

## Smart Energy Storage Devices with Visual Charge Monitoring

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### Overview

The growing demand for energy devices that store and deliver power and offer additional functionalities, like instant performance monitoring, is evident. We introduce a groundbreaking method to visually display the charge status of an energy storage device through its color changes based on a unique molecular network of an electrochromic (EC) material. This inventive approach has significant potential in various markets, including optical telecommunication, medical, industrial, consumer electronics, wearable technology, and automotive sectors.

### Background and Unmet Need

Electrochromic (EC) materials change their optical transparency when voltage is applied. A particularly promising category of EC materials are metal-organic coordination complexes. Given the impressive EC characteristics of these complexes, there's much potential to develop processes for preparing high-performance EC materials and films containing them. Furthermore, the full potential of electrochromic molecular- and polymer-based devices remains largely untapped. This is partly due to challenges in production, cost and issues with stability and device integration that limit widespread use.

Combining different functions in organic devices and coupling them with conventional technologies is still at an early stage. A key objective in energy device development is to amalgamate energy storage and distribution with extra capabilities and the market is increasingly seeking advanced electronic devices that leverage the electrochromic properties of their components for enhanced and integrated functionality.

### The Solution

Prof. van der Boom and his team have developed an innovative energy storage device in which a color change visually indicates the charging status and its operation (charging&#128;&#147;discharging) is indicated by optical changes (from colored to transparent). Based on that a functional, integrated electrochromic-hybrid supercapacitor (EHSC) was developed.

### Technology Essence

Metal-coordinated organic complexes form an interesting category of electrochromic (EC) materials, characterized by a metal ion coordinately bonded to an organic molecule (ligand). In the newly developed energy storage devices, the metal-ion coordinated organic complex serves as a redox-active material on at least one electrode. The color or absorption spectrum of the EC material shifts in response to the oxidation or reduction state of the metal ions. The heart of the device is an electrochromic metallo&#128;&#147;organic layer that functions as both the battery-type electrode and the charge indicator. The capacitive electrode is a layered composite of carbon nanotubes (CNTs) and a conductive polymer. The device operates under low potentials (â&#136;&#146;0.6 to 2

V), displays high energy and power densities, a high coulomb efficiency (99%), a short charging time ( $\approx 2$  s), and a charge retention of  $\approx 60$  min. The electrochromic hybrid supercapacitor is wired with a conventional circuit board to be charged and subsequently to operate a diode. The results demonstrate the potential of metalloorganic assemblies for usage in these types of supercapacitors.

## Applications and Advantages

- Visually indicates the charge level of energy storage devices. A wide range of colors are available.
- Suitable for various energy storage devices, including electrodes, capacitors, supercapacitors, hybrid supercapacitors, and batteries.
- Utilizes the electrochromic properties of the device to offer varied functionalities within a single device.
- Implementation in construction materials products like smart windows, light filtering windows, tintable reflective surfaces, and wearable technology.
- Applicable in electronic display systems, including color filter displays, monitors, and televisions.
- Useful in optoelectronic systems such as optical switches and optical/laser equipment.
- Capable of being produced on a large scale by using green solvents. The coating can be prepared using different methods, including dip, spin, and spray coating.

## Development Status

Prof. van der Boom and his team have developed smart energy storage devices that enable monitoring of its charging status by the naked eye. The team has successfully demonstrated film fabrication and characterization of EC materials on both rigid and flexible supports. They have also demonstrated the incorporation of EC films in solid configurations, for example - in the basic structure of an electrochromic device and explored various EC deposition methods. Furthermore, the researchers have shown an integrated optoelectronic device where the level of charge is indicated through color change and have developed a unique composite capacitive electrode to obtain efficient hybrid supercapacitors. Stability, both in color and energy, for more than 1000 consecutive charging&discharging cycles was demonstrated and no significant changes in device temperature were indicated under the operating conditions. Moreover, the team has shown that their devices can be used to operate in widespread used printed circuit boards (PCBs).

## Market Opportunity

are numerous and significant market opportunities, including (1) Optical Telecommunications: various optoelectronic systems such as lasers, optical systems, and optical switches; (2) Medical: Applications in healthcare technologies and devices involved with lasers and optical systems; (3) Industrial: Use in machining and manufacturing processes; (4) Consumer electronics: Retail of color filter displays, monitors, and televisions; (5) Military: Implementation in defense-related optoelectronic systems; (6) Space Exploration: Utilization in space-related optoelectronics; (7) Construction and Building and (8) Automotive. Both sectors involve the creation of smart windows, light-filtering windows, and developing mirrors or reflective surfaces.

## Patent Status

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