www.transducers2017.org

The 19th International Conference on
Solid-State Sensors, Actuators and Microsystems

TRANSDUCERS '17
Kaohsiung

JUNE 18 - 22, 2017 ■ KAOHSIUNG, TAIWAN

FINAL PROGRAM


Source: Kaohsiung Exhibition Center (KEC)

GENERAL CHAIR
Weileum Fang
National Tsing Hua
University, TAIWAN

GENERAL CO-CHAIR
CP Hung
ASE Group, TAIWAN

PROGRAM CHAIR
Shuichi Shoji
Waseda University, JAPAN

TECHNICAL PROGRAM SPONSORS

IEEE

Electron Devices Society

TRANSDUCERS '17 KAOHSIUNG

CONFERENCE AT A GLANCE

SUNDAY, JUNE 18

11:00 - 20:00	Conference Registration and Check-In
12:30	Industry Sessions Registration
13:00 - 15:10	**Industry Session** - Start-Up (Room 301a)
15:10 - 15:30	Break
15:30 - 17:30	**Industry Session** - IoT (Room 301a)
17:40 - 20:00	Welcome Reception

MONDAY, JUNE 19

07:30 - 17:30	Registration			
08:30 - 09:10	Welcome Address and Technical Program Introduction			
09:10 - 09:50	**PLENARY PRESENTATION I** Alexander Kalnitsky, *Taiwan Semiconductor Manufacturing Company, Ltd. (TSMC), TAIWAN*			
09:50 - 10:30	**PLENARY PRESENTATION II** Albert van den Berg, *University of Twente, NETHERLANDS*			
10:30 - 11:00	Break and Exhibit Inspection			
11:00 - 11:40	**PLENARY PRESENTATION III** Kenneth S. Johnson, *Monterey Bay Aquarium Research Institute, USA*			
11:40 - 11:50	Transducers 2019 Conference Presentation			
11:50 - 12:00	Announcements			
12:00 - 14:00	Lunch and Exhibit Inspection			
12:30 - 14:00	**Industry Session** - IDM (Room 301a)			
14:00 - 16:00	**Poster/Oral Session M3P** (Refreshments Available)			
	ROOM 301a	**ROOM 301b**	**ROOM 304a**	**ROOM 304b**
16:00 - 17:30	**Session M4A** Bio Probes	**Session M4B** *In Vivo*	**Session M4C** Microphones & Other Physical Sensors	**Session M4D** RF MEMS I
18:20 - 21:00	Sunset Beach Reception			

TUESDAY, JUNE 20

	ROOM 301a	**ROOM 301b**	**ROOM 304a**	**ROOM 304b**
08:30 - 10:00	**Session T1A** Droplets INVITED SPEAKER	**Session T1B** Bio Imaging INVITED SPEAKER	**Session T1C** Piezoelectric Transducers INVITED SPEAKER	**Session T1D** RF MEMS II INVITED SPEAKER
10:00 - 10:30	Break and Exhibit Inspection			
	ROOM 301a	**ROOM 301b**	**ROOM 304a**	**ROOM 304b**
10:30 - 11:45	**Session T2A** Cell Analysis	**Session T2B** Chemical Sensors	**Session T2C** Graphene	**Session T2D** Optical Transducers I
11:45 - 14:00	Lunch and Exhibit Inspection			
12:30 - 14:10	**Industry Session** - Fab (Room 301a)			
14:00 - 16:00	**Poster/Oral Session T3P** (Refreshments Available)			
	ROOM 301a	**ROOM 301b**	**ROOM 304a**	**ROOM 304b**
16:00 - 17:45	**Session T4A** Cell Culture	**Session T4B** Gas Sensors I	**Session T4C** Stretchables & Wearables	**Session T4D** Energy Harvesters

HIGHLY EFFICIENT SUPERHYDROPHOBIC SURFACE-BASED TRIBOELECTRICNANOGENERATOR FOR ROTATIONAL MACHINERIES

Chae-Rin.Yu[1], *Min-Jin Jung*[1], *Yeong-Il Song*[1], *Jung-Hwa Park*[1] *and Dong-Weon Lee*[1*]
[1]MEMS and Nanotechnology Laboratory, School of Mechanical Engineering,
Chonnam National University, Gwangju, KOREA

ABSTRACT

In this paper, we propose super-hydrophobic surface-based triboelectric nanogenerators (TENGs) which can be employed to harvest mechanical energy from rotational machineries to power battery-less sensor nodes. The proposed TENGs consist of a coaxial cylindrical structure connected with a motor and two Al electrode covered by various PDMS films. Surface-structured PDMS thin films induce more charges on the surface due to the increase of contact area. The PDMS thin film with pyramid structures on the surface shows the highest output performance in comparing with others. However, among three different surface structures, dual-scaled PDMS film made by an under-baked and under-exposed PR mold shows a better hydrophobicity compared to pyramid and artificial lotus leaf PDMS structures. Self-cleaning effect is also demonstrated with the proposed TENG system. We believe that the proposed TENG has a great potential to realize battery-less sensor systems.

KEYWORDS

Energy Harvest, Wireless Sensor Network, Triboelectric Nanogenerator (TENG), Hydrophobic, Self-cleaning

INTRODUCTION

With the growing of air pollution and global warming by the continuous use of nonrenewable fossil fuels, the development of clean and renewable sources become one of important challenges in today's world [1]. The category of the clean energy that converts natural energy to electrical energy can be divided into several different ways such as solar cell [2], wind energy [3], mechanical energy [4-5] etc. In general, these energy sources can be effectively converted to electricity by using abandoned energy. Although there is great potential as the use of the alternative energy sources for the large-scale systems, electrical power generated is still not high enough and mainly employed for the small-scale systems such as a wireless sensor network(WSN) [6-7].

Due to the widespread use of WSN-based sensor technology, the need of miniaturized energy harvesters(EH) is increasing even more [7]. This is due to the limited life of coin-sized batteries and high maintenance cost for periodic replacement [8]. In general, harvesting technology utilizing mechanical motion or vibration is a very attractive way for the small electronic devices such as the WSN. The mechanical energy can be converted using well-known physical phenomena such as piezoelectric [9], thermoelectric [10], and electromagnetic [11]. The miniaturized EHs converts mechanical vibrations into electrical energy without the help of external power, but it is difficult to produce enough power for the WSN applications because of the low output voltage or current.

Triboelectric nanogenerator (TENG) is one of new methods to convert mechanical energy into electricity [12-13]. The TENG is based on the conjunction of triboelectrification and electrostatic induction, and it utilizes the most common materials available in our daily life, such as papers, fabrics, PTFE, PDMS, Al, PVC etc. The TENG shows much higher efficiency in power generation and has relatively simple configuration in comparison with other methods mentioned above [14]. Thanks to the advantages various design and applications have been proposed from many research groups [14-15]. A TENG proposed by Zhang et. al. generates electric energy by rotating motion of tires. They employ an asymmetrical disk of the power shaft and the TENG produces more electricity with higher power density than the symmetrical disk [15]. However, since one electrode of TENG is attached to the disk, there is an issue that the durability is deteriorated due to friction caused by sliding. In other way [16], the vibration generated by the wind is proposed by Zhao et. al. It consists of a polyamide (PA) as the wind-induced vibration layer and two electrodes covered by super-hydrophobic films with a contact angle of about 150°. However, there is a drawback that the output voltage differs according to the angle of the wind.

In this study, we propose a new structure of TENG that has a self-cleaning effect and generates a constant voltage irrespective of wind direction. The proposed TENG consists of a PDMS thin film with super water repellent behavior and CAM to make repeated mechanical contact between two plates. The surface-patterned PDMS film used in the TENG was produced by using a photoresist (PR) mold having a unique structure. The fabricated PDMS films with artificial lotus structures on the surface exhibit superior hydrophobicity compared to pyramidal and duplicated lotus leaf PDMS structures. In addition, the self-cleaning effect prevents the contamination of the PDMS in a harsh working environment, enabling TENG to produce electric power efficiently. The proposed TENG is expected to be used as a core energy source instead of a battery in the WSN applications.

DESIGN ANF FABRICATION

As shown in Fig. 1, the proposed TENG consists of TENG's electrodes, substrates, rotating parts, and housing units. The electrodes of TENG consisted of Al, Cu, PDMS, and PMMA films. The substrates were manufactured by using a 3D printer and mounted on an acrylic box, and a rotating part in the TENG was mounted between two substrates. The size of the entire TENG substrate is 50 mm × 50 mm × 10 mm. The size of the PDMS film used in the TENG system is 40 mm × 40 mm and the thickness is 2 mm. PMMA and Al electrodes were attached to the right part of TENG, and surface-patterned PDMS and Cu electrodes were attached to the other part. As shown in the Fig. xx, wind cups combined with a rotatable shaft can generate the output voltage regardless of the direction of the wind.

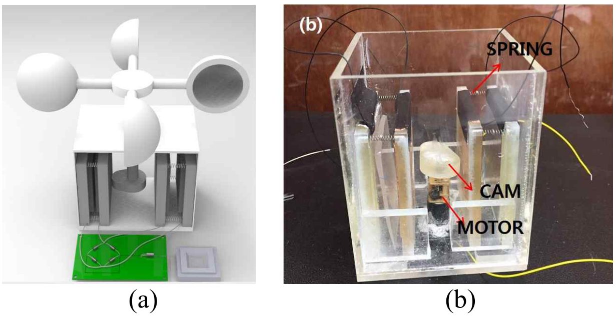

Figure 1: Optical images of (a) fabricated TENGs and (b) TENGs combined with a cylindrical shaft for output performance characterization. A CAM structure placed between two TENGs impacts the surface of TENG electrode during the rotation.

As shown in Fig. 2, four different PDMS films were prepared as electrodes to compare the performance in output voltage. Pyramid structures are made by reversed silicon mold fabricated by TMAH wet etching and the width of the structures at the bottom was about 12.5 µm. The duplication of lotus leaf film was replicated with the real lotus leaf as a mold. In addition, a dual-scaled structure, which is a super water-repellent film, is fabricated using a photoresist mold proposed in our previous report [17]. The photoresist mold is spin-coated with AZ4620 at 1,000 rpm for 20s and then subjected to soft baking twice for 3 min. It was baked again for 45 min to produce a mushroom-like structures having a pitch distance of 80 µm. The fabricated PDMS film with the super-hydrophobic surface makes it possible to easily clean contaminants generated on the surface when TENG operates in the external environment.

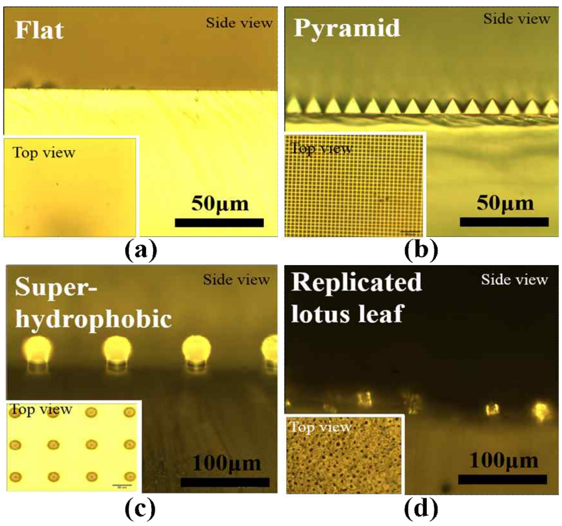

Figure 2: Optical microscope images of the PDMS film which have four different type structures: (a) flat, (b) pyramid, (c) dual-scaled super-hydrophobic and (d) replicated lotus leaf.

The working principle of the proposed triboelectric nanogenerator can be explained on the basis of the contact electrification coupling with electrostatic induction. The two electrodes of the proposed TENG make a contact as the cam rotates by the rotation energy generated from natural wind. The movable electrode of the TENG is linearly contacted, which improve the ware problem of conventional TENGs employing a sliding contact. When the aluminum film maintains full contact with the PDMS surface, the charge transfer occurs between two triboelectric layers. Owing to the opposite triboelectric polarities, the negative electrons from the aluminum film are transferred onto the surface of the surface-patterned PDMS thin film. Since the surfaces of the two triboelectric friction layers make complete contact, these two opposite polarity charges are balanced out, and no electron flow occurs in the external circuit. Once a relative distance is caused as a result of cam rotation, the triboelectric charges on the two discontiguous surfaces cannot be compensated. The negative electrodes drive free electrons on the back copper electrode to the aluminum electrode through a circuit. The induced electron flow lasts until the distance between the two discontiguous surfaces reaches the maximum. As the rotation continues, the PDMS film comes into contact with the aluminum electrode again and the induced electrons flow back in the opposite direction until the fully aligned position is restored. The AC voltage output from the TENG device is converted into a DC voltage by using a rectifier and stored into a capacitor. The stored electrical energy can be used for battery-less sensor systems.

EXPERIMENT AND RESULTS

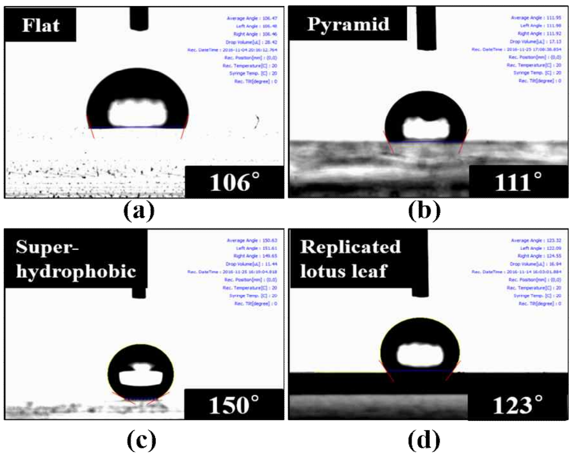

Figure 3: Water contact angle images of various PDMS thin films employed for TENG applications. Higher contact angle is desirable to minimize the contamination

The water contact angle of four different PDMS films were measured by dropping a certain volume of water droplets onto a PDMS film using a syringe. The higher contact angle has the greater the super-hydrophobic nature. In particular, when the water contact angle between water and the PDMS film exceeds 150°, the cleaning effect become more excellent due to the super-hydrophobic property. Fig xxx show experiment results of the water contact angle for the four different PDMS films having different surface structures. Water contact angle for flat PDMS, PDMS with pyramid structures, replicated lotus leaf PDMS film did not exceed 150°, however, dual-scaled super-hydrophobic PDMS film exceed 150°.

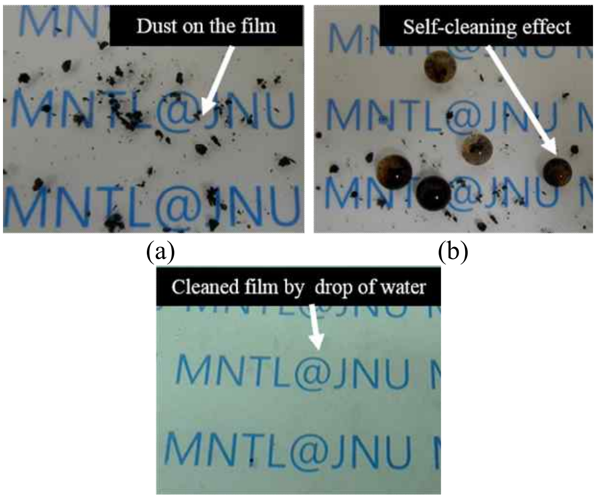

Figure 4: Optical images showing the self-cleaning capability of ultra-hydrophobic PDMS film.

In order to investigate the cleaning effect of the fabricated super-hydrophobic PDMS film, the dual-scaled surface was contaminated with dust and water was sprayed on the contaminated film to observe how well the dust was cleaned by the water. Figure 4 shows the experiment results. As shown in Fig. 6 (c), excellent cleaning effect of the dual-scaled super-hydrophobic PDMS thin film was experimentally observed.

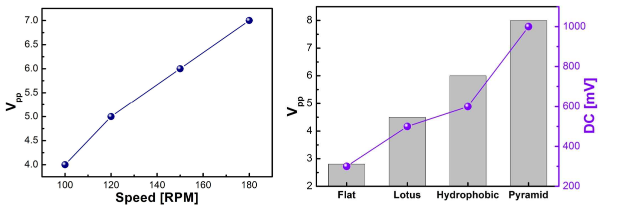

Figure 5: (a) Output voltage as a rotating speed on a motor connected to a cylindrical shaft, (b) output performance of four types of TENGs. The pulse voltage is storage in a capacitor.

Output voltages for four types of PDMS film were measured to determine the surface effect of super-hydrophobic PDMS film. The proposed TENG system employs an electrical motor instead of wind power for the basic experiment. When the motor rotates at 160 rpm, output voltage is about 7V. Figure 5(a) shows that the output voltage is a function of the rotational speed of the motor. The higher rpm of the motor generates the higher peak voltage thanks to the increase of contact force. After the rpm was set at 180 rpm, the output voltage of the dual-scaled super-hydrophobic PDMS film with higher water contact angle was compared with the peak voltage of other PDMS thin films. The output voltage of the dual-scaled super-hydrophobic PDMS film was about 6V. The Pyramid PDMS film and the flat PDMS film were 8V and 4V, respectively. This is thanks to the large surface area of surface-patterned PDMS thin films. It seems that the micro-structures with a pointed-end would be more effective in order to concentrate charge density which influences to the peak-voltage.

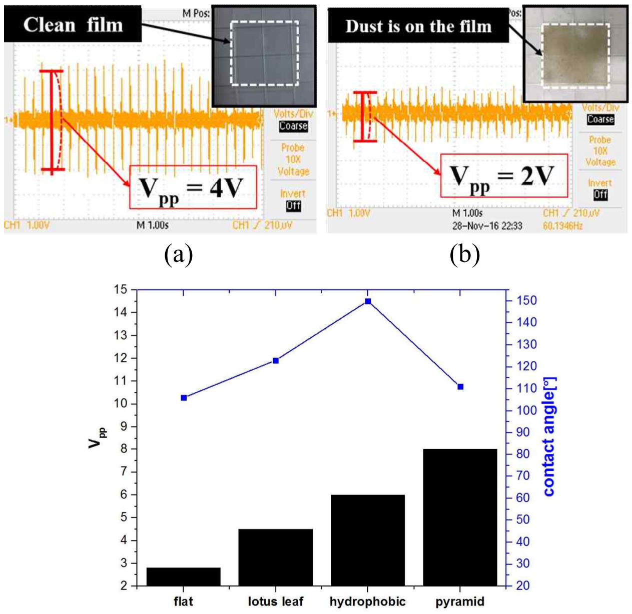

Figure 6: Comparison of output power between (a) TENGs with clean surface and (b) TENGs with contaminated surface. (c) Output voltage is slightly decreased, however, water contact is increased about 150%

Experiments were conducted to experimentally confirm the change in output voltage when the PDMS film surface was contaminated by dust. First, we compared the output performance generated by TENGs when dust was applied to a flat PDMS film and when no dust was applied. The voltage of the PDMS film with dust on the surface was about half that of the PDMS film without dust on the surface. This result indicates that if the conventional TENG is used outside for a long time, the surface may be contaminated and the efficiency of the TENG generator may be lowered. To reduce the degradation of power generation from the TENG due to contamination, a self-cleaning super-hydrophobic PDMS film was applied in the proposed TENG system that exhibits stable efficiency even in an external environment.

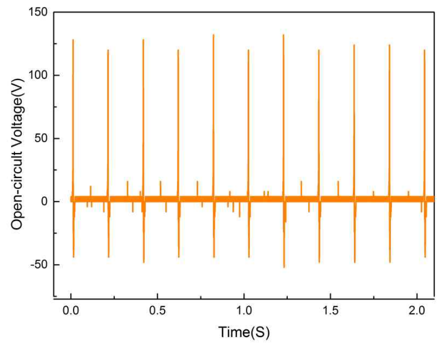

Figure 7: The out voltage is can be increased up to about 200V by replace the motor that provides much high force to TENGs.

Since the output voltage of the fabricated TENG is a small for practical use, a larger output voltage is required for WSN applications. The output voltage varies depending on the magnitude of the force acting on the TENG system. Additional experiment was conducted to verify that the proposed TENG system can produce enough output voltage in real life. Experimental results show that the output voltage of about 150V is obtained when the large force is applied to the fabricated TENG. We experimentally confirm that it is suitable for practical use by increasing the contact force through the optimum design of the system in the future.

CONCLUSIONS

In this study, we proposed a new concept of TENGs, which uses a dual-scaled super-hydrophobic PDMS film as an electrode and efficiently produce electric energy by using abandoned energy such as a wind power. The output voltage of the TENG with the dual-scaled super-hydrophobic PDMS film was about 6V, which was 2 times higher than that of the flat PDMS film. The output voltage of clean surface was also 2 times higher than the output voltage of the TENG with the contaminated surface. The self-cleaning effect on the surface was due to the advantage of super-hydrophobic PDMS film. It was experimentally confirmed that the dual-scaled super-hydrophobic PDMS film was excellent in using as the TENG electrode. By changing the rotational motion into a linear motion, it was possible to eliminate the issue caused by the frictional force during the rotation. As the result, the efficiency and reliability of the TENG was improved. These results show that the proposed TENG is suitable for obtaining electrical energy from the rotating machine under various environmental conditions. The proposed TENG structure is very simple and can increase the output voltage up to 200V through additional structural optimization. We believe that the proposed TENG has great potential to implement battery-free sensor systems.

ACKNOWLEDGEMENTS

This research was supported by the Commercialization Promotion Agency for R&D Outcomes (COMIPA) funded by the Ministry of Science, ICT and Future Planning (MSIP)(No.2016K000209)

REFERENCES

[1] Z. L. Wang, "Enhanced Triboelectric Nanogenerators and Triboelectric Nanosensor Using Chemically Modified TiO2 Nanomaterials", ACS Nano, vol. 7, pp. 4554-4560, 2013.

[2] H. S Kim, C. R Lee, Im, J. H., Lee, K. B., Moehl, T., Marchioro, A. Grätzel, M, "Lead iodide perovskite sensitized all-solid-state submicron thin film mesoscopic solar cell with efficiency exceeding 9%". SCI REP vol. 2, pp. 591, 2012.

[3] J Sirohi, R. Mahadik, "Piezoelectric wind energy harvester for low-power sensors". J INTEL MAT SYST STR vol. 22, pp. 2215-2228, 2011.

[4] Y. Qin, X. Wang, Z. L Wang, "Microfibre–nanowire hybrid structure for energy scavenging". Nature, vol. 451, pp. 809-813, 2008.

[5] M. Lee1, C.Y Chen, S. Wang, S. N. Cha, Y. J. Park, J. M. Kim, L.J. Chou, Z. L. Wang, "A Hybrid Piezoelectric Structure for Wearable Nanogenerators" Adv. Mater. Vol. 24, pp. 1759– 1764, 2013.

[6] S. Roundy, D. Steingart, L. Frechette, P. Wright, J. Rabaey, "Power sources for wireless sensor networks", EWSN , pp. 1-17, 2004.

[7] J. Hill, D. Culler, "Mica: A Wireless Platform for Deeply Embedded Networks", IEEE Micro, vol.22, pp. 12–24, 2002.

[8] E. Jovanov, A. Milenkovic, C. Otto, P. C. De Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation", J NEUROENG REHABIL, vol. 2, 2005.

[9] H. A. Sodano, D. J. Inman, G. Park, "Comparison of piezoelectric energy harvesting devices for recharging batteries", J INTEL MAT SYST STR, vol.16, pp.799-807, 2005.

[10] E. J. Carlson, K. Strunz, B. P. Otis, "A 20 mV input boost converter with efficient digital control for thermoelectric energy harvesting", IEEE J SOLID-ST CIRC,vol. 45, pp. 741-750, 2010.

[11] S. P. Beeby, R. N. Torah, M. J. Tudor, P. Glynne-Jones, T. O'donnell, C. R. Saha, S. Roy, "A micro electromagnetic generator for vibration energy harvesting", J MICROMECH MICROENG, Vol.17, pp.1257-1265, 2007.

[12] R. D. Kornbluh, R. Pelrine, H. Prahlad, A. Wong-Foy, B. McCoy, S. Kim, J. Eckerle, T. Low, " From boots to buoys: promises and challenges of dielectric elastomer energy harvesting", Proc.SPIE,vol.7976, pp.67-86, 2011.

[13] G. Zhu, C. Pan, W. Guo, C. Y. Chen, Y. Zhou, R. Yu, Z. L. Wang, "Triboelectric-Generator-Driven Pulse Electrodeposition for Micropatterning", Nano Lett, vol. 12, pp. 4960– 4965, 2012.

[14] G. Zhu, Z. H. Lin, Q. Jing, P. Bai, C. Pan, Y. Yang,& Z. L. Wang, "Toward large-scale energy harvesting by a nanoparticle-enhanced triboelectric nanogenerator", Nano Lett, vol. 13, pp. 847-853, 2013.

[15] H. Zhang, Y. Yang, X. Zhong, Y. Su, Y. Zhou, C. Hu, Z. L. Wang, "Single-electrode-based rotating triboelectric nanogenerator for harvesting energy from tires", Acs Nano, vol. 8, pp. 680-689, 2013.

[16] K. Zhao, Z. L. Wang, Y. Yang, "Self-Powered Wireless Smart Sensor Node Enabled by an Ultrastable, Highly Efficient, and Superhydrophobic-Surface-Based Triboelectric Nanogenerator", ACS nano, vol. 10, pp. 9044-9052, 2016.

[17] Y. Yoon, D. Lee, et al., "Fabrication of optically transparent PDMS artificial lotus leaf film using underexposed and underbaked photoresist mold", J MICROELECTROMECH S, vol. 22.5, pp. 1073-1080, 2013.

CONTACT

*D.W. Lee, tel: +82-62-530-1669; mems@jnu.ac.kr