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The Power of Li-Ion

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Despite some of its limitations, Li-Ion reigns as the superior battery performer.

For many years, NiCd was the only battery available for portable devices such as wireless communications. In 1990, NiMH and Li-Ion emerged, offering higher capacities. Both chemistries fought nose to nose, each claiming better performance and smaller sizes.

Which chemistry will be the true winner, and what system will pave the way in the new millennium? The favorite appears to be the Li-Ion family, especially for portables with a small form factor.

Li-Ion is a low-maintenance battery, an advantage that no other chemistry can claim. There is no memory effect, and no scheduled cycling is required to prolong the battery's life. In addition to high energy density and light weight, the self-discharge is less than half compared to NiCd and NiMH, making Li-Ion well-suited for modern fuel-gauge applications.

On the negative, Li-Ion is fragile and requires a protection circuit to maintain safe operation. The load current is moderate and charging must be done according to strict standards. Also, Li-Ion is subject to aging, whether used or not.

History

Pioneering work for lithium batteries began in 1912 by G. N. Lewis, but it was not until the early 1970s when the first non-rechargeable lithium batteries became commercially available. Attempts to develop rechargeable lithium batteries followed in the 1980s, but failed due to safety problems.

Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest energy content. Rechargeable batteries using lithium metal as the negative electrodes (anode) are capable of providing both high voltage and excellent capacity, resulting in an extraordinary high energy density.

After much research on rechargeable lithium batteries during the 1980s, it was found that cycling alters the lithium electrode, thereby reducing its thermal stability and causing potential thermal runaway. If this occurs, the cell temperature quickly approaches the melting point of the lithium, which results in a violent reaction.

Because of the inherent instability of lithium metal, especially during charging, research shifted to a non-metallic lithium battery using lithium ions. Although slightly lower in energy density than lithium metal, Li-Ion is safe, provided certain precautions are met when charging and discharging. In 1991, Sony commercialized the first Li-Ion. Other manufacturers followed suit. Today, Li-Ion is the fastest growing battery chemistry in the world.

Li-Ion Versions

There are several types of Li-Ion batteries that have emerged. Sony's original version used coke as negative electrode (anode). Since 1997, most Li-Ion, including Sony's, has shifted to graphite. This electrode provides a flatter discharge voltage curve than coke and offers a sharp knee bend, followed by a rapid voltage drop before the discharge cut off. As a result, the useful energy of the graphite system can be retrieved by discharging only to 3V, whereas Sony's coke version must be discharged to 2.5V to get the same performance.

For the positive electrode (cathode), two distinct chemistries have emerged. They are cobalt and manganese, also know as spinel. Although the cobalt has been in use longer, spinel is inherently safer and more forgiving if abused. Protection circuits can be simplified or even eliminated. Small prismatic spinel packs for mobile phones may only include a thermal fuse and temperature sensor. In addition to the added safety, the raw-material cost for manganese is lower than cobalt.

As a trade-off, the spinel offers a slightly lower energy density, suffers capacity loss at temperature above 40°C and ages quicker than cobalt.

At present, NEC Moli is the only commercial producer of the spinel Li-Ion. Although other manufacturers stated that the manganese system is not feasible because of low cycle count, the NEC Moli cells are known to perform as many as 1,000 cycles in a lab condition. Optimizing the cell design, such as carefully selecting materials, attains this performance.

Chemicals and additives help to balance the critical trade-off between high energy density, long storage time, extended cycle life and safety. High energy densities can be achieved with relative ease. For example, adding more nickel in lieu of cobalt increases the Ah rating and lowers the manufacturing cost, but makes the cell less safe. Although a start-up company may focus on high energy density to gain quick market acceptance, safety, cycle life and storage may be compromised. Reputable manufacturers, such as Sony, Panasonic, Sanyo and NEC Moli, place high importance on safety.

Although Li-Ion cells have some environmental impact, they cause less harm when they are disposed than lead- or cadmium-based batteries. Among the Li-Ion battery family, the spinel is the friendliest.

Charging the Li-Ion Battery

The Li-Ion charger is a voltage-limiting device similar to that of the VRLA charger. The main differences of the Li-Ion charger are higher voltage per cell, tighter voltage tolerance and the absence of trickle or float charge at full charge.

Whereas VRLA offers some flexibility in terms of voltage cutoff, the manufacturers of Li-Ion cells are strict about the voltage choice. When first introduced, the charge voltage limit of the graphite system was 4.10V/cell. Although higher voltages deliver increased energy density, cell oxidation severely limited the service life in the early graphite cells if charged above the 4.10V/cell threshold. This effect now has been solved with chemical additives, and most new Li-Ion cells are set to 4.20V. The tolerance on all Li-Ion batteries is a tight ±0.05V/cell.

The charge time of Li-Ion batteries is about three hours at a 1°C initial charge current. Full charge is attained after the voltage reaches the upper voltage threshold and the current drops and levels off at about 3% of its nominal rating, or about 0.03°C.

Increasing the charge current on a Li-Ion charger does not shorten the charge time by much. Although the voltage peak is reached quicker with higher current, the topping charge will take longer. The voltage and current signature of a charger is shown as the Li-Ion cell passes through stages 1 and 2.

Claims of fast-charging a Li-Ion battery in one hour or less usually results in lower charge levels. Such a charger simply eliminates stage 2 and goes directly into "ready" once the voltage threshold is reached at the end of stage 1. The charge level at this point is about 70%. The topping charge typically takes twice as long as the initial charge.

No trickle charge is applied because the Li-Ion is unable to absorb overcharge. Trickle charge could cause plating of metallic lithium, a condition that renders the cell unstable. Instead, a brief topping charge is applied to compensate for the small amount of self-discharge the battery and its protective circuit consume.

A topping charge may be implemented once every 500 hours or 20 days. Typically, the charge kicks in when the open terminal voltage drops to 4.05V/cell and turns off when it reaches 4.20V/cell.

Protection Circuit

Commercial Li-Ion battery packs contain redundant protection devices to assure safety under all circumstances. Typically, a FET opens if the charge voltage of any cell reaches 4.30V, and a fuse activates if the cell temperature approaches 90°C (194°F). In addition, a pressure switch in each cell permanently interrupts the charge current if a safe pressure threshold is exceeded, and internal voltage-control circuits cut off the battery at low and high voltage points. Exceptions are made to prismatic and cylindrical spinel packs containing one or two cells.

The Li-Ion typically is discharged to 3V/cell. The lowest low-voltage power cutoff is 2.5V/cell. During prolonged storage, however, a discharge below this voltage level is possible. Manufacturers recommend a trickle charge to raise such a battery gradually back up into the acceptable voltage window. Not all chargers are designed to apply a charge once a Li-Ion battery has dipped below 2.5V/cell.

Some batteries feature an ultra-low voltage cutoff that permanently disconnects the pack if a cell dips below 1.5V. This precaution is done to prohibit recharge if a battery has dwelled in an illegal voltage state. A deep discharge causes copperplating, which can lead to a short circuit in the cell.

Most manufactures do not sell Li-Ion cells by themselves but make them available in a battery pack, complete with protection circuit. This precaution is understandable when considering the danger of explosion and fire if the battery is charged and discharged beyond its safe limits.

A major concern arises if static electricity or a faulty charger has managed to destroy the battery’s protection circuit. Such damage often causes the solid-state switches to fuse to a permanent "on" position without the user’s knowledge. A battery with a faulty protection circuit may function normally but does not provide the required safety. If charged beyond safe voltage limits with a poorly designed accessory charger, the battery may heat up, then bulge and in some cases vent with flame. Shorting such a battery can be hazardous.

Analyzers for the Li-Ion Batteries

In the past, battery analyzers were used to restore batteries affected by memory effect. With today's nickel-free batteries, memory is no longer a problem, and the emphasis of an analyzer is shifting to battery performance verification, quality control and quick-test.

Conventional wisdom says that a new battery always performs flawlessly. Yet many users have learned that a battery fresh from the shrink-wrap does not always meet manufacturer's specifications. With a battery analyzer, all incoming batteries can be checked as part of a quality-control procedure. Warranty claims can be made if the capacity drops below the specified level at the end of the warranty period.

A typical life of a Li-Ion is 300 to 500 discharge/charge cycles or two years from time of manufacturing. The loss of battery capacity occurs gradually and often without the user's knowledge. Although fully charged, the battery eventually regresses to a point where it may hold less than half of its original capacity. The function of the battery analyzer is to identify these weak batteries and weed them out.

A battery analyzer also can be used to troubleshoot the cause of short run times. The charger may not provide a full charge or the portable device may draw more current than expected. Many of today's battery analyzers can simulate the load signature of a digital device and verify the run time based on the available battery capacity.

Perhaps the most important feature of a modern battery analyzer is its ability to read the internal battery resistance. As part of natural aging, the internal resistance of a Li-Ion gradually increases due to cell oxidation. The higher the resistance, the less energy the battery can deliver.

Li-Ion Benefits

The Li-Ion battery receives good grades in performance and reliability. Supply shortages have eased and prices have become affordable. As a result, more portable equipment is being fitted with Li-Ion batteries.

Li-Ion has found a strong market niche with portable devices demanding a small form factor. The most popular uses are wireless phones and notebook computers. Because of the aging aspect, Li-Ion is most suitable for applications with a hectic user pattern. Where Li-Ion falls short is on high-current applications and operations that regularly need a full discharge.

Another field where Li-Ion has proved less favorable is in applications that require occasional battery use. On a laptop that is mostly powered by ac, for example, the Li-Ion battery ages in time and the full benefit of the battery cannot be realized. For these applications, other battery chemistries may serve better. High heat levels inside some laptops also cause a Li-Ion to fail prematurely. Field tests have revealed, however, that Li-Ion is less affected by heat than NiMH.

The lithium polymer systems, which are in early production states, are struggling to meet and surpass the performance of Li-Ion batteries. High initial cost and limited supply are the main drawback. Once mass-produced, lithium polymer is expected to be lower priced than Li-Ion because simpler packaging methods are possible.

On the positive, lithium polymer provides slightly higher energy densities and reduced weight. No standard form factor has been established for lithium polymer because this battery can be formed into virtually any shape and size. One day, the battery may be part of the protective housing or serve as a soft carrying case.

Battery Resistance

Cadex has developed a proprietary pulse method to measure the internal battery resistance. Known as OhmTest, a mW reading is obtained in five seconds without discharging the battery. Available with the C7000 battery analyzers, the OhmTest enables testing a large volume of batteries in a matter for minutes. This technique is especially useful for organizations that need to verify the state-of-health of a batch of batteries before release.

OhmTest does not provide definite conclusions as to the state-of-charge and state-of-health of a battery. The readings may vary widely and depend on battery chemistry, cell size (mAh rating), type of cell, number of cells connected in series, protection circuit, wiring and contact type. The state-of-charge at the time the reading is taken also plays a role. A battery must have at least a 50% charge to obtain a meaningful mW reading. Solid terminal connection is essential because a poor contact will provide a high mW reading. Alligator connections and long battery leads are not suitable.

To use the OhmTest as a battery validation, it is essential to obtain a reference reading of a good battery with known performance. Because each battery type may be different, a reference reading will be required for each model.

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