New Forms of Nanogenerator using Piezoelectric $BaTiO_3$ Nanoparticles

***Kwi-Il Park*[1], *Geon-Tae Hwang*[1], *and Keon Jae Lee*[1]**
[1]**Dept. of Mater. Sci. and Eng., Korea Advanced Institute of Science and Technology (KAIST)**
291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Korea
Tel.:+82-42-350-3383, E-mail: keonlee@kaist.ac.kr

Keywords: ***$BaTiO_3$ nanoparticle, Carbon-nanotube, Nanogenerator, Energy harvesting***

Abstract

The piezoelectric generation using perovskite $BaTiO_3$ nanoparticles has been applied to convert mechanical deformation to electrical energy for the first time. A piezoelectric nanocomposite is produced by the simple process of dispersing nanoparticles and carbon-based nanomaterials in a polydimethylsiloxane matrix and subsequent spin-casting onto a metal-coated plastic substrate. The nanogenerator device generates an output voltage of ~3.2 V and a current of ~350 nA under periodic mechanical deformation to a strain of 0.33 %. This technology can offer innovative opportunities for portable or wearable consumer electronics, fiber-ITs, and permanent self-powered energy sources for health care systems and sensor devices.

1. Introduction

Piezoelectric energy harvesting technologies that scavenge electricity from vibrational and mechanical energy by human activities (such as pressure, bending, and stretching motions) have attracted a great interest recently due to their availability in indoor environments. Wang and co-workers have used piezoelectric ZnO nanowire arrays to develop nanogenerator technologies, who have demonstrated the feasibility using this type of generator to power commercial light-emitting diodes (LEDs), liquid crystal displays (LCD), and wireless data transmission.

Herein, we report the new forms of nanogenerator achieving a simple, low-cost, large scalable approach, and mass production based on $BaTiO_3$ nanoparticles (NPs) synthesized via hydrothermal reaction and multi-walled carbon nanotubes (MW-CNT). The $BaTiO_3$ NPs and MW-CNT are dispersed in polydimethylsiloxane (PDMS) by mechanical agitation to produce a piezoelectric nanocomposite (p-NC). The p-NC is spin-casted onto metal-coated plastic substrates and cured in an oven. The periodic external mechanical motions are applied to the nanogenerator by bending stage. These motions are generated the repeatedly output voltage and current signals.

2. Experimental procedure

Figure 1a shows schematic diagrams of the following fabrication steps. Cr (10 nm) / Au (100 nm) layers are deposited on a flexible plastic substrate by rf magnetron sputtering. A 20 μm thick PDMS layer is spun-coated on Au-coated plastic substrates. A PDMS layer is hardened at 85 ºC for 10 min in oven. The $BaTiO_3$ NPs used in this experiment is prepared by hydrothermal reactions. The $BaTiO_3$ NPs and MW-CNT are mixed, then stirred for 5hr in ethanol using magnetic bar. After subsequent drying and granulation, the nano-powders are soaked into PDMS matrix (p-NC). The p-NC is spun-coated on PDMS-coated plastic substrates and hardened in oven. We placed a PDMS-coated plastic substrate in uniform contact with p-NC/PDMS/ flexible substrates and fully hardened at room temperature for one day. The $BaTiO_3$ NPs in p-PDMS are poled at 150 °C by applying an electric field of 100 kV/cm for about 20 hr. The photograph in Fig. 1b shows a nanocomposite-based nanogenerator device. Copper (Cu) wires were attached the two electrodes on plastic substrate by a (Ag) paste and used to measure the output voltage and current signals. We also fabricated and characterized the bulk-type NCG (piezoelectric rubber, about 4 inch wafer scale), on which the Al foils are used to electrodes (Fig.1c). A large area device can also be fabricated by a process of Mylar bar-coating technique.

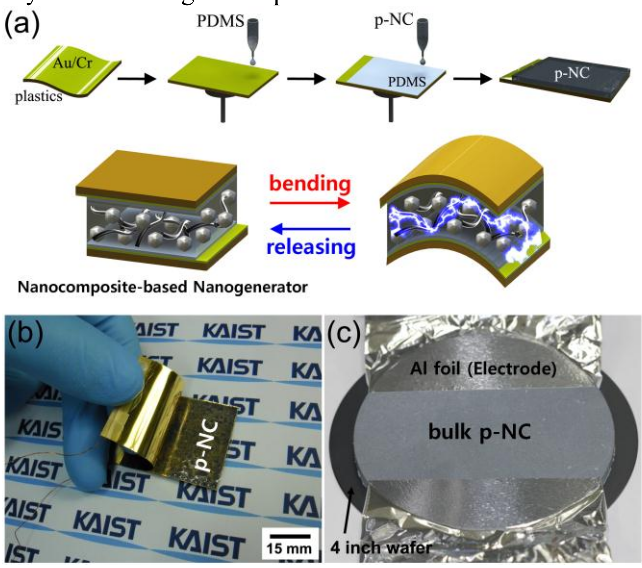

Fig. 1. (a) Schematic illustration of the process for fabricating nanogenerator. (b) Photograph of the nanogenerator (3 cm x 4 cm) (c) A bulk-type NCG (~ 4 inch wafer scale) fabricated by simple process.

3. Results and Discussion

Figure 2a shows the hydrothermal $BaTiO_3$ NPs having a rounded shape with size of 100 nm. The MW-CNTs, which are prepared via catalyst chemical vapor deposition, have a diameter of 5 to 20 nm and a length of ~10 μm (Figure 2b). Figure 2c shows the mixed nanomaterial with NPs and CNTs. Figures 2d shows SEM images of p-NC that is sandwiched between the top and bottom metal-coated plastic substrates. $BaTiO_3$ NPs and the CNTs are well distributed in the PDMS matrix. The $BaTiO_3$ NPs generate piezoelectric potential under external stress and act as an energy generation source. The CNT's role in device is dispersant, stress reinforcing agent, and conducting functional material.

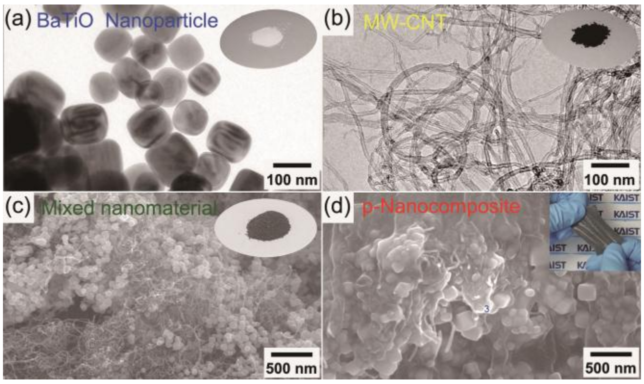

Fig. 2. (a) A TEM image of the $BaTiO_3$ NPs synthesized by hydrothermal method. (b) The MW-CNTs have a diameter of 20 nm and a length of 2 μm. (c) A SEM image of mixed nanomaterials. (d) A cross-sectional SEM photograph of the p-NC.

We measured the generated outputs of device during periodically bending and releasing motion by bending stage, as shown in the Figure 3. To verify that the measured output signals were generated by the sample, we also carry out the widely used 'switching-polarity' test. When a measurement instrument is forward connected to the device, the device generates the positive signals during bending by bending stage. In the case of the reverse connection, the negative output pulses are measured. These two results indicate that the measured outputs are the signals generated from the nanogenerator strained by bending motion. Figure 3a and b show the measured output voltage and current during periodically bending/releasing motions. Under a continual bending and releasing motions, the nanogenerator devices repeatedly generated an output voltage of ~3.2 V and a current signals of 250 ~ 350 nA. Figures 3c-i and ii show the measured output voltage (i) and current signals (ii) of the bulk-type NCG device (Fig. 1c) during periodically bending motion. We demonstrate the energy harvesting which is converting muscle movement into electrical energy. The small-scale bulk NCG device (area of 3 cm x 4 cm) is driven by human foot motions and generates the output voltage and current signals (Fig. 3d). The voltage produced by foot motions reach up to ~ 1.2 V.

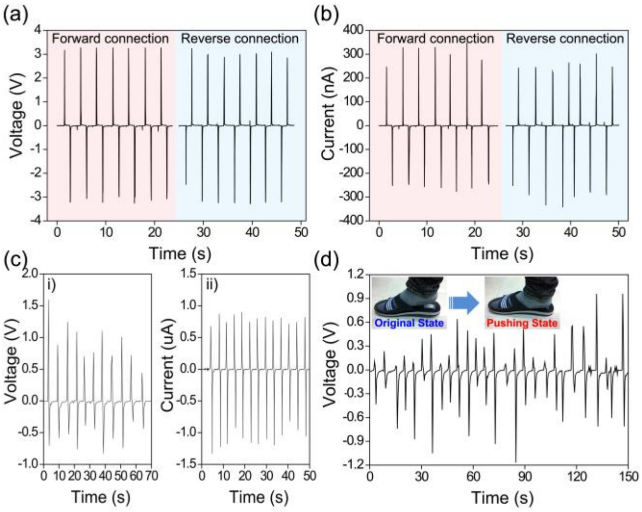

Fig. 3. The measured output voltage (a) and current signals (b) of the nanogenerator during the periodic bending and releasing motions. (c) Output signals measured from the bulk-type device. (d) The generated voltage from human foot motions.

4. Summary

We have fabricated the nanogenerator based on piezoelectric $BaTiO_3$ NPs and CNT. The $BaTiO_3$ NPs are mixed with CNTs to prepare the p-NC. When the device fabricated by spin-coating of p-NC is periodically bent by bending stage, the generated output voltage and current reached up to 3.2 V and 350 nA, respectively. Our technique has the advantages of simple process, low cost, and large area capacity and also demonstrates the feasibility for consumer electronics and sensor device-related works. These energy harvesting technology have also clear potential for energy harvesting in indoor environment and provide progressive opportunities for implantable devices. They are expected to be improved by using of conductive polymer electrodes for stretchable electronics and stacking structure for high output power density.

Acknowledgment

This work was supported by the Basic Science Research Program (grant code: CAFDC-2012-0000824) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology.

References

1. Z. L. Wang, J. H. Song, *Science*, 312, 242 (2006).
2. K.-I. Park, S. Xu, Y. Liu, G. T. Hwang, S. J. L. Kang, Z. L. Wang, K. J. Lee, *Nano Lett.*, 10, 4939 (2010).
3. K.-I. Park, M. Lee, Y. Liu, S. Moon, G.-T. Hwang, G. Zhu, J. E. Kim, S. O. Kim, D. K. Kim, Z. L. Wang, K. J. Lee, *Adv. Mater.*, 24, 2999 (2012)