TAIYO YUDEN

Whitepaper

TAIYO YUDEN Lithium Ion Capacitors: An Effective EDLC Replacement

Lithium Ion Capacitors overcome the pitfalls of EDLCs, providing superior self-discharge characteristics, high-energy density, reliability, longevity and safety.

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Background

An accepted energy solution, conventional Electrical Double Layer Capacitors (EDLC) have many notable drawbacks relating to self-discharge characteristics, energy density, reliability, longevity and thermal design. TAIYO YUDEN Lithium Ion Capacitors overcome these issues and are an effective replacement for EDLCs. Lithium Ion Capacitors are hybrid capacitors, featuring the best characteristics of both EDLC and Lithium Ion Secondary Batteries (LIB).

EDLCs were first created in Japan in the 1970s and began appearing in various home appliances in the 1990s. Since the 2000s, they have been used in mobile phones and digital cameras. EDLCs are typically used to protect against sudden momentary drops or sudden interruptions in power. They can instantaneously output large amounts of power, while a battery cannot. They are frequently used as backup power sources in servers and storage devices for integrated circuits, processors, memory and more.

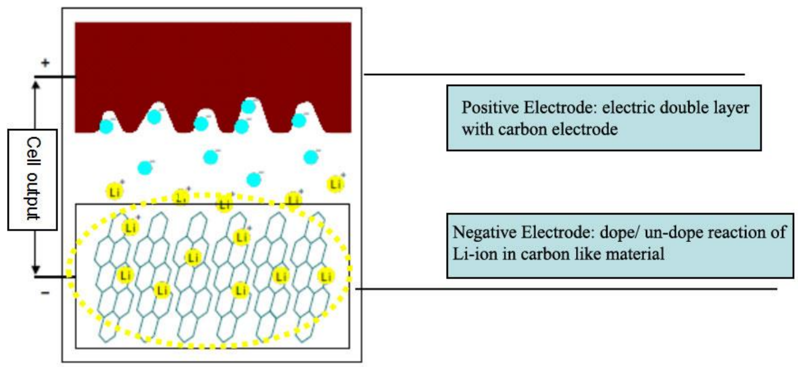
While EDLCs are intended to be backup power sources, conventional EDLCs suffer from a phenomenon known as self-discharge, where the capacitor will gradually lose its charge over time. Self-discharge can occur more rapidly during exposure to high temperature environments. **The extremely low self-discharge of an Lithium Ion Capacitor, even in high heat environments, ensures a long-lasting charge.**

Furthermore, Lithium Ion Capacitors have no risk of thermal runaway. No additional thermal design considerations, space or components are necessary when designing with an Lithium Ion Capacitor.

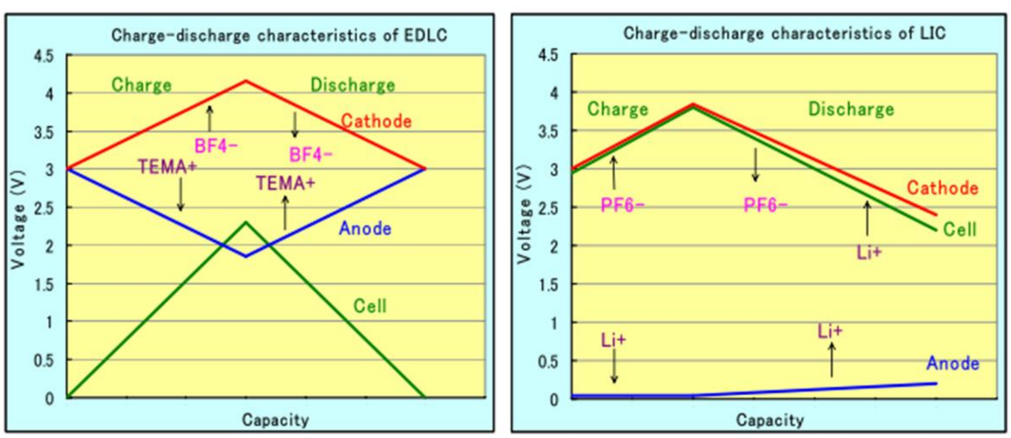
The use of Lithium Ion Capacitors is steadily growing. They are increasingly relied on as supplementary power sources in manufacturing and medical equipment, where even momentary drops in voltage can be critical. They serve to compensate for uneven voltage levels with solar panels and even as primary power sources in small devices. Most significantly, Lithium Ion Capacitors are becoming a preferred backup solution for power interruption in servers and other devices.

Principles and Features of Lithium Ion Capacitors as Compared to EDLCs

Lithium Ion Capacitors are hybrid capacitors that use a carbon-based material as the negative electrode that can be doped with lithium. Just as in a conventional EDLC, they use activated carbon for the positive electrode.

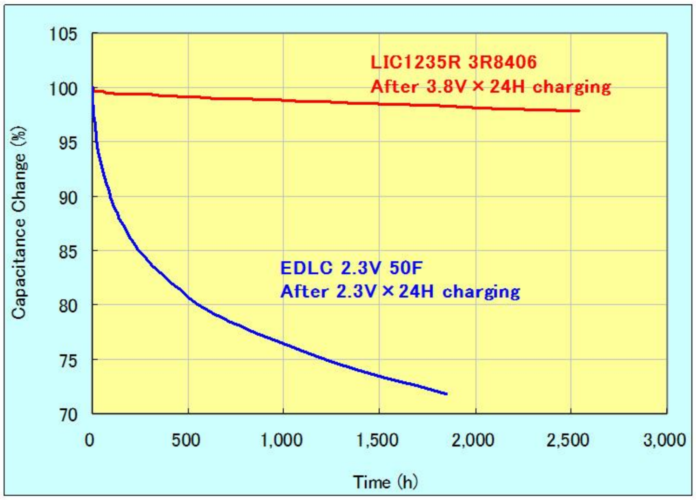


Metallic lithium, electrically connected to the negative electrode, forms a local battery at the same time as immersion of the electrolytic solution. Then, doping of Lithium Ions begins on the carbon-based material at the negative electrode. Once doping is complete, the initial voltage of the Lithium Ion Capacitor drops to 3V or less as the electric potential of the negative electrode almost matches that of lithium. Therefore, compared to the charging/discharging potential of conventional EDLCs, a higher voltage can be obtained by using Lithium Ion Capacitors without a high potential at the positive electrode, which results in improved reliability in Lithium Ion Capacitors.



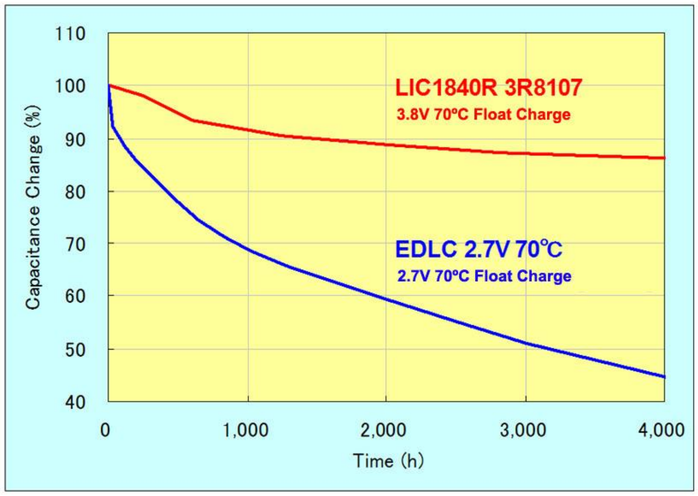
1. Self-Discharge Characteristics

One major feature of the Lithium Ion Capacitor is its excellent 'self-discharge property,' which is enabled by pre-doping of lithium to the negative electrode to stabilize the potential of the negative electrode, The graph below shows the self-discharge property of the cylinder type Lithium Ion Capacitor with 40F charged for 24 hours in 3.8 V at a temperature of 25ºC and those of a symmetrical type EDLC whose capacitance is similar to the Lithium Ion Capacitor. As seen here, the symmetrical type EDLC has a large self-discharge. After a month under 25ºC, its voltage lowered to 80% of the initial volt-age. In contrast, the Lithium Ion Capacitor shows far better self-discharge. It can maintain a voltage of over 3.7 V even 100 days later under a temperature of 25ºC.

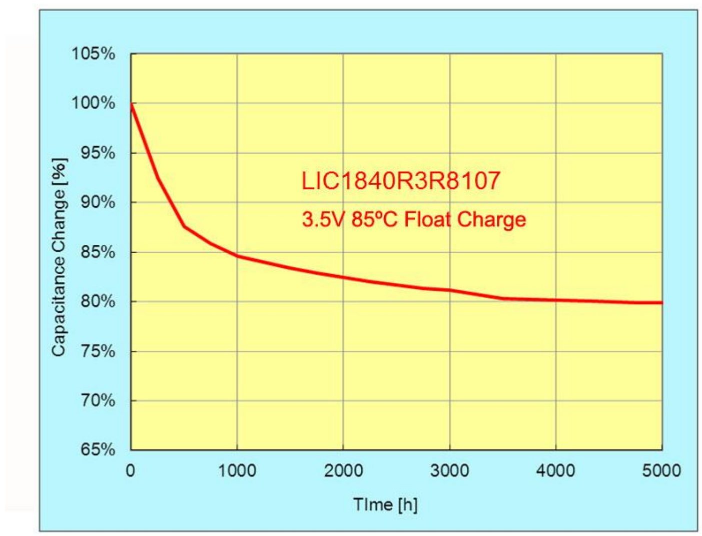


2. Float Charge Characteristics

The float charge characteristics (consecutive-charge) of a cylinder type Lithium Ion Capacitor and symmetrical EDLC whose capacitance is almost similar to the Lithium Ion Capacitor under a temperature of 70ºC. As mentioned in "Principles and Features of Lithium Ion Capacitors", one of the features of Lithium Ion Capacitors is that even with a high voltage charge of 3.8 V, the capacitors can lower their potential at the positive electrode to less than that of conventional symmetrical EDLC, which prevents their float charge from deteriorating and makes them highly reliable.



Moreover, charged at 3.5 V, the float charge characteristics (consecutive-charge) of a cylinder type Lithium Ion Capacitor under a high temperature of 85ºC shows good results with about 80% of the initial voltage maintained even 5,000 hours later.



3. Charge/Discharge Cycle Characteristics

Unlike Lithium Ion secondary batteries, Lithium Ion Capacitors are chemically stabilized products that employ the adsorption-desorption reaction of ions so that they do not cause a crystalline change at the positive electrode during the charge-discharge cycle. In addition, lithium is doped to a carbon-based material of the negative electrode in advance and the Lithium Ion Capacitor can be designed to lower the Lithium Ions availability in the negative electrode. This gives the Lithium Ion Capacitor to excellent charge/discharge cycle characteristics of over 100 thousand times, equivalent to that of conventional symmetrical type EDLCs. Some of these applications are already in practical use.

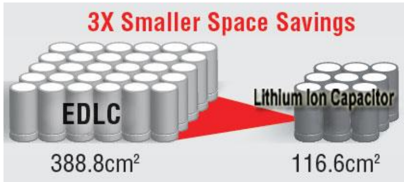
4. Temperature Characteristics

A stable discharge is obtained even at high temperatures and a volume-maintenance rate of over 60% is achieved even at a low temperature of -20ºC. In addition, a strong volume-maintenance rate of about 50% is achieved at extremely low temperatures, even when affected by the voltage drop caused by lesser mobility of ions in the electrolytic solution. With that, it is clear that the Lithium Ion Capacitor has good temperature characteristics.

5. High Energy Density

The maximum voltage of Lithium Ion Capacitors, 3.8 V, is higher than that of a symmetric type EDLC, and the capacitance is twice that of the EDLC. Therefore, the energy density of Lithium Ion Capacitor is quadruple that of the EDLC, based on the formula of "Q=1/CV2".

As the capacitance of this Lithium Ion Capacitor is about 88 mAh at the range of 3.8 V to 2.2 V, the Lithium Ion Capacitor has strong characteristics in discharge at the rate of 1C to 100C. As it can obtain about 60% of the discharged capacity at a discharge rate of 100C, the Lithium Ion Capacitor can be said to be a capacitor with excellent discharge characteristics in high output. In a Ragone plot comparison of a cylinder type Lithium Ion Capacitor with 200F and a conventional symmetric EDLC whose size is similar to the Lithium Ion Capacitor, the energy density of the Lithium Ion Capacitor is 8.6WH/kg, far larger, about 6.5 times larger, than the 1.5Wh/kg of the conventional EDLC.



6. Space Savings

Thanks to its high energy density, multiple EDLCs can be replaced with one Lithium Ion Capacitor. In applications such as servers and integrated circuits that use dozens of EDLCs, this can result in significant space savings allowing for an overall reduction in space or more space between each component. Utilizing fewer capacitors also helps improve thermal design by reducing the number of heat generating components.

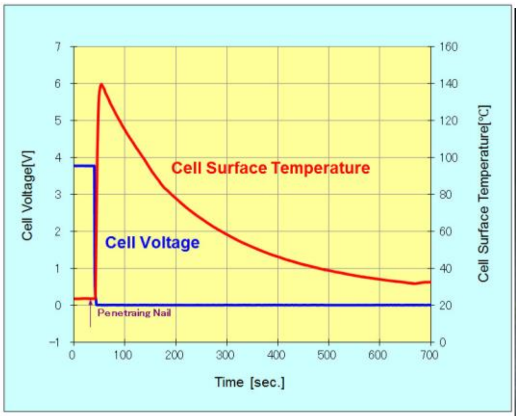
Safety of Lithium Ion Capacitor

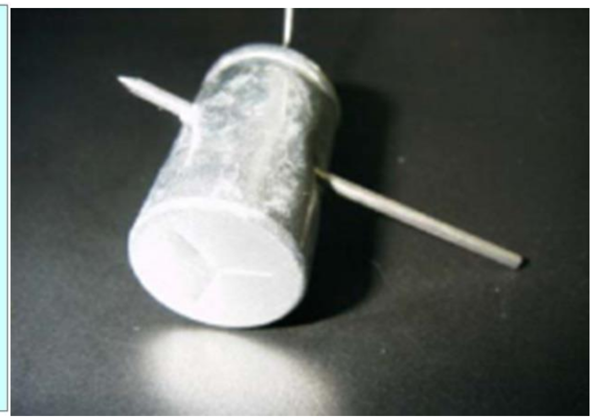
Using a carbon-based material doped by Lithium Ions at the negative electrode may create concerns about the safety, similar to Lithium Ion Batteries (LIB). However, the material composition of their positive electrodes are very different: LIB uses metal oxide and Lithium Ion Capacitor uses carbon-based materials such as activated carbon, which does not contain oxygen. This differentiates their reactions when an internal short-circuit occurs.

In LIBs, when an internal short-circuit occurs, the temperature of the internal cell rises by the short-circuit current. A following reaction between the negative electrode and the electrolytic solution causes an increase in the pressure of the internal cell, followed by a collapse of the crystal at the positive electrode and a release of oxygen in oxidation products of the positive electrode. This causes another thermal runaway, and, in some cases, an ignition or an explosion might occur due to a further rise in pressure of the internal cell and vaporization of the electrolytic solution.

In contrast, the internal pressure of the cell also rises in Lithium Ion Capacitors, but after that, thanks to the difference of the materials in the positive electrodes, the thermal runaway phenomenon will not occur and the reaction quietly finishes with the opening of the safety valves.

Thus, Lithium Ion Capacitors will not cause any serious accidents such as fires or explosions by the thermal runaway even of an internal short-circuit or other accident occurs, thanks to the difference of the material of its positive electrode compared to LIBs. Lithium Ion Capacitor can be said to be as logically safe an energy device as conventional non-aqueous solvent based EDLCs. Below are the results of a nail penetration test to a cylinder type Lithium Ion Capacitor with 200F, assuming an actual internal short-circuit.





These results show that the Lithium Ion Capacitor is a safe device. Even if the temperature of an external wall of the cell increases to 100ºC after short-circuiting, the temperature gradually decreases and the cell does not cause serious problem such as major deformations or explosions. With these results, Lithium Ion Capacitor is a good device equivalent to the symmetrical type EDLC in safety, has a number of features such as that it does not cause the thermal runaway even with rising internal cell temperatures, unlike LIBs, it does not contain any metal oxides as a material of the positive electrode. In addition, if an internal short-circuit should occur, internal short-circuits from an elution in base materials of the negative electrode are unlikely as the potential of the negative electrode does not exceed the elution potential of Cu.

Lithium Ion Capacitor Applications

- Backup power source in servers and storage devices for integrated circuits, processors, memory and more. The Lithium Ion Capacitor is ideal for tight, high temperatures spaces, as it provides energy density up to 4 times that of EDLCs, superior heat performance characteristics, voltage maintenance over time and low deterioration of floating charge.
- Power sources for small appliances, applying the quick rechargeable, lightweight, and low self-discharge features.
- Energy devices combined with photovoltaic cells or wind power generators (such as raised markers, light-emitting load signs, street lights, small LED illuminations)
- Auxiliary power devices for energy saving devices (such as rapid drum heating in copiers and on star-up for projectors)
- Computerized devices for automobiles, such as idling-stop devices, drive recorders and brakes by wire

Author Biography

Atsuya Sato is the field application engineering supervisor in TAIYO YUDEN's ECD (Electric Chemical Device) Project of the New Business Planning Development Division. He has worked in TAIYO YUDEN ENERGY DEVICE CO., LTD. (formerly Shoei Electronics Co., Ltd.) Osaka, Japan office, where he oversaw business with European, Chinese and South Korean mobile phone manufacturers. After company restructuring in 2010, Mr. Sato moved to TAIYO YUDEN Co., Ltd. ECD Project, and currently supports sales offices in Europe, the United Sates and Singapore.

About TAIYO YUDEN

Since its establishment in 1950, TAIYO YUDEN has invested in research and development to offer leading-edge technology to capacitors, inductors, circuit products, Surface Acoustic Wave (SAW)/Film Bulk Acoustic Resonator (FBAR) devices, energy devices and recording media under the philosophy that the process of product commercialization starts with material development. TAIYO YUDEN's extensive range of products demonstrates world-leading support to development and progress in the information technology and electronics industries. The company's North American affiliate, TAIYO YUDEN (U.S.A.) INC., operates sales and engineering offices in Chicago IL, Boston MA, Dallas TX, Denver CO, San Diego CA, San Jose CA, and Ontario, Canada.

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