

**A “Smart” Reserve Battery Provides Power as Needed**

*The Pitch*

Battery technology is still one of the most efficient and cost-effective ways to store energy and provide power for a wide range of applications. While many significant changes have occurred over time with respect to form, fit, and function, problems remain when using currently available batteries in certain consumer, industrial, and military applications, particularly those that depend on reliability and convenience. mPhase Technologies (Little Falls, NJ) is developing a “smart” reserve battery, which is a primary battery typically designed for a special purpose such as emergency or military use.

There are basically two types of batteries: primary batteries, which are nonrechargeable energy storage units that are discarded or recycled after discharge (these include alkaline, lithium, silver oxide, zinc-air, and zinc-carbon/zinc-chloride), and secondary batteries, also known as rechargeable batteries (these include nickel-cadmium, nickel-metal hydride, lithium-ion, lead-acid, and a range of other types based on electrochemical systems). Markets for secondary batteries include motor vehicles (both starting/lighting/ignition and hybrid/fuel cell vehicle batteries), backup (or standby) power, motive power, portable devices, and consumer electronics.

According to the Freedonia Group (Report No. 2178), world demand for primary and secondary batteries is forecast to increase approximately 6.5% annually from \$55.5 billion in 2006 to \$104.3 billion in 2016. Growth will be driven by demand for battery-powered products like cellular phones and digital cameras. Market gains will also be assisted by an ongoing shift toward more costly batteries (e.g., rechargeable lithium cells) that deliver improved performance for high-drain electronics.

*The Technology*

In the reserve battery, the electrolyte is usually stored separately from the electrodes, which remain in a dry inactive state. The battery is only activated when it is actually needed by introducing the electrolyte into the active cell area containing the electrodes. This has the dual advantage of avoiding deterioration of

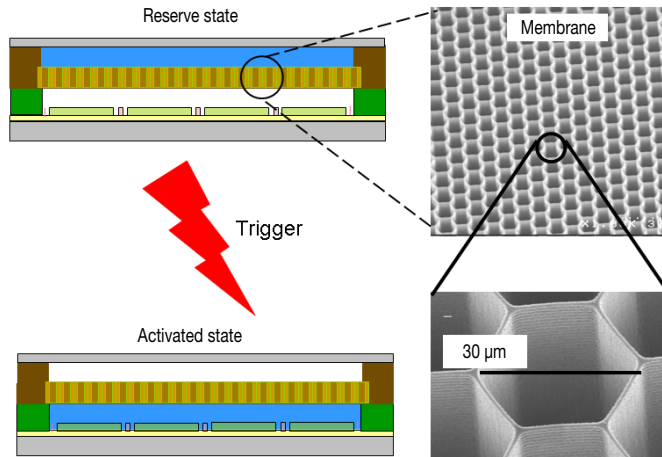


Figure 1. A schematic of the battery action depicting the battery transitioning from the inactive state to the active state as the electrolyte passes through a porous silicon membrane. Shown on the right are a superhydrophobic membrane chip (top) and the electrode chip (bottom). Overall dimensions are 20 cm × 20 cm; the dimension of the active area of the membrane and electrode are 1 cm.

the active materials during storage and eliminating the loss of capacity due to self-discharge before use.

The production of the Smart Battery by mPhase is enabled by nanotechnology, microfluidics, and microelectromechanical system fabrication methods. The result is a proprietary membrane made using standard silicon processing techniques used in the semiconductor industry (e.g., lithography and etching) that keeps the electrolyte physically separated from the electrodes until activation is needed (see Figure 1). Until then, the battery remains in a quiescent state with no self-discharge, power drain, or leakage. Activation can occur by a remote control switch or a triggering mechanism such as a mechanical jolt, electrical pulse, or wireless rf signal, thereby providing Power On Command™-stored energy when and where it is needed. This enables significantly longer shelf life compared to a typical battery (infinite in theory because there is no self-discharge prior to activation). This is valuable in situations where reliable power is critical, such as in emergency or medical equipment, remotely accessible sensors, or for the mil-

lions of radio frequency identification tags sitting in inventories.

In addition, individual cells, or groups of cells, can be independently addressed and therefore switched on at different times or under different operating conditions. A single battery can consist of several subcells that can be triggered individually, independent of each other, or sequentially by triggering the next unused cell as each reaches its limit. For example, a Smart Battery based on chemistry that typically lasts 10 years can have three groups of cells that turn on sequentially as one group exhausts its capacity, thereby providing up to 30 years of uninterrupted service. It also makes practical the idea of integrating different chemistries (electrodes and electrolytes) into a single system. This potentially allows for a single battery

to be built that runs continuously under temperature extremes from very hot to very cold.

The unique architecture of the battery makes it adaptable to multiple configurations, some that could even consist of integrating the battery architecture directly onto the circuit board during the manufacturing process to provide reserved power for electronic devices.

The Smart Battery has already been used in a reserve zinc chloride battery configuration trial. It activated at an extremely high g-force on being shot out of an Army tank and provided continuous power over a four-mile trajectory. Although the focus to date has been on zinc chloride and lithium batteries, the Smart Battery can accommodate any chemistry using a liquid electrolyte, depending on the energy and power requirements. The size, shape, and weight of the battery can be adjusted to meet the requirements of the application.

*Opportunities*

mPhase is in the advanced development stages of design and is open to discussing earlier adopter opportunities for joint application, collaborative development, and licensing.

Source: Steve Simon, Chief Technology Officer, mPhase Technologies., 150 Clove Rd., Little Falls, NJ 07424; 732-973-2451; email [ssimon@mphasetch.com](mailto:ssimon@mphasetch.com); and [www.mphasetch.com](http://www.mphasetch.com).

TECHNOLOGY ADVANCES seeks materials developments on the threshold of commercialization. Send suggestions to Renée G. Ford, Renford Communications, [renford@comcast.net](mailto:renford@comcast.net).

## Sensitive Nanomaterials-Based Detection System Rapidly Measures Heavy Metals in Liquids

### The Pitch

A low-cost, highly sensitive system—using a field-portable instrument—to measure heavy metals in water, saliva, and urine samples has been developed at the Pacific Northwest National Laboratory (PNNL). The device is approximately the size of a lunch box and weighs about 5.5 kg (Figure 1). Sensitivities below 1 ppb in both rat urine and river water with low relative standard deviations have been achieved within a few minutes. The PNNL system has been compared to inductively coupled mass spectrometry, the gold-standard measurement for heavy metals, and has consistently demonstrated comparable performance for detection of toxic heavy metals such as lead and cadmium. The retail price of the new instrument has not yet been determined. However, since its components cost about \$12,000 to \$15,000, it is anticipated to be considerably less expensive than the typical \$100,000 to \$150,000 for existing plasma mass spectrometry systems.

Functionalized nanomaterials that serve to preconcentrate the species to be measured for electrochemical detection are a key element of the system. These nanomaterials are of two basic types: a self-assembled monolayer on mesoporous supports (SAMMS<sup>®</sup>) or functionalized magnetic nanoparticles that provide excellent detection sensitivity at a parts per billion level. SAMMS possess the desired characteristics for metal preconcentration at an electrode surface including (a) high selectivity, (b) high loading capacity, (c) fast sorption kinetics, (d) excellent stability, and (e) the ability to be regenerated. The functionalized magnetic nanoparticles dispersed in solution are designed to have high affinities for target metals while promoting the mass transfer of the metals to the electrode surface and allowing for a refreshable electrode surface.

Although mercury-based electrode materials also have been demonstrated to provide good analytical performance in the electrochemical system, mercury is a toxic material that may be subject to future regulation. In biological samples, use of the nanomaterials avoids using mercury as a preconcentrator. It elimi-



Figure 1. The biomonitoring detection system, developed by the Pacific Northwest National Laboratory, uses two classes of sensors to analyze water, saliva, or urine samples. The system is also being evaluated for use with blood samples. Although small and portable, the system provides detection levels at parts-per-billion.

nates the need for sample pretreatment, the use of internal standards, and the use of sonication at the electrode coupled with large sample dilution.

### The Technology

The rapid, portable detection system developed at PNNL is based on combining electrochemical detection with tailored chemistries designed to selectively extract a species of interest from a liquid sample. Chemistries used for SAMMS include SAMMS tailored with thiol (for “soft” heavy metals, e.g., lead), acetamide phosphonic acid (for rare earth metals, e.g., cerium), and iminodiacetic acid ligands (for common transition metals, e.g., mercury). Although functionalization of iron oxide magnetic nanoparticles with dimercaptosuccinic acid (DMSA) is the only one that has been publicly reported, various other tailored chemistries are being explored on the nanoparticles,

including acetamide phosphonic acid, glutathione, and quaternary amines.

In the SAMMS approach, the materials are mixed with other materials to form a paste or ink that is used to coat the electrode of the sensor to increase its affinity for the analytes of interest. Examples include: (a) combining the thiol-functionalized SAMMS with carbon paste, (b) forming a paste with iminodiacetic-acid-functionalized SAMMS and carbon nanotubes, and (c) mixing acetamide-phosphonic-acid-functionalized SAMMS with conductive graphite ink to form a screen-printed electrode in a disposable sensor. Each of these alternatives has demonstrated good analytical performance, with the SAMMS/carbon nanotube electrode providing the lowest limits of detection for lead.

In the magnetic nanoparticle approach, the functionalized magnetic nanoparticles are infused into the liquid sample. Because the nanoparticles have a high affinity for heavy metal ions, the analytes are efficiently bound to their surface; and because the nanoparticles are magnetic, they can be immobilized on a magnetic-based electrode prior to voltammetric detection. The DMSA nanoparticles are synthesized by forming a functionalized chemical surface on an iron oxide particle core. Use of an electromagnetic electrode is the most efficient means of collecting the magnetic nanoparticles for subsequent detection due to the ability to readily remove the nanoparticles from the electrode after analysis by turning off the current to the coils.

### Opportunities

Pacific Northwest National Laboratory is seeking commercialization partners interested in further developing, licensing, manufacturing, and marketing their electrochemical heavy metals sensor systems. Qualified partners could include both instrument companies and materials suppliers. The SAMMS system is believed to be more appropriate for measuring heavy metals in biological samples (e.g., urine). The magnetic nanoparticles system is believed to be preferred for use in environmental samples such as natural waters. However, the analytical approach can be tailored to the needs of individual partners.

Source: Bruce Harrer, 509-375-6958; e-mail [bruce.harrer@pnl.gov](mailto:bruce.harrer@pnl.gov); and <http://availabletechnologies.pnl.gov/technology.asp?id=238>.



**Child Care Services Now Available at the 2008 MRS Fall Meeting**

For more information on this, and other 2008 MRS Fall Meeting activities, visit [www.mrs.org/fall2008](http://www.mrs.org/fall2008)

**One-Step Process Produces Microcellular Carbon and Graphitic Composite Foams Cost-Effectively**

*The Pitch*

The conventional manufacturing techniques for carbon composites require several processing and post-processing steps at very high temperatures and for long periods of time, which significantly affect the price of these materials. The post-processing oxygen stabilization of the carbon-carbon composite precursors, mesophase pitch or pitch, can be markedly shortened to a few hours using an innovative one-step patented process developed at Wright Materials Research Co. (WMR). The post-processing steps also play a key role in determining the mechanical, thermal, and electrical properties of these carbon-based materials.

With the WMR process, the oxidative stabilization can be completed in as little as three hours—compared with 24 hours to over 48 hours by the conventional approach. In addition, a rapid post-processing catalytic technique for carbon and graphitic foams has been developed. With the WMR method for processing the microcellular carbon and graphitic foams, the thickness of the material does not affect either the post-processing time or the thermal-mechanical properties of the product. The carbon foam and the graphitic foam can be reinforced with chopped fibers, unidirectional fabric, or woven fabric, and the mechanical, thermal, and electrical properties of the carbon and graphitic foams can be tailored by means of the reinforcement. Large blocks of these composites can be manufactured cost-effectively.

Carbon and graphitic foams for space structure applications are a relatively new and growing industry, for which the market is on the order of tens of million of dollars. The market for heat exchangers was about \$2.04 billion in 2002, according to a Frost & Sullivan report. It is expected to grow at a compounded annual rate of 1.5% with the market reaching \$2.23 billion by 2009. Additional markets for the carbon and graphitic composite foams include high-temperature structures and components that require exceptional dimensional stability with no out-gassing. In addition to space applications, the lighter, higher performance material produced using the WMR process could replace composites in automobile brakes and battery electrodes at lower cost.

*The Technology*

Researchers at WMR have developed an environmentally sound technique for the processing of carbon and graphitic foams



Figure 1. Typical carbon foam produced by the one-step process developed at Wright Materials Research Co. (WMR).

such as those shown in Figure 1. A carbon mixture is heated under high pressure in a one-step process to produce a lightweight carbon foam or carbon-carbon composite. Carbon fiber precursors are used to create an open-celled microcellular/carbon graphitic network throughout the foam material. Inert gases are used as the foaming agent and there is no toxicity involved. The raw materials can be mesophase pitch, pitch, or any similar materials and can be reinforced with chopped fiber, unidirectional, or woven fabrics.

In a related WMR invention, the carbon and graphitic foam is processed by a catalytic approach. It has been shown that the time needed for the oxygen stabilization step can be reduced by an order of magnitude compared with conven-

tional techniques. The post-processing time for similar conventional carbon composites requires lengthy heating stages followed by slowly cooling the materials. Reducing the post-processing time to as little as one-tenth of the time to produce carbon composites conventionally is expected to reduce their cost considerably.

The structural properties of the WMR carbon and graphitic foams are also superior to conventional foams. In terms of strength, the WMR composite can withstand between 60–80% strain before breaking compared with ~2% for conventionally produced carbon composites (see Figure 2). The WMR materials also have a coefficient of thermal expansion near zero.

*Opportunities*

Wright Materials Research Co. can produce composite blocks with thicknesses to meet customer requirements. The company is now scaling up to meet requirements for much larger and thicker (ca. 1 m) machinable blocks. The company is seeking to develop sales, marketing, and distribution channels as well as working with investors interested in a joint venture or licensing of their technologies.

Source: Seng C. Tan, President, Wright Materials Research Co., 1187 Richfield Center, Beavercreek, OH 45430; 937-431-8811; fax 937-431-4746; e-mail scstan@sprintmail.com; and www.wrightmat.com.

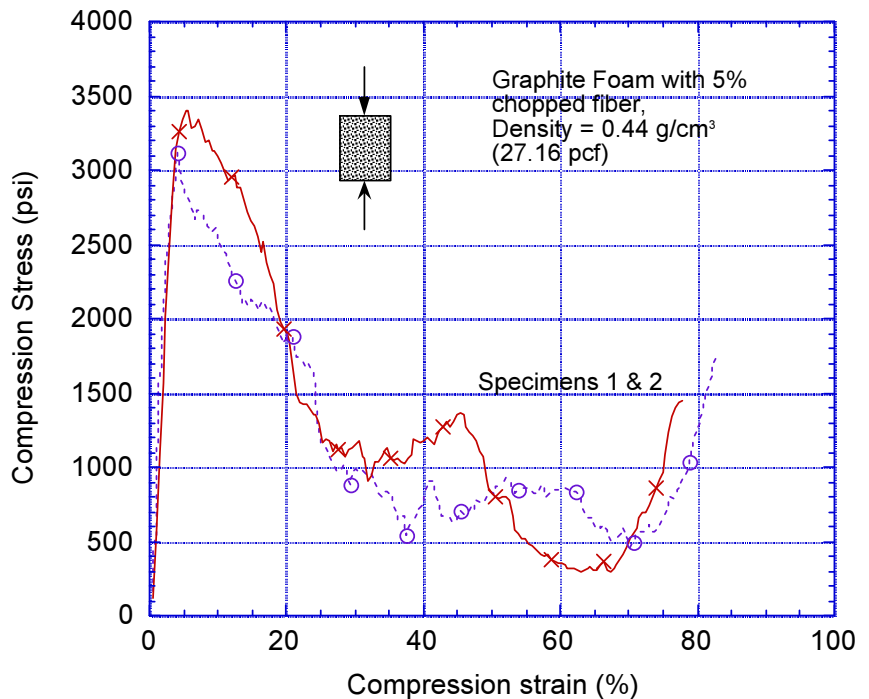


Figure 2. Typical compression stress-strain curve for WMR-produced carbon foam.