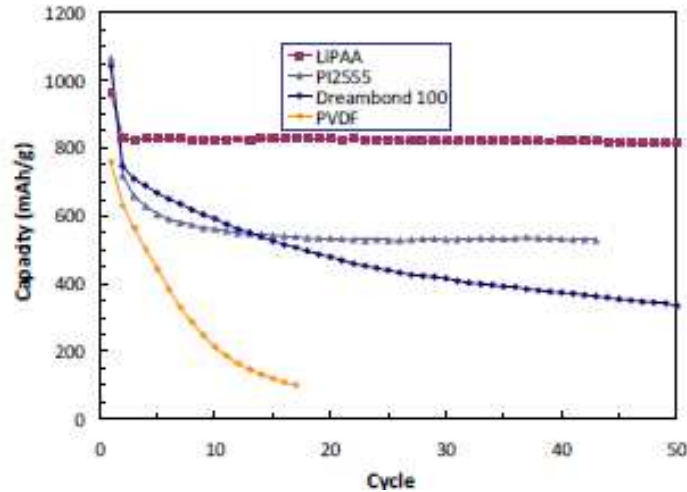


- Shift in differential capacity plots indicate crystallization processes.

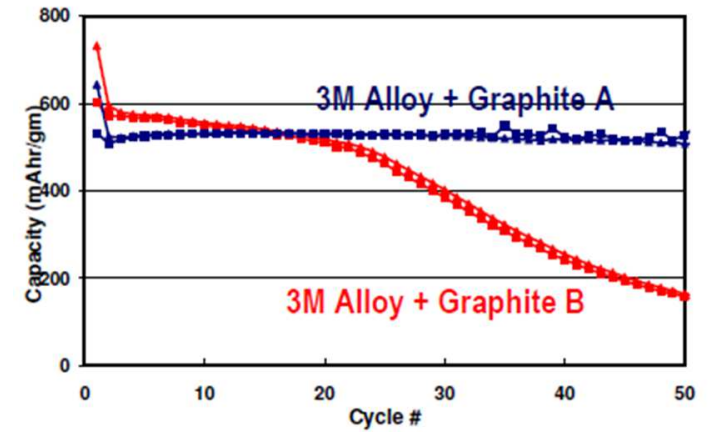
Chevrier et al., Journal of The Electrochemical Society, 161 (5) A783-A791 (2014)

Si based anode development

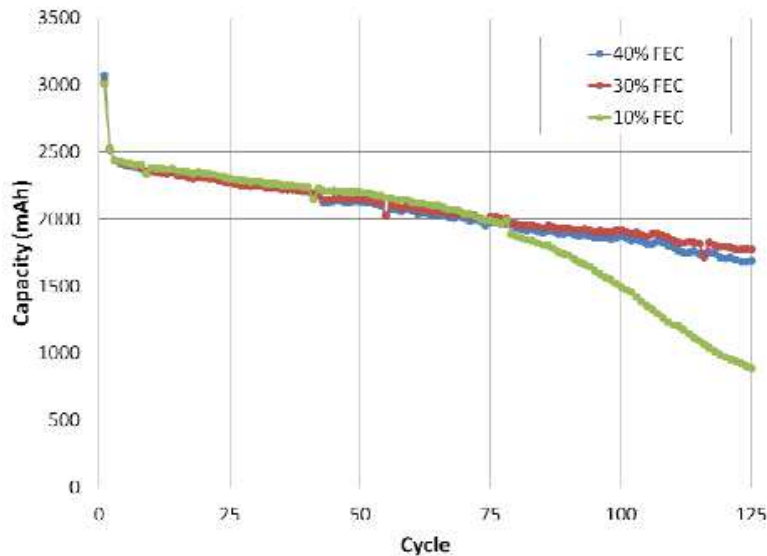
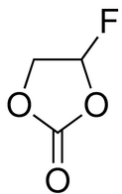
Binder



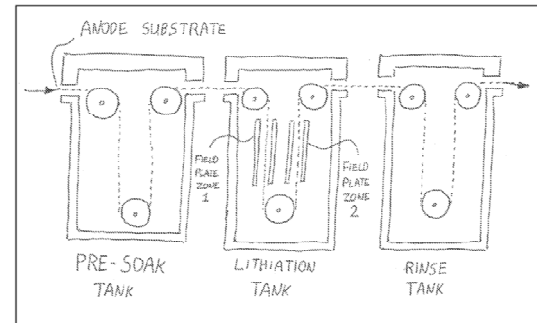
Formulating & Mixing



Electrolyte



Pre-lithiation
= Introduction of Lithium directly into anodes



Nanoscale Components Inc., NH, USA

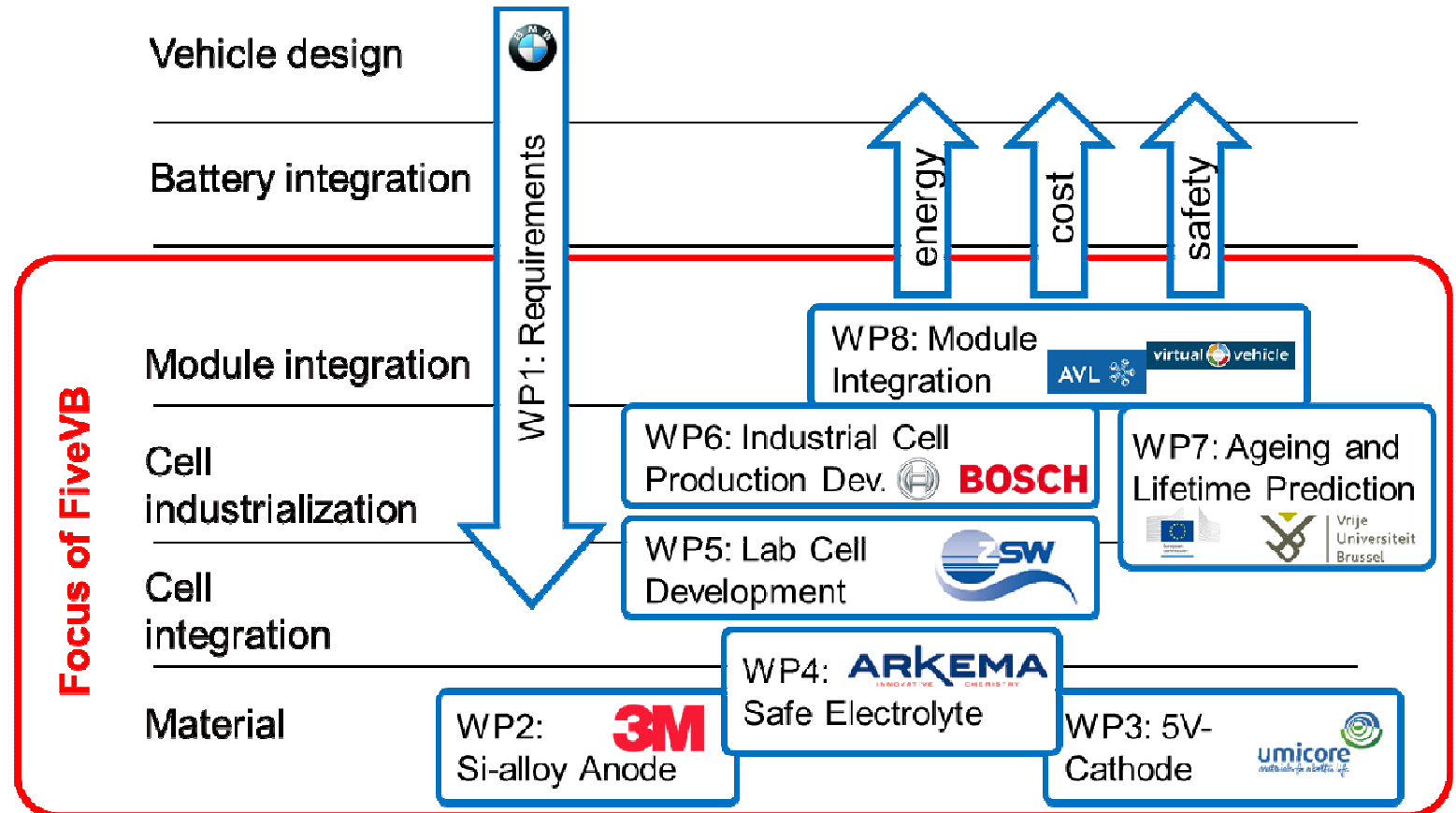
3M Investment in Si Alloy
Prelithiation Technology

- improved capacity
- improved energy
- Improved cycle life

EU funded project FiveVB



Horizon 2020
Work Program 2014-2015
“Smart, Green and
Integrated Transport”



FiveVB - Status



- Development of single and double side coated Si-based anodes
- Production of anodes at pilot line facilities at ZSW in Ulm
- Electrodes show high density and high areal capacity (up to 4 mAh/cm²)
- Very encouraging results with pouch cells (> 320 cycles with capacity retention over 80%)
- Specific energy (Wh/kg) increased by 13% compared to Graphite/NMC
- Volumetric energy density (Wh/l) increased by 23%



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n° 653531



Leading Through Innovation

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3M Science.
Applied to Life.™

“ Innovation is our biggest competitive advantage and the heart of 3M. ”

Inge Thulin, CEO, 2012