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2019

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Introduction

International Conference on Micro Electro Mechanical Systems (MEMS 2019) is one of the premier annual events reporting research results on every aspect of Microsystems technology. This Conference reflects from the rapid proliferation of the commitment and success of the Microsystems research community. In recent years, the MEMS Conference has attracted more than 700 participants, 800+ abstract submissions and has created the forum to present over 200 select papers in podium and poster/oral sessions. Its single-session format provides ample opportunity for interaction between attendees, presenters and exhibitors. MEMS 2019 will be held in Seoul, Korea, from 27-31 January 2019.

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1. **Materials, Fabrication and Packaging for Generic MEMS & NEMS**
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5. **MEMS for Electromagnetics**
6. **MEMS Actuators & Power MEMS**
7. **MEMS Products**

Important Dates

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Manuscript Submission	Nov. 20, 2018

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Xiaojian Xiang, Xuhan Dai, Kai Kang, Shi Sun, and Guifu Ding
Shanghai Jiao Tong University, CHINA

In this paper, we designed and fabricated a highly nonlinear suspension flexure with geometrically predetermined eighth order force-displacement relation for extension of the stable travel range of electrostatic actuator. Its strong nonlinearity is obtained by a rolling slide between a customized curved trajectory and a ball at the tip of the mandril. The customized nonlinear behavior can be adjusted and dominated by a geometrically predetermined trajectory. The experimental result illustrates that the restoring force of the fabricated nonlinear flexure is proportional to the eighth power of the electrode displacement approximately, and the stable travel of the electrostatic actuator with this flexure is extended to at least 63% of the nominal gap. The proposed scheme can also be implemented to other systems where the nonlinearity is needed, such as energy harvesting and the damper in the micro-scale.

Power MEMS Components & Systems

Swati J. Patil, Jong Sung Park, and Dong Weon Lee
Chonnam National University, KOREA

In the present work, we have fabricated a flexible and efficient micro-supercapacitor for future advanced electronic applications. A simple time saving, eco-friendly electrodeposition method was employed for nanostructured thin film materials formation on a micropattern flexible polyethylene terephthalate (PET) substrate, and the resulting outcome shows that its promising applications in miniaturized power electronics devices. The nanostructures-based flexible microsupercapacitor can deliver areal capacitance of 0.253 mF/cm^2 at a current density of 0.03 mA/cm^2. The maximum power and energy densities of the fabricated flexible asymmetric micro-supercapacitor are estimated to be 30 mW/cm^2 and 0.056 mWh/cm^2, respectively.

Jin-Chern Chiou, Cheng-En Shieh, Kuan-Ting Yeh, and Shun-Hsi Hsu
National Chiao Tung University, TAIWAN

This paper, for the first time, reports a thin-film supercapacitor as an energy storage component for smart contact lens applications. By using previously developed 3D packaging technology, the proposed supercapacitor with 130 μm thickness can be packaged into a standard hydrogel contact lens with smooth wrinkle-free surface. Based on experiments, the proposed thin-film supercapacitor can work in saline solution and shows the future vision and eye disease related applications. Note that the previous developed radio frequency identification (RFID) based smart contact lens can now be changed from passive system to semi-passive system with the aid of proposed supercapacitor.

Makoto Kashiwagi, Tomoya Koshi, and Eiji Iwase
Waseda University, JAPAN

A Thermoelectric device (TE-device) is promising way to achieve energy harvesting from wasted heat. For energy harvesting, flexibility and stretchability are necessary since a heat source surface has complex shape such as free-form surface. We realized high performance flexible TE-device which combining rigid BiTe-based thermoelectric elements (TE-elements) and flexible structures such as stretchable substrate and expandable electrical wirings. In this device, the BiTe-based TE-elements ensures thermoelectric performance and the flexible structures ensures flexibility. By designing as that, the device has high thermoelectric conversion performance which is comparable with conventional TE-device while having flexibility.

ALL SOLID-STATE FLEXIBLE MICRO-SUPERCAPACITOR BASED ON HYBRID ELECTRODES FOR POWER APPLICATION

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ABSTRACT

In the present work, we have fabricated a flexible and efficient micro-supercapacitor for future advanced electronic applications. A simple time saving, eco-friendly electrodeposition method was employed for nanostructured thin film materials formation on a micro-pattern flexible polyethylene terephthalate (PET) substrate, and the resulting outcome shows that its promising applications in miniaturized power electronics devices. The nanostructures-based flexible micro-supercapacitor can deliver areal capacitance of 0.253 mF/cm^2 at a current density of 0.03 mA/cm^2. The maximum power and energy densities of the fabricated flexible asymmetric micro-supercapacitor are estimated to be 30 mW/cm^2 and 0.056 mWh/cm^2, respectively.

INTRODUCTION

Nowadays, planar micro-supercapacitors for micro-integrated power systems used in the research area are more progressive and have a tendency to build integrated electronic devices with smaller in size, lightweight and more flexible [1]. The batteries and supercapacitors are most promising electrochemical energy storage devices used in present race for different applications. However, batteries work on the basis of bulk storage mechanism, exhibiting high scale energy storage capacity but they usually suffer from low power density and restricted lifespan [2]. Otherside, supercapacitors act to store electric charge via non-faradaic surface adsorption and/or faradaic redox reactions and characterized by high power densities for excellent cycle stability. Micro-supercapacitors are a new type of green energy storage devices show better power efficiency and much faster charge/discharge characteristics than batteries, good cyclic reversibility, and long stability life [3]. In addition, flexibility and portability are two broadly expected specialties for modern industrial electronic technologies that enable the fabrication of a variety of sophisticated applications such as in wearable sensors, smart clothing, flexible touch screens, etc [4, 5]. Within this circumstance, miniaturized electronic devices such as micro-sensors require new power sources with small dimensions and high power densities used in centuries owing to their advantages such as miniaturization, lightweight, and good mechanical flexibility. To tackle this need for flexible and wearable applications, micro-supercapacitors have been fabricated onto flexible substrates. Existing micro-supercapacitors were manufactured by several techniques [6-8]. However, such types of processes confine the output power performance like because of the marginal potential window (less than one volt) and limited use for the future large-scale application [9]. Hence, enormous research attempt has been consecrated for improving micro-supercapacitor performance by employing novel nanostructured electrode materials with advanced architectures for innovative technological applications.

Considerable efforts have been dedicated to developing high-performance flexible solid-state micro-supercapacitors based on various nano-structured material electrodes. There have been used different strategies to promote the electromechanical efficiency of the energy storage devices by choosing the pseudocapacitive materials that store energy via fast and reversible redox reactions occurring mainly at their surface. Herein, we proposed two different nanostructured electrode materials have attracted intense interest for promising applications in energy storage application, due to its wide potential range, excellent conductivity and mechanical flexibility, large specific surface area, and good chemical stability [10].

METHODOLOGY

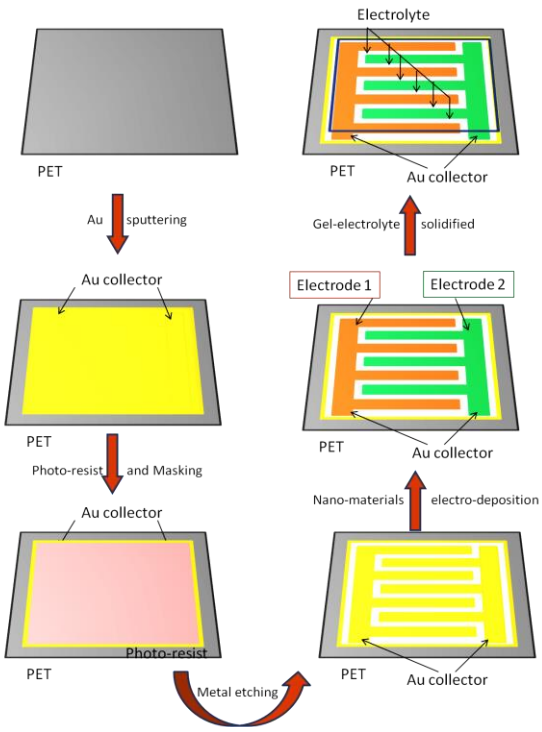

Figure 1: *Schematic diagram of the process flow of an all-solid-state micro-supercapacitor fabrication based on MEMS technique. The major process flow includes Sputter deposition of an Au-collector current on PET substrate, micro-patterning, metal etching, electrodeposition and drops casting gel electrolyte on the integrated microelectrode.*

The schematic diagram for the fabrication process of flexible planner micro-supercapacitor on PET substrate is described in Figure 1. An important component of the flexible energy storage device is a current collector that formed on the flexible substrate. Initially, micro-patterns were implemented on a flexible PET substrate. In a typical process, Au/Ti current collectors with a thickness of 100/10 nm were formed onto the flexible PET substrate using a sputtering technique. Subsequently, a photolithographic process was carried out to pattern the microelectrodes on the substrate. After removing photoresist, the electrodes for micro-supercapacitor were simultaneously prepared. Further, the nanostructured MnO_2 and MoO_2 (act as a positive and negative electrode) electrode materials in the thin film forms were deposited [9]. In the present work, an efficient and versatile electrodeposition method has been proposed for electrode material deposition. Latterly; solidified gel-electrolyte was drop-casted on the nanostructured electrode material to form the micro-supercapacitors assembly and the fabricated micro-supercapacitors were used for further electrochemical characterizations.

RESULTS AND DISCUSSION

Surface Microstructural Studies

The surface morphologies of electrodeposited materials are characterized by a field emission scanning electronic microscope (FE-SEM). Figure 2 (A and B) shows surface micrographs of the electrodeposited nanomaterials. The electrode material shows the nanostructure surfaces with uniformly distributed nanoparticles of MnO_2 (Figure 2 (A)) while a MoO_2 exhibits the visible microspheres with a porous surface (Figure 2 (B)). Both electroactive material surfaces have rough and porous surface microstructure that can lead the surface wettability and corresponding increase the electrolyte ion diffusion rate is attributed for the improvement in electrochemical performances [11].

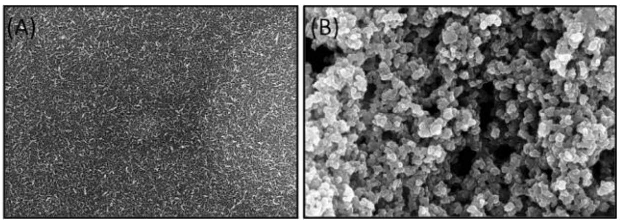

Figure 2: *SEM, images for (a) MnO_2 and (b) MoO_2 material.*

Electrochemical Studies

The digital photographs of the fabricated flexible micro-electrode patterns at different bending and twisting positions are seen in Figure 3(A). The electrochemical performances of the fabricated flexible micro-supercapacitor based on two electrode materials were recorded in a two-electrode cell configuration in polymeric electrolyte gel with KOH salt, results as illustrated in Figure 4. The cyclic voltammogram measurements for the micro-supercapacitors were performed in different potential windows at a fix scan rate of 50 mV/s and results as shown in Figure 4(A). It is seen that with an increase in potential window range the current density increased up to limit and then small decay in curves was observed.

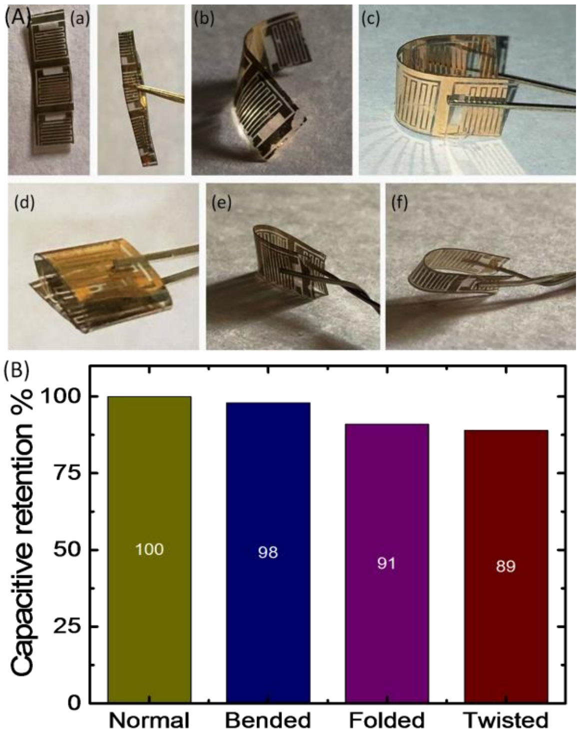

Figure 3: *(A) Actual photographs of the fabricated micro-patterns at different bending and twisting positions. (B) The performance evaluation of the fabricated flexible micro-supercapacitor at normal, bended, folded and twisted position.*

Further, the rate performances of the flexible asymmetric micro-supercapacitor were assessed from the charge-discharge profiles performed at different current density rates in 0 to 1.2 V potential windows. Obviously, the areal capacitance values of micro-supercapacitor show a linear dependence on current density rates was calculated from equation (1),

$$C = {I \times t_d}/{\Delta V \times A} \quad (1)$$

$$E = {C \times V^2}/{3.6} \quad (2)$$

$$P = {E \times 3600}/{t_d} \quad (3)$$

Where, I (mA) and ΔV (mV) are the current density and potential window, respectively. td (s) and A (cm^2) are the discharge time and area of the device, respectively. C (mF), E (mWh) and P (mW) is the areal capacitance, energy density and power density of the device, respectively.

Figure 4(B) exhibits the areal capacitances of the fabricated nanostructured-based flexible micro-supercapacitor were calculated from the equation (1) from charge-discharge studies. The high areal capacitance of 0.253 mF/cm^2 obtained at the current density of 0.03

mA/cm^2 in PVA/KOH gel electrolyte. The calculated capacitances of 0.23, 0.21, 0.19 and 0.18 mF/cm^2 are corresponding to current densities of 0.035, 0.04, 0.045 and 0.05 mA/cm^2, respectively. The fabricated micro-supercapacitor exhibits a more than 70 % of capacitive retention with charge-discharge rates. Further, energy and power density performances of the fabricated nanostructures-based flexible micro-supercapacitor were calculated from the equation (2) and (3), respectively. At a high scan rate of 0.05 mA/cm^2, the micro-supercapacitor delivers 30 mW/cm^2 power densities and it decreased to 18 mW/cm^2 at a current density of 0.03 mA/cm^2. The Ragone plot as illustrated in Figure 4(D), the energy density of the fabricated flexible micro-supercapacitors decreases from 0.051 to 0.036 mWh/cm^2, whereas the power density for the device increases from 18 to 30 mW/cm^2, as the discharge current increased from 0.03 to 0.05 mA/cm^2. The comparative power performances of the fabricated all-solid-state flexible micro-supercapacitor based on a MnO_2 and MoO_2 electrode materials is better than, $CF/MnO_2//MoO_3$ (0.53 μW/cm^2) [12], $MnO_x/C/PSiNWs$ (18 mW/cm^2) [13]. Further, the flexibility of the fabricated flexible micro-supercapacitor device was studied at normal, bending, folding and twisting positions, the results as shown in Figure 3(B). It means that the fabricated nanostructure-based micro-supercapacitor exhibits good power performance and excellent flexibility.

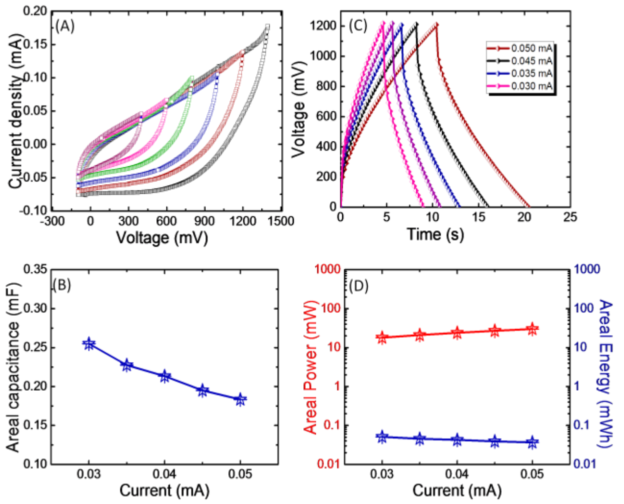

__Figure 4:__ Electrochemical performances of the micro-supercapacitor fabricated based on nanostructured electrode materials: (A) cyclic voltammetry curves of different potential ranges at a constant scan rate of 50 mV/s. (B) The charge/discharge profiles recorded at different current densities. (C) The areal capacitance as a function of current densities of the micro-supercapacitor. (D) Ragone plot (areal power and energy densities) of flexible micro-supercapacitor at current densities of 0.03, 0.035, 0.04, 0.045 and 0.05 mA.

CONCLUSION

In summary, nanostructured electrode materials were successfully electrodeposited in a thin film form on the micro-patterns of the PET substrate. The micro-electrode exhibits excellent flexibility at different bending and twisting. The fabricated asymmetric micro-supercapacitor on a flexible substrate exhibits the highest areal capacitance of 0.253 mF/cm^2 at a current density of 0.03 mA/cm^2 and the maximum power density of 30 mW/cm^2. This result shows that the fabricated flexible micro-supercapacitors have potential to use in power applications.

ACKNOWLEDGEMENT

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