



Materials

Lithium-Ion Electrolytes Containing Phosphorous-Based, Flame-Retardant Additives

This technology can enhance the safety of lithium-ion batteries for portable electronic devices and hybrid electric vehicles.

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Future NASA missions aimed at exploring Mars, the Moon, and the outer planets require rechargeable batteries that can operate over a wide temperature range (-60 to $+60$ °C) to satisfy the requirements of various applications. In addition, many of these applications will require improved safety, due to their use by humans. Currently, the state-of-the-art lithium-ion (Li-ion) system has been demonstrated to operate over a wide range of temperatures (-40 to $+40$ °C); however, abuse conditions can often lead to cell rupture and fire. The nature of the electrolyte can greatly affect the propensity of the cell/battery to catch fire, given the flammability of the organic solvents used within.

Li-ion electrolytes have been developed that contain a flame-retardant additive in conjunction with fluorinated co-solvents to provide a safe system with a wide operating temperature range. Previous work incorporated fluorinated esters into multi-component electrolyte formulations, which were demonstrated to cover a temperature range from -60 to $+60$ °C. This work was described in "Fluoroester Co-Solvents for Low-Temperature Li⁺ Cells" (NPO-44626), *NASA*

Tech Briefs, Vol. 33, No. 9 (September 2009), p. 37; and "Optimized Li-Ion Electrolytes Containing Fluorinated Ester Co-Solvents" (NPO-45824), *NASA Tech Briefs*, Vol. 34, No. 3 (March 2010), p. 48.

Other previous work improved the safety characteristics of the electrolytes by adding flame-retardant additives such as triphenyl phosphate (TPhPh), tributyl phosphate (TBuPh), triethyl phosphate (TEtPh), and bis(2,2,2-trifluoroethyl) methyl phosphonate (TFMPo). The current work involves further investigation of other types of flame-retardant additives, including tris(2,2,2-trifluoroethyl) phosphate, tris(2,2,2-trifluoroethyl) phosphite, triphenylphosphite, diethyl ethylphosphonate, and diethyl phenylphosphonate added to an electrolyte composition intended for wide operating temperatures.

In general, many of the formulations investigated in this study displayed good performance over a wide temperature range, good cycle life characteristics, and are expected to have improved safety characteristics, such as low flammability. Of the electrolytes studied, 1.0 M LiPF₆ in EC+EMC+DEP (20:75:5 v/v %) and 1.0 M LiPF₆ in EC+EMC+DPP

(20:75:5 v/v %) displayed the best operation at low temperatures, whereas the electrolyte containing triphenylphosphite displayed the best cycle life performance compared to the baseline solution. It is anticipated that further improvements can be made to the life characteristics with the incorporation of a SET promoters (such as VC, vinylene carbonate), which will likely inhibit the decomposition of the flame-retardant additives.

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InGaP Heterojunction Barrier Solar Cells

Nanostructured cells could enhance the performance of terrestrial high-efficiency solar cells.

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A new solar-cell structure utilizes a single, ultra-wide well of either gallium arsenide (GaAs) or indium-gallium-phosphide (InGaP) in the depletion region of a wide bandgap matrix, instead of the usual multiple quantum well layers. These InGaP barrier layers are effective at reducing diode dark current, and photogenerated carrier escape is maximized by the proper design of the

electric field and barrier profile. With the new material, open-circuit voltage enhancements of 40 and 100 mV (versus PIN control systems) are possible without any degradation in short-circuit current.

Basic tenets of quantum-well and quantum-dot solar cells are utilized, but instead of using multiple thin layers, a single wide well works better. InGaP is used as a bar-

rier material, which increases open current, while simultaneously lowering dark current, reducing both hole diffusion from the base, and space charge recombination within the depletion region. Both the built-in field and the barrier profile are tailored to enhance thermionic emissions, which maximizes the photocurrent at forward bias, with a demonstrated voltage increase.