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Micro-Supercapacitors with Carbon Nanotubes and Flexible Components

Fumiaki Tanaka[1], Atsuko Sekiguchi[2], Karolina U. Laszczyk[1], Kazufumi Kobashi[2], Shunsuke Sakurai[2], Don N. Futaba[2], Takeo Yamada[2] and Kenji Hata[2]

[1] Technology Research Association for Single Wall Carbon Nanotubes (TASC)
1-1-1 Higashi, Tsukuba 305-8565, Japan
Phone: +81-29-861-3463 E-mail: f-tanaka@tasc-nt.or.jp
[2] National Institute of Advanced Industrial Science and Technology
1-1-1 Higashi, Tsukuba 305-8565, Japan

Abstract

We developed a stable fabrication process for carbon nanotube (CNT) micro-supercapacitors with flexible components. The micro-supercapacitors were designed as in-plane interdigital shapes and revealed a capacitive behavior in the frequency range from 10 to 0.1 Hz. The energy and power densities of the micro-supercapacitors were 3.7 mWh/cm^3 and 39.8 W/cm^3, respectively. This shows all components were stably connected with good electrical contacts in various combinations of flexible materials, widening the potential applications of CNT micro-supercapacitors.

1. Introduction

Supercapacitors or electoric double-layer capacitors have attracted increasing attention in the past decade because of their high power density, safety, and long cycling lifetimes compared to conventional batteries. Although the energy density of supercapacitors is relatively low, this drawback has been reduced by using carbon based materials that have exceptionally high surface area [1, 2]. Furthermore, by utilizing micro-patterning methods, supercapacitors can be miniaturized and fabricated on a silicon substrate, called micro-supercapacitors [3-8].

Recently, we have demonstrated a CNT micro supercapacitor, which was 1,000 times smaller than current aluminum electrolytic capacitors, while keeping the equivalent energy and power densities (submitted). To realize commercial applications with this technology, however, the CNT micro-supercapacitor should be stable and uniform, which is strongly affected by a stability and uniformity of its fabrication process.

In this presentation, to widen the potential applications, we developed a stable fabrication process for a CNT micro-supercapacitor with a flexible current collector and flexible substrate. In the following sections, after describing the process flow of our micro-supercapacitors, the performance is demonstrated through electrochemical measurements.

2. Device Fabrication

Fig. 1 shows a schematic illustration of fabrication process for our CNT micro-supercapacitor. First, thin CNT film (~3 μm) as electrodes having high surface area is deposited on a SiO_2/Si substrate. After micro-patterning of it, a flexible composite of CNT and fluorinated elastomer (~10 μm) as a current collector is deposited and micro-patterned. Then, the CNT electrodes and flexible current collectors are transferred onto a flexible substrate consisting of fluorinated elastomer. Finally, aqueous electrolyte solution (35wt% H_2SO_4) was dropped onto the electrodes.

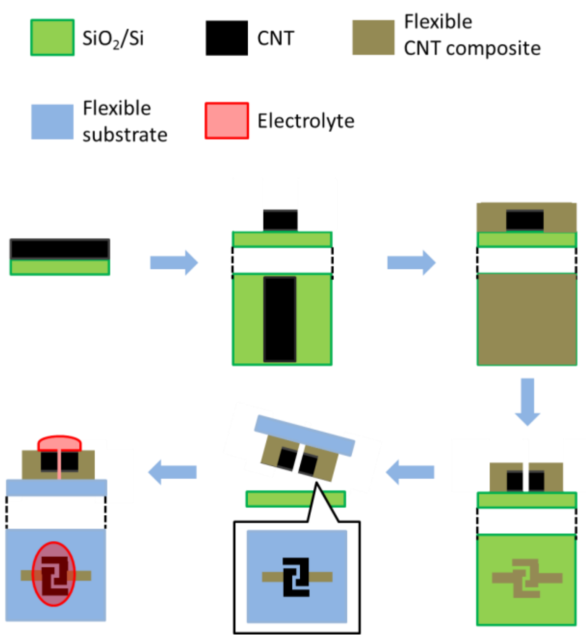

Fig. 1 Schematic illustration of fabrication process for CNT micro-supercapacitor.

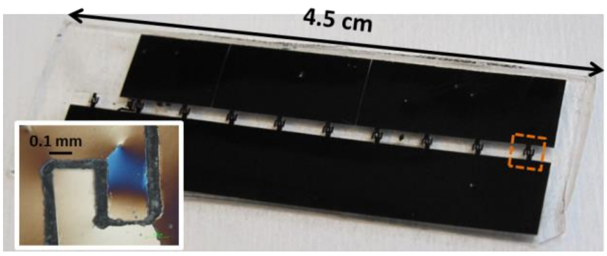

Fig. 2 Photograph of CNT micro-supercapacitors. Inset: enlarged view of capacitors indicated by orange dashed line in the photograph.

As shown in Fig. 2, CNT electrodes and flexible current collector consisting of CNT-elastomer composite can be successfully patterned into in-plane interdigital shapes and transferred onto a flexible elastomer substrate without destroying the pattern.

3. Performance of micro-supercapacitor

As shown in Fig. 3, cyclic voltammetry (CV) of our CNT micro-supercapacitor revealed a reasonable rectangularly-shaped curve, showing that the fabricated device indicated a capacitive behavior rather than a resistive one.

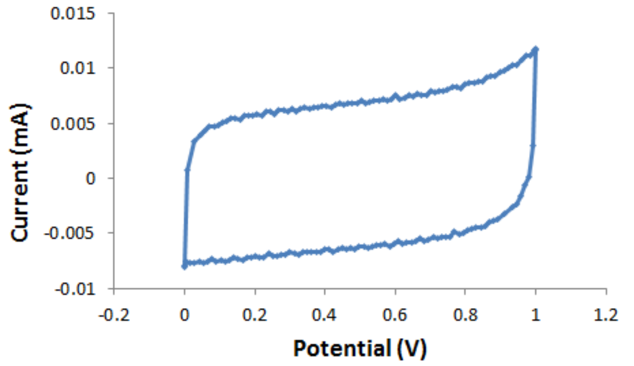

Fig. 3 Cyclic voltammetry curve.

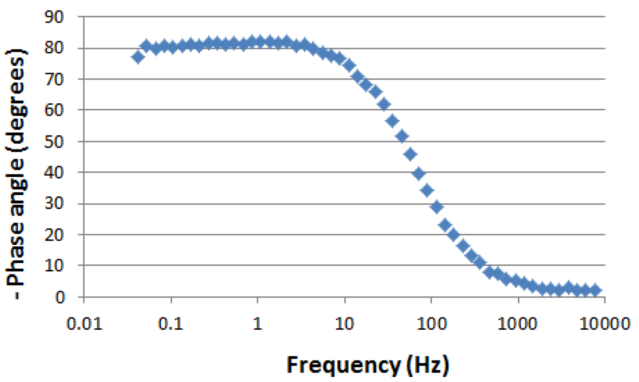

Fig. 4 Plot of impedance phase angle versus frequency.

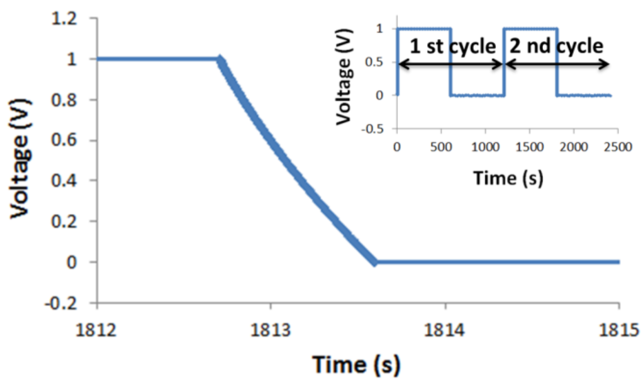

Fig. 5 Galvanostatic discharging curve at 1 V extracted from the second cycle in the inset. Inset: the first and second charge/discharge cycles.

A plot of impedance phase angle versus frequency is shown in Fig. 4. The phase angle approaching 82° also demonstrates that the device revealed a capacitive behavior in the frequency range from 10 Hz to 0.1 Hz.

Fig. 5 shows Galvanostatic cycling, i.e., a plot of voltage versus time on the charge/discharge cycling. From the discharging curve, energy and power densities of our micro-supercapacitors can be calculated as 3.7 mWh/cm^3 and 39.8 W/cm^3, respectively. These values are comparable to those of flexible micro-supercapacitors reported thus far [5, 6, 9, 10]. As a result, the experimental results demonstrate that the device worked as a capacitor and revealed high-performance even with flexible components, including CNT-elastomer current collector and fluorinated elastomer substrate.

4. Conclusions

We successfully developed a stable fabrication process for micro-supercapacitors from CNT electrodes with flexible components including CNT-elastomer current collectors and fluorinated elastomer substrate. From the experimental results, the fabricated device showed expected capacitive behavior in the frequency range from 10 to 0.1 Hz and high performance (energy density: 3.7 mWh/cm^3, power density: 39.8 W/cm^3). These results demonstrate CNT micro-supercapacitors can be stably fabricated with various materials including flexible ones, which broaden their potential applications.

Acknowledgements

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References

[1] T. Chen and L. Dai, Materials Today **16** (2013) 272.
[2] M. El-Kady *et al*., Science **335** (2012) 1326.
[3] M. Beidaghi and Y. Gogotsi, Energy Environ. Sci. **7** (2014) 867.
[4] D. Yu *et al*., Nat. Nanotech. **9** (2014) 555.
[5] M. El-Kady and R. Kaner, Nat. Commun. **4** (2013) 1475.
[6] B. Lim *et al*., ACS Nano **8** (2014) 11639.
[7] Z. Wu *et al*., Nat. Commun. **4** (2013) 2487
[8] T. Chen and L. Dai, J. Mater. Chem. A **2** (2014) 10756
[9] D. Kim *et al*., ACS Nano **7** (2013) 7975.
[10] S. Hong *et al*., ACS Nano **8** (2014) 8844.