National Aeronautics and Space Administration

The Development of Advanced High Voltage, High Specific Energy and High Power Li-ion Cells with Improved Low Temperature Performance

Principal Investigator: Marshall Smart (346); Co-Investigators: Frederick Krause (346), John-Paul Jones (346)

Program: FY21 R&TD Topics **Strategic Focus Area: Energy storage**

Objectives

The objective of the proposed research is to develop advanced small format Li-ion chemistries that can provide high specific energy (175-225 Wh/kg at -40ºC at a C/5 rate), good rate capability (up to C/2 rates), and the capability to operate over a wide temperature range, (-60ºC to +50ºC, including charging at temperatures down to -40ºC). Current state-of-art small format cells generally display 180-230 Wh/kg specific energy at ambient temperature and have poor performance below -20ºC, especially at high rates. The objective will be achieved by coupling high voltage systems (i.e., $LiNiMnCoO_2$ (NMC), $LiCoPO_4$, $LiCoO_2$) with advanced lithium ion electrolyte solutions, which will be incorporated into prototype cells that will be manufactured by a vendor (i.e., E-One Moli Energy and/or Quallion). The focus will be upon the design of novel electrolytes that inherently have increased stability at high voltage and the use of additives to improve the electrode kinetics and limit the propensity of lithium plating occurring and enhance the charge characteristics. The developed wide voltage range and operating temperature range electrolytes will be incorporated into experimental and prototype high specific energy aerospace quality Li-ion cells manufactured by a vendor.

Background

Current state-of-practice (SOP) Li-ion batteries, such as the large format InSight Chemistry consisting of Graphite/$LiNiCoAlO_2$, can operate from -30ºC to +35ºC. [Ref. 1,2,3] At -40ºC, the cells can deliver 105 Wh/kg at a C/5 rate when charged at room temperature. In contrast, commercial 18650 cells perform very poorly at temperatures of -30ºC and below, providing negligible capacity at -40ºC. Rechargeable batteries that can provide high specific energy (175-225 Wh/kg at -40ºC at a C/5 rate), good rate capability (up to C/2 rates), and the capability to operate over a wide temperature range (-60ºC to +50ºC, including charging at temperatures down to -40ºC) are increasingly desirable for a number of JPL future missions. Furthermore, Li-ion batteries configured in a small cell format (similar to SMAP or the Europa Clipper) are becoming more attractive compared to large cell formats, due to enhanced safety characteristics and improved specific energy. Future applications that will be enabled or enhanced by the developed technology include: (i) future Mars landers, (ii) future Mars rovers, including the Mars Sample Return mission, and (iii) future planetary aerial vehicles, where high specific energy, high power and wide operating temperature range is desired.

Approach and Results

The approach of the research program consists of designing lithium-based organic electrolytes that contain electrochemically stable solvents and functional additives, which are targeted at stabilizing the electrode interfaces to achieve enhanced voltage stability and improved kinetics. The key innovative element of this proposed effort is designing of Li-ion electrolytes tailored to support high voltage operation and very low temperature battery operation. The electrolytes feature mixtures of organic carbonates (EC, DEC, DMC, EMC, and FEC), organic esters (methyl formate, methyl acetate, methyl propionate, ethyl propionate, and methyl butyrate), lithium conducting salts ($LiPF_6$, $LiBF_4$, LiDFOB, and LiBOB) and electrolyte additives intended to improve the properties of the anode Solid Electrolyte Interphase (SEI) (such as LiFSI, vinylene carbonate (VC), $LiPO_2F_2$, ethylene sulfite, and propane sultone).

- Performed three-electrode experimental cell studies with graphite and $LiNi_{0.80}Mn_{0.10}Co_{0.10}O_2$ (NMC 811) electrodes. Improved performance observed at C/5 (Fig. 1) at -40ºC.
- Evaluated high specific energy 18650-size prototype 18650 cells from Quallion/Enersys. When the cells were discharged using a C/5 rate at -40ºC (Fig. 2) a three-fold improvement was observed.
- Evaluated available in-house high specific energy E-One Moli18650-size ICRM cells that contain JPL electrolytes.
- The best performing electrolyte at lower temperatures and higher rates was the MP-based solution with FEC, namely 1.20M $LiPF_6$ in EC+EMC+MP (20:20:60 vol %) + 2 wt% FEC
- Over 174 Wh/kg at a C/20 rate at -40ºC (Goal = 175 Wh/kg at C/5), as shown in Fig. 3.
- Results represent dramatic improvement over SOA of 105 Wh/kg at C/5 rate (InSight).
- As shown, this represents an 81% improvement over baseline heritage MER/MSL electrolyte.
- Excellent performance was demonstrated over a wide range of temperatures, as shown in Fig. 4.

Significance/Benefits to JPL and NASA

Upon successfully meeting the program objectives, a number of future applications that would benefit from the developed technology include: (i) future Mars landers, (ii) future Mars rovers, including the Mars Sample Return mission, and (iii) future planetary aerial vehicles, where high specific energy, high power and wide operating temperature range is desired. Upon successful completion of the work, we will plan to contact the Planetary Science Directorate (PSD) to explore any future opportunity to infuse the technology into a future mission. Furthermore, the developed technology will have promise for future mission to the Icy Moons of Jupiter and Saturn, which require high specific energy and wide operating temperature range.

Publications

Marshall C. Smart, F. C. Krause, J. -P. Jones, B. V. Ratnakumar and Mark Shoesmith, “Ester and Carbonate-Based Low Temperature Electrolytes in High Specific Energy and High Power 18650 Li-Ion Cells for Future NASA Missions,” ECS PRiME 2020 Joint International Meeting, (Virtual Meeting), Oct. 8, 2020.

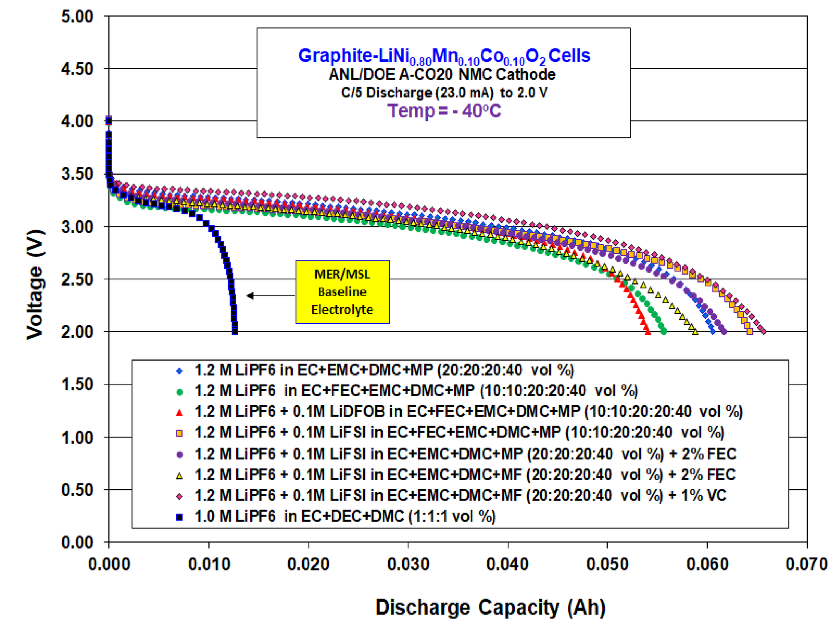

Figure 1

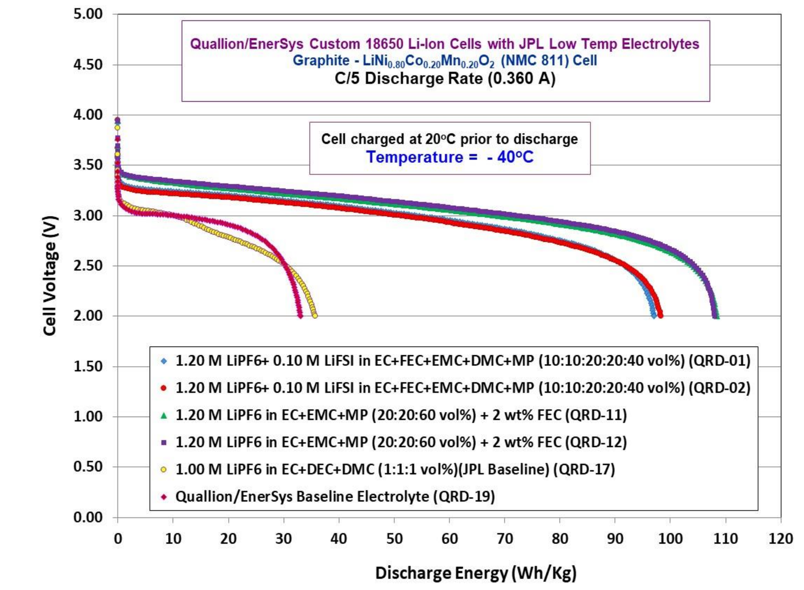

Figure 2

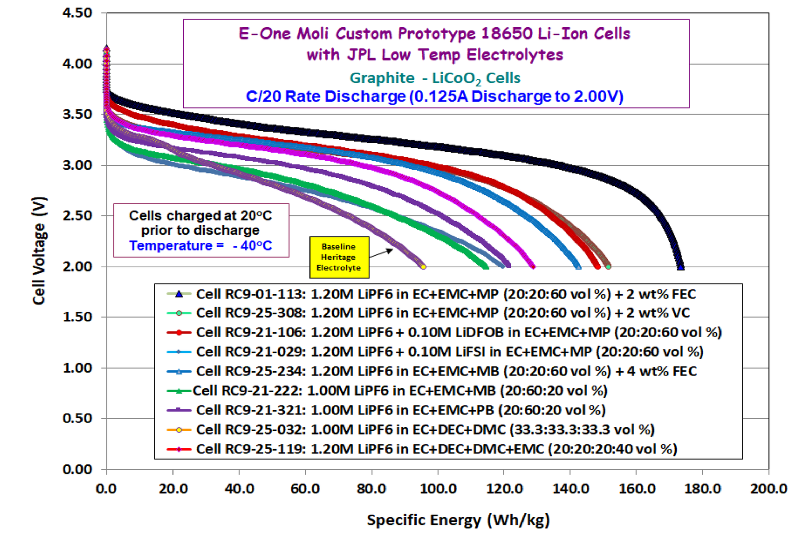

Figure 3

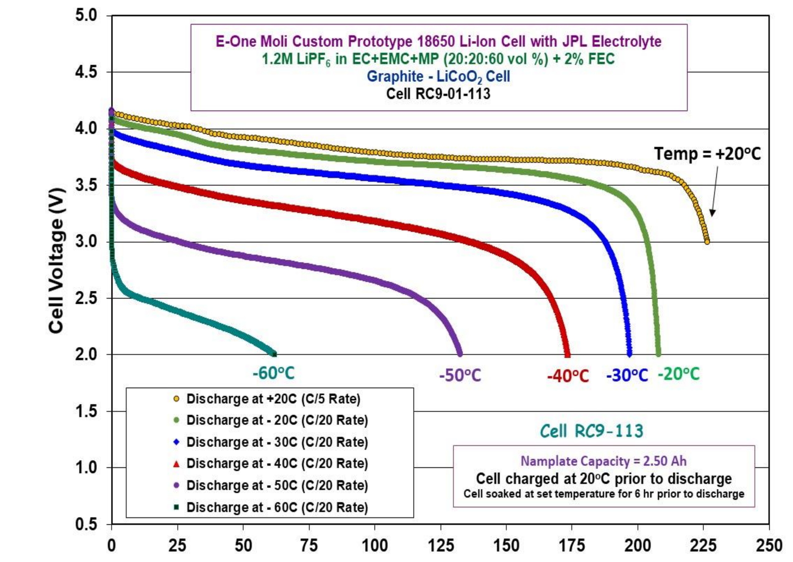

Figure 4

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Marshall.C.Smart@jpl.nasa.gov

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