

Rechargeable Hearing Aid Batteries Draw from NASA Research

NASA Technology

We often imagine that inventions are born whole: Thomas Edison creates the incandescent light bulb and lights up Christie Street in Menlo Park on New Year's Eve, stunning the world and single-handedly ending the tyranny of night.

This is rarely the reality, however. In this case, arc-lamp street lights already existed in 1879, as did incandescent lights, albeit impractical ones. Edison and his team just hit on the right filament: carbonized bamboo. The invention built on more than 50 years of experimentation by others.

Likewise, few modern technologies are the product of a longer, harder slog than the silver-zinc battery, which is finally making an early foray into the consumer market in the form of a line of rechargeable hearing aid batteries, more than two centuries after its first invention.

Considerable effort and resources have been dedicated to making a practical version of the silver-zinc battery, mainly because it can offer more energy per ounce than any other battery couple. Its development, however, has been marked by slow, incremental progress, dead ends, and the occasional breakthrough—a major one of which occurred at NASA's Glenn Research Center, then known as Lewis Research Center.

The main problem with the silver-zinc couple was that its electrodes—the cell's negative and positive electrical conductors—were soluble and deteriorated quickly, especially the negative zinc electrode. In the late 1920s, French Professor Henri André finally made the first practical silver-zinc battery by using a membrane to separate the two electrodes, preventing active materials from migrating between them and causing deterioration. It was a development that presaged the work that would take place at Lewis some 40 years later.

During World War II, the U.S. military, especially the Navy and Air Force, advanced effective silver-zinc primary—or non-rechargeable—batteries, which it still



Several early NASA spacecraft, including the Apollo command module, used silver-zinc batteries. The Agency worked hard to make such batteries rechargeable, with some major advances made at Glenn Research Center, then called Lewis Research Center. Rechargeable silver-zinc batteries didn't make it into space, but NASA's research and development served as a starting point for anyone trying to develop them.

uses to power submarines, torpedoes, missile propulsion systems, and other devices.

In its early days, NASA also used such batteries, for example in launch systems. The Agency was especially interested in a rechargeable—or secondary—version for the long-term, lightweight power it could provide for space systems, but electrode deterioration remained a problem, significantly impeding performance after several deep discharge and recharge cycles. Zinc oxide released by the zinc electrode would dissolve, degrading the electrode, changing its shape, and reducing its surface area. It would also plate back onto the electrode and form structures that could pierce through the cell separator, ruining the battery.

The problem was compounded if the battery was heat-sterilized, a requirement for all Mars rovers to ensure they don't populate the Red Planet with Earth microbes.

During the 1960s, NASA carried out many experiments, primarily at the Jet Propulsion Laboratory, Goddard Space Flight Center, and Lewis, to resolve these challenges. Researchers tried other materials in the cell separator, additives to the electrodes and electrolyte, different cell geometries and methods of construction. These often led to minor improvements, but a comprehensive 1968 NASA report, "Batteries for Space Power Systems," noted the persistence of many of the same limitations.

The report did make mention, however, of an experimental cell using a novel, inorganic ceramic separator developed by the Astropower Laboratory of Douglas Aircraft Company, a frequent collaborator with Lewis on silver-zinc batteries, which showed promise but lacked sufficient data.

Astropower had been working to develop an inorganic ion exchange membrane for a fuel cell for Lewis, and researchers at the field center suggested that a similar separator might work in a rechargeable battery. In 1965 Astropower and Lewis began working on a separator that would begin to mitigate many of the challenges to rechargeable silver-zinc batteries.

By 1972 Lewis had tested and proven silver-zinc cells based on a specific inorganic separator and a specially prepared zinc electrode, which were able to function as a rechargeable battery after heat sterilization. The cells were still only reliable up to 400 to 500 shallow discharge cycles, as opposed to the 10,000-cycle life of the nickel-cadmium batteries commonly used in space applications of the time, but they could result in batteries one-third the size of nickel-cadmium units, a substantial saving in weight.

The cells also exhibited none of the zinc electrode shape-changing and degradation seen in typical silver-zinc batteries. A 1972 paper out of Lewis titled “A Versatile Silver Oxide-Zinc Battery for Synchronous Orbit and Planetary Missions” called this durability “striking” and “most unusual,” considering that the electrode hadn’t been treated to inhibit shape-change.

Astropower went on to create an even more effective inorganic-organic separator that further extended silver-zinc battery life and eliminated problems of low conductivity exhibited by other inorganic separators. Lewis started a separator development program in 1973, obtaining a license for Astropower’s inorganic-organic separator and experimenting with it heavily to discover why it worked as well as it did. Finally armed with this understanding, the team went on to create three alternate recipes with superior performance, as well as a method for efficiently manufacturing such separators, all of which it announced in 1979.

Whereas Astropower’s cells based on its inorganic-organic separators lasted about 150 cycles at 50 percent discharge, Lewis’ survived more than 200. The Astropower separators were also brittle and difficult to work with, but Lewis managed to make its versions flexible, as well as more uniform, which produced a more uniform current density and likely was responsible for extending battery life. Based on the materials used and the manufacturing process the engineers came up with, their separators also only cost about 35 cents per square foot, compared to \$1.25 for their Astropower predecessor.

Technology Transfer

Despite all of this research, NASA has not made heavy use of the secondary silver-zinc battery, likely because of

remaining limitations to the number of times they can be recharged and major advances to nickel-cadmium batteries in the mid-1970s. Nickel-cadmium had already been the Agency’s preferred choice for many applications. Lithium-ion batteries, which came along in the 1990s, now offer nearly as high an energy-to-mass ratio as silver-zinc cells, and they can be recharged many more times.

Meanwhile, the costs associated with silver electrodes, along with the relatively short cycle life, have largely kept the technology out of commercial markets—until recently.

Zinc Matrix Power, now known as ZPower, was founded in Camarillo, California, in 1996 for the purpose of commercializing the rechargeable silver-zinc battery. At the time, the technology could still only endure 10 to 30 deep discharge cycles before losing significant capability, so the company picked up where NASA and others had left off.

The results of most of the Agency’s research and development was publicly available, and the company’s engineers used them as part of their starting point. Ross Dueber, the company’s president and CEO, also had personal knowledge of some of that work. Early in his Air Force career, he was assigned to the Battery Branch at Wright Aeronautical Laboratories, which frequently collaborated with NASA on rechargeable battery systems, including some based on silver-zinc technology.

“What we’ve done at ZPower is take that chemistry that NASA did a lot of development on, along with the military, and moved it into the commercial sector,” Dueber says.

But it took another long struggle to get it there.

The company focused on improving all four active components of the battery—the two electrodes, the electrolyte, and the separator. In its final product, among other improvements, the company uses a proprietary coating on its silver electrode to improve conductivity, a paste material to reduce zinc ion diffusion from the zinc electrode, and a specialized electrolyte that extends the life of both electrodes. The engineers also patented designs for stacking the separators.

Another company’s work on silver-zinc batteries under Small Business Innovation Research contracts with Glenn and NASA’s Johnson Space Center in the early 2000s brought ZPower’s attention to a third company, Advanced Membrane Systems, which had provided battery separators

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— Ross Dueber, ZPower

for testing. ZPower bought the patent and all rights to the technology.

That’s in addition to the 100 or so of its own patents the company has taken out over the years.

“There was a tremendous amount of development that went into it,” Dueber says.

The batteries can now survive 500 to 1,000 discharge cycles without losing significant capacity.

After more than a decade of research and development, the company announced in 2007 that it would launch a line of laptop batteries the following year. However, Dueber says, the economic crash of 2008, coupled with a sharp rise in the price of silver, made affordability a serious obstacle. The company went back to the drawing board.

The smaller the battery, the less the price of silver is an issue, Dueber explains. So ZPower hit on another application: hearing aids. In late 2013—17 years after its founding—the company released its first major product line.

With a viable, truly rechargeable silver-zinc battery finally in hand, though, the company expects that hearing aids represent just one of a number of markets ripe for conquest.

Benefits

Traditional hearing aids run on disposable batteries, usually of the zinc-air variety. These have a high energy-to-mass ratio but can’t be recharged. Rechargeable battery types such as nickel-metal hydride haven’t been able to carry enough energy to last a full day in the small sizes required for hearing aids.





ZPower rechargeable silver-zinc hearing aid batteries fit into a specialized door that can be retrofitted onto most existing hearing aids. The door carries a charge from the charger to the battery, eliminating the chore of removing and inserting the batteries.

As a result, hearing aid users have to replace their batteries every week or so, causing a two-fold inconvenience: changing out the tiny batteries requires considerable dexterity and visual acuity, which can be an issue for the seniors who are their primary users, and the batteries die unpredictably, encouraging users to shut them off whenever possible and inevitably leaving them without hearing at inconvenient moments.

“Can you think of any other high-end electronic device where you’ve got to do that?” Dueber asks. “It’s just unfathomable in this day and age.”

There are also environmental implications to the disposable-battery model. Around 1.5 billion zinc-air hearing aid batteries end up in landfills every year, according to the company.

Lithium-ion batteries are the only ones that compete with the silver-zinc couple in terms of high energy storage. These, however, are prone to a phenomenon known as thermal runaway, which, in rare but disastrous cases, causes them to combust. “You want to make sure what’s in your ear is not going to catch fire or explode,” Dueber points out. This is not a possibility with silver-zinc batteries, which use a water-based chemistry.

Lithium-ion batteries also require more packaging and other components that take up a larger percentage of their space the smaller they get, so it’s a less efficient technology for tiny batteries.

To address the difficulty of removing and inserting the batteries, ZPower batteries recharge inside the hearing aid. They fit into a specialized door that can replace the battery door on most existing hearing aids, and the door carries the charge from the charger to the battery. “Now you just take the hearing aids out and put them in the charger,” Dueber says, adding that the battery can reach full charge overnight.

A charge lasts from one to two days, and the company recommends replacing the batteries once a year. At \$25 to \$30 for each battery, that’s a considerable savings compared to what a year’s worth of disposable batteries would cost.

ZPower also developed a recycling process for its batteries, each of which is 95 percent recyclable metal. Users trade in the batteries at their audiologist’s office, and the company collects them and sends them to a refiner for recycling. “Because of the fact that we use a precious metal, it’s really cost-effective for us to bring it back and recycle it,” Dueber says.

The company launched its product line through the Beltone network of hearing aid providers and plans to expand beyond. It’s also in talks with a couple of manufacturers interested in building the batteries into their hearing aids, and Dueber is working toward a contract with the Department of Veterans Affairs, which processes 8,000 to 10,000 orders per week for hearing aid batteries at its logistics center. “The benefit we would deliver to the program is, all of that goes away,” he says.

The rechargeable battery system won a 2016 Consumer Electronics Show Innovation Award and a 2016 Edison Award.

Manufacturing all of its products in Southern California, ZPower expanded from about 35 to 100 employees after its product launch. Now the Thomas Edison of rechargeable silver-zinc batteries, the company sees further expansion on the horizon.

“It’s an area that hasn’t received a whole lot of attention over the years, but with a new focus on wearables, people are looking more and more at small, high-energy batteries,” he says. For example, the company is working with a sunglasses manufacturer on a pair of non-losable sunglasses. A cell phone app would locate a beacon in the glasses powered by a ZPower battery.

“We really view this as an enabler for new product designs going forward,” he says. “Hearing aids are just our first market of many.” ❖

Disposable hearing aid batteries die unpredictably, which tends to encourage users to turn them off at times to conserve power and inevitably leaves them without hearing at inconvenient times. On a full charge, the rechargeable silver-zinc batteries that ZPower built off of previous research and development by NASA and the military reliably last all day and then some.

