Press release

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Akita University

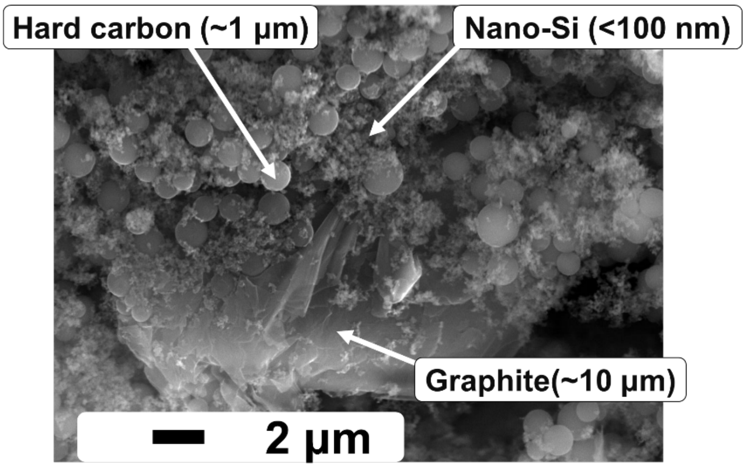
Research findings of Akita University were published in Journal of Power Sources

A novel ternary composite anode material for high-performance Li-ion capacitors

A research group at the Graduate School of Engineering Science of Akita University, led by Dr. Cheng Jie Chng (Postdoctoral researcher) and Prof. Seiji Kumagai, has successfully developed a ternary composite anode for high-performance Li-ion capacitors using graphite, hard carbon and nano-Si.

They leveraged the high specific capacity of Si to improve the device energy density, the amorphous carbon in hard carbon to buffer the drastic volume expansion of Si during charging, and the high electrical conductivity of graphite to enhance power performance. Ultimately, a Li-ion capacitor with high energy density, good rate compatibility, and outstanding cycling performance was developed.

The findings of this research were published online on April 7th, 2025 in the scientific journal “Journal of Power Sources”.



Ternary composite anode for Li-ion capacitors

【Paper details】
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※Please also see Appendix ‘Research details’.

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Research details

1. Research background

High-density electrochemical energy storage devices, such as Li-ion batteries and electric double-layer capacitors, are widely used in mobile terminals, automobiles, household and large-scale energy storage systems, making them essential devices in modern society. Ultimately, the demand for a high-performance energy storage device for wider applications are increasing.

Li-ion capacitors are a type of energy storage device that offers a good balance among energy density, power density, and cyclability, which cannot be achieved by other conventional energy storage devices. Li-ion capacitors are hybrid capacitors that use carbon-based anode materials similar to those of Li-ion batteries and activated carbon used in electric double-layer capacitors as the cathode material (see Figure 1). However, the energy density of current Li-ion capacitors is not as high as that of Li-ion batteries. This is mainly due to the low specific capacity of the carbon material used in the anode (approximately 350 mAh/g for graphite and 200–400 mAh/g for hard carbon). Therefore, it is crucial to improve the energy density of Li-ion capacitors without compromising their power density and cyclability.

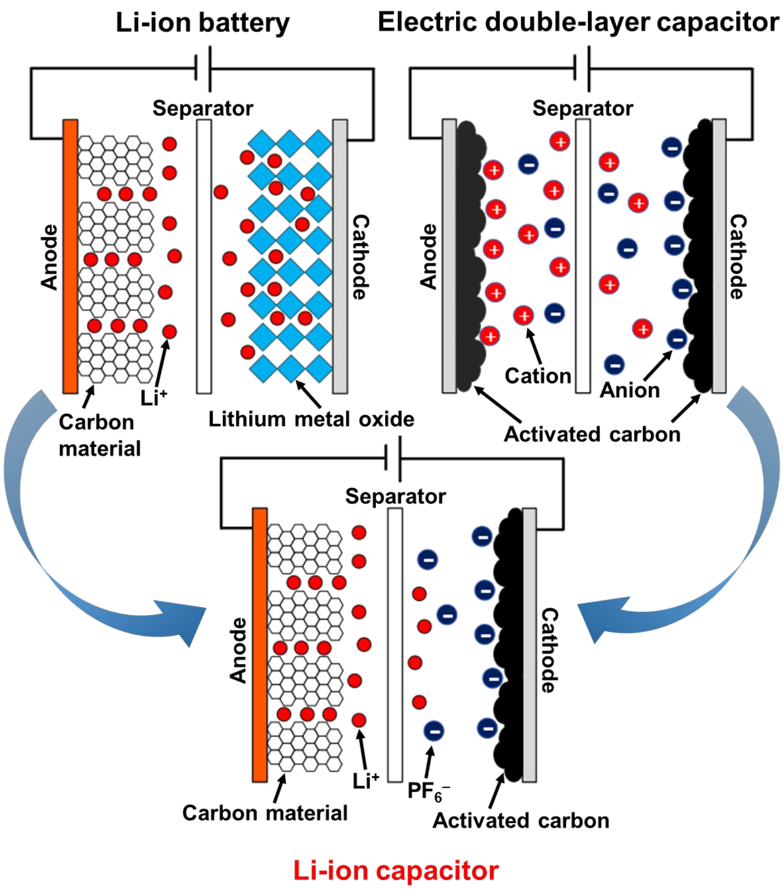

Fig. 1. Working mechanism of Li-ion capacitor.

In 2024, a carbon-based anode material with excellent energy density and durability was developed. A Li-ion capacitor using a composite carbon anode with a graphite:hard carbon mass ratio of 1:3 demonstrated a superior performance to the Li-ion capacitors using graphite-only and hard carbon-only anodes. Additionally, the Li-ion capacitor using the composite carbon anode retained 80.5% of its initial energy density after 10,000 cycles of repeated charge-discharge. The findings of this work were published in a scientific journal.
https://doi.org/10.1016/j.est.2024.112193

Our research focus shifted to silicon (Si) due to its extremely high specific capacity (approximately 3600 mAh/g at room temperature), as we aimed to improve the energy density of Li-ion capacitors. However, Si anodes generally exhibit poor cycling stability as Si undergoes drastic volume changes during charge-discharge processes, owing to its high Li-ion intake. Ultimately, the addition of nano-Si in the graphite anode improved the energy density of Li-ion capacitors, and the graphite was able to remediate the pulverization effects induced by the large volume changes of Si. The Li-ion capacitor using this composite anode achieved a high energy density of 87.3 Wh/kg and retained 87.2% of its initial energy density after 10,000 charge-discharge cycles. The details are reported in a scientific journal.
https://doi.org/10.1002/aesr.202400238

However, a higher energy density is still needed to be a viable alternative to existing Li-ion batteries.

2. Research results

The aim of developing a high-performance composite anode with high energy and power densities, and stable cycling performance for Li-ion capacitors was challenging. Although higher Si content can improve the energy density, it also results in poor cycling performance, owing to the pulverization of anode materials induced by the large expansion of Si particles during charging. Consequently, a ternary composite anode was fabricated using hard carbon, graphite and nano-Si, leveraging the amorphous carbon in hard carbon to buffer the large volume expansion of Si during charging. Ultimately, a ternary composite anode with a mass composition of 60% hard carbon, 20% graphite, and 20% nano-Si demonstrated high energy and power densities, and excellent cycling stability.

The amorphous carbon in the hard carbon effectively buffered the expansion of the Si particles during charging, thereby improving device cycling performance. Additionally, the presence of graphite enhanced ionic conductivity, facilitated Li-ion diffusion, and thus improved the power density of the Li-ion capacitors. Ultimately, the Li-ion capacitor using the ternary composite anode achieved a maximum energy density of 129.3 Wh/kg, and retained 88.4% of its initial energy density after 10,000 charge-discharge cycles at 2.0–4.0 V (see Figure 2). Furthermore, the developed Li-ion capacitor successfully retained 90.1% of its energy density, even after an additional 5,000 charge-discharge cycles at a cell voltage of 1.5–4.2 V, a more rigorous condition. In other words, a Li-ion capacitor with outstanding durability was successfully developed.

3. Research significance

The electrification of vehicles and the introduction of renewable energy are gaining momentum, aiming to build a carbon-neutral society by 2050. In order to meet the increasingly stringent reduction of greenhouse gas emissions in the future, the energy storage devices must not only deliver high performance, but also meet a wider range of operational requirements.

In the development of high-performance Li-ion batteries, composite anode materials with a small amount of Si added to graphite have been widely used. However, in capacitor-based energy storage devices, where long cycle life is essential, the use of Si in anodes has been very limited due to its poor cycling stability. In this study, a ternary composite anode material for Li-ion capacitor applications with high energy and power densities along with excellent durability has been developed through a simple and easily scalable method, which is mechanically mixing graphite, hard carbon, and nano-Si powders.

This research provides valuable insight into the innovative design of anode materials for Li-ion capacitors and their aging mechanisms. The findings will greatly contribute to enhancing the performance and diversification of energy storage devices, while supporting technological innovation for decarbonization of this country and the world.

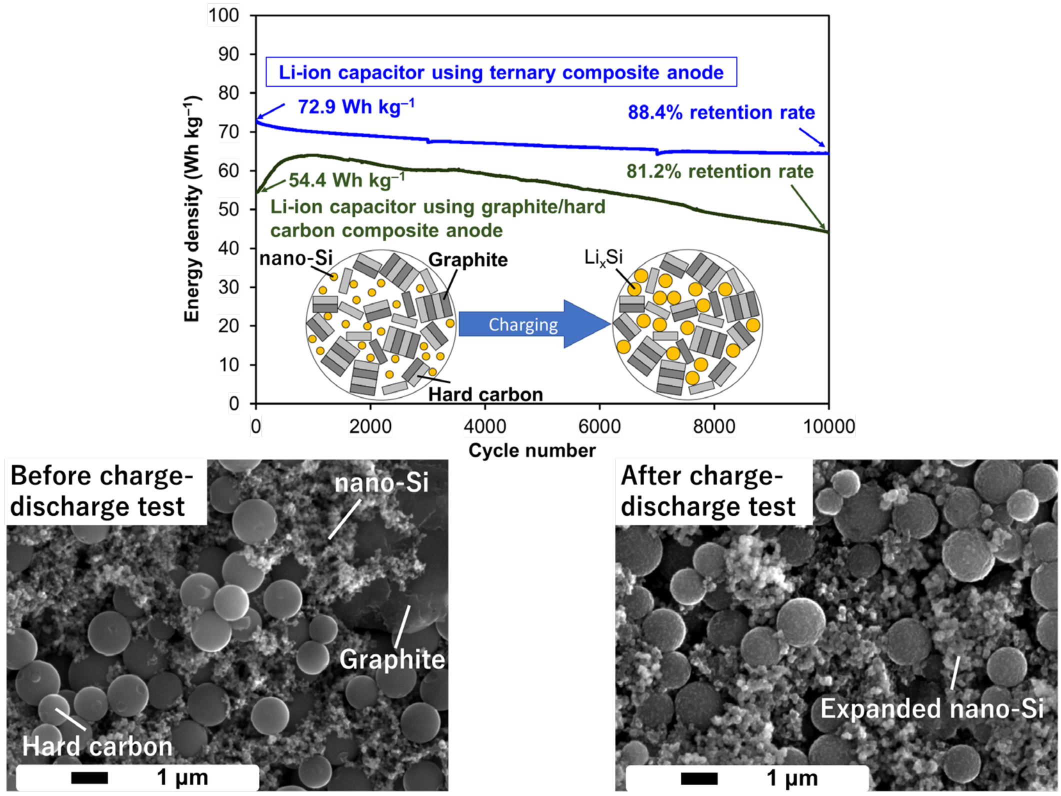

Fig. 2. Cycling performances of Li-ion capacitors and the SEM images of the ternary composite anode before and after charge-discharge test.

4. Research prospect

At present, nano-Si is an expensive material, which may hinder the industrial application of ternary composite anode materials. Therefore, we plan to explore alternative approaches using more cost-effective submicron- and micron-sized Si particles. We will also explore the use of environmentally friendly materials, such as Si recovered from spent photovoltaic panels.

Simultaneously, we aim to develop an anode material production technology that can stabilize the cycling performance of Si-based anodes, even with increased Si content. Ultimately, our research group aims to develop Li-ion capacitors with superior charge-discharge performance compared with currently available devices.