# Development of High-Power Lithium-Ion Capacitor

MIYAGAWA Risa, HATO Yukinori, INAGAWA Masako, INOUE Koji, SEKI Daisuke

**Abstract**

Recent deterioration of the global environment has tended to promote the development of power storage devices aimed at a more effective utilization of energy. Featuring a capability for instantaneous discharge and recovery of large current supply, the capacitor is being evaluated for application in momentary dip/interruption protector devices, energy regeneration from solar cells and wind energy, construction machinery, control of natural energy systems and energy regeneration in automobiles. This paper introduces a newly developed high-power lithium-ion capacitor featuring high capacitance, high energy and a large current charge/discharge capability.

**Keywords**

lithium-ion capacitor, high power, energy regeneration, power storage device, high durability

## 1. Introduction

Recent deterioration of the global environment has made it an urgent matter to discontinue use of fossil fuels and to reduce gas emissions that contribute to global warming. As shown in **Fig. 1** , Japan is considering various environmental and energy technologies by setting targets for the reduction of greenhouse gas emissions by 25% by 2020 compared to those that existed in 1990, as declared in the 2009 UN Summit on Climate Change ( **Fig. 2** ). In particular, the development of power storage devices such as lithium-ion batteries and capacitors is being actively promoted in order to effectively support energy utilization.

The lithium-ion battery has a large capacity and is currently under active development for use as the main power source for environmentally clean automobiles, including electric vehicles and hybrid electric vehicles. On the other hand, the capacitor is effective for the instantaneous charge/discharge of large current supplies and its application is being studied in various new fields such as for the regeneration and control of energy from solar cells and wind energy, construction machinery and momentary dip/interruption protector devices. The deployment of capacitors in the field of automobiles is also being actively pursued, e.g. to back up heating of the catalyst and sensors during idling. In addition, device applications are also being studied for the storage of the regenerated energy produced from idling and for controlling the current supply of

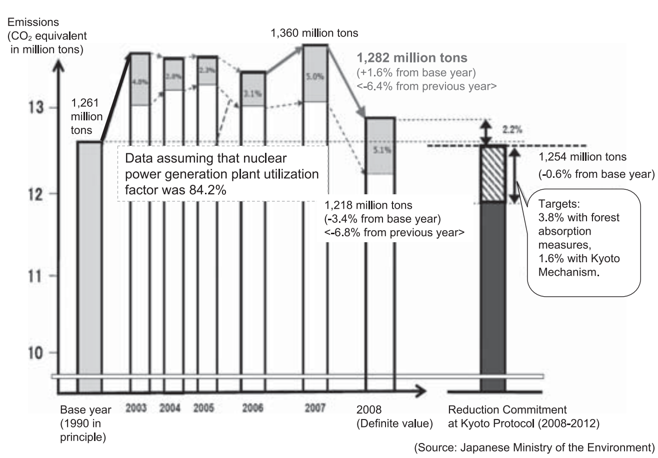


Fig. 1 Greenhouse effect gas emissions of Japan (Source: Japanese Ministry of the Environment).

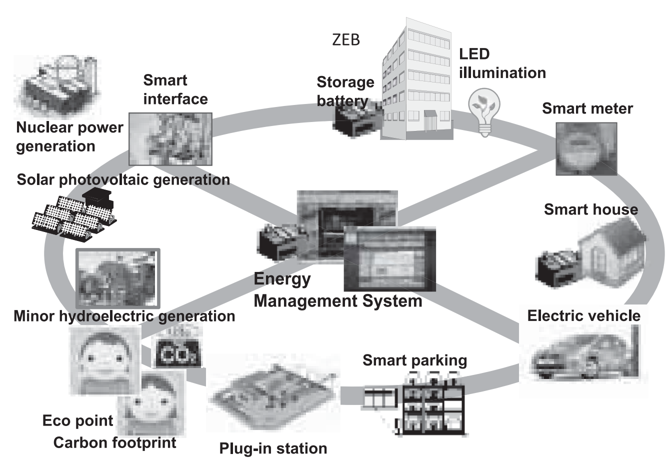


Fig. 2 Energy management system (Source: Japanese Ministry of Economy, Trade and Industry).

lithium-ion batteries of clean automobiles. Consequently, the need to increase the capacitance and power output of capacitors is strongly desired.

Recently attracting attention as the power storage device to meet the above needs is the newly developed lithium-ion capacitor. This is a capacitor that combines both the lithium-ion battery and electric double-layer capacitor technologies. The lithium-ion capacitor has a smaller capacity than the lithium-ion battery but the power output is higher and its endurance of high temperatures is much greater than that of the lithium-ion battery. As it is a power storage device that is superior to the electric double layer capacitor in terms of capacity, energy and durability, it has a great potential for being applied to functions that have hitherto not been considered as a feasible option.

NEC TOKIN is the general power storage device manufacturer that commercialized the aqueous electrolyte-based electric double layer capacitor as a world leading device in this field and a company that possesses technology capable of developing and commercializing large laminate-type lithium-ion batteries including those for car-mount use. Accordingly we proceeded to the development/commercialization of the lithium-ion capacitor by taking advantage of our expertise. Below, we introduce the newly developed high-power lithium ion capacitor that features high capacitance and a large current charge/discharge capability.

## 2. The Lithium-Ion Capacitor (LIC)

### 2.1 Principles of the Lithium-ion Capacitor

The lithium-ion capacitor introduced here belongs to the class of hybrid capacitors for which the positive electrode (cathode) and negative electrode (anode) adopt different principles in storing energy. As shown in **Fig. 3**, the positive electrode uses the activated carbon l that is used in the electrodes of the electric double layer capacitor (EDLC), while the negative electrode uses a carbon material such as the graphite that is used in the negative electrode of the lithium-ion battery. The negative electrode is pre-doped with lithium-ion. When the lithium-ion capacitor is charged, lithium ion is absorbed further at the negative electrode and the anions are physically adsorbed (physisorbed) at the positive electrode. When the lithium-ion capacitor is discharged, the lithium-ion

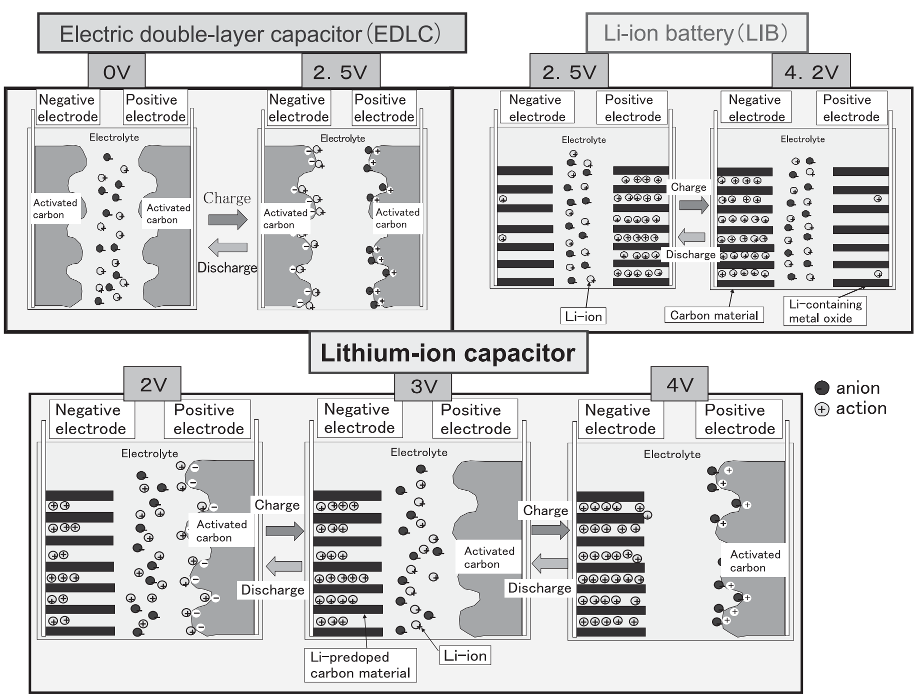


Fig. 3 Operating principles of the lithium-ion capacitor.

is desorbed from the negative electrode and adsorbed at the precise location on the positive electrode from which the anion has been desorbed. As seen here the lithium-ion capacitor exhibits a different mechanism to the other power storage devices. The positive electrode adopts the same physical adsorption mechanism as for the electric double layer capacitor and the negative electrode is accompanied by the chemical reaction involving lithium-ion pre-dope/discharge just as for the negative electrode material of the lithium-ion battery.

### 2.2 Features of the Lithium–ion Capacitor

The most significant feature of the lithium-ion capacitor is its capability of increasing the voltage to about 4 V because lithium ions are pre-doped at the negative electrode in advance as shown in **Fig. 4** . The voltage is as high as about 150% of that of the electric double layer capacitor.

With regard to the cell capacitance (C = Q/V) that can be expressed by the inclination of the charge/discharge curve as shown in Fig. 4, the capacitance of the electric double layer capacitor is equal to 1/2 that of the inclination of the positive/negative electrode potentials. This is because the positive electrode also uses activated carbon like the negative electrode. On the other hand, the positive electrode of the lithium-ion capacitor presents the same potential behavior as the electric double-layer capacitor but the negative electrode uses a carbon material like the lithium-ion battery with an even potential. The cell capacitance (inclination) thus becomes equal to the positive electrode potential, which is twice the capacitance of the electric double layer capacitor. The capacitance can be increased to about four times by design modification.

With a higher voltage and capacitance than the electric double layer capacitor, the lithium-ion capacitor can be regarded as a power storage device that is capable of providing advantages both of high energy and high power densities.

## 3. Characteristics of the High–Power Lithium–Ion Capacitor

### 3.1 Initial Performance of the High–power Lithium–ion Capacitor

This section deals with the performance of our recently developed high-power lithium-ion capacitor. The high-power lithium-ion capacitor shown in **Fig. 5** achieves high power by applying the various technologies that were previously refined in the development of the lithium-ion battery. Lithium-ion cell size of about 100 cc, weight of 190 grams, rated voltage of 3.8 V, cut-off voltage of 2.2 V, low ESR of 1.3 mΩ and low DC-IR of 1.8 mΩ, are featured. The charge and discharge of large current supplies are thereby enabled thanks to the power-emphasized design. Furthermore, we applied various improvements to the developed model and we eventually succeeded in developing a cell with a lower DC-IR of 1.3 mΩ while retaining the same size as shown in **Table** below. The improved model features reduced resistance at a level that is not inferior to that of the electric double layer capacitor of the same capacitance.

**Fig. 6** shows the discharge curves of the improved model for various discharge currents. Even in discharge of a current as high as 200 A, the inclination of the curve is almost identical to that at 10 A and it is possible to discharge up to about 75%

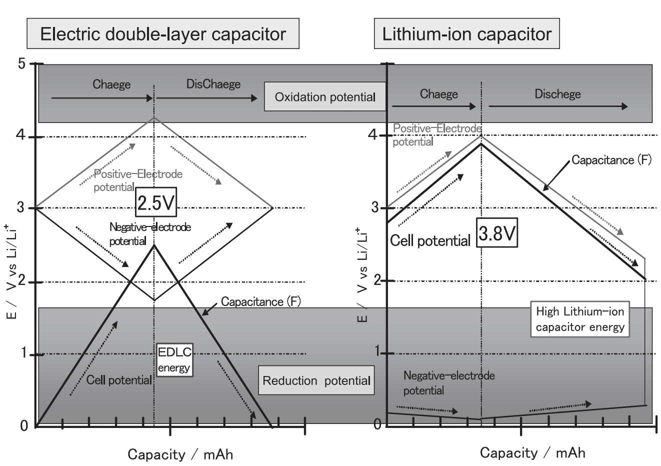


Fig. 4 Charge/discharge behavior of the lithium-ion capacitor.


Basic performance (Typical values)
◆Rated voltage:2.2V - 3.8V ◆Size (mm): 192(L) x 95(W) x 5.5
◆ Capacitance: 1,100 F ◆Weight: 190 g

Fig. 5 High-power lithium-ion capacitor.

of the available discharged capacity at 10 A.

**Fig. 7** shows a Ragone plot of the improved high-power lithium-ion and electric double layer capacitors. As shown here, we confirmed that the energy density of the lithium-ion capacitor is about 240% that of the electric double layer capacitor and that the energy density is maintained as high as about 10 Wh/L, even under a high power density.

Table Performance of high-power lithium-ion capacitor.

| Evaluation Items | | Phase 1 | Phase 2 (Improved model) |
|---|---|---|---|
| Rated voltage | Upper limit | 3.8V | 3.8V |
| | Lower limit | 2.2V | 2.2V |
| Cell size | L ×W ×H | 192 ×95 ×5.4 mm | 192 ×95 ×5.5 mm |
| | Weight | 190g | 190g |
| Initial performance | Capacitance | 1,200F | 1,100F |
| | ESR | 1.3mΩ | 1.0mΩ |
| | DC-IR | 1.8mΩ | 1.3mΩ |

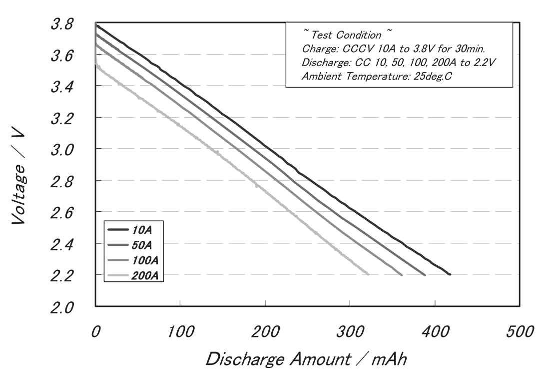


Fig. 6 Discharge curves of discharge currents.

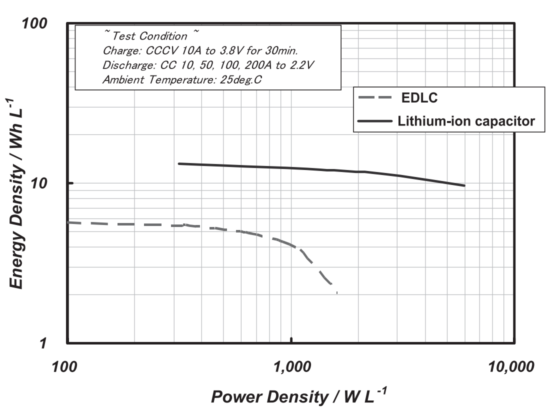


Fig. 7 Ragone plot (Energy vs. output characteristic).

### 3.2 Durability of the High-power Lithium-ion Capacitor

**Fig. 8** shows the performance change when the cell is subjected to a 3.8 V load in an ambient temperature of 60°C. After 2,000 hours of load, the capacitance is maintained at about 95% of the initial value while the DC-IR remains almost identical to the initial value.

**Fig. 9** shows the performance change after cyclic charging/discharging at 100 A between 3.8 V and 2.2 V in an ambient temperature of 60°C. The capacitor presented little degradation after the cycle test just as it did after the load test: After 10,000 cycle, the capacitance was maintained at about 90% of the initial value and the DC-IR was increased only by about 20% of the initial value. In the safety testing including the nail piercing test, over charge test, over discharge test, short-circuit test and thermal test, the cell did not explode or produce fire. The high level of safety featured in our innovative lithium-ion capacitor was thus confirmed.

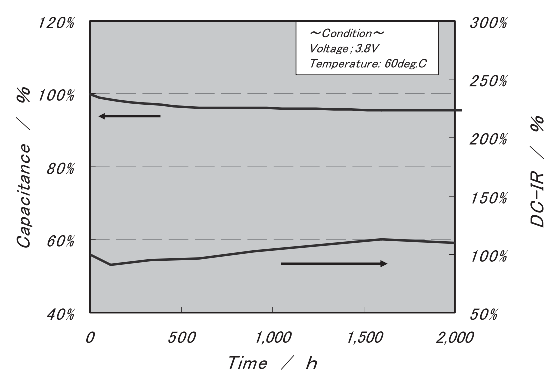


Fig. 8 Life test at 60°C (3.8 V).

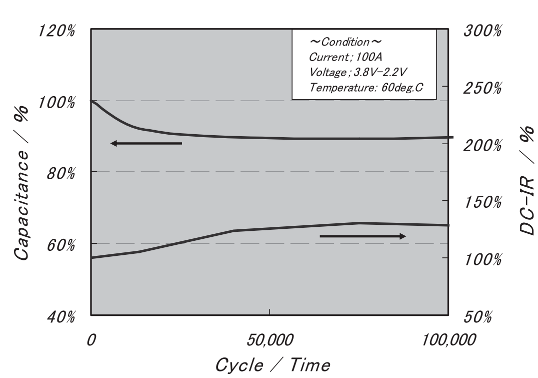


Fig. 9 Cycle test at 60°C (100 A, 3.8 V - 2.2 V).

## 4. Conclusion

As described above, we have succeeded in the development of a high-power lithium-ion capacitor that features high capacitance and excellent durability.

We believe that the high-power lithium-ion capacitor has a promising future in various fields. In particular in the high-power applications that are not currently suitable for the lithium-ion battery in spite of its high capacity or under high temperature/high voltage load environments that are not suitable for the electric double layer capacitor. We aim to develop cells and modules by accurately identifying such needs as match customer applications.

NEC TOKIN is a general device manufacturer of both electric double layer and lithium-ion capacitors. From this standpoint, we aim to contribute to the sustainable development of world resources by proposing optimum power storage devices that can improve the performances of the environmental equipment that is expected to be serially developed in the future.

### Authors' Profiles

**MIYAGAWA Risa**
Assistant Manager
Capacitor Division
NEC TOKIN Corporation

**HATO Yukinori**
Senior Expert
Capacitor Division
NEC TOKIN Corporation

**INAGAWA Masako**
Expert
Capacitor Division
NEC TOKIN Corporation

**INOUE Koji**
Assistant Manager
Capacitor Division
NEC TOKIN Corporation

**SEKI Daisuke**
Assistant Manager
Capacitor Division
NEC TOKIN Corporation