A "Magic Box" that has Evolved So Far

The Lithium Ion Polymer Rechargeable Battery

According to Japan's Ministry of Posts and Telecommunications, as of July 1999, there were over 50 million PHS (Personal Handyphone System) and cellular telephone subscribers in Japan.
Thus two out of every five Japanese citizens are taking advantage of mobile equipment.
One important product that has supported miniaturization and weight reduction in mobile equipment is the lithium ion rechargeable battery, which was first made practical by Sony.
In this article, we introduced a further evolutionary step in batteries, the lithium ion polymer rechargeable battery, in which the electrolyte has a gel form.

Leisurely Evolution over 2000 Years

Do you know what the world's first battery was? It was called the Baghdad battery and consisted of a clay jar into which a copper vessel and an iron rod were inserted. It is thought that it was used by being filled with wine. In experiments, the copper acts as the positive electrode, the iron acts as the negative electrode, and the wine becomes the electrolyte, thus forming a fully functional battery. It is thought to have been used to create electroplated ornaments, and to date from around the beginning of the western calendar. Thus this battery existed about 2000 years ago.

"A battery is really a rather simple device, consisting of positive and negative electrodes and an electrolyte. If you want to call it a "classic technology" then, I suppose I'd have to agree that it really is classic."

This was Kiyokazu Oiyama's comment. Oiyama is a manager in the Battery R&D Department at Energy Company's Nishi Battery Laboratories. First, let's discuss the history of the battery. The next device that appeared in battery history after the Baghdad battery was the Volta Battery, invented in 1800. It used copper for the positive electrode, zinc for the negative electrode, and sulfuric acid for the electrolyte. It was, of course, a crude device that could not operate for extended periods, but it was here that the principles of battery operation were discovered. However, given that there was an 1800 year blank, we must say that the battery is not a simple concept.

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Tracing history a bit further, the lead-acid battery, which is a storage battery (i.e. a rechargeable battery) whose energy can be replenished many times, was invented in 1859, and the manganese dioxide battery was finally invented in 1866. The nickel-cadmium rechargeable battery, commonly known as the Ni-Cd battery, first appeared in 1899. The manganese and Ni-Cd batteries are still used, 100 years later, with the same basic principles of operation.

We can see that the impact and value of these batteries were extremely large, even considering the social conditions of the times, and the next revolutionary developments in batteries, the primary lithium metal battery and the nickel metal hydride rechargeable battery, were developed and put into practical use quite recently. However, there are aspects of recent battery evolution that are cause for interest. One of these is the lithium ion rechargeable battery, first created as a viable commercial product by Sony in 1991. This battery was well received due to its light weight and long life, and its use has been growing rapidly as the power supply for mobile equipment such as cellular telephones and notebook PCs. The lithium ion rechargeable battery ushered in the most significant epoch in battery history since the Baghdad battery.

This brings us to the topic of this article, the lithium ion polymer rechargeable battery.

Thin because of Gel, High Performance Despite Gel

"It is certainly true that batteries did not evolve continuously. Perhaps products with this level of functionality were simply not required prior to Japan's period of rapid economic growth. However, we are in an age where mobility is everything, and large heavy batteries are no longer acceptable. The thickness of most of the lithium ion rechargeable batteries currently used in cellular telephones is 5 or 6 mm. However, the lithium ion polymer rechargeable battery we have just released is only 3.8 mm thick. The concept behind this development effort was 'thin and light', and we put everything we had towards that goal."

Of the samples we were shown, some were a mere 0.5 mm thick, like the thickness of thin cardboard. These could be stacked and placed in a 2 mm gap behind the LCD in a notebook PC.

"The point was that we switched from an electrolyte to a polymer electrolyte in a gel form. Leakage was eliminated and safety achieved by solidifying the liquid as a gel. Since there is no possibility of leakage, it was possible to create a battery in the form of a thin pack."

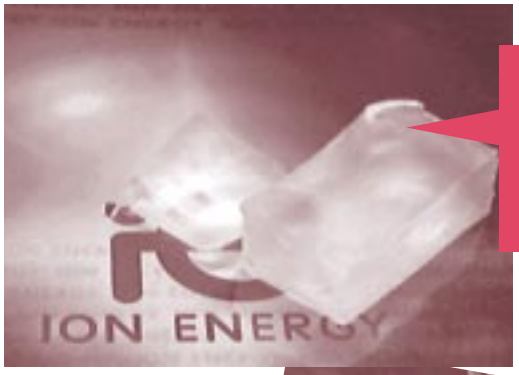
Since the laminated film pack is lighter than the metal outer casing used in earlier batteries, it is possible to increase the weight energy density (the amount of energy that can be taken from a unit volume of battery) by about 10%.

"Users have three requirements for these batteries: the first is the capacity, the second is the cycle characteristics, and the third is the low temperature characteristics. Functionally, we increased the priority of the cycle characteristics when we designed these batteries." Concretely, we aimed for a residual capacity ratio of 80% after 1000 cycles. This means that the per cycle degradation is so low that a typical user would not notice a difference if they recharged the batteries once a day for 3 years.

These batteries also have superlative temperature characteristics. For example, a cellular telephone using these batteries would operate correctly in an environment with a temperature of –20°C. Really? Minus 20 degrees Centigrade? "Cellular telephones are extremely popular in Sweden, Finland, and other northern European countries. Users in those countries are extremely concerned about being able to make emergency calls in cold weather."

I see. The point is that the use of polymers gives these batteries their superlative cycle and temperature characteristics, right?

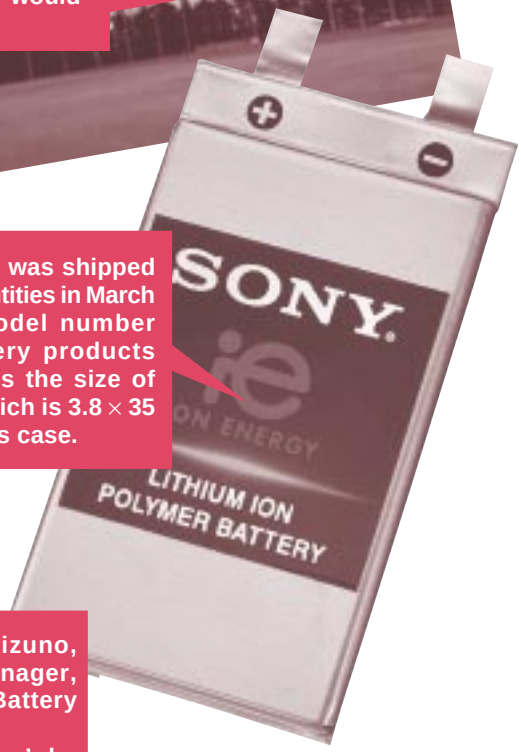
"However, it turns out that polymer electrolytes have a lower ion conductance, that is their capacity to move ions between the positive and negative electrodes, than liquid electrolytes. This is because the liquid is solidified into a gel. If we created these batteries in a normal manner, their performance would be nowhere near that of liquid-electrolyte batteries. Our struggle was to get the performance of these new batteries as close to that of the liquid-electrolyte ones as possible."



Newly-developed gel polymer electrolyte.
Ion permeability was increased by applying this material in a layer only a few microns thick.

Two prototype lithium ion polymer rechargeable batteries that weigh only 30 grams are installed in the back of the wings of a model airplane.

This was a test to see if this "dream" would fly.



The UP383562 was shipped in sample quantities in March 1999. The model number used in battery products often indicates the size of the device, which is 3.8 × 35 × 62 mm in this case.

With Yumi Mizuno, Assistant Manager, Lithium Ion Battery Sales Dept.
"Our customers' demands for lithium ion rechargeable batteries are increasing every year."

■ **Lithium Ion Polymer Rechargeable Battery (UP383562) Main Specifications**

Size (D ×W× H)	3.8 × 35 × 62 mm
Nominal capacity	540 mAh
Nominal voltage	3.7 V
Charging voltage	4.2 V
Charging time	Approx. 2.5 hours
Positive electrode	Lithium cobalt oxide
Negative electrode	Graphite
Volume energy density	270 Wh/l
Weight energy density	130 Wh/kg
Number of recharge cycles	Over 500 cycles
Operating temperature range	–10 to +60 °C
Weight	15.2 g

Disposable Diapers and a Jelly Confection

The development of the lithium ion polymer rechargeable battery started in July 1996 as part of a project that aimed at improving product safety.

"At first there were 20 or 30 researchers working on polymer electrolytes. Although all of us spent a lot of time working with gels, the gels were quite uncooperative about functioning in batteries. We were unable to come up with any concrete content, let alone numbers for our progress reports, and handed in tables and graphs that were empty. We spent a lot of time apologizing and promising results later." (Laughs.) "This was my first report as a project leader."

Anyway, no one had ever heard of a gel battery before. We even tried using bread-making equipment and sausage stuffers. It is said that, from an electrochemical standpoint, it has been understood for over ten years what materials to use for electrodes and what materials to use for the electrolyte to get the best performance. However, in this development project, we had to run experiment after experiment, day and night, to allow us to adopt a gel electrolyte to achieve thinner, lighter, and safer batteries while still maintaining high quality standards despite using a gel electrolyte.

"What we were aiming for is something like disposable diaper material. Instead of absorbing and holding moisture, the material has to absorb and hold the electrolyte. In particular, if the material is squeezed, it must not allow any electrolyte to leak out. We racked our brains for ideas for appropriate materials. We tried everything that was available in the lab; rubber, plastic, polymers. These experiments determined what sort of polymer material could best hold the electrolyte."

Once we determined that an electrolyte in a gel form would work, we were faced with the problem of packaging.

"The packaging, is, if you insist, the key to the whole system. Although we had a rough idea of using a laminated film, this was an area in which we had no experience. One day I was eating a jelly confection. Looking closely, I realized that the container it came in was quite strong. I learned quite a bit from that candy. Anyway, I went to the nearest supermarket and purchased every vacuum-packed food product in the so-called "retort pouch" package I could find, and analyzed the packaging technology. Although these retort pouch packages initial all seemed similar to each other, they actually are quite different, for example frozen food packages and the packages used for foods that can be boiled in the package. Since it would have been wasteful not to, we ate the contents. Of course, that left the laboratory reeking of curry." (Laughs.) (Many readers may not be aware that the Japanese version of curry is the most commonly served meal in Japanese homes, and widely available in a wide range of instant, ready-to-eat, and partially prepared forms.)

In addition to cellular telephones, this new battery can also be used in wide range of products including PDAs, digital cameras, IC cards, games, and clocks. Their thinness alone opens a whole range of unforeseen applications.

"Lithium ion rechargeable batteries do not use environmentally harmful heavy metals such as cadmium and lead, and thus can be said to be environmentally friendly. However, the cobalt used in the positive electrode material is a limited resource, and we are still not satisfied with the performance. As a long term goal, our dream is a battery that can be inserted as a page in Filofax or other notebook and then connected."