net movement. Conventional electronics typically use a circuit configuration called a full-wave rectifier to convert AC to DC. This circuit is arranged in such a way that an AC signal current may be used while still maintaining a forward flow of current. For ionic currents, this allows for extended periods of operation with charge capacities surpassing that of conventional metal electrodes.

Berggren's group constructed a bipolar membrane-type ion current rectifier using conducting poly(3,4-ethylene dioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) electrodes. A typical bipolar membrane contains oppositely charged ion-selective membranes; this functions like a diode for ionic currents. The group then puts this material through the rigors of a typical four-diode full-wave rectifier and found that it performed well and was able to maintain an overall rectifying ionic current efficiency of 86%, with higher efficiencies of 95% during steady-state operation.

To demonstrate its suitability as a drug delivery system, the researchers constructed a cation-selective channel inside the ionic four-diode bridge. They then used this channel to deliver a common neurotransmitter called acetylcholine (ACh) from a source to a target electrolyte. They find that this system permits a nearly undisturbed delivery of ACh over an extended period of time without the production of adverse side reactions.

While their device suffers from some voltage and frequency limitations, Berggren and colleagues have demonstrated that this type of four-diode bridge could be used to improve select types of electrokinetic devices. Particularly when compared to similar systems that utilize moving parts for ion transport, this simple approach paves the way for smaller ionic circuits with no moving parts, perfect for implantable devices.

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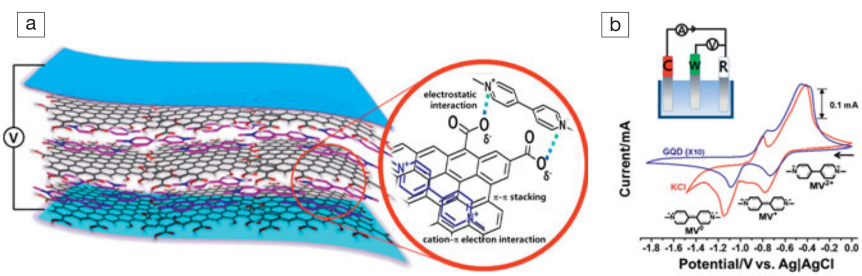
Nano Focus

Electrolyte-free electrochromic device fabricated using graphene quantum dot-viologen nanocomposites

The uniqueness of electrochromic materials lies in their ability to undergo a reversible change in optical properties with applied voltage. These electro-optical properties can be used to fabricate novel, technologically advanced electrochromic devices (ECDs) ranging from e-paper to smart windows to display panels. Conventional ECDs require the use of an electrolyte to support electrochromic reactions. Now E. Hwang, H. (Hanleem) Lee, and their colleagues from Sungkyunkwan University, South Korea, have introduced an electrolyte-free ECD that functions using graphene quantum dot-viologen nanocomposites. They published their research in the August 13 issue of *Advanced Materials* (DOI: 10.1002/adma.201401201; p. 5129).

According to the researchers, the use of electrolytes in an ECD system could lead to the unwanted decomposition of metal-ion containing electrochromes at high voltages. In order to combat the negative effect of electrolytes on device stability and performance, the researchers developed a flexible ECD where the electrochrome, methyl-viologen (MV^{2+}) is combined with electrostatically strong, conductive graphene quantum dots (GQDs). There is strong adherence between the MV^{2+} (cation) and GQDs (anion) as a result of strong electrostatic and π–π interactions. The resultant ECDs demonstrate stable electrochromic performance without the use of an electrolyte.



(a) Illustration of an electrolyte-free flexible electrochromic device of MV^{2+} graphene quantum dots (GQDs). (b) Cyclic voltammogram of 5 mM MV^{2+} at an indium-tin-oxide electrode in an aqueous solution containing 8 mg mL^{-1} GQD (blue line) and 0.1 M KCl (red line) at a scan rate of 100 mVs^{-1}. Inset: A depiction of a three-electrode cell composed of a working electrode (W), a counter electrode (C), and a reference electrode (R). Reproduced with permission.

Panel (a) of the figure shows an illustration of an electrolyte-free flexible electrochromic device with MV^{2+}-GQDs. The researchers used a three-electrode electrochemical cell to demonstrate the electrochromic behavior of MV^{2+} in a GQD solution using cyclic voltammetry, as depicted in the inset in panel (b) of the figure. The color change of the electrochrome from colorless (MV^{2+}) to purple (MV^{+}) is represented as two redox peaks in the cyclic voltammogram trace of MV^{2+}-GQD (blue line), where the voltage is swept between –1.8 V and 0 V. The researchers also compared the electrochromic behavior of MV^{2+} in GQDs to MV^{2+} in a KCl electrolyte [red plot in the figure (b)]; a comparison of the corresponding cyclic voltammogram traces showed an exact match in the peaks for MV^{2+} in GQDs and the peaks for MV^{2+} in the KCl electrolyte.

The research team concluded that GQDs are stable enough to perform electrolyte-like charge transfer in solution and that they act as an electron transfer medium to facilitate oxidation or reduction of organic species. The researchers also extended their experiments to demonstrate the thermal and mechanical stability of GQDs. The results provide useful guidelines for the fabrication of stable, durable, and flexible electrolyte-free ECDs in the future. □

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