Textile-enable Flexible and Foldable Lithium-ion Batteries

Yuan Gao, Dongrui Wang and Zijian Zheng*

*Laboratory for Advanced Interfacial Materials & Devices, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong SAR, tczzheng@polyu.edu.hk

ABSTRACT

Lithium ion batteries with high electrochemical performance and high flexibility are regarded as promising energy storage devices for portable and wearable electronics. Here, we report a flexible and foldable lithium-ion battery based on highly conductive three dimensional (3-D) metallic textiles. The 3-D metallic textile current collectors are fabricated through a polymer-assisted metal deposition (PAMD) process. After deposition, these textiles possess a sheet resistance less than 1 ohm/sq., and exhibit great flexibility and good washing ability (30 commercial washes). Benefiting from the large surface area and high conductivity of the textile current collectors, the as-fabricated lithium-ion pouch cells achieve a highest energy density of 45 Wh/L and highest power density of 600 W/L. Moreover, the 3-D architecture of metallic textiles further enhances the mechanical stability of the device, thus the device can be folded for more than 1000 times without obvious change in the electrochemical performance.

Keywords: polymer-assisted metal deposition (PAMD), flexible and foldable, lithium-ion battery, wearable electronics

1 INTRODUCTION

Wearable and portable electronic technology is emerging as the next huge market opportunity after smartphones. Its market revenue is growing at a rate of ~ 25% to reach ~ USD 80 billion by 2025. The blooming market of such technology also leads to the increasing requirements for energy storage devices that possess both high performance and attractive form factors. [1, 2] Therefore, lithium-ion (Li-ion) batteries with high electrochemical performance and high mechanical durability, which can be integrated into wearable forms, are highly desired to serve as the power supply in wearable and portable electronics. However, current technology utilizes metal foils as the battery current collectors, which results in a low energy density and poor flexibility of the battery devices. [3] Such technical challenge stems from the difficulty to fabricate current collectors with large surface area, light weight, high conductivity and excellent flexibility. To solve such problem, our laboratory recently developed a patented technology to fabricate highly flexible and conductive 3-D metallic textiles via polymer-assisted metal deposition (PAMD) method, in which metal thin films were conformally and uniformly deposited on functional polymer modified textiles such as cotton and carbon fibers. The as-fabricated metallic textiles current collectors showe a sheet resistance smaller than 1 ohm/sq, and render great flexibility, drapability, and good washing ability. The flexible Li-ion pouch cell built based on these textiles achieves a highest energy density and power density of 45 Wh/L and 600 W/L, respectively. Both the performance are much higher than the state-of-art thin film lithium ion batteries. More importantly, the cell is highly flexible and foldable and it could be folded with the curvature radius smaller than 0.2 mm for more than 1000 times without affecting the electrochemcial properties of the device.

2 RESULTS AND DISCUSSION

2.1 Design of 3-D metallic textile current collectors

The schematics of the as-built 3-D metallic textiles current collectors are shown in Figure 1. The fabrication mainly consists of three steps: i) Activation of textile yarns. ii) Deposition of metal thin film via PAMD method. iii) Weaving of yarns into 3-D metallic textile current collectors. It is worth to mention that in the first step, several untreated textile fibers were firstly twisted together to form yarns in order to increase the mechanical strength. Then, these yarns underwent activiation process to enhance their hydrophilicity, and such physical property was highly required in the following PAMD process. In the second step, highly conductive metal thin films including copper (Cu) and nickel (Ni) could be uniformly and conformally deposited onto pre-treated yarns. The detailed fabrication process could be traced back to our previous work. [4, 5] The thickness of the metal film and sheet resistance of the metallic yarns could be easily controlled by the PAMD deposition time. In our experiment, it is possible to decrease the sheet resistance of the yarns less than 1 ohm/sq. More interestingly, the deposited metal exhibited remarkable adhesion on the textile

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yarns. These metallic yarns could maintain low sheet resistance under bending conditions and even 30 commercial washes. In the final step, these metallic yarns could be weaven into 3-D metal fabrics with the appealling physical and electrical properties such as high conductivity, light weight and large surface area, etc. Thus, they are highly promising to serve as the current collectors for Li-ion batteries.

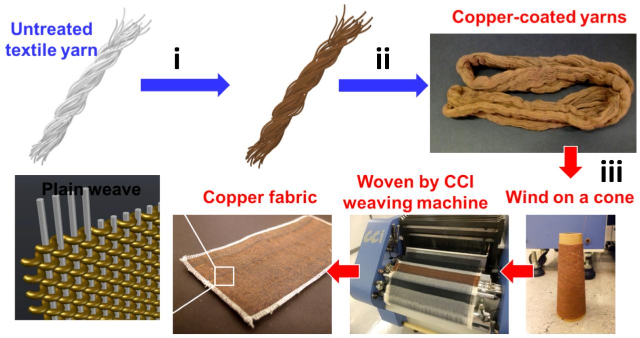

Figure 1. Fabrication of metallic textiles.

2.2 Electrochemical performance of Li-ion pouch cell

To evaluate the feasibility of 3-D metallic fabrics for serving as current collectors, active materials such as lithium iron phosphate (LFP) was deposited onto Ni-coated fabrics for battery cathode and lithium titanate (LTO) was directly deposited onto Cu-coated fabrics for battery anode. These electrodes were further assembled into Li-ion pouch cell with the device geometry size of 8 cm by 5 cm, which is shown in Figure 2a. Figure 2b renders the charging/discharging voltage profiles of the device under different C rates. Apparently, the device achieves a highest capacity of 120 mAh/g at 0.2 C and still maintains 70 mAh/g at 5 C. Such excellent rate capability could be attributed to the highly conductive 3-D textile current collectors, which accelerating the electron transport and electrolyte ion diffusion. The Ragone plot is shown in Figure 2c. Taking the advantages of large surface area and high conductivity of 3-D textiles current collectors, the device obtains a highest energy density and power density 45 Wh/L and 600 W/L without consideration of package materials, and still maintains 67 % of the values when calculated based on total device volume. These performances are far better than the state-of-art thin film lithium ion batteries.

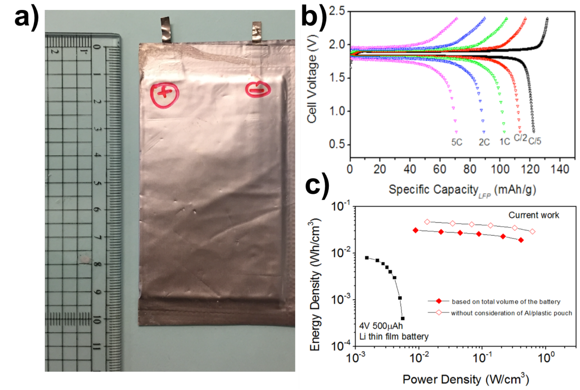

Figure 2. Li-ion pouch cell and its electrochemical performance. a) Photograph of as-fabricated Li-ion pouch cell. b) Typical galvanostatic charging/discharging voltage profiles of the full cell device within voltage window of 1.0-2.5 V under C rates from 0.2 C to 5 C (1 C= 170 mAh/g of LFP). d) Ragone plot of full cell in comparison with commercialized thin film Li-ion battery.

2.3 Mechanical stability of Li-ion pouch cell

To serve as the energy back-up in wearable and portable electronics, it is highly required that Li-ion batteries could work under mechanical deformation without performance degradation. We tested the open circuit voltage (VOC) of the metallic textile-based batteries. It was found that there was negligible change in the VOC during 1000 folding cycles. After folding for 1000 times, the charging/discharging curves of the device were nearly the same as those before folding, which indicates the Li-ion pouch cell exhibits marginal capacity degradation during the harsh mechanical deformations. The excellent mechanical properties of such Li-ion pouch cell could be ascribed to two reasons: i) PAMD enhances the adhesion between metal thin film and textiles substrate. As a direct consequence, metal thin film could firmly attach to the substrate even the device undergoes bending/folding process. ii) 3-D architectures naturally possess higher mechanical strength and could anchor the active materials from peeling off. [5]

3 CONCLUSIONS

In summary, we report a unique PAMD technology to fabricate highly flexible and conductive 3-D metallic textile. Such textile possesses low sheet resistance, light weight, high conductivity, large surface area, excellent flexibility and washing ability, etc.. These appealling physical and mechanical properties make 3-D metallic textiles a promising candidate to serve as current collector for Li-ion battery application. The as-fabricated Li-ion pouch cell based on these textiles achieves a highest energy density of 45 Wh/L and power density of 600 W/L. These performances are far better than the state-of-art lithium thin film batteries. More importantly, the Li-ion pouch cell has high tolerance to mechanical deformations. The device can be folded for more than 1000 times with marginal capacity degradation. These superior electrochemical results demonstrate that PAMD technology can not only find huge impact in battery industry, but also provides competitive energy storage products for the next generation consumer electronics such as bendable/foldable smartphones, wearable healthcare equipment, etc.

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