NanoSafe™ Battery Technology

Altairnano, Inc. is a leader in advanced nanomaterials and alternative energy solutions. In alternative energy the company has developed novel electrode nanomaterials and its NanoSafe™ rechargeable, nano titanate battery system provides fundamental advantages over existing, traditional lithium ion battery designs.

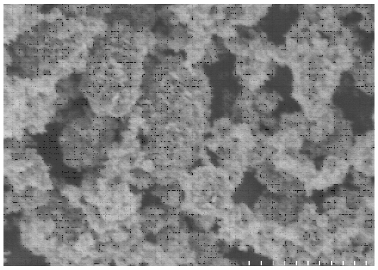
Until now conventional lithium ion/graphite battery technology was seen as the wave of the future in rechargeable batteries. Of all the available metals for use as a basis for practical batteries, lithium is the lightest and most energetic. Specific energies for lithium ion cells can approach 200 Whr/Kg, and typical lithium ion (Li-Ion) cells exhibit voltages of about 3.6 volts (V) compared to about 1.2V for nickel cadmium (NiCd) and nickel metal hydride (NiMH), and 2.0V for lead acid (PbA) cells. Li-Ion cells are stable exhibiting low self discharge. Lithium based batteries are essentially no maintenance systems and exhibit no memory effect. The current markets for lithium battery technology are small electronics such as cell phones and portable computers. In these types of applications, high energy and light weight are important.

The same types of attributes are desired for electric vehicles (EV), hybrid electric vehicles (HEV), power tool and backup power subsystems (UPS) markets. However, these applications are principally high power demand applications and pose other demands on usage such as extremes of temperature, need for short recharge times, high proportional (to stored energy) current rates and even longer extended lifetimes.

Thus the problems with conventional lithium ion technology remain life (cycle and calendar), safety, recharge time, power delivery, and extreme temperature performance.

Novel Research Program leads to Innovative Battery

Altairnano established a research program in 2000 to solve these problems and develop electrode materials that would enable a battery to be charged in minutes, deliver high power and sustain a long life. Fundamental research of the electro-chemistry of battery materials lead to the conclusion that nanotechnology would provide dramatic new material properties that could solve these requirements. Altairnano already had substantial knowledge of nano-titanate materials and it postulated that by replacing graphite in conventional Li-Ion batteries with nano-titanate materials would result in batteries with breakthrough properties solving charge time, lifecycle, power and safety. It has always been known that the graphite component of Li-Ion batteries is the catalyst for thermal runaway leading to fire and explosion of the battery.



Scanning Electron Microscope picture of Altairnano's nano-titanate material

A multi-year research program ensued to refine the nano-titanate materials and rigorously test it in battery cells. This work resulted in key patents being granted. This fundamental breakthrough in battery materials was announced in February 2005 and since then Altairnano, through the acquisition of a leading battery development team, has developed battery systems using these nanomaterials. The first Altairnano NanoSafe™ batteries, based on this technology, were delivered in September 2006.

NanoSafe™ battery cell

High Power Batteries

Altairnano has initially focused on the high power battery market – batteries suitable for the EV market where fast charge has been a primary hurdle to the growth of this potentially multi-billion dollar industry.

Figure 1 on the following page plots energy versus power for a variety of battery technologies (note the axes are logarithmic). Altairnano has developed a battery technology that delivers optimum energy/ power balance in the high power region – a primary attribute for EVs.

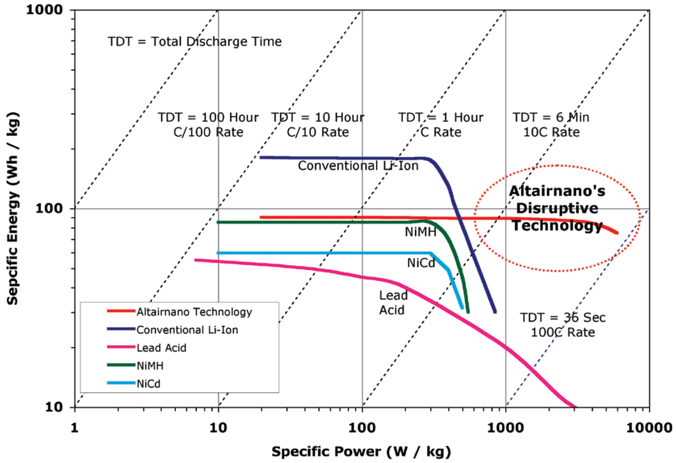


Figure 1 - The Altairnano Advantage in High Power

The Altairnano NanoSafe™ Battery Advantage

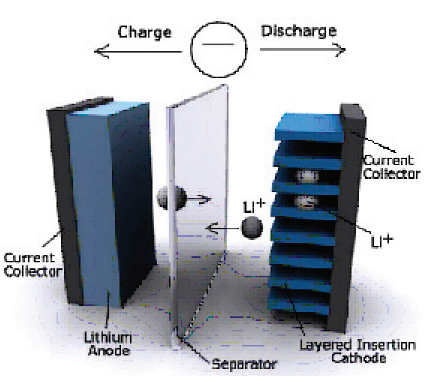
In addition to high power the Altairnano NanoSafe batteries deliver:

- Long life – potentially up to 20+ year life
- Very fast charge - rechargeable in minutes
- Extremely wide operating temperature range from -50°C/-60°F to +75°C/165°F
- Inherent safety – no risk of thermal runaway

The rest of this document will detail how these attributes are obtained by reference to the underlying novel electro-chemistry.

How Does a Rechargeable Battery Work?

A battery consists of a positive electrode, a negative electrode, a porous separator that keeps the electrodes from touching, and an ionic electrolyte, which is the conducting medium for ions (charged particles) between the positive and the negative electrodes – see Figure 2. When the battery is being charged lithium ions transfer from the positive to the negative electrodes via the electrolyte. On discharge these lithium ions return to the positive electrode releasing energy in the process.



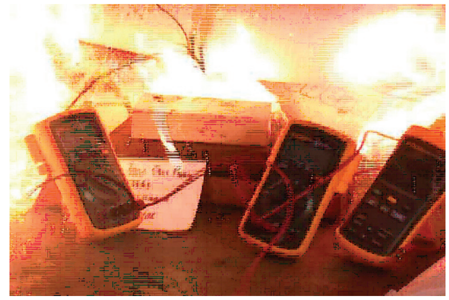
Courtesy of www.laptop-batteries-guide.com

The electrolyte is a lithium salt dissolved in an organic solvent which is flammable. When a lithium ion battery is first charged a protective layer (called the Solid Electrolyte Interface or SEI) is formed on the surface of the highly reactive negative electrode.

Battery Safety

The Disadvantage of Conventional Lithium Ion Batteries

The SEI layer, under normal operating temperatures, maintains a safety barrier between the reactive negative electrode and the electrolyte. However, if the temperature of the battery rises above about 120°C the SEI breaks down. In this situation the negative electrode has a high tendency to chemically react vigorously with the electrolyte in a heat generating reaction that accelerates exponentially as the breakdown of the SEI occurs. This uncontrollable reaction is called a thermal runaway and ultimately leads to the destruction of the battery, and a resulting fire which could ignite the device to which the battery is connected such as an electric vehicle, laptop or cellphone.



Thermal Runaway in a Conventional Li-Ion Battery!!

The initial increase in temperature could be caused by a number of problems including external shorting of the battery, internal shorting of the electrodes resulting from mechanical damage to the battery or a manufacturing defect, overcharging of the battery, electronic control unit failure or external heat. Impurities in the battery could be introduced during the manufacturing process ultimately leading to an internal shorting of the battery.

The NanoSafe Advantage

By using its nano-titanate material as the negative electrode, Altairnano has achieved a high powered battery that is thermally stable, and therefore can not exhibit thermal runaway. By removing the highly reactive graphite from the battery design, and instead using nano-titanate materials as the negative electrode material no interaction takes place with the electrolyte in the Altairnano batteries. This results in an inherently safe battery. In addition, Altairnano performed high-rate overcharge, puncture, crush, drop and other comparative tests alongside a wide range of graphite-based battery cells with, again, no malfunctions, explosions or safety concerns exhibited by the Altairnano battery cells. In comparison, the graphite cells, put to the same tests, routinely smoked, caught fire and exploded.

The wide thermal operating range of the Altairnano NanoSafe battery means that it is well suited for hostile environments where physical movement, corrosion, high and/or low temperature extremes, electrical circuit complexity could cause shorting or battery malfunction resulting in thermal runaway of traditional lithium ion batteries. Such environments can be found in electric vehicles and hybrid electric vehicles.

Battery Life

The Disadvantage of Conventional Lithium Ion Batteries

During charge, lithium ions deposit inside the graphite particles and are then released on discharge. When the lithium ions enter or leave the graphite particles, the particles expand or shrink to accommodate the lithium ion's size which is larger than the original site within the graphite particle that the ion occupies. Over the life of the battery, this repeated expansion and shrinkage fatigues the graphite particles. As a consequence the particles break apart, causing a loss in electrical contact between the resulting particles thereby reducing battery performance. The same process is repeated over the dynamic life of the battery - particle fatigue breakage and diminished performance until the battery is no longer useful.

The NanoSafe Advantage

The nano-titanate electrode material is a "zero strain" material in terms of lithium ion internal deposition and release. The lithium ions have the same size as the sites they occupy in the nano-titanate particles. As a result the nano-titanate particles do not have to expand or shrink when the ions are entering or leaving the nano-titanate particles, therefore resulting in no (zero) strain to the nano-titanate material. This property results in a battery that can be charged and discharged significantly more often than conventional rechargeable batteries because of the absence of particle fatigue that plagues materials such as graphite. Conventional lithium batteries can be typically charged about 750 times before they are no longer useful, whereas, in laboratory testing, the Altairnano NanoSafe battery cells have now achieved over 9,000 charge and discharge cycles at charge and discharge rates up to 40 times greater than are typical of common batteries, and they still retain up to 85% charge capacity.

As an example of the application significance of this feature if a conventional lithium battery is charged and discharged every day then it would typically last for about 2 years. Under the same scenario, an Altairnano battery would be projected to last 25 years. This durability is critical in a high value application like electric vehicles.

Battery Power

The Disadvantage of Conventional Lithium Ion Batteries

Nanosafe™ Battery Module

An important attribute of large format batteries is their ability to deliver power quickly. During charge, lithium ions deposit inside the graphite particles. However, the rate at which lithium ions can be removed during discharge – the useful power-producing cycle of a battery - is limited by the electro-chemical properties of the graphite and the size of the graphite particles. The electrochemical properties relate to the existence of a high resistance crust (call the Solid Electrolyte Interface or SEI) that impedes the removal of lithium – the first step in power production. Also, graphite's large particle size means that lithium atoms inside the particle must travel a long distance to escape. This further increases the impedance and reduces power.

So power is restricted by the ion removal capability in lithium ion batteries, resulting in power levels of the order of 1000 watts per kilogram (W/Kg). Also, power can be affected by external factors such as temperature. At low temperatures, the lithium ion removal rate is significantly less than at room temperature resulting in power delivery at these temperatures that is greatly reduced.

The NanoSafe Advantage

NanoSafe batteries deliver power per unit weight and unit volume several times that of conventional lithium ion batteries. Altairnano laboratory measurements indicate power density as high as 4000 W/Kg and over 5000W/litre. By using nano-titanate materials as the negative electrode material, the formation of an SEI is eliminated. In addition, the nano-titanate particles are up to 100 times smaller than a typical graphite particle thereby greatly reducing the distance a lithium atom must travel to be released from the particle. These properties also mean that even at very cold temperatures, a nano-titanate battery will produce high power.

Battery power is important for a number of reasons for example a burst of power is needed for a freeway electric vehicle accelerating rapidly. The NanoSafe cell has demonstrated that surges of power can be delivered without risking thermal runaway or performance damage to the battery.

Battery Charge Rate

The Disadvantage of Conventional Lithium Ion Batteries

During charge, lithium ions deposit inside the graphite particles. However the rate at which lithium ions can deposit is limited by the electro-chemical properties of the graphite, and if they can not enter the graphite particles they, instead, may collect (plate) on the negative electrode's surface as lithium metal. This can occur if the ions are deposited too rapidly on the graphite electrode as might be the case if the battery is charged too quickly. If this plating occurs, the battery will severely degrade in performance and in extreme cases, will short, causing overheating and thermal runaway - a major fire hazard.

So the time to charge (charge rate) is restricted by the ion incorporation rate capability in lithium ion batteries, resulting in charge times measured in hours. Also, charge rate can be affected by external factors such as temperature. At low temperatures, the lithium ion incorporation rate is significantly less than at room temperature so charging at these temperatures may be much longer or impossible.

The NanoSafe Advantage

By using nano-titanate materials as the negative electrode material, lithium metal plating does not occur because the electro-chemical properties of the nano-titanate allow the deposition of lithium in the particles at high rates. These electrical properties mean that even at very cold temperatures there is no risk of plating. No undesirable interaction takes place with the electrolyte in the Altairnano batteries, which permits the battery to be charged very rapidly, without the risk of shorting or thermal runaway. In fact, in recent laboratory testing, Altairnano has demonstrated that a NanoSafe cell can be charged to over 80% charge capacity in about one minute.

Rapid charge is important for next generation electric vehicles so they could be charged in a few minutes rather than hours as with current lithium ion technology.

Battery Operating Temperature Range

The Disadvantage of Conventional Lithium Ion Batteries

Conventional lithium technology batteries are intolerant of temperature extremes. Below 0°C and above 50°C the batteries can not be charged, and above 130°C they are unsafe because of the potential for thermal runaway ultimately leading to battery explosion. Also at low temperatures, the lithium ion incorporation rate is significantly less than at room temperature so charging at these temperatures will be much longer, or impossible.

The NanoSafe Advantage

Altairnano nLTO-based batteries can operate at temperatures as low as -50°C and as high as +75°C — again, with no unsafe characteristics. To put the NanoSafe batteries to the test, Altairnano performed "hot box" exercises on its batteries at temperatures up to 240°C — which is more than 100°C above the temperature at which graphite-based batteries can explode — with zero explosions or safety concerns. Altairnano has demonstrated that their NanoSafe batteries can be changed to 90% of their room temperature charge even at -30°C. This has application in a wide variety of markets including electric vehicles, where they are required to operate in sub-zero conditions, and aircraft and military applications where at high altitude temperatures are frequently in the -30°C range.

At high temperatures Altairnano has demonstrated that batteries constructed using their nano-electrode materials are safe at temperatures up to 250°C. This extreme temperature operation has application in dessert environments for both civilian and military needs.

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