LITHIUM ION'S NEW FRONTIER

Eric. M Leslie, Managing Director, TRION Energy Solutions

The use of silicon in lithium ion battery anodes promises to provide a step-change in battery density. However, there are a number of hurdles to achieve this. Here, **Benchmark Minerals** talks with **Eric M. Leslie**, Managing Director of **TRION Energy Solutions**, about the use of silicon in batteries and TRION's plans for the industry

Benchmark: Could you let our readers know about the history of TRION Energy Solutions as well as why TRION was set up and what the company aims to achieve?

Eric. M Leslie: Back in June of 2013, a business associate called me and asked me if my advisory firm had any bandwidth to take on a new client. When I heard that the potential client was convinced that he had figured out a way to make batteries last 10 times longer, not light on fire and charge in minutes, I quickly arranged an introductory call. I vividly remember that conversation as what was going through my mind was - Maybe, just maybe, this individual might be able to cure not only me, but hundreds of millions of others around the world that suffer daily, from LBA - Low Battery Anxiety!

Two months later we incorporated the company with the goal to commercialise a solid-state battery that would revolutionise the battery world within a few years, which turned out to be an unrealistic goal that was nowhere near remotely achievable.

Fast forward a little over six years and the world is still suffering from LBA.

There is however a bright light on the horizon, as back in 2014, we were able to have the foresight to pivot away from the original solid-state idea and channel our R&D efforts into figuring out how to deliver about a 35% step-change improvement to energy density in lithium ion batteries by improving the anode, which to date has been the choke point in delivering higher energy density in lithium ion batteries.

We are now on the cusp of commercialising our patented advanced Silicon Modified Graphite (SiMoGraph) anode materials that have the potential to deliver, as a drop-in, low cost solution, the better performance metrics which the lithium ion battery industry has been striving to achieve for decades.

Benchmark: What are the main benefits of using silicon in anodes?

EL: Lithium ion batteries play an essential role as the energy source for products in multiple different market verticals including electric vehicles (EV) and consumer electronic devices, to name but a few.

The energy density of lithium ion batteries has been remarkably increased since its first commercialisation in the 1980s due to both improved material chemistry and industrial manufacturing processes. The primary challenge now being faced is that lithium ion batteries are reaching the theoretical limit of their energy density, based on the materials currently being used.

As a result, battery cell manufacturers are exploring the use of alternative material chemistries other than those used in conventional lithium ion battery systems (i.e., lithium transition-metal oxides as the cathode and graphite particles as the anode) to increase energy density, thereby extending battery life and/or increasing device functionality between charges, as well as decreasing cost, in terms of $/kWh.

Among all types of alternative anode materials, silicon has attracted the most amount of attention because of its high gravimetric capacity compared to conventional graphite (3,580 mAh/g for silicon and 372 mA/g for graphite).

The low working voltage of silicon makes it more advantageous with regard to energy density enhancement, compared to other potential anode materials with high gravimetric capacities but higher working voltages, such as different types of transition metal oxides. The abundance of silicon also makes it attractive, due to its relatively low price.

Benchmark: Despite the energy density benefits offered by silicon use in anodes there are a number of obstacles. Can you run us through the challenges of using silicon in anodes?

EL: There are several challenges that need to be overcome before commercial application of silicon in lithium ion batteries can be realised. One of the major challenges of silicon is its huge volume change which is greater than 300% expansion and contraction

FIGURE 1: SILICON AGGLOMERATION ISSUES

The image on the left shows a silicon/graphite anode material produced by current, state-of-the-art, mixing techniques. It is evident that nano-sized silicon agglomerates form ~10 micrometre spheres. The agglomerated silicon expands dramatically during cycling which leads to failure of the anode. The image on the right shows the results using TRION's silicon modified graphite (SiMoGraph)

CREDIT: TRION Energy Solutions

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during alloying and de-alloying with lithium, which occurs during charge-discharge cycling. This leads to several issues, including particle pulverisation and anode cracking, continuous solid-electrolyte interface (SEI) growth and associated increases in ion transport resistance, and even peeling of the active material from the copper current collector.

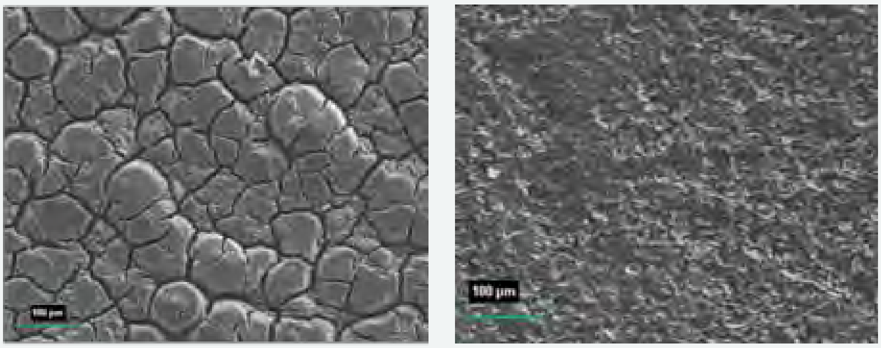
Another problem is the poor electrical conductivity of silicon, which requires the silicon particles to be robustly connected to a network of electrically conductive material throughout the lifetime of the battery. Without sufficiently strong attachment between the silicon and the electrically conducting material, the expansion and contraction of the silicon particles tends to disrupt the network, resulting in electrical isolation of the silicon and severe degradation of anode performance.

To address these issues associated with silicon, numerous efforts have been devoted to investigating the electrochemical and mechanical behaviour of novel silicon or silicon-based anode architectures. The use of nano-structured silicon, such as nanowires, nanotubes, and void-containing structures like yolk-shell architectures, have achieved significant enhancement in specific capacity and cyclability. However, while technically creative and scientifically sound, most of these approaches cannot be applied commercially because the fabrication processes are expensive and hard to scale-up.

Furthermore, the advantageous cell

FIGURE 2: ANODE CRACKING ISSUES

Traditional mixing silicon/graphite anode after 40 cycles (left) versus silicon modified graphite (SiMoGraph) after 100 cycles (right).



CREDIT: TRION Energy Solutions

performance of silicon anode solutions reported in the literature frequently relies on electrode fabrication and cell cycling conditions being far outside commercial requirements. These include mass loadings and electrode densities (areal capacity) that are too low, and low active material fraction (due to too much binder and/or conductive additives being in the binder).

Instead of pursuing complex and expensive nano-architecture strategies to accommodate silicon in the anode, a common approach has been to simply mix silicon with buffering agents which can be used to alleviate the volume change issue. The buffering agents can be electrochemically active or non-active, but certain carbon-based materials which are both electrically conductive and electrochemically active are advantageous, compared to non-active buffering agents, in terms of anode battery performance enhancement.

Since graphite (natural or synthetic) is the current state-of-the-art anode material for commercial lithium ion batteries, with performance near graphite's theoretical capacity of 372 mAh/g, the primary commercial approach has been to blend graphite with small amounts of silicon, or more commonly with silicon oxide (SiOx), which has about half the capacity of elemental silicon but is a little easier to work with.

However, existing technologies do not result in stable performance if the addition of the silicon material exceeds about 5% by weight. A major cause of this limitation is the lack of uniform distribution of the silicon in graphite/silicon (or graphite/SiOx) blends, resulting in severe agglomeration of the silicon particles, especially with respect to preferred nano-sized silicon particles, which do not fracture on expansion. The capacity of a graphite/silicon anode with agglomerated silicon will fade quickly due to the mechanical failure of the anode. Even distribution of nano-silicon on graphite remains one of the bottle necks for commercial utilisation of silicon.

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In addition, the well-distributed silicon must be robustly attached to the graphite, so that the silicon particles do not detach from the graphite during charge/discharge cycling (involving the large volume expansion and contraction at every cycle) and disrupt the electrical connectivity.

Finally, all anodes comprising silicon face the problem of parasitic reactions with the electrolyte, which can result in premature electrolyte degradation and cell failure. Tackling this problem may involve applying protective coatings to the silicon and/or formulation of the electrolyte to diminish unwanted chemical reactions.

Benchmark: What is TRION's approach to using silicon and what benefits does this offer?

EL: TRION has a growing portfolio of patents, centred on a "self-assembly" technology that permits layer by layer engineering of particle functionality. Of central importance to the lithium ion battery application, is that this proprietary technology enables silicon particles to be attached uniformly and robustly on the surface of graphite particles (via non-covalent and/or covalent interactions) by means of a controllable, easy-to-scale, low-cost process. In addition to nano-silicon, other high-capacity electrochemically active materials, such as tin nanoparticles, can be attached on graphite with uniform distribution, offering further opportunity to engineer the anodes performance.

The amount of silicon that can be uniformly attached in a single deposition depends only on the surface area of the graphite. For battery grade graphite, the surface area is usually less than 5 m2/g which can hold about 15% by wt of 50 nm silicon without agglomeration, and with room for particle expansion. With TRION's process, this results in a highly dispersed deposition of the particles across the graphite surfaces.

TRION's Generation I anode materials, with 15% by wt silicon added in a proprietary way to graphite, provide an increase in full cell volumetric energy density of about 35%. Although it can be calculated that the addition of further amounts of silicon will lead to diminishing returns in increased energy density for any graphite/silicon system, TRION's Generation II SiMoGraph technology does nevertheless permit higher silicon loadings by self-assembling a multi-layer structure in which the primary silicon layer on the graphite core is followed by successive graphene/silicon layers. The silicon loading level can thereby be designed to meet a range of even higher battery performance requirements.

Benchmark: Can you share some of the results from TRION's testing?

EL: TRION's proprietary process of achieving uniform distribution of silicon, which is in intimate contact with the graphite, has overcome the cracking issues that occur when silicon is added to graphite using traditional mixing methods. When disassembled after only 40 charge/discharge cycles, as shown in Figure 2, an anode prepared by traditional mixing methods shows severe cracking, resulting in rapid degradation of anode capacity. The SiMoGraph anode, on the other hand, shows no indications of cracking when disassembled after 100 cycles. Consequently, the SiMoGraph anode retains a constant capacity in excess of 500 mAh/g for over 500 cycles at an aggressive 1C cycling rate.

Dimensional change due to the electrode expansion and gassing is another important factor that requires attention. For commercial applications, the battery must generally not exceed a 10% thickness increase during cycling of the cell, especially for portable electronics which are only designed to accommodate a small volume expansion of the battery. Therefore, the thickness of a pouch-type full cell containing SiMoGraph (with 15% wt Si) was monitored during cycling. The results showed approximately a 2.3% anode thickness increase, corresponding to approximately a 0.8 % increase in full cell thickness, which is well within the required limit.

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In order to maximise full cell cycling longevity, TRION's current focus involves application of proprietary approaches to optimizing the SEI formation and reducing, or eliminating, parasitic electrolyte reactions. Unlike a number of silicon based architectures, the structure of SiMoGraph materials is well suited to precise application of low-cost, state-of-the-art coating technologies that address these issues.

Benchmark: What is TRION's approach to commercialisation ? Are you targeting specific batteries and applications?

EL: TRION will be pursuing a licensing approach to the commercialization of SiMoGraph.

We are currently focused on pursuing applications that will benefit the most from increases in energy density such as consumer electronic devices and EVs, not so much from increases in power. We are confident that, over time with a larger scientific team in place, we will be able to deliver next generation anodes that significantly reduce Low Battery Anxiety across a broad spectrum of energy and power applications.

Benchmark: What type of interest are you receiving from downstream OEM, cell manufacturers, material companies?

EL: Although we have only recently begun down the path of transitioning out of conducting R&D in stealth mode, we have been pleasantly surprised at the reception that we have been receiving from multiple different large companies about starting their due diligence process to potentially participate in our Series B round and or becoming a strategic partner.

Benchmark: Anode manufacturers are predominantly based in Asia and the sector is dominated by large companies. Where do you see the market going in the future?

EL: That's a great question and a tough one to answer. In light of the fact that our Generation I SiMoGraph anode materials are made with 85% synthetic graphite and 15% by weight silicon our materials could be manufactured anywhere in the world. Only time will tell how this plays out.

Benchmark: If you were to have a crystal ball, what does the future hold for TRION?

EL: We believe that with the performance data that we are currently achieving, which we are happy to share with interested parties, we will be able to attract one or more strategic investors into our Series B round of funding that will accelerate bringing our low cost, proprietary SiMoGraph anode materials to the market. We further believe that once the battery world and consumers understand just how large a step-change in energy density our SiMoGraph anode materials can deliver, our anode materials will become the "Gold Standard" specified to be used in the production of billions of lithium ion batteries annually.

TRION's WEBSITE TRION's LINKEDIN