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BATTERY TECHNOLOGY EVALUATION AT SANDIA NATIONAL LABORATORIES

OVERVIEW

Sandia National Laboratories Battery Technology Group develops and evaluates battery concepts for a variety of applications, including electric vehicles. We have designed thermally-activated batteries, active and reserve ambient-temperature primary batteries, rechargeable secondary batteries, and other power sources for specific ordnance, aerospace, and commercial applications.

Sandia National Laboratories became involved with electrochemical power sources in the early 1950s with the development of nickel/cadmium batteries to replace the heavy lead-acid batteries used in the first nuclear weapons. This was followed with the development of zinc/silver oxide batteries. The thermally-activated battery was introduced in 1955 to solve the wet-stand time limitation of the aqueous systems. Subsequently, we have used thermal batteries as the main power source for nuclear weapon systems.

Sandia has been developing and evaluating ambient-temperature lithium systems since 1972. The current focus is on lithium/sulfur dioxide high-rate and low-rate cells and lithium/thionyl chloride primary and reserve batteries. The packaging of cells in specific battery packs and system safety issues are important aspects of the lithium battery development program.

Although the genesis of our rechargeable battery activities can be traced to the early nickel/cadmium systems, this effort greatly expanded in the late 1970s when the United States Department of Energy (USDOE) requested Sandia's assistance for developing and evaluating batteries for energy storage in solar applications. In 1981, DOE chartered the Battery Technology Group (then called the Power Sources Department) as a lead center for the exploratory development of secondary battery systems. Targeted applications were solar energy, electric vehicles, and stationary energy storage.

Most recently, some of our programs have progressed to developing and testing rechargeable batteries directly with industry. Sandia has Cooperative Research and Development Agreements (CRADAs) with the United States Advanced Battery Consortium (USABC) for electric vehicle battery research, and with several consumer battery companies to develop lithium battery materials. We have also worked with Wilson-Greatbatch, Ltd.; Virginia Power; and Phillips Laboratory to evaluate and provide consulting services for advanced batteries.

Battery development and engineering activities are augmented by material research, the investigation of new electrochemical couples, and extensive testing and evaluation. The synergism between these activities has enabled this group to efficiently respond to the needs of its customers.

FACILITIES

Our comprehensive testing and evaluation facilities include two dry rooms, numerous wet laboratories, several battery test laboratories, and computer data-based management equipment.

A 3000-square-foot dry room has equipment to start with raw materials and fabricate and assemble finished thermal batteries. Pretest and posttest analysis of thermal batteries are performed here as well as research and failure analysis using a scanning electron microscope. We also use the dry room for thermal analysis of battery components using differential scanning calorimetry, differential thermal analysis, and thermogravimetric analysis. In a second, smaller dry room, where a full-ventilation hood is available, we assemble lithium batteries. In other laboratories, research is conducted in several areas, including lithium-cell intercalation cathodes, lithium-cell electrolytes, and rechargeable battery cathodes. Distributed throughout our labs are capabilities such as electrolyte distillation and reflux, cathode rolling,

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cell-roll assembly, can welding, and filling, which support production of lithium ambient-temperature cells, and posttest capability.

The rechargeable battery test laboratory is a fully-automated facility used to evaluate various storage and electric vehicle battery technologies. We use the results of these tests to characterize the performance of prototypes and to assist in identifying strengths and weaknesses of each technology. Another tester area is used for performing nondestructive and functional, computer-controlled testing of cells and batteries. The thermal battery functional tester, which also tests active lithium batteries and double-layer capacitors, does multichannel testing in any combination of resistance, constant current, and constant power with a load-change time step of 10 milliseconds. We use two other computer-controlled test areas. One performs long-life, temperature-controlled, 128-channel discharge studies, typically on lithium cells. The second computer test area is remotely located, thereby facilitating abuse tests, typically on lithium cells. Key to the testing function is the ability to design testers for any battery being developed. A tester central serves as the data analyzer, providing summaries for reports and graphic plots of data.

In addition to the facilities available in the Battery Technology Group, Sandia has numerous facilities including testing, analysis, materials processing, and complex modeling. Computerized environmental testing (such as vibration, shock, or spin), abnormal testing (such as fire or crash), and safety testing are available.

RECHARGEABLE BATTERY TECHNOLOGIES

Safety and environmental concerns are primary considerations in all of our research and development projects. They are a priority in program planning; the selection of materials and processes; battery handling, storage, and operation; and the disposal of residue and spent batteries. Reliability is also an important aspect of our battery design and development activities. This emphasis on safety and reliability is reflected in the rechargeable technologies being developed for commercial applications. We perform a wide range of laboratory activities to support the advancement of several rechargeable technologies. The majority of these activities involve various aspects of component development including the selection and characterization of materials.

Sodium/Sulfur

Sandia managed the DOE programs for developing the sodium/sulfur battery technology for use in both motive traction and large-scale, stationary energy-storage applications. This technology is one of the most promising advanced rechargeable concepts because of its combination of desirable characteristics including relatively high power and energy density, low maintenance, long service life, excellent electrical efficiency, flexible operation, and low intrinsic cost. Specifically, this is the leading technology for satisfying the demanding energy, power, and cost requirements for future passenger/commuter electric vehicles.

Sodium/sulfur batteries are constructed with various series/parallel combinations of single cells contained within a thermal enclosure. The cell operating temperature is normally +330°C to +350°C. Each cell consists of a molten sodium negative electrode, a solid beta"-alumina electrolyte, a molten sulfur/sodium polysulfide positive electrode, several hermetic seals, and a cell container. The beta"-alumina electrolyte is an excellent separator, conducting only sodium ions. The high operating temperature requires effective internal thermal control, but negates the need for a system to compensate for ambient-temperature changes.

The sodium/sulfur technology has been under active development for over 20 years in the United States, Europe, and Japan. Substantial progress has been made in performance, durability, manufacturability, and safety. Important accomplishments include the design and qualification of several baseline cell technologies and the fabrication and performance evaluation of a number of modules and full-size batteries. Sandia programs have addressed several aspects for improving the safety and commercialization potential of the sodium/sulfur technology (thermal management, accident behavior, and durability) along with the evaluation of a number of contract deliverable cells and modules.

Although the sodium/sulfur technology is approaching commercialization, several important improvements are still required. The critical remaining issues are service life and selling price. Battery life must be extended by a factor of 5 and cost reduced by a factor of 5 to 10. Current optimism in both areas is based on several new components that have been identified and the use of automated manufacturing.

Lithium Ion & Lithium Polymer

The group's Battery Technology Initiative is a Cooperative Research and Development Agreement (CRADA) between Sandia and four industrial partners: AT&T Bell Labs, Eveready Battery Co., Rayovac Corp. And Wilson Greatbatch, Ltd. The goal of the CRADA is to develop a carbon, based on a prior Sandia technology, that is suitable for use as an anode in lithium ion rechargeable cells. Certain carbon foams, developed for military applications, have been shown to intercalate lithium ions very efficiently. Processing variables are being studied in a controlled fashion, and the resulting carbonaceous materials are then physically characterized. Electrochemical screening is conducted on the samples (e.g., intercalation efficiency and irreversible passivation). Materials that pass the test are sent to our industrial partners for evaluation in their electrode configurations. The research and development steps are performed in parallel, shortening the time to commercialization. Results to date have been encouraging, with some carbon samples achieving a reversible capacity of over 450 mAh/g. However, the irreversible passivation is high. Work is now focusing on reducing the passivation, while maintaining the high reversible capacity.

Zinc/Air

The zinc/air battery technology is somewhat unique in that the battery components are relatively benign and inexpensive, the battery operates at an ambient temperature, and the energy and power densities are relatively high. These performance advantages are attainable because of the low weight of the zinc and oxygen reactants and a relatively high cell voltage. The electric vehicle is the targeted market for this technology.

Current zinc/air batteries are widely used in hearing aids and are designed to be primary batteries. Recent technical developments in zinc electrode structures and air electrodes have initiated new interest in rechargeable zinc/air batteries. Although only relatively small batteries have been constructed with the recent technical advances, cycle life and performance have exceeded expectations.

Nickel/Cadmium

Sandia has used nickel/cadmium batteries in weapons applications since the early 1960s. The key requirements are portability, operations over a wide temperature range (-40°C to +70°C), and a life of 500 charge/discharge cycles (or 5 years).

Recently, we reconsidered available battery technologies before developing an new power supply to replace a nickel/cadmium batter that had been used for over 25 years. Vented nickel/cadmium batteries were identified as the only type that could meet all requirements. Sandia, in conjunction with industrial contractors, designed, tested, and placed in production in 1988 an improved nickel/cadmium power supply. Under Sandia guidance, the development project was accomplished on time, and the resulting product cost less than half that of the older version. Sandia contributed tot he development process by conducting extensive prototype testing. This testing resulted in significant improvements in the charging regime selected and facilitated acceptance of the first lot of product. Sandia continues to support power sources in the field, and to survey the technology or improvements and innovations.

Advanced Lead-Acid

We initiated an advanced lead-acid technology project in 1990. This initiative is directed at developing a lead-acid storage battery suitable for electric utility applications in the near-term. The initiative seeks to overcome performance shortcomings of existing sealed lead-acid batteries by undertaking an industry cooperative development effort to improve battery life and reduce cost. In a parallel effort, possible applications and benefits of battery storage on an electric utility grid will be identified. Electric utilities and lead-acid battery manufacturers will participate extensively to foster a better understanding of user requirements and facilitate the commercialization of the technology for the electric utility sector. Batteries of this type may be useful for quick-charge stations for electric vehicles.

OTHER TECHNOLOGIES

Double-Layer Capacitors

Double-layer capacitors can pack high energy (20 j/cm^3) and power (200 W/cm^3) densities in small volumes. Double-layer capacitors have these high energy and power densities because they use high-surface-area electrodes like carbon and ruthenium oxide and have small "plate separations" (on the order of 10 angstroms). This thin dielectric layer is created at the interface of the electrode and the liquid electrolyte when voltage is applied. Since this is a readily reversible process, double-layer capacitors also have long cycle life.

We are currently evaluating three commercially available double-layer capacitors with a goal of qualifying them for use in military applications. To qualify, they must provide over 30 V at several amperes for about 2 seconds under stringent temperature, vibration, shock, and other environmental conditions.

We are working with other organizations to build higher performance, lower cost devices. This could include units for supplying high-power pulses for electric vehicles.

We are currently working with customers to design, develop, and qualify hybrid double-layer capacitor systems to meet specific needs. For example, for burst power applications, we could combine a high-energy battery with a high-power double-layer capacitor.

CONCLUSION

The Battery Technology Group is uniquely positioned to solve a wide array of problems relating to batteries and energy-storage devices. Past successes have included new designs based on unique requirements, improved processes and materials for existing products, and analysis of system irregularities. Staff within the department maintain a continuous working relationship with Sandia system engineers, representatives of the military and aerospace community, other national laboratories, and the private sector. This relationship has not only benefited the power sources community, but has continuously expanded the experience base of our group.