Lithium-Ion Battery Offers Wide Latitude in Choice of Power, Discharge Profile, Battery Voltage

The lithium-ion battery has become the industry standard for many consumer-electronics applications despite numerous problems associated with its chemistry and high cost. The use of higher-voltage cathodes places special requirements on battery charging and precludes the use of low-viscosity, low-cost electrolytes, thus limiting high-rate applications. In addition, performance and safety issues have been raised for large-cell applications such as hybrid electric vehicles. Lithium Power Technologies has developed a lithium-ion battery that operates in the range of 2–3 V, compared with existing lithium-ion batteries at 3.7 V. This lightweight and potentially less-expensive battery delivers specific energies in excess of 200–250 Wh/kg. The battery allows wider latitude to the electronic-device designer in the choice of power, discharge profile, and battery voltage. Its improved safety offers the potential for larger battery applications.

All current lithium-ion cathodes behave in virtually the same way in that the values of the cell voltage and discharge profile are similar. Furthermore, the higher-viscosity carbonate-based electrolytes are expensive and have lower conductivity, thus they limit low-temperature operation. Since the introduction of lithium-ion batteries in 1992, major improvements have not been made. Typical energy densities are about 160 Wh/kg for $LiCoO_2$ (lithium cobaltite) cathodes with carbon-based anodes. Most recently, research has focused on mixed metal oxide cathodes based on lithiated nickel cobalt oxide. This has allowed greater stability and somewhat increased capacity, resulting in battery energy densities of about 180 Wh/kg. Some research groups are evaluating lithiated metal phosphates based on a wide composition range, including Li_xFePO_4 and $Li_xV_2(PO_4)_3$, with greater safety claims but with lower energy densities and rate capabilities. As the demand for higher energy and power requirements for electronics increases—pushing the envelope of current battery electrochemistry—the present lithium-ion technology appears to have reached a roadblock.

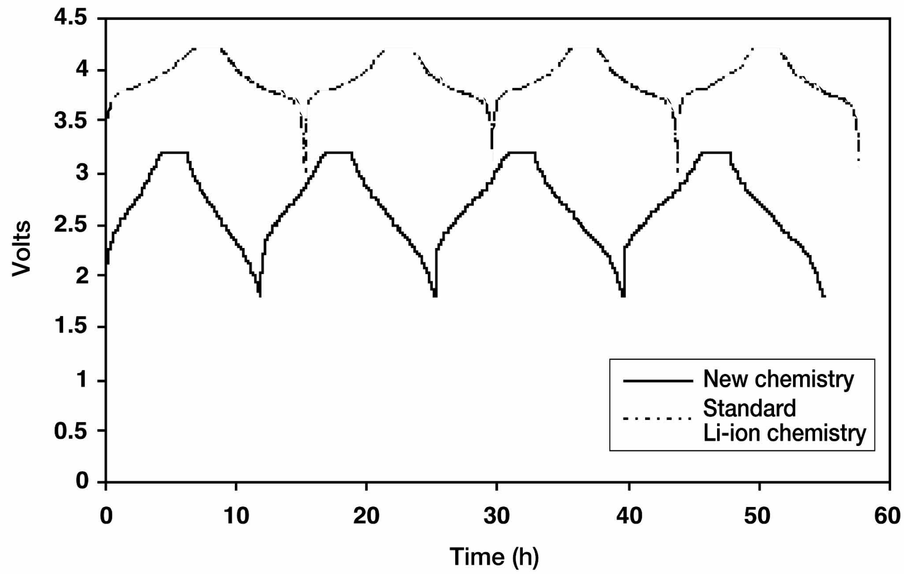

Figure 1. Typical charge–discharge profile for the new lithium-ion battery from Lithium Power Technologies, compared with standard lithium-ion battery chemistry.

The new battery by Lithium Power Technologies has a discharge profile that can be tailored to the application (sloping or flat). It uses a wider selection of lower-viscosity organic solvent electrolytes, enabling higher conductivity and hence higher power, greater safety, and lower operating temperatures.

This battery technology is based on a series of proprietary cathode materials with very high lithium intercalation capacities (200–600 mAh/g) that are easy to produce and electrochemically stable with low-viscosity solvents. The carbon anode is similar to existing lithium-ion anodes. However, since the battery voltage is significantly lower, it is possible that higher-capacity anodes, such as those based on tin oxide and carbon, may cycle more favorably than in existing lithium-ion batteries. Furthermore, it is expected that due to its lower voltage, the self-discharge of the battery should also be lower. Figure 1 shows a typical charge–discharge profile for one type of cathode comparedwith a standard lithium-ion battery. The manufacture of the battery is similar to that of existing lithium-ion batteries.

Lithium Power Technologies is developing this new chemistry in combination with ultrathin-film lightweight metallized plastic current collectors—such as polyester or polypropylene—and thin-film polymer gel electrolytes to deliver not only higher energy but also higher power per unit weight and volume. A key characteristic of this battery is its behavior on overcharge. Unlike present lithium-ion batteries in which oxygen is liberated on overcharge from the metal oxide cathode and reacts with the carbonate solvents to yield an explosive mixture, the new chemistry appears to be less prone to this type of reaction and thus is safer.

Opportunities

Lithium Power Technologies has filed a patent application for this battery. Since the technology is relatively new, further validation tests of the performance of the various chemistries, including validation on safety tests, are being conducted. The company is seeking potential licensees, strategic industrial partners, and investors to develop this technology for the replacement of existing lithium-ion batteries.

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Miniature Magnetoelastic Physical, Chemical, and Biological Sensors Practical for One-Time Use

Amorphous, ferromagnetic, magnetoelastic materials efficiently convert magnetic energy to mechanical energy at characteristic resonance frequencies. This enables their application as environmental sensors. A magnetic-field impulse, ≈4 A/m, is used to impart elastic energy into a magnetoelastic sensor, which in turn acts to mechanically strain the material in a transitory, time-decaying response. The magnetoelastic sensor magnetically "rings" at its resonance frequency, which can rapidly (<1 ms) be determined through microprocessor-based frequency-counting techniques. While magnetoelastic sensors have long been used as anti-theft devices for electronic surveillance (e.g., in department stores), researchers at The Pennsylvania State University and SenTech Corporation (State College, Penn.) have demonstrated that magnetoelastic sensors can also be used to make high-performance physical, chemical, and biological sensors.

When an externally applied magnetic field reaches the thin-film sensors, they emit both magnetic flux and acoustic energy with a characteristic resonant frequency—the magnetoelastic thin film changes its magnetic response. Tracking the changes in the resonance frequency of a magnetoelastic sensor enables the determination of such physical parameters as pressure, temperature, fluid-flow velocity, liquid density, and liquid viscosity. The sensor does not require direct physical connections or an internal power source (i.e., a battery). Simultaneous tracking and cross-correlating the response of multiple magnetoelastic sensors enables the absolute determination of environmental parameters in a complex environment.

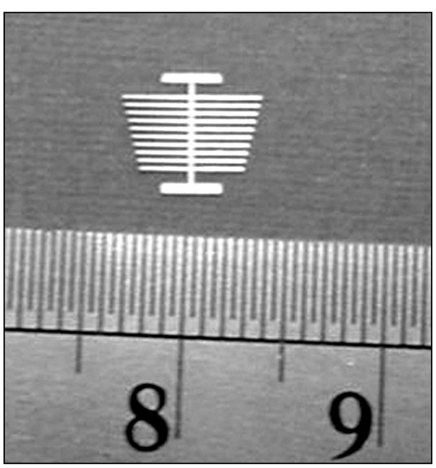

Figure 1. A 10-element magnetoelastic sensor array (footprint ≈ 0.4 cm²) used for simultaneous measurement of humidity, CO_2, temperature, and pressure. The major scale is cm.

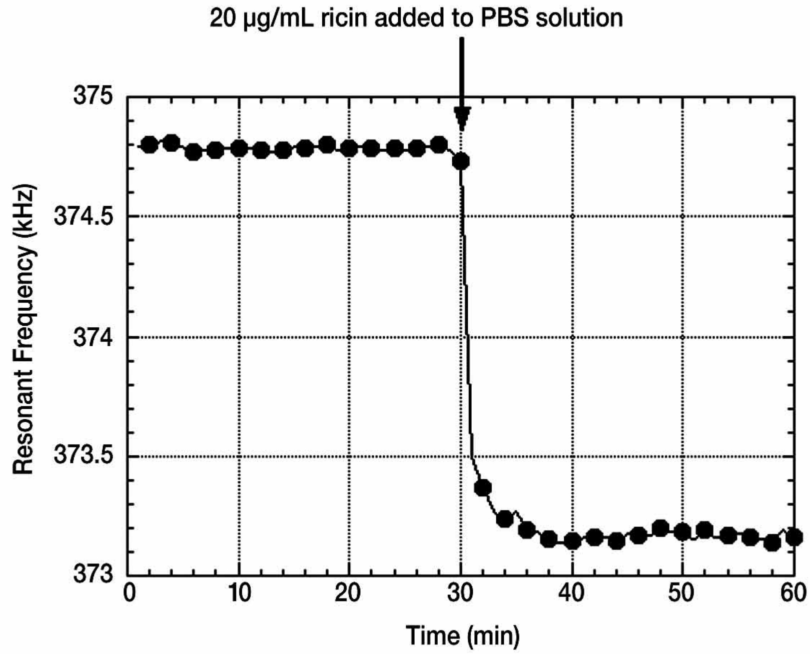

Figure 2. Shift in resonance frequency of a magnetoelastic sensor immersed in phosphate buffered saline (PBS) to which 20 µg/ml of the toxin ricin is subsequently added.

The resonance frequency of a magnetoelastic sensor shifts linearly in response to applied mass load. Hence, magnetoelastic sensors can be used as chemical and biological sensors when combined with a layer that changes mass or elasticity in response to an analyte of interest. With comparable sensitivities, magnetoelastic sensors cost considerably less than surface acoustic-wave sensors (actual costs depend on sensor size and frequency), with a significantly smaller footprint. A 10-element magnetoelastic sensor array used for simultaneous measurement of humidity, CO_2, temperature, and pressure is shown in Figure 1. The sensor array is laser-cut from a 1.0 cm × 28 µm continuous ribbon. Magnetoelastic-based sensors have been used to monitor different gas analytes including humidity, NH_3, CO_2, and ethylene, as well as aqueous chemicals including pH, salt, and glucose concentrations.

Beyond sensitivity, a critical issue in determining the utility of chemical and biological sensor platform is cost, since they are often only needed for a single use. Magnetoelastic sensors are a highly accurate, miniature mass/elasticity-based sensor technology that is inexpensive enough to be disposable.

In recent proof-of-concept measurements, magnetoelastic biosensors have been used for the detection of antibody-antigen reactions. Preliminary results have demonstrated the feasibility of a magnetoelastic sensor for the highly toxic poison ricin (see Figure 2). The small footprint of the magnetoelastic sensor arrays make them well suited for use within sensor network nodes where space and power are at a premium.

Opportunities

SenTech Corporation is seeking to commercialize its patented magnetoelastic environmental sensor technologies. The company welcomes inquiries about joint application development.

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Fluorescent Chemical and Biological Sensors Developed Using Organic Light-Emitting Devices

A platform of fluorescent chemical and biological sensors, based on the structural integration of a fluorescent sensor with the excitation source, an organic light-emitting device (OLED), has been invented jointly by a group at Iowa State University (ISU) in Ames and the University of Michigan (UM) in Ann Arbor. The simple integrated structure consists of an OLED fabricated on one side of a glass or plastic substrate, and a sensor film deposited on the other side of the same substrate. A filter, which blocks the emission from the OLED but passes the fluorescence of the sensor film, is positioned beyond the analyte, and the photodetector is positioned beyond the filter ("front detection" geometry, as shown in Figure 1a). This design enables the construction of compact, lightweight, remotely operated, stand-alone, and eventually inexpensive microarrays of sensors for inorganic chemicals, volatile organic compounds, biochemical compounds, and biological agents.

The integration and miniaturization of fluorescence-based sensors is a first step in developing sensor arrays that can be used for analyzing living cells, organisms, and biochemical compounds. In general, such chemical-sensing devices are composed of three components: a light source that excites the sensing element, the sensing element that produces the fluorescence (usually a fluorescent dye for tagging the sample), and a photodetector. However, conventional sensors that use lasers or inorganic light-emitting devices as light sources are costly and bulky and cannot be integrated with other sensor components.

Recently, the developers at ISU and UM have demonstrated an oxygen sensor operating in the "back-detection" geometry, shown in Figure 1b, in which the sensor is in contact with the biological solution being analyzed on the substrate and the OLED light source is behind the substrate. The OLED light source, powered by a miniature battery, excites the sensor, which fluoresces. When the sensor detects the compound of interest in the sample solution, its fluorescence changes and the change is detected by a photodetector located behind the OLED. Due to the close coupling between the OLED light source and the sensor film, and the ability to operate the device in a pulsed mode, the sensor film and analyte experience negligible heating. Consequently, these devices would be suitable for both *in vitro* and *in vivo* use with sensor films and analytes that are sensitive to heating. The extremely fast subsecond response of this sensor to an alternating flow of 34.5 kPa (5 psi) Ar and O_2 gases is shown in Figure 2. The developers have also fabricated a glucose sensor and are currently developing sensors for other analytes and agents.

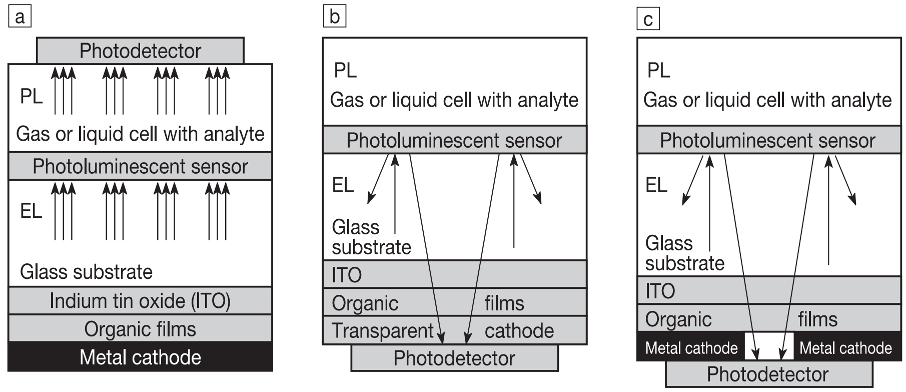

Figure 1. Sensor device geometries: (a) "front detection," (b) "back detection" using transparent organic light-emitting devices (OLEDs), and (c) back detection using an array of OLED pixels. PL is photoluminescence; EL is electroluminescence.

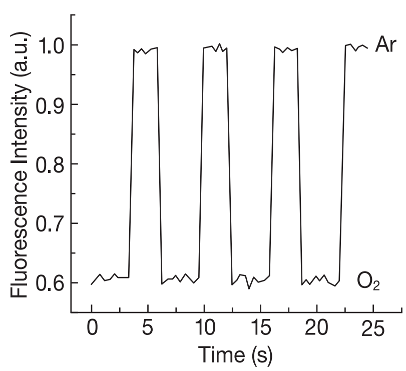

Figure 2. Back-detection of oxygen using an integrated blue OLED/fluorescent sensor. Applied bias to OLED was 9 V; photomultiplier (PMT) voltage was 750 V.

Because this integrated OLED/optical chemical sensor, in which the detector and the light source that excites the fluorescence are integrated with the sensor films, is smaller and less expensive than conventional sensors as well as versatile, it also has potential applications for biomedical and biochemical research, medical testing, and detection of pathogens.

Opportunities

The researchers are interested in collaborating with companies to develop these patented sensors as commercial products.

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