New Paper-Thin Batteries Can Decompose in Soil Within a Month Once Expended

This innovation could potentially be integrated into smart devices and wearable devices like biomedical sensors for health monitoring and foldable smartphones.

Scientists at Nanyang Technological University (NTU), Singapore have created bendable, biodegradable, and paper-thin zinc batteries that can be cut into any shape or size without affecting its function. The battery is composed of electrodes that are screen-printed on both sides of cellulose paper that has been reinforced with hydrogel. Once expended, the battery can be buried in the soil where it will safely and completely decompose within a month as the battery's metals are released into the environment in non-toxic forms, showing promise to become a greener substitute for powering flexible and wearable electronic systems.

"Traditional batteries come in a variety of models and sizes, and choosing the right type for your device could be a cumbersome process. Through our study, we showed a simpler, cheaper way of manufacturing batteries, by developing a single large piece of battery that can be cut to desired shapes and sizes without loss of efficiency. These features make our paper batteries ideal for integration in the sorts of flexible electronics that are gradually being developed," said Professor Fan Hongjin from the NTU School of Physical and Mathematical Sciences and the study's co-lead author.

In general, batteries power devices through an electrochemical reaction that produces electrical energy. They are composed of an anode and a cathode that are housed within metal or plastic cases. Between the anode and cathode is a separator that prevents

A biodegradable printed paper battery. Photo Credit: Nanyang Technological University, Singapore

the two electrodes from touching and allows an electrical charge to flow freely between them, preventing short circuits. Batteries also contain electrolytes, which allow the electric charge to flow between the anode and cathode.

To design a thinner, lighter prototype that eliminates the need for packaging, the researchers adopted a "sandwich design" for their print paper batteries, where the cellulose paper is sandwiched between the electrodes. The fabrication process begins with reinforcing cellulose paper with hydrogel to fill up the fibre gaps that are naturally present in cellulose. This forms a dense separator that effectively prevents the mixing of electrodes, which are formulated as "electrode inks" and screen-printed onto both sides of the hydrogel-reinforced cellulose paper. While the anode ink is primarily composed of zinc and carbon black, the scientists developed two types of cathode ink – one made of manganese and another made with nickel as a proof-of-concept. Once the electrodes are printed, the battery is immersed in an electrolyte. A layer of gold thin foil is then coated on the electrodes to enhance the conductivity of the measured to be about 0.4mm thick.

To demonstrate the functionality of the batteries, the scientists took one step further in their proof-of-concept experiment and showed how a 4cm-by-4cm square of printed paper battery successfully powered a small electric fan for at least 45 minutes. Even when bent or twisted, the battery continued to supply power to the fan. In another test, the team used a 4cm-by-4cm battery to power a LED and demonstrated that cutting away parts of the paper battery did not affect the functionality of the battery as the LED stayed lit.

Once the battery reaches the end of its lifespan, it can simply be buried in soil because hydrogel and cellulose can be naturally broken down by bacteria, fungi, and other microorganisms. Within several weeks, it will be completely biodegraded. As a test of the battery's biodegradability, the scientists buried a used paper battery in the soil of a rooftop garden in the NTU campus and confirmed that it completely degraded within a month.

"When decomposition happens, the electrode materials are released into the environment. The nickel or manganese used in the cathodes will remain in their oxide or hydroxide natural minerals. The zinc found in the anode will be naturally oxidised to form a non-toxic hydroxide. This points to the battery's potential as a more sustainable alternative to current batteries," explained Professor Fan.

"We believe the paper battery we have developed could potentially help with the electronic waste problem, given that our printed paper battery is non-toxic and does not require aluminium or plastic casings to encapsulate the battery components. Avoiding the packaging layers also enables our battery to store a higher amount of energy, and thus power, within a smaller system," added Assistant Professor Lee Seok Woo from the NTU School of Electrical and Electronic Engineering and the study's co-lead author.

In future, the scientists hope to integrate their printed paper battery into electronic skins, energy storage systems used in the environment, and other printed electronics. APBN

Source: *Yang et al. (2021). Printed Zinc Paper Batteries. Advanced Science, 2103894.*