The Fourth International Workshop on
Micro and Nanotechnology for Power Generation and Energy Conversion Applications
PowerMEMS 2004
November 28 - 30, 2004
Kyoto, Japan

Urine-Activated Paper Batteries

Ki Bang Lee
Institute of Bioengineering and Nanotechnology
31 Biopolis Way, The Nanos, #04-01
Singapore 138669
TEL: (+65) 6824-7119/ FAX: (+65) 6478-9082 / Email: kblee@ibn.a-star.edu.sg

ABSTRACT

The first urine-activated laminated paper batteries has been demonstrated and reported in this paper. A simple and cheap fabrication process for the paper batteries has been developed which is compatible to the existing plastic laminating technologies or plastic molding technologies. In this battery, Magnesium (Mg) layer and Copper Chloride (CuCl) in filter paper are used as the anode and the cathode, respectively. A stack consisted of Magnesium (Mg), Copper Chloride (CuCl)-doped filter paper, Copper (Cu) layer sandwiched between two plastic layers is laminated into the paper batteries by passing through the heating roller at 150^{o}C. The paper battery is tested and it can deliver a power greater than 1.5mW. In addition, these urine-activated laminated paper batteries could be integrated with bioMEMS devices such as home-based health test kits providing power source for the electronic circuit.

Keywords: Power MEMS, power source, battery, urine-activated battery, energy conversion.

INTRODUCTION

The field of MEMS and bioMEMS is emerging as an important technology of the new millennium with the capability of creating complex, autonomous, and low cost engineering systems [1]. One critical issue to be addressed is the power sources for microsystems. Although some micro devices such as ink-jet printers may not need on-board energy supplies, remote and distributed systems such as smart dusts do need local power sources [2]. As more MEMS devices are integrated with electronic circuits, the development of micropower sources for microsystems becomes exigent and challenging [3]. A huge amount of research efforts have been focusing on micro power generation for the past decade by using micro fuel cells that utilized oxygen, hydrogen, or other fuels to target continuous power supply in the range of 10 to 100 Watts [4]. Others have investigated the possibility of fabricating low cost and high capacity solar cells [5]. However, these micro power sources commonly require complicated micromachining processes that hindered the possibility of an integration process with MEMS for self-sustained microsystems.

Micro power sources meeting the operation lifetime of disposable devices are attractive in contrast to the long-operation, miniature power sources of micro internal combustion engines [6] or rechargeable, thin-film lithium micro batteries [7]. Disposable on-demand, acid- and water-activated microbatteries using chemical reactions in a cavity [8,9] were demonstrated for bioMEMS and microdevices. All these fabrication processes for power sources [4-9] use micromaching technologies such as the bulk or surface micromaching process based on silicon wafer. The silicon wafer based processes hinders compatibility with bioMEMS devices or medical systems that is fabricated by using plastic process.

This current work demonstrates feasibility of using a simple, cheap plastic lamination technology to fabricate human urine-activated paper batteries. The fabrication process and the battery's performance evaluation are described and discussed in details in this paper.

OPERATION PRINCIPLE

Fig. 1 shows the schematic diagram of a urine-activated paper battery consisted of Copper (Cu) layer, Copper Chloride (CuCl)-doped filter paper and Magnesium (Mg) layer. The whole assembly is sandwiched between two plastic layers and later laminated into a urine activated paper battery by passing it through the heated rollers at 150^{o}C. Fig. 2 shows the operation principle of the urine-

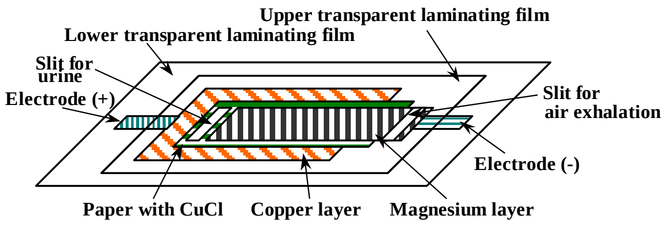
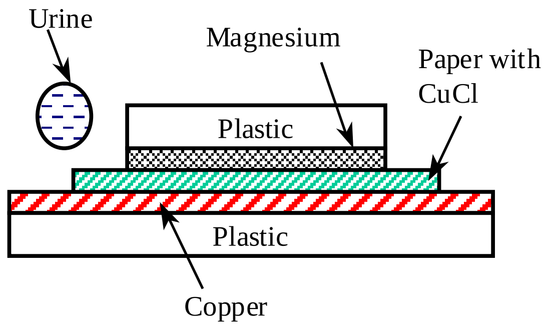
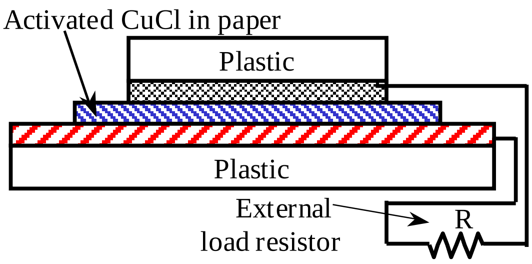


Fig. 1. Schematic diagram of a urine-activated paper battery: a Copper (Cu) film, Copper Chloride (CuCl)-doped filter paper, and a Magnesium (Mg) film are stacked and laminated between two transparent laminating films. Two slits are made to contact urine to the paper and remove the air from the battery.

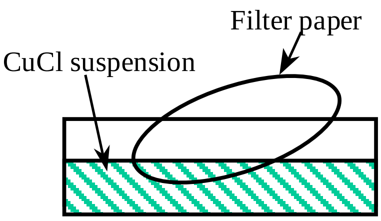


(a) Before activation

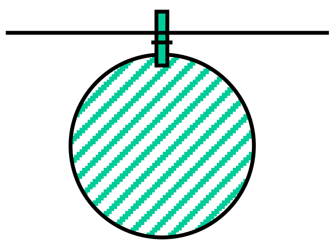


(b) After activation

Fig. 2. Working principle of the urine-activated paper battery. (a) before activation (b) after activation



(a) Soaking filter paper in CuCl suspension



(b) Drying and cutting the paper in air

Fig.3. (a) Preparation of the Copper Chloride (CuCl)-doped filter paper (b) after soaking the Copper Chloride-doped filter paper is dried in the air and cut into small pieces.

activated battery. Magnesium (Mg) and Copper Chloride (CuCl) are used as the anode and the cathode, respectively. The Copper (Cu) layer acts as an electron-collecting layer. When a droplet of human urine is added into the battery as shown in Fig.2, the urine soaks through the paper

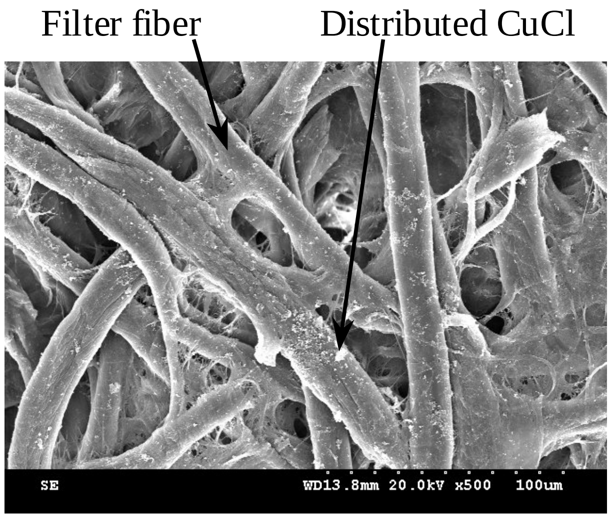


Fig.4. SEM photograph of the paper with CuCl: CuCl is distributed on the filter paper fiber.

between the Magnesium (Mg) and Copper (Cu) layers. The chemicals dissolve and react to produce the electricity. The chemical reactions for the battery at the anode (oxidation) and cathode (reduction) are represented as Eqs. (1) and (2), respectively [9,10]:

$$Mg \rightarrow Mg^{2+} + 2e^{-} \quad (1)$$

$$2CuCl + 2e^{-} \rightarrow 2Cu + 2Cl^{-} \quad (2)$$

and the overall reaction is:

$$Mg + 2CuCl \rightarrow MgCl_2 + 2Cu \quad (3)$$

The theoretical voltage of this battery is a direct function of the anode and cathode materials. The standard potential can be calculated as 2.49V from the standard electrode potentials as the sum of the anode potential and the cathode potential [9,10].

FABRICATION

In order to fabricate the paper battery, we have successfully developed a plastic laminating fabrication technology that is compatible to the existing plastic laminating technologies or plastic molding technologies.

Fig. 2 depicts preparation of the filter paper (Whatman, Cat No 1001070) with Copper Chloride (CuCl). After soaking a sheet of commercial filter paper in Copper Chloride suspension, the paper is dried in the air and cut into small pieces for the battery fabrication (Fig. 3b). Fig. 4 shows SEM micrograph of the paper with CuCl distributed on the filter paper fibers. At the cathode, the distributed CuCl accepts the electrons generated from the Magnesium (Mg) anode as shown in Eg (2) pushing forward the overall reaction. Fig. 5 shows a cheap

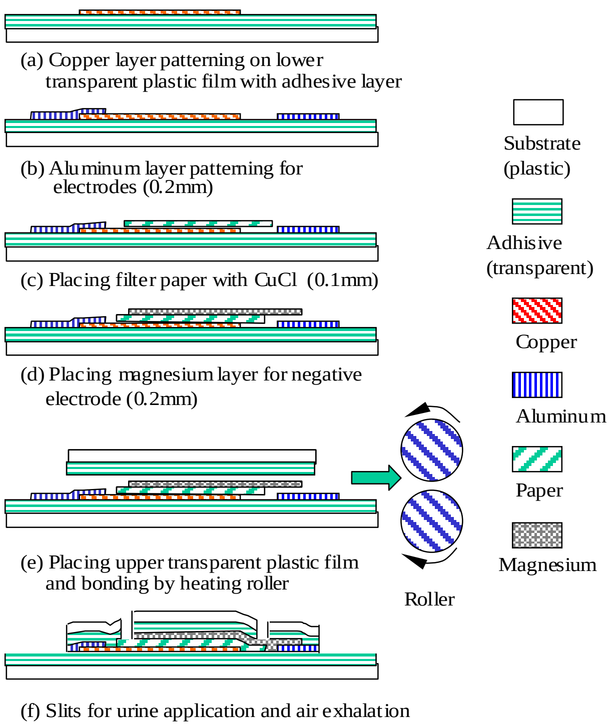


Fig.5. Fabrication process for the paper battery: the stacked layers of the Copper (Cu), CuCl-doped filter paper, and Magnesium (Mg) between the two transparent plastic films are laminated while passing through heating rollers. Adhesive on the plastic film bonds all material together by the heat and pressure of the rollers.

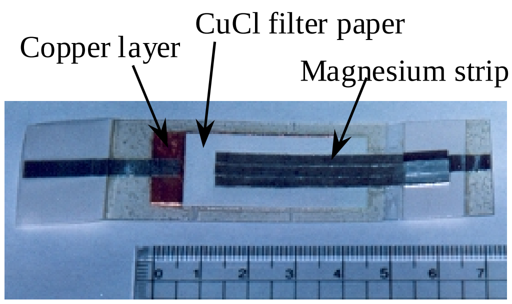


Fig.6. Photograph of the prototype paper battery: the size is 6cm x 3cm.

fabrication process developed for the paper battery. The process starts with a 0.15mm-thick lower transparent plastic film coated with an adhesive and this serves as a substrate for the paper battery. In the next step, a 0.2mm-thick Copper (Cu) layer is deposited (or taped) and patterned as the positive electrode (as shown in Fig. 5a). A 0.2mm-thick aluminum (Al) layer (Fig. 5b) is then deposited and patterned to provide electrical connection and as electrodes. In Fig. 5(c) and (d), a

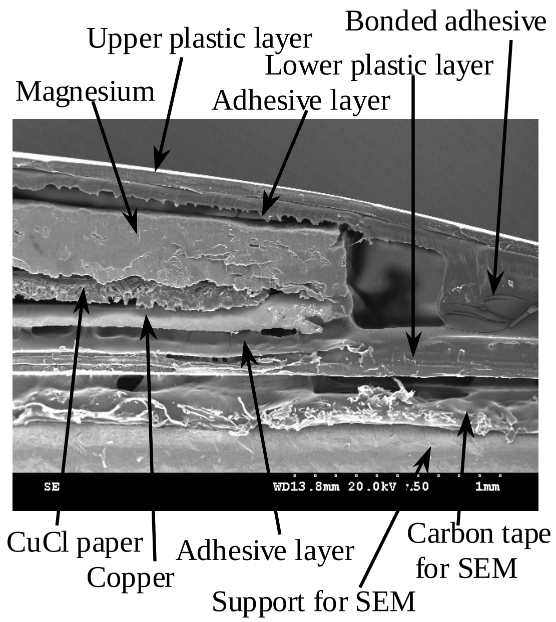


Fig.7. SEM micrograph of the cross-section of the laminated battery: the CuCl-doped paper contacts both Magnesium (Mg) and Copper (Cu). Adhesive of the upper and lower plastic layers adhered all layers together after heating.

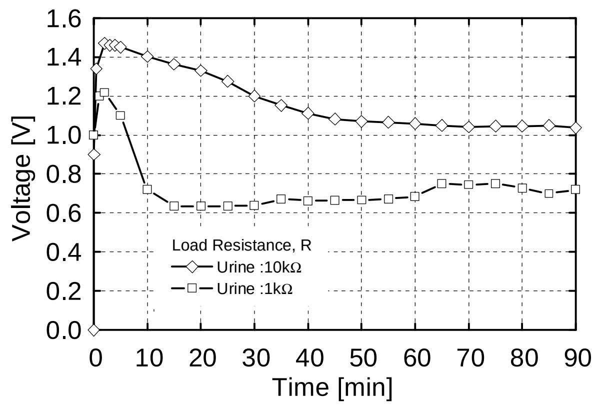


Fig.8. Measured outputs of the battery with load resistor of 1kΩ and 10kΩ after activation by human urine of 0.2*ml*. The urine is placed at the slit of Fig. 5(f) for activation.

0.2mm-thick CuCl paper and Magnesium (Mg) layer are stacked onto the Copper layer thereafter covered on the top by a upper transparent plastic film with an adhesive layer (Fig. 5e). Finally the whole layer is laminated into a paper battery by passing through heating rollers at 150^{o}C. Urine supply slit and air exhalation slit are made on the upper plastic film in Fig. 5(f). It is noted from Fig. 5 (f) that the heating rollers press and bond all layers into the paper battery. Other heating means such as ultrasonic heating equipment could be used instead of the heating laminated paper battery. The overall dimension is 6cm x 3cm and the CuCl-doped paper is 4cmx2cm. All layers of Copper, CuCl-doped filter paper and Magnesium roller. Fig. 6 shows the photograph of the prototype (Mg) are bonded together between the transparent upper and lower plastic films. Three pieces of Magnesium (Mg) of 0.2mm x 3mm x 5cm are used to provide greater reaction area. Fig. 7 shows the SEM micrograph of the cross-section of the laminated paper battery. The stack of the active layers of Magnesium (Mg), CuCl-doped paper and Copper (Cu) could be seen between the upper and lower plastic layers. Adhesive on the upper and lower plastic layers has melted and solidified to hold the active layers together when the whole layer is laminated into the paper battery in Fig. 5(e).

RESULTS AND DISCUSSIONS

The output voltage of the fabricated battery has been measured with respect to time for the load resistor of 1kΩ and 10kΩ. A voltmeter is used to measure the voltage across the load resistor in Fig. 2 (b). Fig. 8 shows the measured voltage outputs of the fabricated batteries with load resistor of 1kΩ and 10kΩ after a droplet of human urine of 0.2*ml* is placed on the urine supply slit of Fig. 1. The output voltage of the battery with the 10kΩ load resistor reaches the maximum voltage of 1.47V, decreases with time and remains at a constant voltage of 1.04V for 90minutes. The output voltage of the battery with the 1kΩ load resistor reaches a maximum voltage of 1.21V, decreases with time and drops to 0.72V after 90minutes. The maximum powers are 1.5mW for 1kΩ load resistor and 0.22mW for 10kΩ load resistor, respectively. This battery can be fabricated and integrated into a BioMEMS to supply power to run the energy consuming devices such as biosensors or the electric type DNA chip.

CONCLUSIONS

The first urine-activated paper battery has been demonstrated for on-demand bioMEMS and disposal usages. Basic concept of a disposal battery is presented and the prototype battery can be fabricated using a simple and cheap plastic lamination fabrication process. The maximum power of the prototype battery with 1kΩ load resistor has been is higher than 1.5mW. Thus, this demonstrates the feasibility of using urine-activated paper battery for on-demand bioMEMS devices including home-based health test kits.

ACKNOWLEDGEMENTS

The author would like to thank Mr. Seungdo An at Samsung Electro-Mechanics for taking SEM microgragh ss and Dr. Chow Pei Yong, EDWIN at Institute of Bioengineering and Nanotechnology for his help. The batteries were fabricated and experiments were conducted in Korea in July 2004.

REFERENCES

[1] M. Madou, *Fundamentals of Microfabrication*, CRC Press, Boca Raton, 1997.
[2] L. Doherty, B.A. Warneke, B.E. Boser,; K.S.J. Pister, Energy and performance considerations for smart dust. International Journal of Parallel and Distributed Systems & Networks, Vol.4, (No.3), Acta Press, pp.121-33, 2001.
[3] P.B. Koeneman, I.J. Busch-Vishniac, K.L. Wood, “Feasibility of Micro Power Supplies for MEMS.” J. Microelectromechanical Systems, pp.355-362, 1997.
[4] A.H. Epstein and S.D. Senturia, "Micro Power from Micro Machinery," Science, Vol. 276, pp.1211, 1997.
[5] J.B. Lee, Z. Chen, M. Allen and A. Rohatgi, "A Miniaturized High-Voltage Solar Cell Array as an Electrostatic MEMS Power Supply," J. Micro-electromechanical Systems, Vol. 4, pp.102-108, 1995.
[6] A. Mehra, X. Zhang, A. Ayon, I. A. Waitz, M. A. Schmidt, and C. M. Spadaccini, “A Six-Wafer Combustion Systems for a Silicon Micro Gas Turbine Engine,” J. Microelectromechanical Systems, Vol. 9, pp.517-527, 2000.
[7] S. D. Jones and J. R. Akridge, “A Microfabricated Solid-State Secondary Li Battery,” Sokid State Ionics 86-88, pp.1291-1294, 1996.
[8] Ki Bang Lee and Liwei Lin, “Electrolyte Based On-Demand Disposable Microbattery,” MEMS 2002 IEEE International Conference, Las Vegas, pp.236-239, 2002.
[9] Ki Bang Lee, Firas Sammoura, and Liwei Lin, “Water Activated Disposable and Long Shelf Life Microbatteries,” MEMS 2003, January 19-23, 2003, pp.387-390.
[10] David Linden, *Handbook of Batteries*, 2nd edition, McGraw-Hill, Inc, 1995.