Researchers fabricate novel flexible supercapacitors on paper

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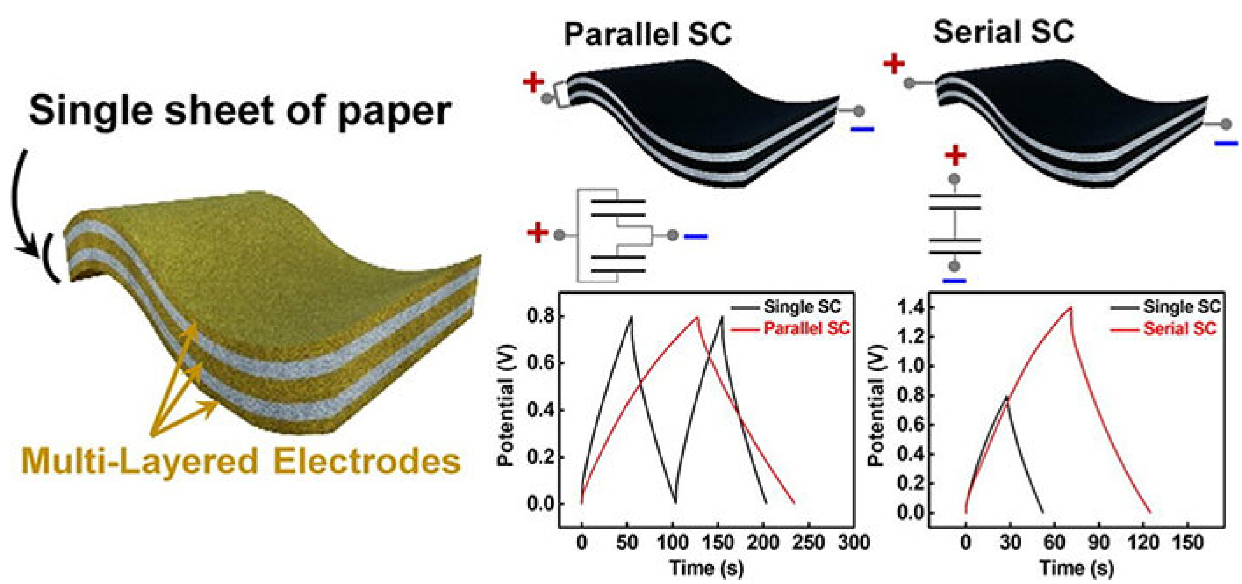

Researchers from Chung-Ang University, Korea have fabricated a flexible paper-based high energy storage device that can be used in both parallel and serial single supercapacitor (SC) configurations without modifying external wires and circuits. The equivalent circuits and corresponding electrochemical performance data are shown on the bottom right. Credit: Dr. Inho Nam and Prof. Suk Tai Chang from Chung-Ang University, Korea

Wearable devices such as smartwatches, fitness trackers, and virtual reality headsets are becoming commonplace. They are powered by flexible electronics that consist of electrodes with plastic or metal foil as substrates. However, both of these come with their own drawbacks.

Plastics suffer from poor adhesion and low durability, while metal foils make the devices bulky and less flexible.

In light of this, paper is a promising alternative. It is porous, light, thin, foldable, and flexible. Moreover, paper has randomly distributed fibers that provide a large surface area for depositing active electrode material, making for excellent electrochemical properties.

Accordingly, researchers have developed various paper-based supercapacitors, devices that store electric charge and energy, by stacking multiple sheets, acting as positive and negative electrodes and separators. However, such an arrangement increases device size and resistance. In addition, they tend to form creases, peel off, and slip over each other, which further deteriorate device performance.

To address these issues, a group of researchers from Chung-Ang University, led by Professor Suk Tai Chang and Associate Professor Inho Nam, recently fabricated a structure comprising multi-layer electrodes vertically integrated within a single sheet of paper. The novel design overcomes the problems associated with stacked sheets while retaining the inherent advantages of a paper-based substrate. Their work was made published in *Chemical Engineering Journal*.

Dr. Nam briefly describes the fabrication process: "First, a water-repellent paraffin wax layer was printed and heated on both sides of a filter paper. This formed a water-friendly channel surrounded by a wax barrier within the paper. Following this, the paper was successively dipped in gold nanoparticle and gold enhancement solutions, which penetrated the channel via capillary action, resulting in a gold electrode in the middle of the paper. Similar electrodes were then fabricated on top and bottom surfaces of the paper to obtain a multi-layer electrode platform."

The researchers completed the supercapacitor design by depositing manganese dioxide—an active electrode material—on the gold-paper electrode, which was then immersed in a polyvinyl alcohol–sodium sulfate gel electrolyte solution. After the gel had solidified, they characterized the manganese dioxide-gold-paper electrodes using various electrochemical measurement techniques, such as cyclic voltammetry, galvanostatic charge and discharge, and electrochemical impedance spectroscopy.

To their delight, the supercapacitor design showed a low electrical resistance, high foldability, and good mechanical strength. Manganese dioxide enhanced its active surface area, which further boosted the electrochemical performance. Additionally, the supercapacitor demonstrated high energy storage with maximum areal energy and power densities of 13.73 μW-hr-cm^{-2} and 1.6 mW-cm^{-2}, respectively. Moreover, it retained its storage capacity even after undergoing 6000 charge-discharge cycles.

In effect, the multi-layer electrode supercapacitor platform is a super-dense energy storage device that utilizes the two-dimensional paper surface as a three-dimensional scaffold. Further, it can be used in parallel as well as serial integrated circuit configurations without modifying external wires and circuits.

"Our proposed platform circumvents most fabrication challenges related to two-dimensional energy storage sheets. We believe that the findings of our study will guide the future fabrication of paper-based electronics with more multi-layered electrodes," says Prof. Chang.

More information: Yeon Woo Kim et al, Vertical integration of multi-electrodes inside a single sheet of paper and the control of the equivalent circuit for high-density flexible supercapacitors, *Chemical Engineering Journal* (2022). DOI: 10.1016/j.cej.2022.140117

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