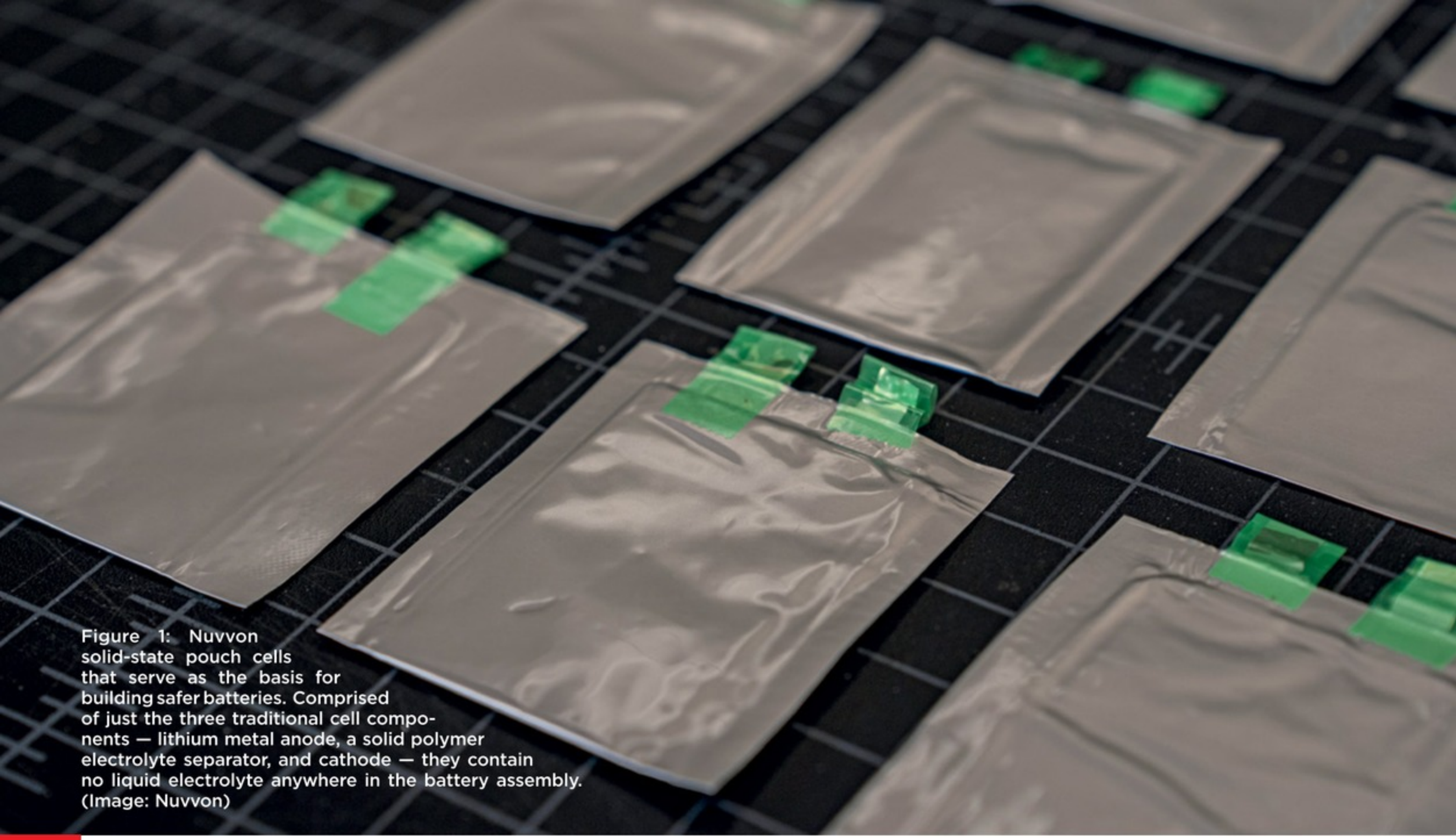
Figure 1: Nuvvon solid-state pouch cells that serve as the basis for building safer batteries. Comprised of just the three traditional cell components — lithium metal anode, a solid polymer electrolyte separator, and cathode — they contain no liquid electrolyte anywhere in the battery assembly. (Image: Nuvvon)

Developing Safer Batteries with Solid-State Polymer Electrolytes

A 100 percent solid state, high-performance polymer electrolyte addresses issues with liquid electrolytes for safer battery cell designs.

As energy storage applications and usage grows, so does the importance of battery safety. Lithium-ion batteries are the most popular energy storage systems used in portable electronics, electric vehicles, and grid energy storage. However, they come with safety concerns.

It is often reported that Li-ion batteries cause fires. This is due to the use of flammable solvent-based liquid electrolytes which can combust in the event of a fault such as a short circuit or overheating. Such problems are exasperated in Li-ion batteries with high energy densities.

According to Gitnux Market Data Report 2024 on Li-ion batteries, 48 percent of cell phone fires are caused by Li-ion batteries, with one battery fire occurring every two days in the U.S. Batteries can catch fire when in operation, being charged, and even when not in use or being recycled.

The development of a novel solid-state polymer electrolyte technology addresses the issues associated with liquid electrolytes used in traditional batteries and in many so-called solid-state batteries, which are often "semi-solid" batteries. Void of combustible, toxic, or flammable materials such as ionic liquids, low-boiling point solvents, or low-viscous oils, and gels, the new solid polymer electrolyte enables the development of highly stable and safer batteries.

Liquid vs. Dry Electrolytes

Standard Li-ion cells typically are composed of a composite cathode and graphite host anode, separated by an inactive polymer. The whole structure is porous for liquid electrolytes to be injected to facilitate ionic transfer.

Sensitive to temperature, liquid electrolytes have a narrow ideal operating range and become less stable above 40 °C. When exposed to increased temperatures or in the event of a fault, they pose thermal runaway risks that are associated with chemical reactions, smoke, fire, and possible explosions. When overheated or

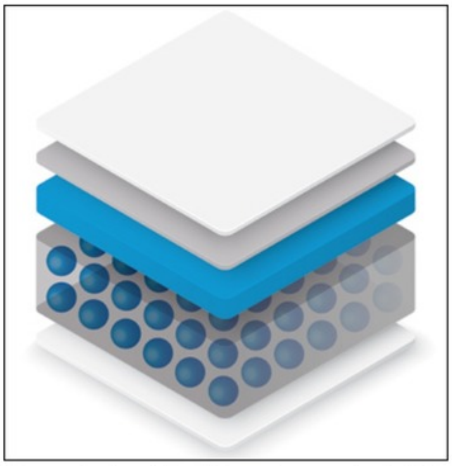

Figure 2: A solid-state polymer electrolyte developed by Nuvvon serves as both the active separator and electrolyte in battery pouch cells. The use of a solid polymer electrolyte in the structural design of a new solid-state battery addresses many of the shortcomings of liquid electrolyte Li-ion cells. (Image: Nuvvon)

Figure 3: Nuvvon's cast separator on a cast cathode. (Image: Nuvvon)

overcharged, the battery can emit gas, which degrades performance and can result in a fire.

An innovator in alternative solid-state battery materials has developed a solid-state battery pouch cell using traditional cell architecture: three layers or components including a lithium metal anode, cathode, and polymer electrolyte separator (Figure 1).

The solid polymer electrolyte (SPE) serves as both the separator and electrolyte (Figure 2). The technology does not contain any combustible, toxic, or flammable materials in the product or process. The SPE separator serves a dual purpose: ensuring the battery does not short-circuit by keeping the anode from contacting the cathode and providing a channel for lithium ions to migrate between the electrodes. If, for any reason, there is a short circuit, the failure mode is benign.

The lithium metal anode plates and strips lithium to charge and discharge the battery. This is now possible because the safety concerns of liquid electrolyte cells have been mitigated — meaning that it is no longer necessary to manage lithium ions with a less efficient intercalating carbon host.

The resulting solid-state battery is dry and does not contain any liquid components. In addition, no liquid electrolyte or polyionic/ionic liquids are injected into the host cathode. The cathode contains solid polymer catholyte.

Solid-State Polymer Electrolyte Makes for Safer Batteries

As the polymer electrolyte technology is compatible and stable with lithium metal, metal anodes are used in the solid-state pouch cells instead of a graphite or silicon-graphite host. This significantly increases volumetric and gravimetric energy density and allows more energy storage in smaller or lighter batteries supporting longer runtimes.

The technology is unique in that it provides 100 percent solid-state cells using a standard Li-ion production process. While the process makes cells using traditional cell architecture and standard equipment, it provides an improved bonding technology (Figure 3) by coating the polymer electrolyte directly onto the cathode. This replaces the inactive porous polymer separator that is normally inserted into traditional Li-ion cells from a roll. The improved bonding provides various benefits to the electrochemical interfaces of the solid-state battery.

This technique and the unique SPEs enable a stable operation over a large thermal window (Figure 4) without mechanical degradation or emission of toxic gas. In tests, the solid polymer electrolyte operates normally, even when a naked cell is exposed to a naked flame. Cells eventually show benign failure when heated above the melting point of lithium metal. With the solid polymer electrolyte, solid-state pouch cells can operate across wide temperature ranges without external systems for cooling, heating, or pressure.

Inherent bonding is a key benefit of using a standard casting process for the cathode and the separator. This lowers internal battery impedance, which results in less heat building up in the battery and, thereby, enabling faster charging due to lower internal resistance.

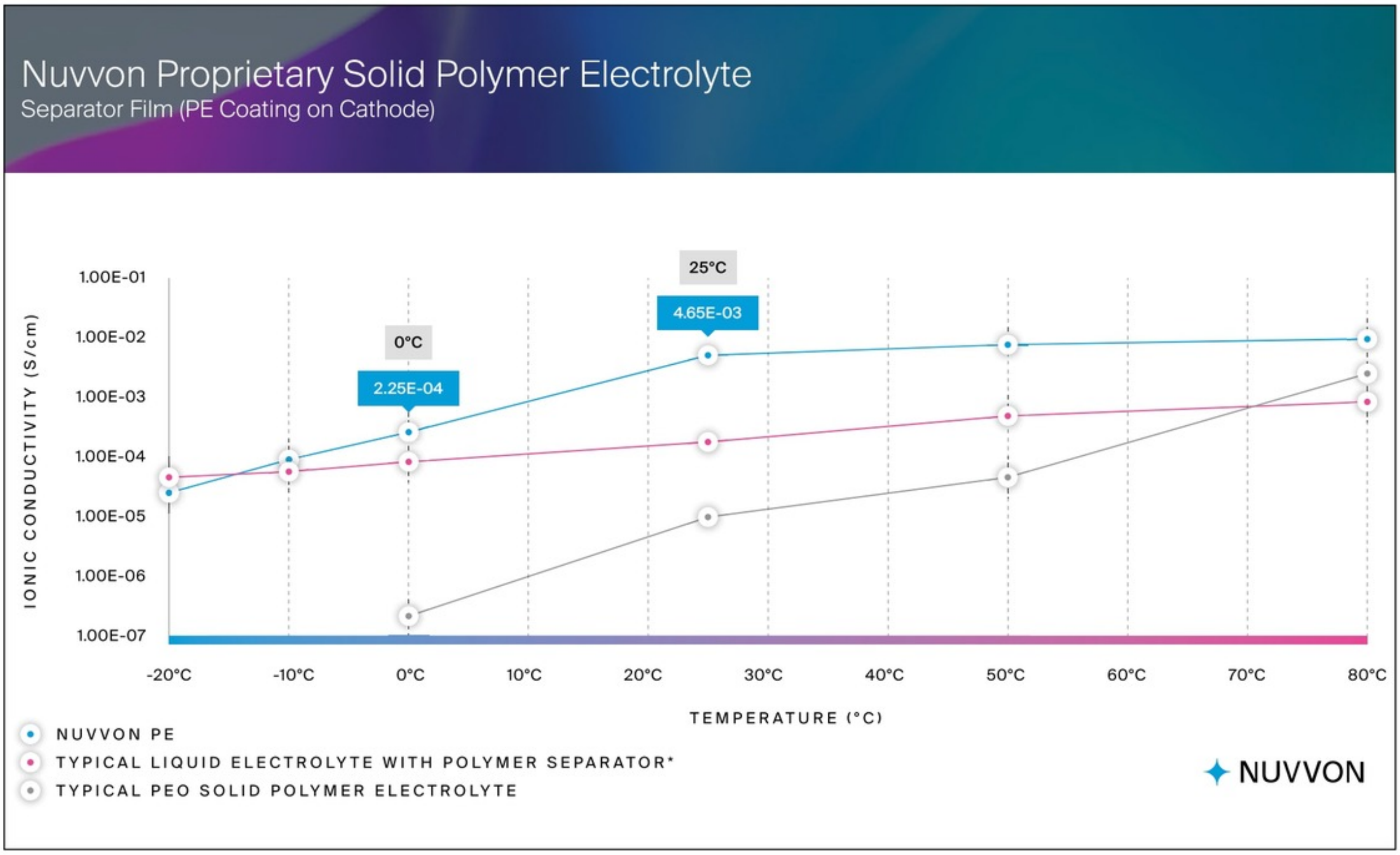

Figure 4: Data from third-party testing on solid polymer electrolytes shows its ionic conductivity across a wide temperature range. *Liquid electrolyte is typically 10^{-2} S/cm without a separator and 10^{-4} S/cm with a porous polymer separator. (Image: Nuvvon)

Proof in Testing

Third-party test results as well as certifications will help in the acceptance of solid-state batteries built with solid polymer electrolytes as a safer alternative to traditional liquid electrolytes.

Prototype pouch cells passed independent abuse testing by the safety organization Underwriters Laboratories (UL) that included overcharge and over-discharge cycling and the naked flame test using protocol 1973. UL certified to DOT standard SP20798, the solid-state pouch cells have been approved as safe for global air shipment.

Applications

The characteristics of the innovative polymer electrolytes meet the need for a safer energy storage technology as the basis for stable cell designs used in solid-state batteries for a variety of markets.

- **Electric vehicles:** The Gitnux Market Data Report 2024 discloses that 70 percent Li-ion battery fires in electric vehicles occurred while the vehicle was in use or motion. Battery development will be a major focus to protect against thermal runaway. Combining a lithium-metal anode with this novel solid electrolyte would provide the safety, electrochemical performance, and energy density required to develop a viable solid-state battery for more efficient and safer EVs in the future.
- **Portable electronics:** Battery safety is a major concern for portable electronics as current battery chemistries overheat and can catch fire or even explode under extreme conditions. The solid polymer electrolyte can provide a more efficient and safer material to develop longer-lasting and safer portable electronics including battery packs for smartphones, laptops, and tablets.
- **Stationary energy storage:** Battery energy storage systems are an integral part of backup microgrids and renewable energy systems. Applications for microgrids include telecoms, marine, and industrial systems in the case of power failures or stand-alone systems. Wind turbines and solar farms also use microgrids to store excess power and release it during periods of low energy production.

Solid-state polymer electrolytes could be the secret 'drop-in' ingredient in developing high-energy density batteries that are safe and operate over a wide thermal window. They avoid the issues with leaks and overheating associated with flammable solvent-based electrolytes that lead to safety issues.

Unlike liquid electrolytes, solid polymer electrolytes resist thermal runaway. This has been shown in prototypes exposed to a naked flame and heated above the melting point of lithium metal. These and other factors make the proprietary polymer electrolyte technology a worthy contender for the holy grail of solid-state batteries.

This article was written by Karmjit Sidhu, Founding Director, Nuvvon (Bordertown, NJ). **For more information, visit www.nuvvon.com.**