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Flexible Water-Activated Battery on a Polyester–Cotton Textile †

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Abstract: This work presents a simple, scalable and flexible water activated primary battery, fabricated on top of a textile substrate. The textile-based battery was fabricated with inexpensive screen-printed materials to form the functional battery electrodes, novel polymer separator and buffer layers. Upon activating the device with water, the battery demonstrated an areal capacity of 88 μAh·cm^{-2} between 1 and 0.6 V.

Keywords: e-textile; flexible battery; water-activated battery

1. Introduction

Electronic textiles (e-textiles) are the combination of electrical devices with flexible substrate such as woven, knitted or non-woven textiles. Alongside the electrical functionality of e-textile systems, the power supply of these electronics is the key challenge for their application in real world scenarios [1]. Integrating flexible energy storage/supply elements (such as batteries) within textiles is seen as a key technology to overcome this challenge, and has rightfully seen a significant increase in research interest [2].

Water-activated batteries are a single use electrical energy storage device. In comparison to ordinary primary batteries, they do not contain the fluidic electrolyte and need to be activated with water to power the connected electrical system. This type of battery demonstrates distinct advantages, such as the following: light weight, reliable, flexible, long shelf life prior to activation and high power and energy density [3]. It has been used in textile devices such as life jackets, medical sensing diapers and military garments [4]. Historically, textile water-activated batteries have been fabricated with multiple textile layers that are coated with different functional materials. In 2015, Liu, et al. [5] reported the first water-activated battery with three textile layers with different functional materials and two metal layers for the current collectors and anode/cathode material. This device achieved a voltage of 1.3 V and could power an LED for 30 min when two were connected in series. The battery cell was sealed with double sided tape to prevent the battery from short circuiting and to ensure all material layers were in contact with each other. In 2018, Vilkhuet et al. [6] implemented a full water-activated battery with battery electrodes printed on the same side of the textile. After wetting the battery with a highly alkaline solution with sodium hydroxide (6 M), the unpackaged battery cell achieved an initial voltage of 1.46 V, with an approximate areal capacity of 400 μAh·cm^{-2} above 0.2 V. In 2020, Yi et al. [7] presented a flexible, encapsulated and printable water activated primary battery. The battery/galvanic cell was fabricated from two pieces of modified cotton textile to form the anode and porous separator, with an aluminium metal foil as the cathode. Upon activation, the battery achieved an open circuit voltage of 1.32 V and an areal capacity of 166.8 μAh·cm^{-2} above 0.8 V. These examples demonstrate the capability of fabricated water-activated batteries within textile material. However, the use of multiple

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functional textile or metal layers increased the device thickness and mechanical inflexibility, introducing extra encapsulation challenges for real-world power source units in e-textile systems. In addition, the requirement of highly concentrated alkaline solution as the battery activation agent (as in the work of Vilkhuet et al.) leads to extra encapsulation difficulties to stop solution leakage, accompanied by environmental hazards. Therefore, these designs were not suitable for real-word e-textile applications.

This paper reports an approach for fabricating a water-activated battery with one textile and one metal/polymer film. The battery's anode was a flexible zinc polymer film prepared via screen printing, whilst the battery's cathode was a flexible and screen-printed silver polymer layer on a polyester cotton textile. The separator and buffer layers were implemented on top of the battery's anode and cathode with doctor blading or screen printing followed by a phase inversion process. The battery was tested after it had been activated with water to study its discharge performance.

2. Material and Methods

The proposed water activated primary battery was fabricated on top of a polyester-cotton textile of thickness of ~200 μm using solution-based processes and inexpensive materials. Figure 1 shows the proposed structure of the primary battery. Firstly, silver paste (Fabinks TC-C4001) was screen printed onto the polyester–cotton textile, where the silver paste soaked through the textile, forming the current collector and cathode of the device (Figure 2a). Then a gel paste (containing 2 M silver nitrate ($AgNO_3$) and polyvinyl alcohol (PVA) (1:10 by wt.%)) was screen printed on top of the silver-coated textile. The textile was then sonicated for 10 min in isopropyl alcohol until a white porous film formed on top of the silver-coated textile. The coated textile was then dried under a 25 mbar vacuum at room temperature (23 °C) for 30 min. The separator layer was fabricated via doctor blade coating with a gel solution containing 6 M sodium nitrate ($NaNO_3$) and polyacrylamide (PAM) (1:20 by wt%) onto the textile cathode. It was sonicated for 30 min with acetone and completely dried under vacuum at room temperature (23 °C) for 2 h (Figure 2b). The anode of the water-activated primary battery was fabricated with the same processes as the cathode textile layer: A zinc paste containing zinc metal powder and polymer binder polyethylene-vinyl acetate (5:95 by wt%) was screen printed onto a teflon sheet and peeled off after complete evaporation of the solvent under vacuum at room temperature (23 °C), which formed the current collector and anode of the device (Figure 2c). Then, a gel paste containing 3 M zinc chloride ($ZnCl_2$) and PVA (1:10 by wt%) was screen printed on top of a flexible zinc anode film, before undergoing the same sonication and drying process (Figure 2d).

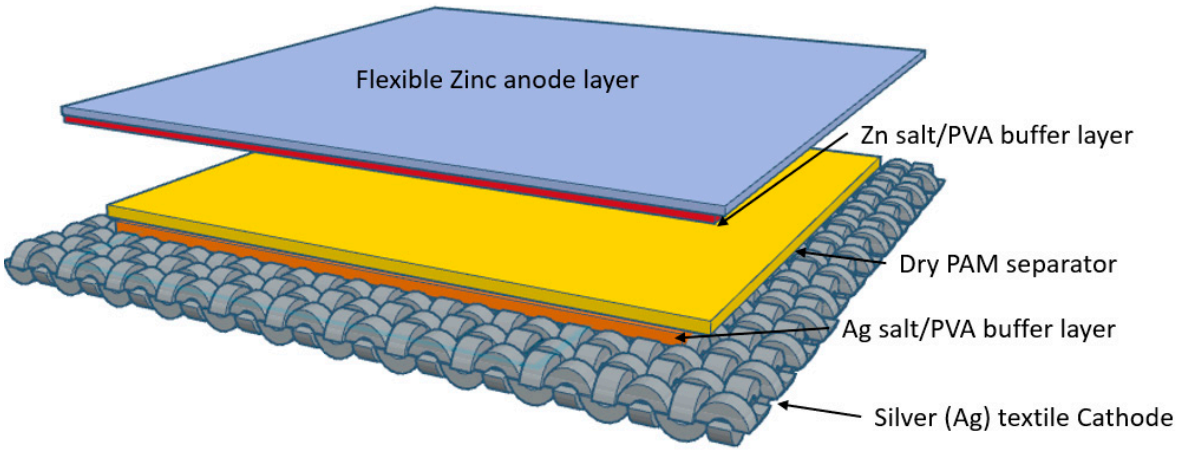
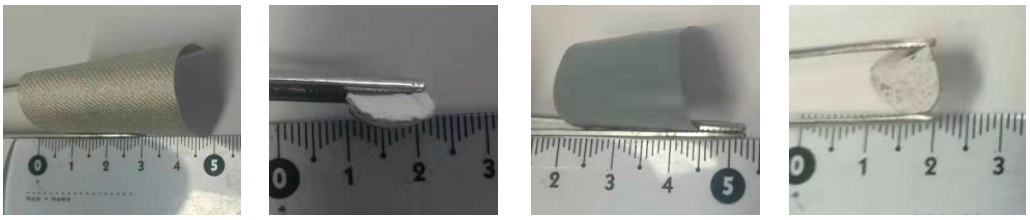


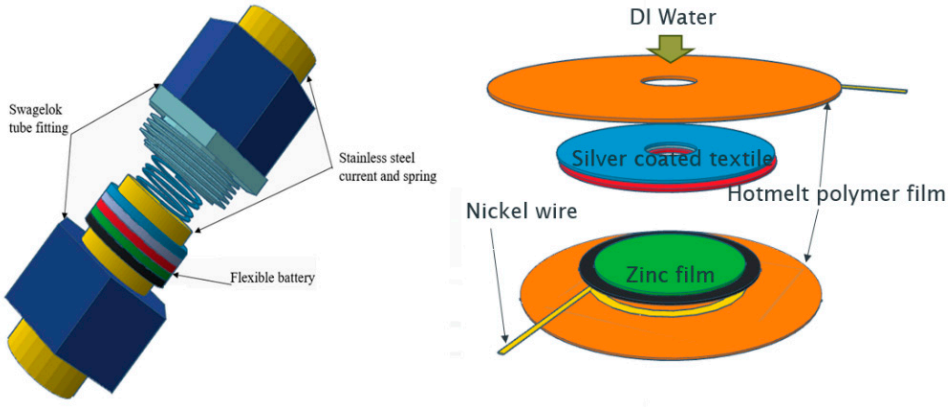
Figure 1. Water-activated battery schematic.



(**a**) (**b**) (**c**) (**d**)

Figure 2. (**a**) Flexible silver textile. (**b**) Silver textile with separator. (**c**) Flexible zinc film. (**d**) Zinc film with buffer film.

Figure 3a shows the test setup for the battery performance testing. The proposed water-activated primary battery was made with one piece of zinc anode film and silver textile cathode/separator each; these layers were punched into circular shapes with a diameter of 1 cm and encapsulated within a Swagelok tube fitting for the discharge performance test. The total thickness of the battery, including the zinc anode, textile cathode, two salt buffer layers and PAM separator layer, was ~2 mm. Figure 3b shows the test setup for the encapsulated battery. Two pieces of hotmelt polymer film were used to encapsulate the water-activated primary battery. An air hole with a diameter of 0.3 cm was punched in the centre of cathode textile, PAM separator and one of the encapsulation films to allow the device to be activated by a deionised (DI) water droplet before testing.



(**a**) (**b**)

Figure 3. (**a**) Battery test in Swagelok tube fitting. (**b**) Encapsulated battery test configuration.

3. Results

The discharge performance of the textile water-activated batteries were characterised with an Autolab Pgsatat101 (Metrohm Autolab, Utrecht, The Netherlands). DI water (0.1 mL) was used to activate the battery before being put into the test tube fitting or through the air hole for the encapsulated device. The discharge current was set to be 0.5 mA·cm^{-2} or 0.395 mA.

The water-activated battery in the Swagelok test configuration (Figure 4a) achieved an initial voltage above 1 V, with an areal capacity of 88 µAh·cm^{-2} or energy density of 144 µWh·cm^{-2} above 0.6 V. The results of the water-activated battery on textile encapsulated with polymer films (Figure 4b) demonstrates that the device voltage rose from 0.75 to 0.9 V for 100 s after water activation, with the total capacity of this type of device reaching 55 µAh·cm^{-2} (97.2 µWh·cm^{-2}) above 0.6 V. In both types of device, the polymer separator layer was wetted by the water, which turned the separator into a porous gel membrane that contained dissolved $NaNO_3$. This membrane acted as the salt bridge, allowing ion transfer between the cathode and anode whilst preventing any electrical short circuits. With the

polymer film encapsulated device, the wetting process took longer than that of the battery in the Swagelok, which explains the voltage increase before discharge.

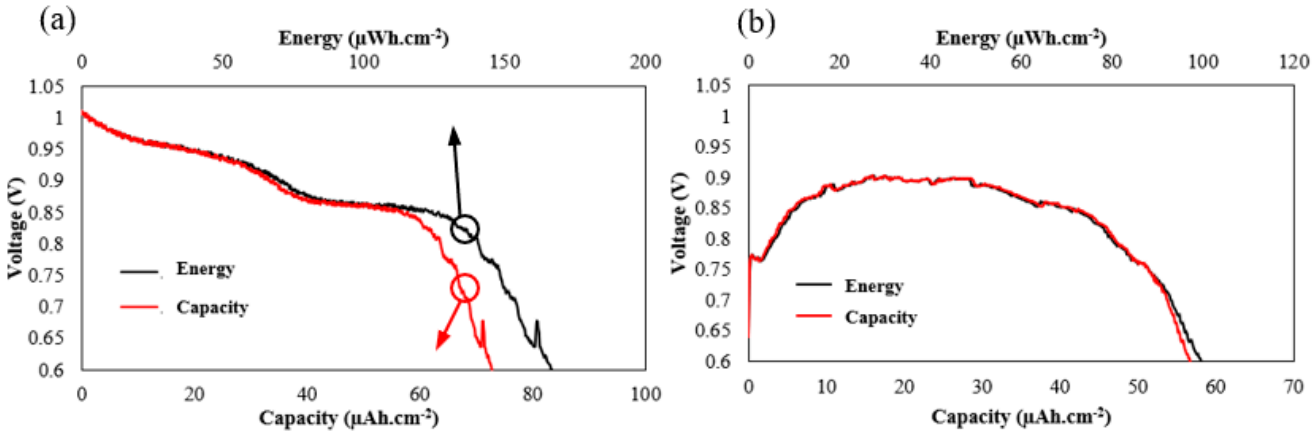


Figure 4. Discharge test (discharge current = 0.5 mA·cm^{-2}) of the water-activated battery on textile. (**a**) In tube fitting. (**b**) Encapsulated with polymer films.

4. Discussion and Concussions

This paper demonstrates a simple and straightforward fabrication method of a textile water-activated battery with a single piece of textile and metal/polymer layer, with both layers being flexible and scalable. The printed and phased inverted separator layer on top of the textile cathode shows a promising way of fabricating a porous gel membrane that can act as salt bridge in future batteries. The battery tested in a Swagelok achieved an areal capacity of 88 μAh·cm^{-2} or energy density of 144 μWh·cm^{-2}, whilst the polymer film encapsulated battery demonstrated an areal capacity of 55 μAh·cm^{-2} or energy density of 97.2 μWh·cm^{-2}. The proposed battery is flexible and scalable, and can be easily integrated into e-textile systems as an emergency electrical power supply. Future works will include optimising the device structure and material formulation for better energy storage performance.

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Conflicts of Interest: Beeby is the director of Smart Fabric Inks.

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