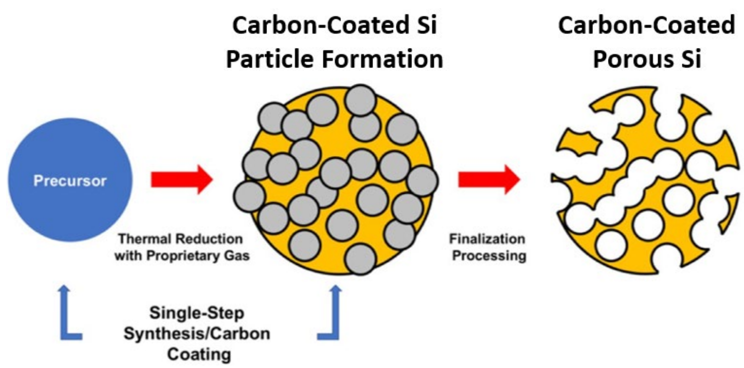
BATTERY INNOVATIONS

Our Technology

Ecellix's eCell is a micro-porous silicon-carbon composite anode material that represents a new horizon for lithium-ion batteries, replacing traditional graphite materials to dramatically improve battery life and performance. We avoid using expensive, difficult-to-handle chemicals and nanomaterials - approaches that build anode materials from the bottom up - a few atoms at a time. In contrast, we start with low cost and easy to handle micron-sized silicon particles that are 250 to 1000 times larger than nanomaterials. When we combine these silicon particles with metal particles, it forms pockets in the silicon. We simultaneously remove the metal while coating the remaining silicon with carbon, leaving a structure that has nano-scale pores and structures.



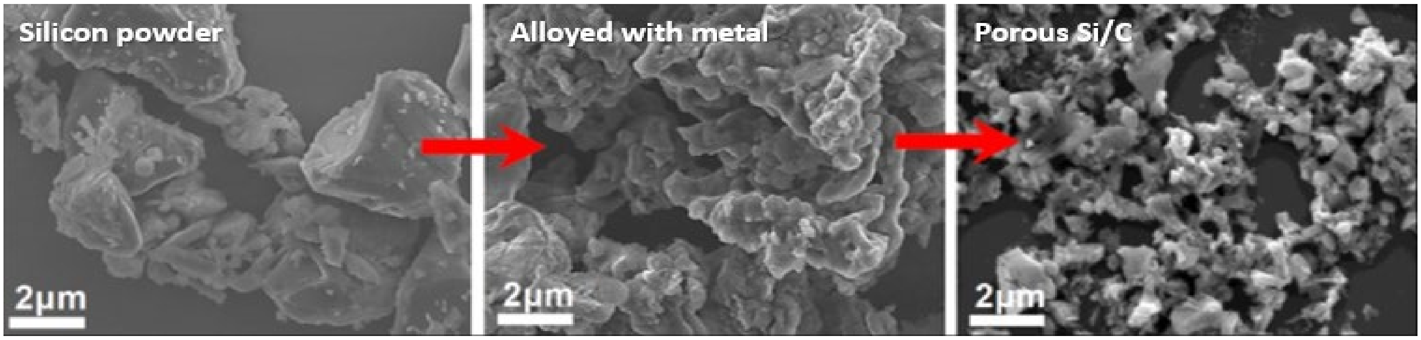
The resultant micro porous silicon/carbon composite (μP Si/C) material holds more than five times the lithium of today's anode material, graphite. It has been demonstrated (in half-cell testing) to have good life expectancy, holding 80% of its capacity for almost 600 cycles. When combined with today's cathode materials, batteries with 30-40% more energy storage may be possible. Additionally, this high-capacity anode material enables increased battery energy gains from future improvements in cathodes.

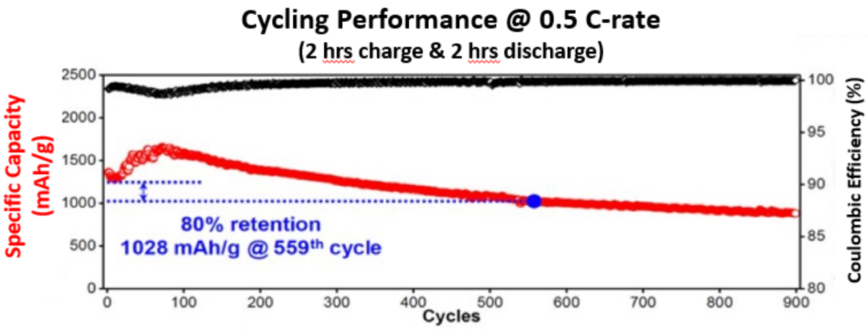
Battery Background

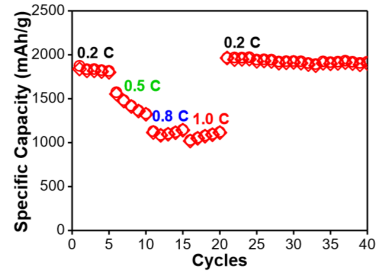
Electrochemical batteries have four key components: an anode (-), a cathode (+), electrolyte and a separator. Ions (Li^+ in the case of a lithium ion battery) move between the anode and cathode, and electricity moves through an external circuit. Liquid electrolyte enables ions to move between electrodes and to pass through the separator, which prevents shorting between the anode and cathode.

Since lithium ion batteries' market introduction in 1991, their cathodes have been made from a variety of metal oxides derived from cobalt, nickel, manganese, iron and aluminum. In combination with cathode developments, advances in electrolytes, separators and manufacturing have led to today's batteries having a capacity roughly 2.5 times higher than in 1991. However, throughout this time, the battery anodes have been a constant: graphite powder.

The porous structure creates small silicon particles that don't crack when they bind lithium ions, with pore spaces into which those particles can expand. The carbon coating extends the life of the battery, improves electrical conductivity, and strengthens the structure. The resultant anode powder packs densely, leaving more space inside a battery for cathode material. Using eCell, the anodes can be constructed using techniques like those used to make today's graphite-based anodes, enabling the industry to continue using existing manufacturing lines and equipment. Because the ingredients are readily available and low cost, and because the powder-making process is straight-forward and simple, we anticipate that manufacturing of the eCell material will be readily scalable at an attractive price.







Silicon Anode Materials

Silicon has more than ten times the capacity to hold lithium than does graphite, offering the potential to bind much more lithium with a much smaller mass or volume. However, when silicon binds lithium, it swells and it cracks if the dimensions of the silicon are greater than 150nm. For this reason, much of the historical development of silicon anode materials has centered around nanomaterials.

The surface of silicon also reacts with lithium and with some electrolytes, depleting the lithium present in the battery, and thereby depleting its stored energy. These Solid-Electrolyte-Interphase (SEI) reactions are complex but are generally surface reactions. High surface area materials are more prone to strong SEI layer formation.

> *"The Si-based multicomponent systems exhibit reasonable tap densities, which is crucial for applications where volumetric energy density is vital. Besides, the synthetic routes of the Si-based multi component systems are normally simple, scalable, low-cost, and safe, which makes the Si-based multicomponent systems particularly promising for practical applications".*
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> *Jin et al, Challenges and Recent Progress in the Development of Si Anodes for Lithium-Ion Battery, Adv. Energy Mater. 2017, 7, 1700715.*

Silicon anode materials are therefore caught between opposing forces. Particle dimensions must stay small, or the particles crack. However, as particle diameters get smaller, surface area grows quite rapidly. As a result, smaller diameter particles have much larger surface areas, and generally much higher and much more performance sapping SEI reactions.

Other Approaches to Silicon Anodes

To overcome this conflict, most silicon anode technologies start with small components. They put these small pieces together to build larger structures. They then apply coatings, manipulate chemistry and use other mitigations to reduce the effects of the associated SEI.

Companies have raised hundreds of millions of dollars to commercialize myriad approaches, from carbon-coated silicon nanoparticles, to vapor deposited silicon on carbon nanostructures, to silicon-metal alloys, to thin-film silicon, to multi-walled carbon and silicon nanotubes, to silicon composites, to porous silicon structures. To our knowledge, each starts with nanomaterials and bottom-up synthesis, later employing additional technologies to overcome challenges presented by these architectures, including SEI management, conductivity, areal loading density, and cost.

Nanomaterials:		Micro Porous Silicon/Carbon Composite µP Si/C:
+	lithium capacity	+
+	cracking	+
-	surface area / SEI	+
-	diffusion path length	+
-	conductivity	+
-	tap density	+
-	cost	+

> *"While nanostructured silicon anodes show great potential in lithium-ion battery, the commercial application can be limited by high cost related to the complex fabrication and expensive raw materials. Traditionally, silicon nanostructures are fabricated either from top-down (chemical etching) or bottom-up (CVD) method, which typically involve either toxic silane precursors or expensive high purity silicon sources."*
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> *Zuo et al, Silicon based lithium-ion battery anodes: A chronicle perspective review. Nano Energy. 2017. 31, 113-143.*

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