Composite Li-Ion Anodes from Recycled Silicon

Wanli Xu[1], John Fussell, and John Komidor
Electrochemical Materials, LLC
8000 GSRI Ave.,
Baton Rouge, LA 70820

Conventional Li-ion cells are made using lithium metal oxide cathodes and graphite anodes with full cell storage capacities near 100 mAh·g^{-1} or 300 kWh·kg^{-1}. Silicon is a promising material to replace graphite since it has a theoretical capacity of 4200 mAh·g^{-1}, which is over ten times higher than that of conventional graphite material. Despite the extremely high specific capacity, silicon shows high volumetric expansion when fully lithiated. The volumetric expansion typically results in cracking and pulverization of silicon and poor cycle performance for silicon anodes. [1]

Recent research with nano-structured silicon anodes (including silicon nanoparticles, nanowires, nanotubes, complex 3-D structures, and etc.) has demonstrated great improvements in both high capacity and cycle life. Silicon anode materials typically originate from growth methods such as CVD, or solution growth, or from subtractive methods such as laser ablation, etching, or mechanical attrition.[1] Nano-silicon based technologies suffer from extremely slow and expensive silicon fabrication methods and for this reason alone can not be commercially viable.

Currently, about 80% of silicon used to make solar cells or wafers for microelectronic devices is wasted during the process. For example, sawing of single crystal ingots with wiresaws results in a lost layer of about 250-280 microns per wafer produced. Depending on wafer thickness, kerf loss represents from 25% to 50% of the silicon ingot. Likewise, waste particles are generated when the wafers are lapped or polished to their final thickness. Lapping and polishing operations remove an additional 5 to 30% of the final product wafer. The waste is difficult to recycle due to the presence of solvents, oils, other impurities such as silicon carbides, and the native oxide at the surface of waste silicon particles. [2]

Silicon byproducts from sources such as kerf are difficult to use directly as lithium-ion batteries since key parameters such as silicon particle size, surface oxides, and impurities, do not fulfill the requirements for silicon anode materials. Thus, there exists great value in recovering silicon from manufacturing processes and the recovered silicon particles can be used as battery anode material. We have developed a method of integrating silicon into a Li-ion battery anode material using a highly scalable approach based on utilizing metallurgical grade recycled material. The process consists of reducing silicon powder to a desired size, subsequent modification of the particles surface and mixing of the resulting powder with a standard anode paste. Depending on the silicon concentration the resulting anode material has specific capacity ranging from 700 to 900 mAh·g^{-1} which is 2 to 3 times higher than compositions based on graphite only.

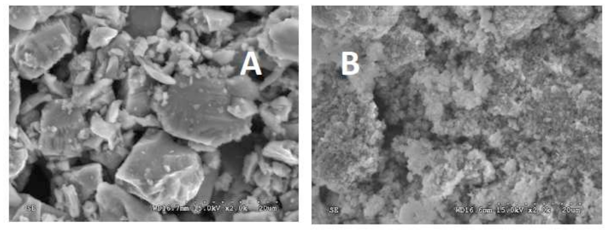

Figure 1 (A)Silicon particles before resizing and (B) Silicon particles after resizing

As shown in SEM images in Figure 1, silicon waste particles in micrometer scale can be resized to nanometer scale and coated using a proprietary method. [3, 4]

The resulting anode from recycled silicon was assembled and evaluated in a lithium secondary coin cell with a lithium cobalt oxide cathode. The coin cell is demonstrated with a reversible capacity over 160 mAh·g^{-1} for over 500 cycles. The work, demonstrates silicon anodes can be prepared from recycled silicon. The process to recover silicon as anode material from waste shows great commercial potential for future silicon-based lithium rechargeable batteries.

1. Kasavajjula, U., C.S. Wang, and A.J. Appleby, *Nano- and bulk-silicon-based insertion anodes for lithium-ion secondary cells.* Journal of Power Sources, 2007. **163**(2): p. 1003-1039.
2. Barraclough, K.G. *Waste Not, Want Not!-A case for Recycling Silicon Waste Powder Kerf*. 2006.
3. Xu, W., *METHOD TO PREPARE SILICON PARTICLES FOR USE IN LITHIUM SECONDARY BATTERY ANODES*, 2013.
4. Xu, W., Fussell, J., *PREPARATION METHOD OF LITHIUM RECHARGEABLE BATTERY COMPOSITE ANODE FROM SILICON KERF*, 2012.

[1] Corresponding author, Email: wanli.xu@electro-mat.com