Wildcat Discovery Technologies

White Paper | May 2015

How to Increase Cycle Life, Coulombic Efficiency, and Thermal Stability of Li-ion Batteries

SuperFilm™ Electrolyte Technology

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Wildcat's SuperFilm™ Electrolyte Technology

Background and Current State-of-the Art

Substantial improvement in the energy density of rechargeable lithium batteries is required to meet the future needs for electric and plug-in electric vehicles (EV and PHEV). Present day Li-ion technology is based on shuttling lithium between graphitic carbon and inorganic oxides. Blends of cyclic and linear carbonates containing lithium salts and additives dominate the electrolyte technology. However, today's lithium ion battery electrolytes are not reductively stable on graphite anodes at typical operating potentials.

The properties and quality of the solid electrolyte interphase (SEI) layer are critical to achieving high cycle life, high rate performance, and wide operating temperature ranges in a battery. However, SEI layers on graphite anodes are generally non-uniform and have incomplete surface coverage (Figure 1).

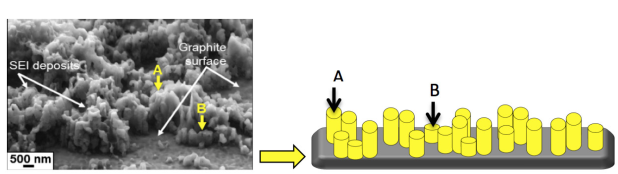

Figure 1: SEM of graphite showing non-uniformity of SEI layer

To achieve the most stable performance, additives must accomplish two things: deposit uniformly on the electrode surface and form a mechanically and electrochemically stable coating. These multiple constraints severely limit the set of viable additives.

Complicating things even further, improvements in cell energy density generally require higher cell operating potentials. Today's electrolytes are not stable at cathode potentials above around 4.2V. Ideally, solutions for high voltage applications will form passivation layers on the cathode, preventing oxidation of the bulk electrolyte. Like the anode SEI, passivation films on the cathode require sufficient film uniformity to protect the cathode surface as well as chemical and electrochemical stability of the moieties.

More uniform and stable SEI is required on both the cathode and anode. Wildcat has developed a new electrolyte technology to address this challenge.

Wildcat's SuperFilm™ Electrolyte Technology

Wildcat Discovery Technologies has developed a new, modular additive concept in which functional additives are bound to film-forming cores to enable uniform deposition on the electrode surface.

The attachment of functional additives to the core molecules also improves SEI stability, resulting in increased coulombic efficiency, cycle life, and thermal stability with minimal impact on initial capacity or coulombic efficiency. By decoupling the requirements for uniform coating and chemical stability, new and promising classes of additives can now be used for the first time.

Wildcat's SuperFilm™ technology is a family of electrolytes built of formulations with unique combinations of cores and functional group additives that have been tailored to improve performance of specific cathodes and voltages. Four case study examples involving different cathodes are used to demonstrate the versatility of Wildcat's SuperFilm™ discovery.

SuperFilm™ Case Studies

The first example of SuperFilm™ is shown in Figure 2 and involves a high voltage NMC//graphite cell. The baseline performance of the control electrolyte with no additives shows capacity retention of about 60% at 150 cycles (red line). Addition of a functional group additive (FG-1) by itself decreases the capacity retention to below 50% (green). Attachment of a vinyl functionality to the same FG-1 additive, which can reductively polymerize on the anode similar to vinylene carbonate, slightly improves the performance relative to the baseline (orange). However, Wildcat's SuperFilm™ technology consisting of FG-1 attached to a film-forming core moiety yields the best performance at 80% capacity retention (blue). All additives were added at 0.5 weight % to the baseline electrolyte (EC:EMC, 1:2 v/v, 1M $LiPF_6$).

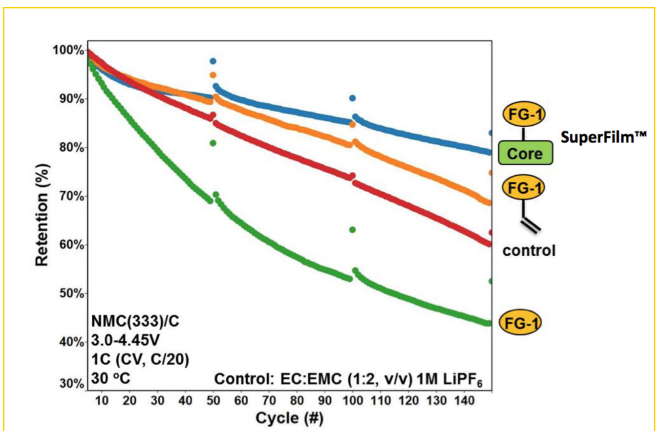

Figure 2: Modular electrolyte additive with core species and functional group gives best capacity retention during high voltage cycling

Wildcat's SuperFilm™ exhibits a similar benefit in a $LiCoO_2$//graphite cell cycled to 4.35V at elevated temperature, which is shown as a second example in Figure 3. Simply adding the functional additive FG-2 at 1 weight % is detrimental to capacity retention (green), and the addition of the film forming core moiety alone also degrades performance (orange). However, the SuperFilm™ combination of both the functional additive FG-2 and the film-forming core yields significant improvement in the high temperature cycle life relative to a conventional baseline electrolyte (blue).

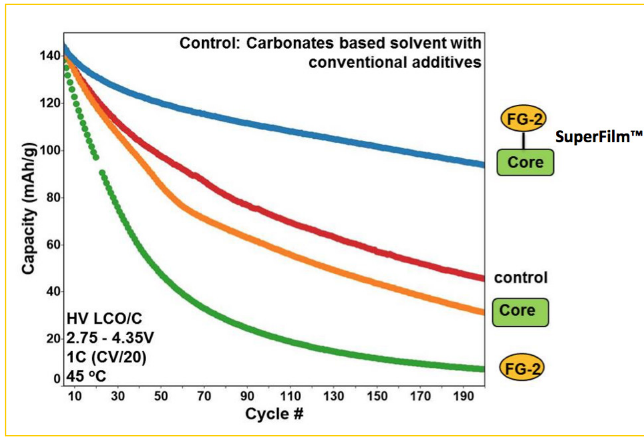

Figure 3: Modular electrolyte additive with core species and functional group gives best capacity retention at during elevated temperature cycling

A third example of Wildcat's SuperFilm™ technology is demonstrated with $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO), which is a promising high energy density cathode material under development for several commercial applications. In this case, however, the cell is cycled up to 4.9V where today's electrolytes are not oxidatively stable.

Figure 4 shows the capacity retention improvement using Wildcat's modular additive concept in LNMO//graphite cells cycled under very harsh conditions. These cells were cycled to 4.9V at 50°C, and the cells were held at 4.9V top-of-charge for 1.5 hours on each cycle to increase the electrolyte exposure to high voltage. The baseline electrolyte without additives has relatively poor

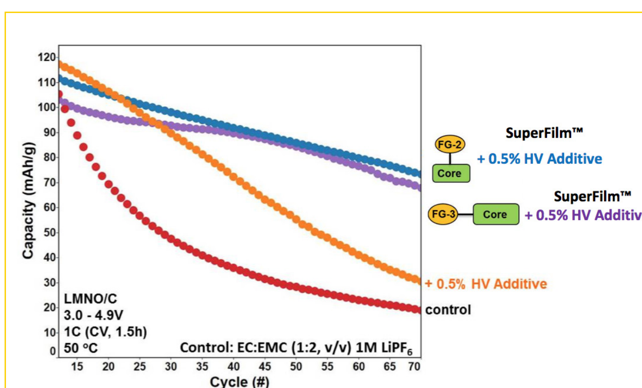

Figure 4: Wildcat modular electrolyte additives show synergies with other additives

cycle life (red). The addition of a conventional high voltage additive in 0.5% concentration improves performance moderately (orange). Two different versions of Wildcat's SuperFilm™ electrolytes with the same HV additive significantly improve high temperature cycle life and are demonstrative of the synergistic effects of the SuperFilm™ concept (blue and purple).

Finally, the versatility of SuperFilm™ is demonstrated again using nickel-rich NCM at elevated voltage and temperature. This cathode is believed to be one of the most promising near term cathodes for EV or HEV application due to its low cost and high energy density. Unfortunately, the cycle life of Ni-rich NCM with conventional electrolytes at elevated temperature is not adequate.

Figure 5 shows the high temperature cycle life improvement due to SuperFilm™ in 4.35V NCM(523)//graphite cells. The performance of two SuperFilm™ electrolyte formulations with different functional group additives is shown. In this case, the best SuperFilm™ electrolyte significantly improved cell performance and resulted in 90% retention at more than 200 cycles.

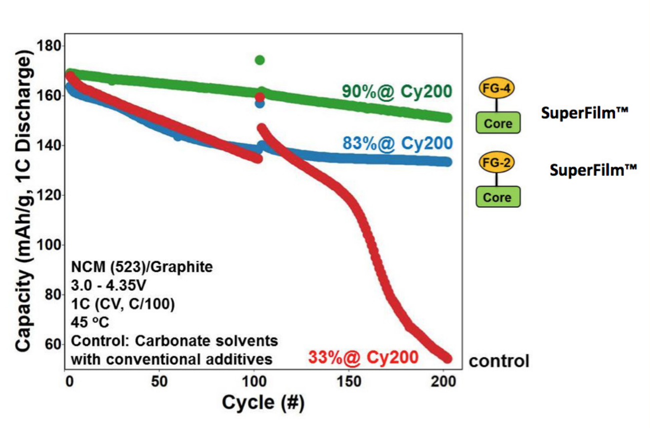

Figure 5: Wildcat modular electrolyte additives show significant cycle life improvement for NCM (523) at elevated temperature and voltage

About Wildcat Discovery Technologies

Wildcat Discovery Technologies is involved in the discovery and development of new materials for rechargeable and primary batteries. Using proprietary high throughput tools, Wildcat can synthesize and test thousands of new materials every week – measuring capacity, power, voltage, and cycle life of those new materials in actual batteries.

Wildcat works with companies throughout the battery supply chain including chemical companies, material suppliers, cell makers and OEM's. Wildcat's projects can target any component of the battery – cathodes, anodes, formulations, electrolytes and additives are all possible. Now recognized as a one of the world's premier battery R&D companies, Wildcat's business model is to help global industry leaders accelerate battery performance improvements, reduce R&D costs and speed the introduction of their products to market.

For more information about licensing Wildcat's SuperFilm™ electrolytes or Joint Development Agreement opportunities, please contact:

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