Bad virus put to good use: Breakthrough batteries

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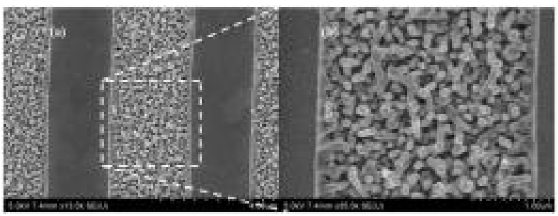


SEM images of nickel-coated TMV arrays patterned using photolithography onto a silicon wafer Credit: University of Maryland, College Park

(PhysOrg.com) -- Viruses have a bad rep--and rightly so. The ability of a virus to quickly and precisely replicate itself makes it a destructive scourge to animals and plants alike. Now an interdisciplinary team of researchers at the University of Maryland's A. James Clark School of Engineering and College of Agriculture and Natural Resources, brought together by Professor Reza Ghodssi, is turning the tables, harnessing and exploiting the "self-renewing" and "self-assembling" properties of viruses for a higher purpose: to build a new generation of small, powerful and highly efficient batteries and fuel cells.

The rigid, rod-shaped Tobacco mosaic virus (TMV), which under an electron microscope looks like uncooked spaghetti, is a well-known and widespread plant virus that devastates tobacco, tomatoes, peppers, and other vegetation. But in the lab, engineers have discovered that they can harness the characteristics of TMV to build tiny components for the lithium ion batteries of the future. They can modify the TMV rods to bind perpendicularly to the metallic surface of a battery electrode and arrange the rods in intricate and orderly patterns on the electrode. Then, they coat the rods with a conductive thin film that acts as a current collector and finally the battery's active material that participates in the electrochemical reactions.

As a result, the researchers can greatly increase the electrode surface area and its capacity to store energy and enable fast charge/discharge times. TMV becomes inert during the manufacturing process; the resulting batteries do not transmit the virus. The new batteries, however, have up to a 10-fold increase in energy capacity over a standard lithium ion battery.

"The resulting batteries are a leap forward in many ways and will be ideal for use not only in small electronic devices but in novel applications that have been limited so far by the size of the required battery," said Ghodssi, director of the Institute for Systems Research and Herbert Rabin Professor of Electrical and Computer Engineering at the Clark School. "The technology that we have developed can be used to produce energy storage devices for integrated microsystems such as wireless sensors networks. These systems have to be really small in size--millimeter or sub-millimeter--so that they can be deployed in large numbers in remote environments for applications like homeland security, agriculture, environmental monitoring and more; to power these devices, equally small batteries are required, without compromising in performance."

TMV's nanostructure is the ideal size and shape to use as a template for building battery electrodes. Its self-replicating and self-assembling biological properties produce structures that are both intricate and orderly, which increases the power and storage capacity of the batteries that incorporate them. Because TMV can be programmed to bind directly to metal, the resulting components are lighter, stronger and less expensive than conventional parts.

Three distinct steps are involved in producing a TMV-based battery: modifying, propagating and preparing the TMV; processing the TMV to grow nanorods on a metal plate; and incorporating the nanorod-coated plates into finished batteries. It takes an interdisciplinary team of UM scientists and their students to make each step possible.

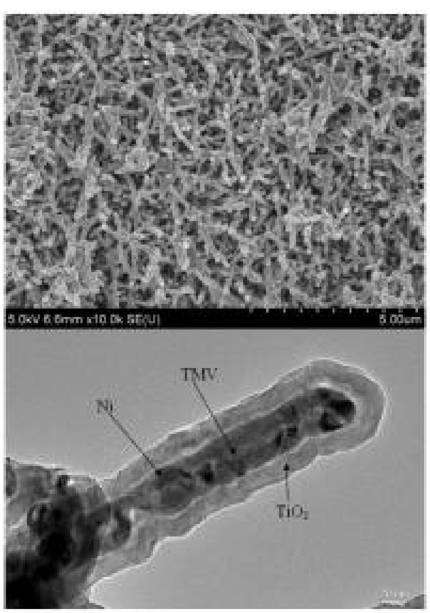
James Culver, a member of the Institute for Bioscience and Biotechnology and a professor in the Department of Plant Science and Landscape Architecture, and researcher Adam Brown had already developed genetic modifications to the TMV that enable it to be chemically coated with conductive metals. For this project they extract enough of the customized virus from just a few tobacco plants grown in the lab to synthesize hundreds of battery electrodes. The extracted TMV is then ready for the next step.

Scientists produce a forest of vertically aligned virus rods using a process developed by Culver's former Ph.D. student, Elizabeth Royston. A solution of TMV is applied to a metal electrode plate. The genetic modifications program one end of the rod shaped virus to attach to the plate. Next these viral forests are chemically coated with a conductive metal, mainly nickel. Other than its structure, no trace of the virus is present in the finished product, which cannot transmit a virus to either plants or animals. This process is patent-pending.

Ghodssi, materials science Ph.D. student Konstantinos Gerasopoulos, and former postdoctoral associate Matthew McCarthy (now a faculty member at Drexel University) have used this metal-coating technique to fabricate alkaline batteries with common techniques from the semiconductor industry such as photolithography and thin film deposition.

While the first generation of their devices used the nickel-coated viruses for the electrodes, work published earlier this year investigated the feasibility of structuring electrodes with the active material deposited on top of each nickel-coated nanorod, forming a core/shell nanocomposite where every TMV particle contains a conductive metal core and an active material shell. In collaboration with Chunsheng Wang, a professor in the Department of Chemical and Biomolecular Engineering, and his Ph.D. student Xilin Chen, the researchers have developed several techniques to form nanocomposites of silicon and titanium dioxide on the metalized TMV template. This architecture both stabilizes the fragile, active material coating and provides it with a direct connection to the battery electrode.

In the third and final step, Chen and Gerasopoulos assemble these electrodes into the experimental high-capacity lithium-ion batteries. Their capacity can be several times higher than that of bulk materials and in the case of silicon, higher than that of current commercial batteries.



SEM image of Ni/TiO2 nanocomposite electrode (top), cross-section TEM image of an individual nanorod showing the core/shell nanostructure Credit: University of Maryland, College Park

"Virus-enabled nanorod structures are tailor-made for increasing the amount of energy batteries can store. They confer an order of magnitude increase in surface area, stabilize the assembled materials and increase conductivity, resulting in up to a10-fold increase in the energy capacity over a standard lithium ion battery," Wang said.

A bonus: since the TMV binds metal directly onto the conductive surface as the structures are formed, no other binding or conducting agents are needed as in the traditional ink-casting technologies that are used for electrode fabrication.

"Our method is unique in that it involves direct fabrication of the electrode onto the current collector; this makes the battery's power higher, and its cycle life longer," said Wang.

The use of the TMV virus in fabricating batteries can be scaled up to meet industrial production needs. "The process is simple, inexpensive, and renewable," Culver adds. "On average, one acre of tobacco can produce approximately 2,100 pounds of leaf tissue, yielding approximately one pound of TMV per pound of infected leaves," he explains.

At the same time, very tiny microbatteries can be produced using this technology. "Our electrode synthesis technique, the high surface area of the TMV and the capability to pattern these materials using processes compatible with microfabrication enable the development of such miniaturized batteries," Gerasopoulos adds.

While the focus of this research team has long been on energy storage, the structural versatility of the TMV template allows its use in a variety of exciting applications. "This combination of bottom-up biological self-assembly and top-down manufacturing is not limited to battery development only," Ghodssi said. "One of our lab's ongoing projects is aiming at the development of explosive detection sensors using versions of the TMV that bind TNT selectively, increasing the sensitivity of the sensor. In parallel, we are collaborating with our colleagues at Drexel and MIT to construct surfaces that resemble the structure of plant leaves. These biomimetic structures can be used for basic scientific studies as well as the development of novel water-repellent surfaces and micro/nano scale heat pipes."

Provided by University of Maryland

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