

Summary: Li-ion batteries have improved incrementally over the past few years and have been one of the main technologies of focus across energy dependent products, especially electric vehicles (EV's). The growing demand for faster charging, longer lasting and more efficient Li-ion batteries for vehicles has in turn, incentivized extensive research in silicon anode-based Li-ion batteries. A breakthrough in the use of silicon technology could be a gamechanger and a huge leap in the advancement of Li-ion battery technology. Silicon can hold about 10 times the number of electrons as the existing material in lithium-ion batteries – graphite, and its use could lead to 20-40% higher energy density. The main obstacle with the use of silicone is that in reaction with lithium during charging it expands over 300% in volume which heavily damages the battery. Sionic brings in this project its cutting-edge solution. This technology uses patented electrode architecture with its special proprietary polymer to produce an expansion-controlled pure micron sized silicon-based Li-ion battery with a long-life span. Sionic's solution will make Li-ion batteries and in turn, EVs more affordable and more efficient. With EVs more economically accessible, the tide towards EVs from combustion engines could shift gears resulting in reduction of vehicle related emissions.

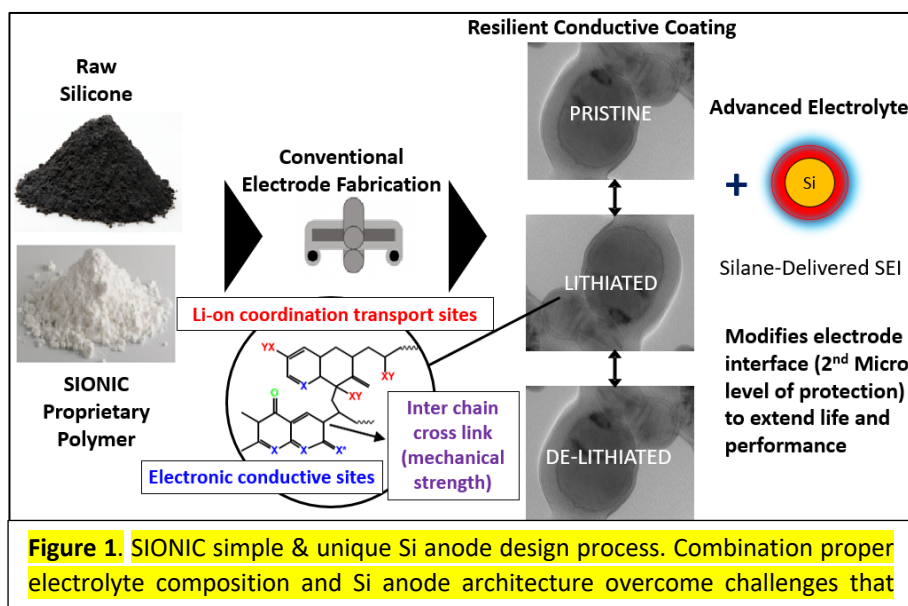
Innovation and Impact: Commercial Li-ion cells contain graphite as the predominant anode active material. Graphite stores Li-ions through a process called intercalation with an overall stoichiometry of LiC_6 , which corresponds to a theoretical specific capacity of 372 mAh/g. Silicon (Si) can absorb substantially greater number of Li-ions compared to layered graphite with an overall stoichiometry of $\text{Li}_{15}\text{Si}_4$, which corresponds to a theoretical specific capacity of 4200 mAh/g. Hence, replacing the graphite to its entirety with Si means that the cell can be made with less anode material and more cathode material, effectively increasing the overall energy that is stored within the same volume. However, Si suffers with performance challenges, due to the extraordinary ability to accommodate large number of Li-ions, the material undergoes enormous volumetric changes (300%). These volumetric changes trigger morphology transformations, which results in cracking of Si particles and re-formation of SEI film due to further reaction with electrolyte. Consequently, the number of repeated redox reactions with Li ions, in the Si dominant electrodes, is typically lower compared to traditional graphite electrodes. Therefore, it is well understood that mitigation of the particle fracturing can substantially overcome the cycle life challenges. To unlock the potential of Si dominant anodes, numerous expensive engineering solutions have been proposed, yet none of these strategies are presently commercially viable.

SIONIC Pure Silicon Anode Design: Instead of the commonly approached techniques of engineering or nano-structuring Si particles, SIONIC's patented electrode architectures overcome the challenges discussed above regarding Si dominant high-capacity anodes.

Figure 1 illustrates a simple yet scalable process of converting low cost, raw micron Si powders into high-capacity Si anode designs. This elegant design enables any Si source into high-capacity anodes.

Figure 1 is confidential

Transmission electron microscopic (TEM) image reveals the dual nature of SIONIC's anode design- providing mechanical integrity and both electronic /ionic conductive pathways. This unique feature paves the path towards commercial viability of low cost, untreated raw micron sized Si powders.



The Expansion Challenge: The most critical aspect of Si dominant anode designs is the electrode expansion after complete lithiation. To meet the cell level expansion target of less than 10%, the electrode level expansion should be lower than 20%. However, individual Si particle expands up to 300% in a fully lithiated state. Particle level local expansion causes delamination at electrode level. Hence, mechanically resilient anode architecture is key for enabling Si dominant anodes. SIONIC designed pure Si anode (4 mAh/cm^2 ; 2000 mAh/g) thickness was measured using scanning electron microscopy (SEM) before and after complete lithiation. **Figure 2** compares the thickness measurements of the Si electrodes before and after lithiation. **Fully lithiated electrode expanded only 11%, which translates to less than 5% expansion on a multi-layer cell level.** The excellent control over natural expansion of individual Si particles is due to the elastic nature of the binder. EDX mapping of Si particles across the electrode confirm the even distribution and size increase after lithiation. This confirms mechanical integrity of the anode architecture and overcome the long-lasting expansion challenge of pure Si anodes. To our knowledge, none of the published

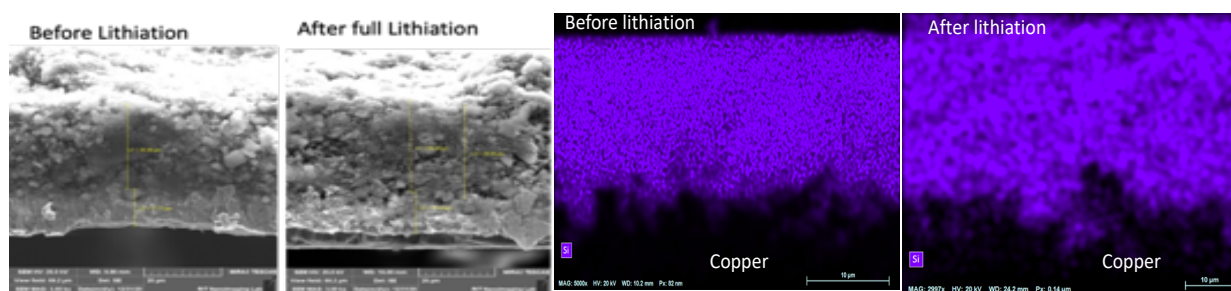


Fig. 2. Cross sectional SEM images of Pure Si anodes. Electrode thickness changed from 26.5mm to 29.5mm post lithiation. This corresponds to 11% expansion. EDX mapping of Si particles show the resiliency of anode design.

work on Si dominant anode provide control over electrode expansion and enable pure raw micron sized Si particles.

Table 1: Comparison of cell performance metrics.

	Cell chemistry	Anode capacity	Rate performance	Energy Density (21700 cell format)
SOA	NMC-Gr	350 mAh/g	1 hr charge time	260 Wh/kg; 720 Wh/L
Sionic	NMC-Si	>2000 mAh/g	15 min charge time	350 Wh/kg; 1050 Wh/L

Preliminary results: To realize high energy density from high-capacity Si anode design, full cell testing against high Ni content cathode is a must. SIONIC fabricated dozens of prototype pouch cells pairing NMC cathode) and pure Si anode designs (60 wt%). These pouch cells are about 20 cm² in footprint. Multiple cells show excellent capacity retention over 200+ cycles at C/4 rate with 100% retention. Anode fabricated using conventional binders (SBR/CMC) and pure μm Si particles failed within just a few cycles. These preliminary results confirm the uniqueness of SIONIC anode designs (**Fig. 3**), which make μm Si particle work.

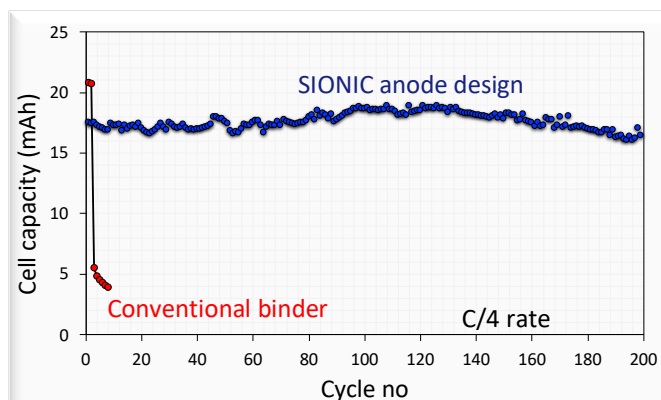


Figure 3. Prototype single layer pouch **full** cells, with footprint of 20 cm², comprised pure μm Si anode & NMC cathode. Combination of SIONIC designed electrolytes Si dominant anode designs outperformed. The cycle life tests are still ongoing. μm silicon anodes with conventional binder system failed drastically.

Technical Risks: Achieving long cycle life and calendar life of pure μm sized Si containing anode design depends on appropriate anode architecture. Sionic's anode architecture overcomes the most key challenge of Si dominant anodes, expansion. With the appropriate electrolyte designs paired with Si dominant anode designs, cycle life challenges can be easily overcome. Meeting the fast charge criterion (15 min to 80% SOC) is critical success factor for electric vehicle applications. Si dominant anode designs, due to high capacity and extremely low loadings, can easily overcome the fast charge requirements. **Figure 4** shows the effect of charge rate on the silicon utilization in one layer pouch cells. During the course of next quarter, we aim deliver 2170 cells that have high energy density, long calendar life and fast charge capability.

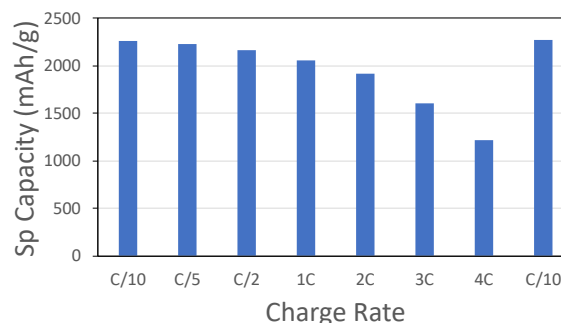


Figure 4. NOHMs μm Si anode specific capacity as a functional charge rate. One-layer cells paired with 622 cathode delivered excellent rate capability and high silicon utilization.

This technology will be instantly commercially relevant in the booming lithium-ion battery industry. The global lithium-ion battery market was valued at USD 36.7 billion in 2019 and is projected to hit USD 129.3 billion by 2027, at a CAGR of 18% from 2020 to 2027.