With increasing demand for efficient energy usage, exploring environmentally friendly and sustainable energy storage devices has received immense attention. In this issue of ACS Central Science, Dong et al. report lithium-ion-assisted, ultrafast charging, double-electrode smart windows with energy storage and display applications. This work opens the gates to next-generation electrochromic energy storage and smart windows.1

There has been a growing interest in low-energy consumption and self-powered electrochromic energy storage devices. Transparent electrochromic windows have the ability to persistently and reversibly change their optical and electrical properties under the influence of an electrical voltage.2,3 At the same time, sunlight can be blocked by smart windows to efficiently adjust the ambient temperature in buildings, which could help conserve energy and thereby fossil fuels.4 There have been many electrochromic smart windows reported in recent years, but they usually have only one electrochromic electrode, and the transmittance cannot go down to a very low value. Most electrochromic electrodes are usually blue when they are in a colored state, which limits windows applications in the protection of personal privacy and efficient use of sunlight. To improve the color conversion efficiency of smart windows, it is preferable to use a second electrochromic thin film as the ionic storage function to form double-electrode electrochromic windows.5 In this case, one electrochromic thin film is colored in its reduced state and bleached in its oxidized state. The second electrochromic film should have the opposite effect, i.e., bleached in its reduced state and colored in its oxidized state. WO_red and PB are cathodic and anodic coloration thin films, respectively.3

Electro-fluorochromic materials capable of a novel luminescent switching open a powerful way to design optoelectronic devices for displays and information storage. The intensity of the fluorescence can be adjusted by electrical stimuliates. However, there are few materials that have both electrical activity and fluorescence properties. To overcome the challenge, previous work from Dong’s group demonstrated that electrochromic materials are cleverly combined with fluorescence materials to form an electro-fluorochromic switching. Fluorescence intensity can be regulated by a redox process of electrochromic materials mentioned in previous reports.6,7

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In their latest work published in ACS Central Science, the system proposed by Dong’s group takes advantage of the complementary electrochromic behavior of asymmetric electrodes (FTO/PB and FTO/WO) such that the all electrochromic smart windows appear extremely dark in their colored states and nearly transparent in their bleached states (Figure 2). Their changed color can be used to modulate the incoming natural light to preserve privacy without blinds and/or curtains. In addition, the self-bleaching/discharge process of the two electrochromic electrodes can be implemented by connecting only the wires between the FTO/PB and FTO/WO electrodes. The large potential difference and complementary electrochromic behaviors between the coloring electrodes ensured that the self-bleaching process occurred quickly and thoroughly. The coloring, or charging, process was achieved through a Mg-O2 battery based on a high-efficiency catalyst (FeN5 single atomic catalyst) of O2 reduction reaction (ORR), which avoids the use of an oxidizing agent in the system and solves the intractable problem of slow self-coloring/charging of PB and WO synchronously. The small radius of Li+ ions facilitates quick insertion and ejection in electrochromic processes of FTO/PB and FTO/WO electrodes. Thus, the Li+ ion plays an important role in the ultrafast charging and discharging process, which significantly shortened the switching response time. In addition, the fluorescence molecule Ru@SiO2 assembled on the FTO/WO and the FTO/PB electrodes respectively to form a fluorescence switching based on double electrochromic electrodes (FSDECEs). Fluorescence quenching can be realized by fluorescence resonance energy transfer (FRET) of the donor (Ru@SiO2) and acceptor (WOred and PB). Reversibly switching on/off states of FSDECEs can be
achieved only by repeatedly connecting and disconnecting wires between the two electrodes. The FSDECEs (FTO/PB/Ru@SiO₂||Ru@SiO₂/WO/FTO) demonstrate a high fluorescence contrast, short response time, and long-term cycling reversibility. The reported double-electrode complementary electrochromic behaviors play an important role in simultaneously lowering the transmittance of sunlight. This system provides a novel way to design other smart windows.

The smart windows are composed of an anode and a cathode with matching potentials and complementary electrochromic behavior to implement a self-bleaching/energy release process by directly connecting only the wire between the electrochromic electrodes, which overcomes the problem of external energy or metal anode being consumed in the self-bleaching process.

It is particularly important to select two suitable electrochromic materials. The alternative double electrochromic materials should meet the requirement of coloring or bleaching simultaneously under the same potential. Double electrochromic electrodes can enhance the optical modulation as well as store and release more energy when needed as compared to single electrochromic electrodes. The darker colors in the coloring state can enhance privacy and store energy more efficiently. The FeN₅ single atomic catalyst was smartly applied in the proposed system. The highly efficient catalytic activity of O₂ reduction reaction can solve the tough problem of the slow self-coloring process of electrochromic electrodes. This work throws light on next-generation electrochromic energy storage, smart windows, and optoelectronic devices for display and information storage. It could lead to highly reactive catalysts to improve the energy storage level as well as higher optical modulation and a faster self-charging/discharging process of electrochromic smart windows.

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Notes
The author declares no competing financial interest.

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