drive the robot forward, the researchers shortened one of the scaffold's pillars, causing the crossbeam to bend slightly and the muscle cells to exert differential force on the pillars.

This bio-bot is no cheetah: it moves at a relatively slow pace of around 1.5 body lengths per minute. However, Bashir hopes that the concept could ultimately be incorporated into a more complex machine with neural connections regulating the muscle cells. "Our next step is working to integrate neurons into the structure, so you could provide a signal to the neuron and the neuron would control the movement," he said.

"It's clear that there's an opportunity to take technological advances and combine them with what nature has developed to come up with ways of making things that are even better," said Ali Khademhosseini, a bioengineer at Harvard-MIT's Division of Health Sciences and Technology who was not involved in the research. "I think [this experiment] opens up a lot of new possibilities."

Laurel Hamers

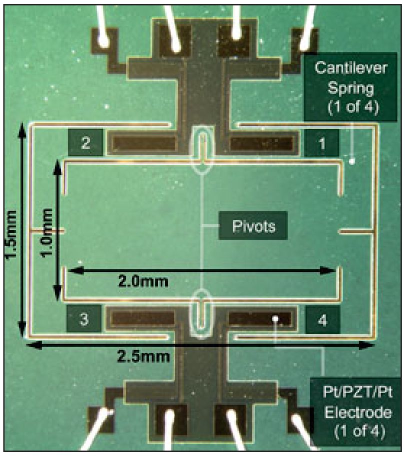
Bio Focus

Fly-inspired PZT sound detector

A team of researchers at The University of Texas at Austin (UT Austin) has developed a tiny prototype device that mimics the hearing mechanism of a parasitic fly, the yellow-colored *Ormia ochracea*. This development may be useful for a new generation of hypersensitive hearing aids. Described in the July 22 online edition of *Applied Physics Letters* (DOI: 10.1063/1.4887370), the 2-mm-wide device uses piezoelectric materials, which turn mechanical strain into electric signals. The use of these materials means that the device requires very little power.

The space between the ears of insects is typically so small that sound waves essentially hit both sides simultaneously. However, the *O. ochracea* has an unusual physiological mechanism in which the sound phase shifts slightly when the sound goes in one ear and when it goes in the other. The fly, whose ears are less than 2 mm apart, has an ear structure that resembles a tiny teeter-totter seesaw about 1.5 mm long. Teeter-totters, by their very nature, vibrate such that opposing ends have a 180° phase difference, so even very small phase differences in incident pressure waves force a mechanical motion that is 180° out of phase with the other end. This effectively amplifies the four-millionths of a second time delay the *O. ochracea* experiences in its hearing.

Neal Hall, an assistant professor in the Electrical and Computer Engineering Department at UT Austin, and his graduate student Michael Kuntzman built a miniature pressure-sensitive teeter-totter in silicon that has a flexible beam and integrated piezoelectric materials. By using multiple piezoelectric sensing ports, the researchers enable numerous vibration modes which then amplify the interaural time and level differences such as the fly experiences. The use of piezoelectric materials was their original innovation, and it allowed them to simultaneously measure the flexing and the rotation of the teeter-totter beam. Simultaneously measuring these two vibration modes allowed the researchers to replicate the fly's special ability to detect sound direction in a device essentially the same size as the fly's physiology.



A photograph of the biologically inspired microphone taken under a microscope, providing a top-side view. The tiny structure rotates and flaps about the pivots (labeled), producing an electric potential across the electrodes (labeled). Credit: N.Hall/UT Austin.

Bio Focus

Conducting polymers utilized to overcome electrode limits in ionic transport systems

The transport of particles through a fluid by an electric current, known as electrokinetics, is a process used in a number of well-known applications such as gel electrophoresis and drug delivery systems. These types of ionic conductors operate based on the interaction of a direct current (DC), applied between metal electrodes and charged ions suspended in a fluid. This process, however, can have a number of critical drawbacks such as the production of chemical side products or gases that may impede particle movement. Moreover, the charge limitations of typical metal electrodes present the largest handicap to current technology in this field.

As reported in the August 13 issue of *Advanced Materials* (DOI: 10.1002/adma.201401258; p. 5143), Magnus Berggren and his research team from Linköping University in Sweden have built a four-diode full-wave rectifier for the transport of ionic species using conducting polymer electrodes to overcome this considerable restriction. Conducting polymers can be used to improve electrode capacity by increasing effective electrode area; however, most conducting polymers cannot withstand prolonged DC, necessitating alternating current (AC) operation. The AC acts just as it would in an electrical circuit, producing a periodic reversal in the direction of particle flow that would produce no

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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.

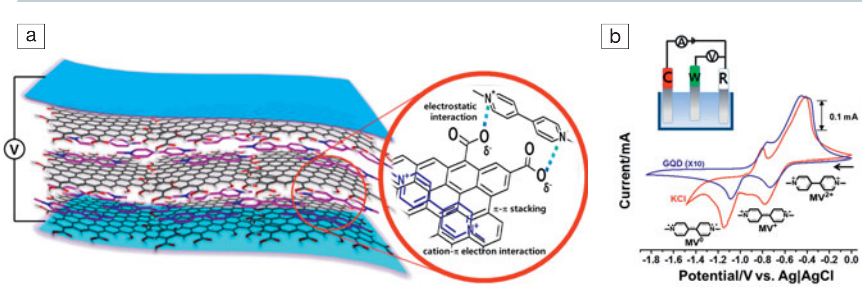
Ian J. McDonald

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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