You've got the power: the evolution of batteries and the future of fuel cells

Power-hungry, wireless, mobile computing devices are everywhere you look, in all kinds of forms and serving a variety of functions. Notebooks, ultra-slim notebooks, PDAs, mobile phones, tablet PCs, wireless Internet appliances and wearable PCs are among the most popular. With mobility and wireless accessibility on the rise, the demand for "always-on" communications is finally on the horizon.

However, that leaves all with one tiny little problem – how can we be "always-on" if our battery fails or needs recharging just as we are in the middle of downloading the latest music video or important business presentation?

When it comes to powering these devices, most of us can easily come up with a wish list of features characterising the ideal battery. Namely, the ideal battery would be light, small, powerful, offer long battery operating times, enjoy a long life and fit easily in any number of mobile devices. This means it would have to be flexible, fitting in snug corners or tight spaces to leave the maximum amount of room for processing power and storage. "The smaller, lighter and more powerful – the better," we say. Better still, wouldn't it be nice if batteries didn't need recharging?

In this article, we take a look at emerging and future battery technologies that promise to fulfil all these requirements, fuelling dreams of a world in which we have the power to be "always on" because our devices have always got the power. As we shall see, Toshiba is leading the way with its developments in Advanced Lithium-ion batteries (AdLB) and fuel cells, including fuel cells for both large-scale and miniature power generation. So, tomorrow, you may be wearing a wireless PC and living in a house that are both powered by fuel cells.

The emergence of the lithium-ion battery

To understand why emerging battery technologies are so innovative, we first need to look at how far we have come in the past 10 years of mobile computing.

Let's begin by looking at the basic elements of a battery. Batteries produce power through the electrochemical reactions of one or more cells. A cell consists of an anode (positive electrode), a cathode (negative electrode), and an electrolyte. An electrolyte is any substance that conducts an electric current between the anode and the cathode of a battery. A separator ensures electrical isolation between the electrodes while still allowing efficient ionic diffusion between them.

Batteries can be composed of various electrochemicals, and, indeed, most of the early enhancements in battery technology have been achieved through the evolution from nickel cadmium to nickel metal hydride and lithium-ion batteries. Early nickel cadmium (NiCad) batteries suffered from memory effects, and were not environmentally friendly. Even the enhancements of the partly recyclable nickel metal hydride (NiMH) battery were just a small step forward. Batteries remained relatively heavy, particularly when judged by the energy to size/weight ratio or the amount of power generated relative to the size and weight of the battery.

The real breakthrough came with lithium-ion batteries. With high electrochemical potential, these batteries offered high-energy density, meaning that a relatively light and powerful battery became possible. Compared to a NiMH battery of the same weight, the lithium-ion battery delivers up to 82% more battery life. Environmentally friendly, these recyclable batteries are reliable, light, and not subject to memory effects. Operating times of up to three-and a-half hours for notebooks are possible.

Today, the lithium-ion battery is an industry standard battery for mobile computing devices. Currently, lithium-ion batteries are found in approx. 90 percent of notebooks and 60 percent of cell phones.

Emerging battery technologies offer flexible design solutions

Despite all of the advantages of the lithium-ion battery, it suffers from one disadvantage when it comes to miniaturisation. The lithium-ion battery uses a liquid electrolyte (as do the nickel cadmium and nickel metal hydride batteries). This means that it requires at least 3-4 mm hard casing for protection. This additional packaging not only increases the weight, but it also means that flexible and ultra-thin batteries are not technologically possible.

However, two new battery technologies, lithium-ion polymer and advanced lithium-ion, are meeting the requirements of miniaturisation. Both of these battery technologies embed the electrolytes into a gel-like substance, and need only be covered in thin, aluminium laminate foil for protection. The absence of excess electrolyte and the presence of a thin, flexible covering mean that new light batteries can be designed to fit in a variety of forms and spaces.

Both offer the following benefits for mobile computing:

- Very low profile: batteries that resemble the profile of a credit card are feasible.
- Flexible form factor: manufacturers are not bound by standard cell formats.
- Light weight: gelled rather than liquid electrolytes enable simplified packaging, in some cases eliminating the metal case.
- Improved safety: more resistant to overcharge, reduced risk of electrolyte leakage.

In the following sections, we will take a look at what each of these emerging technologies has to offer.

Lithium-ion polymer: for sleeker, more compact designs in mobile computing

Lithium-ion polymer batteries differ from other battery systems in the type of electrolyte used. The original design, dating back to 1970, uses a dry solid polymer electrolyte only. This electrolyte does not conduct an electronic current, but allows the exchange of ions (it conducts the “ionic current”).

As a result, the battery can be packaged in resin-laminated aluminium foil, making it perfect for ultra-thin batteries and offering the advantage of design flexibility. Lithium-ion polymer batteries, as thin as 0.4mm, have been produced with the flexibility of a rubber mat.

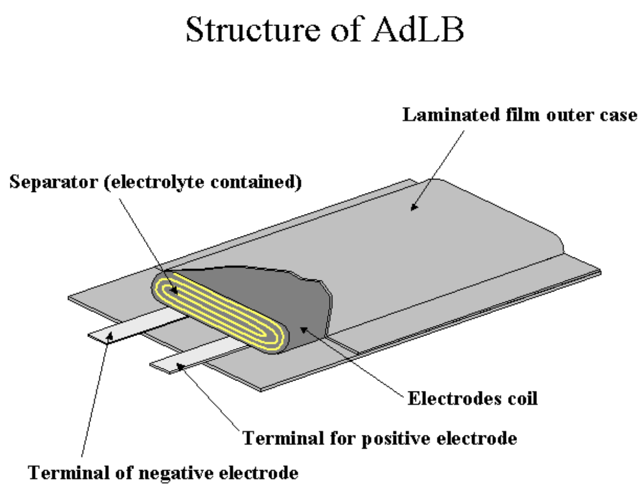
The battery can be moulded into a curved space, making it also ideal for today's mobile phones or other tiny, mobile computing devices. For instance, Toshiba's Portégé® 2000, the slimmest notebook in the world to-date, is accompanied by a lithium-ion polymer battery. This light, thin battery powers the machine without weighing it down or adding bulk.

Moreover, it is possible to create batteries that can be rolled up or embedded into clothing. For wearable PCs, such batteries are ideal. Such innovative batteries are still a few years away, but will soon be part of our lives.

Finally, the absence of excess electrolyte offers safety advantages. Batteries are more stable, non-flammable, and less vulnerable to problems caused by overcharge, damage or abuse. In the event of an accident, there is hardly any risk of danger from exposed lithium electrolyte, especially when compared to the liquid electrolyte alternatives.

Advanced Lithium-ion Batteries: for solid performance in a flexible form

Similar to lithium-polymer batteries, which are made of a gel, Toshiba's Advanced Lithium-ion Battery (AdLB) technology derives its power from a specially developed liquid. This liquid contains the electrolyte, allowing for a flexible outer case. The ruggedness and flexibility of the AdLB's aluminium laminated film casing makes it one of the most advanced battery solutions.



Toshiba's AdLB technology decreases battery swelling to less than 0.1mm under even the most extreme conditions. The reduction in swelling (often an issue for batteries containing polymer) enables designers to create a slimmer, more compact battery. Consequently, a variety of designs, including ultra-thin (as slim as 1mm) and miniature batteries, are possible.

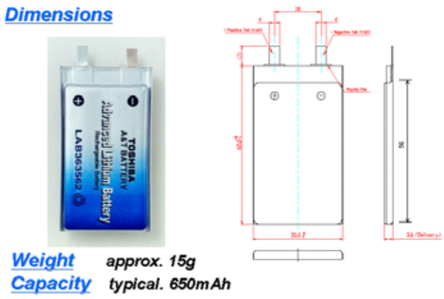
AdLBs also offer performance advantages. Like lithium-ion batteries, they offer high energy density and do not suffer from memory effects. The AdLB technology also provides excellent cycle life performance, maintaining up to 80 percent of initial capacity after 500 cycles.

In addition these batteries are very safe, and perform well even under extreme conditions. Here are some of the performance results for Toshiba AdLB:

- meets over-charge safety testing up to 12V under 3CmA rate, and oven testing up to 170 degrees Celsius at 4.4 volt charge.
- The operating temperature ranges from up to –20 degrees to 60 degrees Celsius, with temperature storage up to 90 degrees Celsius.
- AdLB cells also maintain up to 40 percent of their initial capacity at –20 degrees Celsius.

Overall, the AdLB increases safety while meeting the market demand for smaller, lighter solutions. With all of these advantages, you might well ask what devices could be powered by the AdLB. Generally, Toshiba's AdLBs are also ideal for mobile phones, global positioning systems (GPS), sub-notebooks, scanners, two-way pagers, wearable computers, and personal digital assistants.

An Example of AdLB: LAB363562B



In fact, Toshiba's PDAs incorporate AdLB technology. The capacity of this battery is 1000mAh. It size is a mere 5.4mm thick, 40.0mm deep, and 60.0mm high. Toshiba has also created a notebook prototype using the AdLB. In the future, possibly by the end of 2002, the AdLB will be incorporated in Toshiba notebooks.

Technology for tomorrow: In the future, the fuel cell could "fill" all our power needs

Anyone whose battery has died in the middle of a call on a mobile phone or whose notebook battery has "run out of juice" in the middle of presentation has probably wished that it were possible to live in a world where batteries didn't require recharging. In the future, with the introduction of fuel cells, this wish may come true, as fuel cells only need refuelling, not recharging.

Like the battery, a fuel cell uses two electrodes separated by an electrolyte. However, unlike the battery, the fuel cell is an energy conversion device that combines fuel with oxygen to produce electric power, heat and water. The fuel cell is capable of producing electrical energy as long as fuel and oxidant are supplied to the electrodes. Possible source of fuel include: hydrogen, methanol, butane, propane or natural gas.

To better understand how a fuel cell functions, let's look at a PEM (using Polymer Electrolyte Membrane as the electrolyte) system. In the fuel cell, hydrogen is presented to the negative electrode and oxygen to the positive electrode. A catalyst at the anode separates the hydrogen into positively charged hydrogen ions and electrons. Protons migrate to cathode through the PEM to form water by the reaction with OH minus ions (or ionised oxygen). across the electrolyte to the anodic compartment where it combines with hydrogen. The result is electricity, some heat and water. A single fuel cell produces 0.6 to 0.8V under load. Several cells are connected in series to obtain higher voltages.

As far as safety and effects on the environment are concerned, the fuel cell offers a number of advantages. As this electrochemical process does not generate energy through burning, the fuel cell does not produce harmful emissions. For fuel cells using hydrogen, the only by-product is clean water. For fuel cells using methanol, such as Direct Methanol Fuel Cells (DMFC), both water and carbon dioxide are emitted.

Refuelling our cars, homes and mobile computing devices: "Fill it up, please"

Originally used to power spacecraft in the 1960's, including the Gemini and Apollo missions, fuel cells often elicit futuristic associations. However, far from being a distant technology, Toshiba and others believe that fuel cells are going to play an important role in the 21st century. Toshiba is focussing on developing the PEFC (Polymer Electrolyte Fuel Cell) and the DMFC. In this section, we look at what the near future holds for these two fuel cell technologies.

Toshiba hopes to introduce a fuel-cell battery that turns methanol directly into electricity and that could be available to the public within two years. PEFC technology is the key that will realise remarkable cost reduction and compactness of fuel cells. In the future, we can expect to see miniaturised polymer electrolyte fuel cells (PEFC) that supply power for as long as 12 hours. Within two years, you may find yourself living in a PEFC-powered home, driving a PEFC-powered car, calling using a PEFC- powered mobile phone or working on a PEFC-powered mobile computing device, such as a notebook or PDA.

Prototype of Toshiba's PEFC Car (left).

The PEFC engine achieves 20% higher efficiency than gasoline engine at normal run.

Fuel cells for the car (right).

25V @ 48A (1.2kW)
at normal run

For mobile computing devices, DMFC fuel cells also promise a source of power that never requires recharging, but only refuelling. A direct methanol method is employed for directly feeding aqueous methanol solution onto the fuel cell electrode. Its maximum output is 8W and average output ranges from 3W to 5W. To heighten output density, a motor powered pump is used so that diffusion occurs whenever an aqueous methanol solution is added to the electrode. Two tanks each separately containing methanol and water are also incorporated for internal dilution.

Fuel cells for wireless, mobile computing devices: Toshiba's DMFC-powered PDA on display (left).

Toshiba has incorporated fuel cells in box-shaped devices (as shown in the picture). Although demonstrations using fuel cells for operating mobile devices have been conducted in the past, Toshiba is the first to demonstrate a PDA powered by a fuel cell. Current pilot tests have resulted in a fuel cell that is capable of powering the PDA for two to three consecutive hours. Following further development and testing, Toshiba anticipates that this technology will be commercially available before the end of 2005.

So, thanks to Toshiba's research and development efforts, in the near future, we may no longer be recharging batteries, but saying "fill it up, please" as we refuel the fuel cell powering our homes, cars and mobile computing devices.