Supporting Information

High Output Magneto-mechano-triboelectric Generator Enabled by Accelerated Water-soluble Nano-bullets for Powering Wireless Indoor Positioning System

Kyung-Won Lim,[a,b] Mahesh Peddigari,[a] Chan Hee Park,[a] Ha Young Lee,[b] Yuho Min,[a] Jong-Woo Kim,[a] Cheol-Woo Ahn,[a] Jong-Jin Choi,[a] Byung-Dong Hahn,[a] Joon-Hwan Choi,[a] Dong-Soo Park,[a] Jae-Keun Hong,[a] Jong-Taek Yeom,[a] Woon-Ha Yoon,[a] Jungho Ryu,[c]* Sam Nyung Yi[b]* and Geon-Tae Hwang[a]*

[a]Korea Institute of Materials Science (KIMS), Changwon, Gyeongnam, 51508, Republic of Korea

[b]Department of Electronic Materials Engineering, Korea Maritime and Ocean University (KMOU), Busan 49112, Republic of Korea

[c]School of Materials Science & Engineering, Yeungnam University (YU), Gyeongsan, Gyeongbuk 38541, Republic of Korea

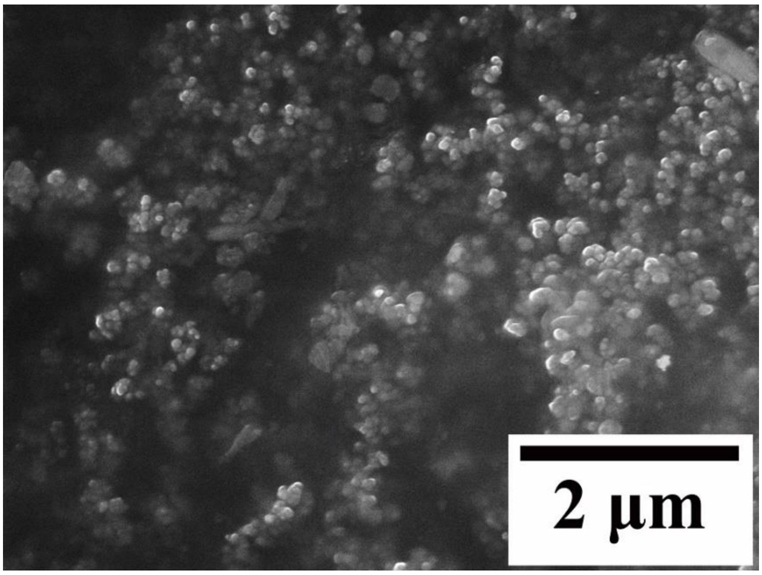


Fig. S1. SEM image of NaCl salt nanoparticles.

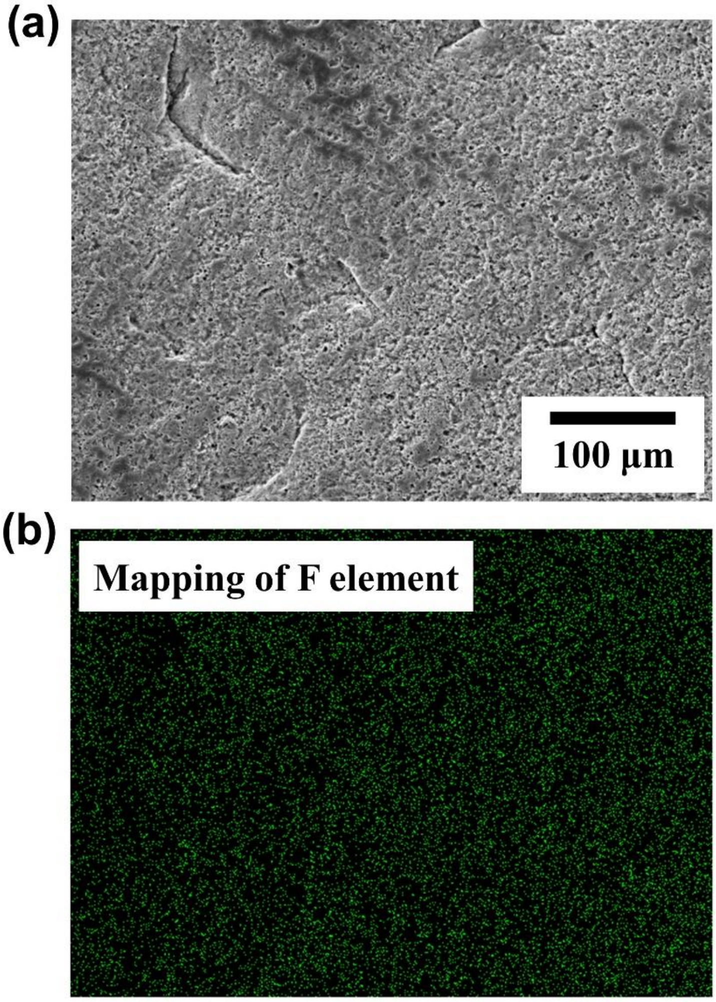


Fig. S2. (a) SEM image of PFA film with nanostructures. (b) Energy dispersive spectroscopy (EDS) mapping result of PFA film with nanostructures to verify surface fluorine element.

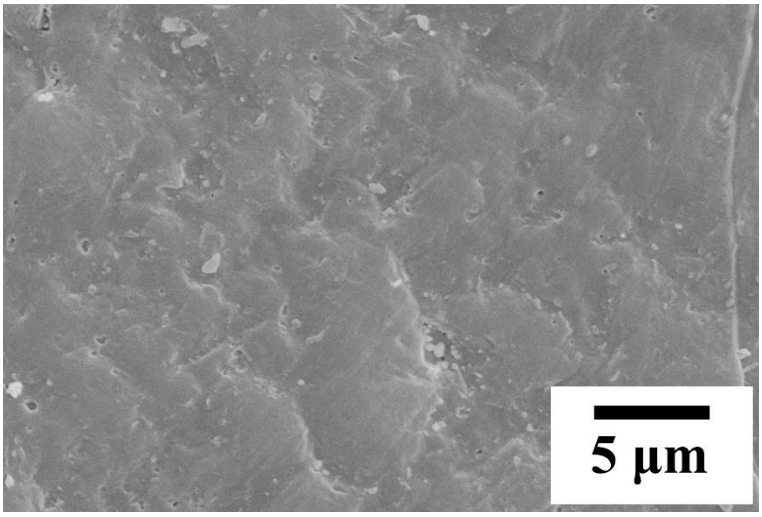


Fig. S3. SEM image of flat PFA film without nanostructures.

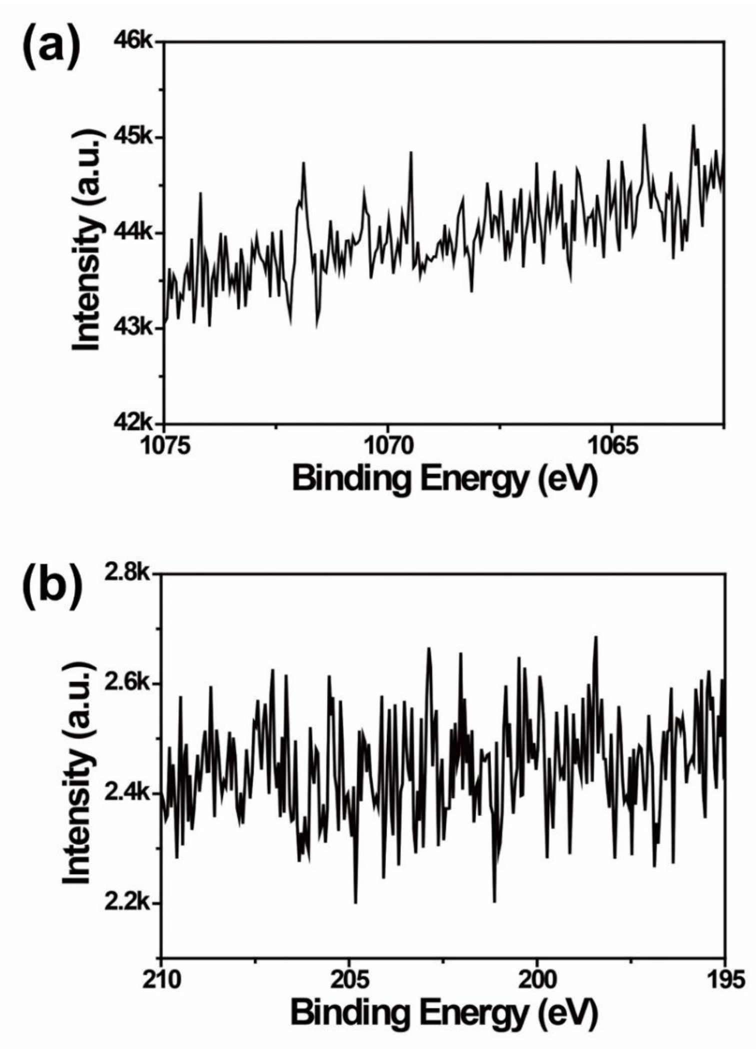


Fig. S4. Surface analysis results of PFA film after formation of nanostructures to confirm residual Na (a) and Cl (b) components using XPS. Na and Cl elements were not observed after the dissolution process of NaCl.

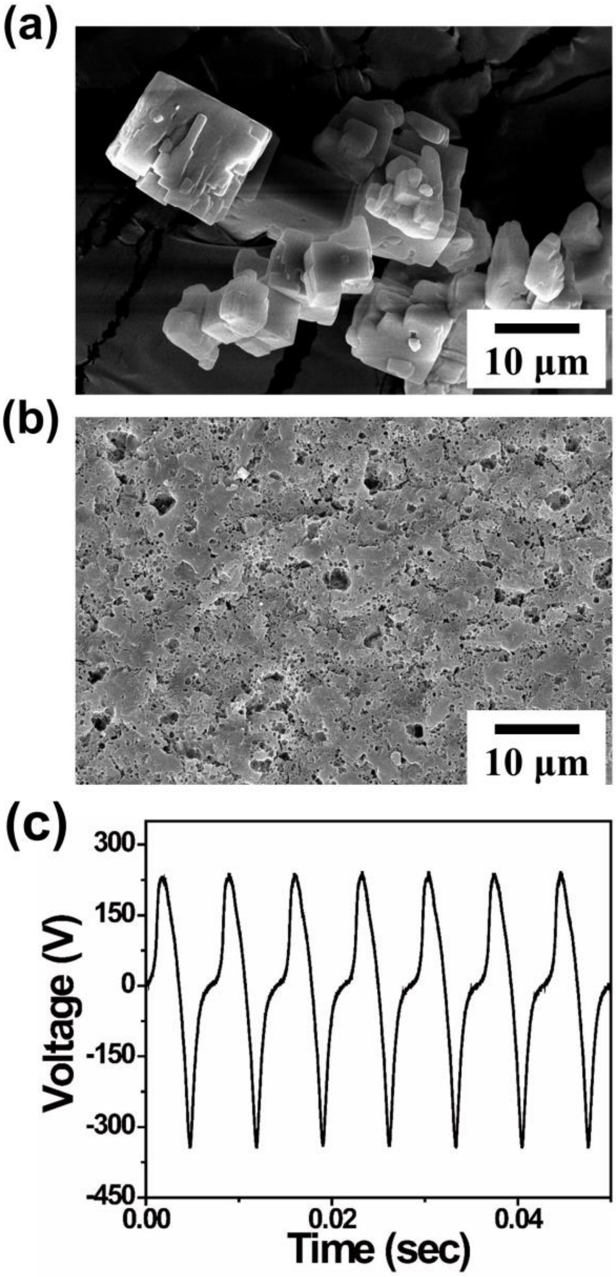


Fig. S5. (a) SEM image of NaCl particles grounded by planetary milling at 150 rpm for 1.5 hours. (b) SEM image of PFA surface after performing the AD process using the 1.5 hours milled NaCl particles. The formed craters on the PFA was nm to μm-scale. (c) Open-circuit triboelectric output voltage (V_{pp} of 589 V) from the PFA film treated with 1.5 hours milled particles.

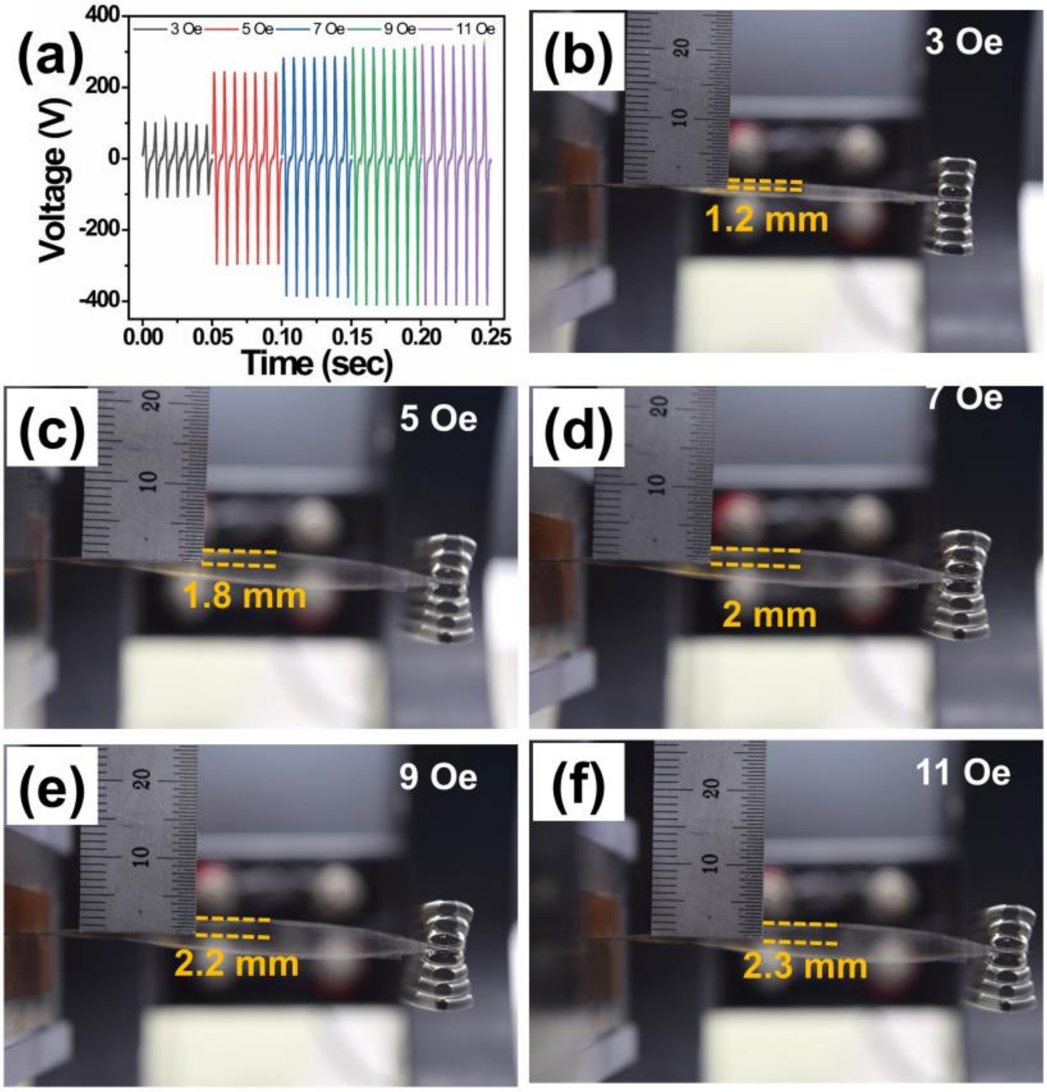


Fig. S6. (a) Open-circuit voltage output of the MMTEG under different AC magnetic fields. Captured side view images of the cantilever structure to verify the moving displacement under magnetic field of 3 Oe (b), 5 Oe (c), 7 Oe (d), 9 Oe (e), or 11 Oe (f). At the first stage (changing of magnetic field from 3 to 5 Oe), the increase margin of cantilever displacement was 0.6 mm, whereas at the final stage (changing of magnetic field from 9 to 11 Oe), the increase margin of cantilever displacement was just 0.1 mm. Since the triboelectric output voltage was theoretically proportional to the distance of two counterpart triboelectric layers, the output voltage of our MMTEG could nearly saturated from magnetic field of 9 Oe.

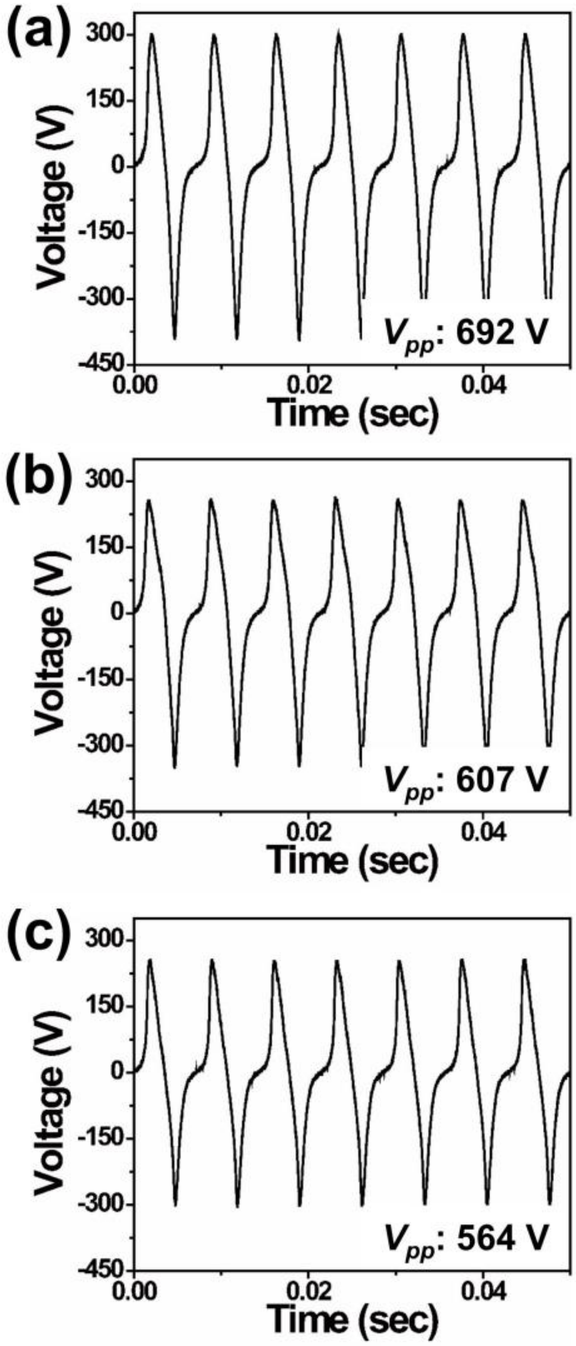


Fig. S7. The open-circuit output voltage from MMTEG with different PDMS thickness of 50 μm (a), 100 μm (b), and 150 μm (c) on the backside of Al foil. The output performance of MMTEG device was noticeably decreased with a thicker PDMS layer on the Al foil.

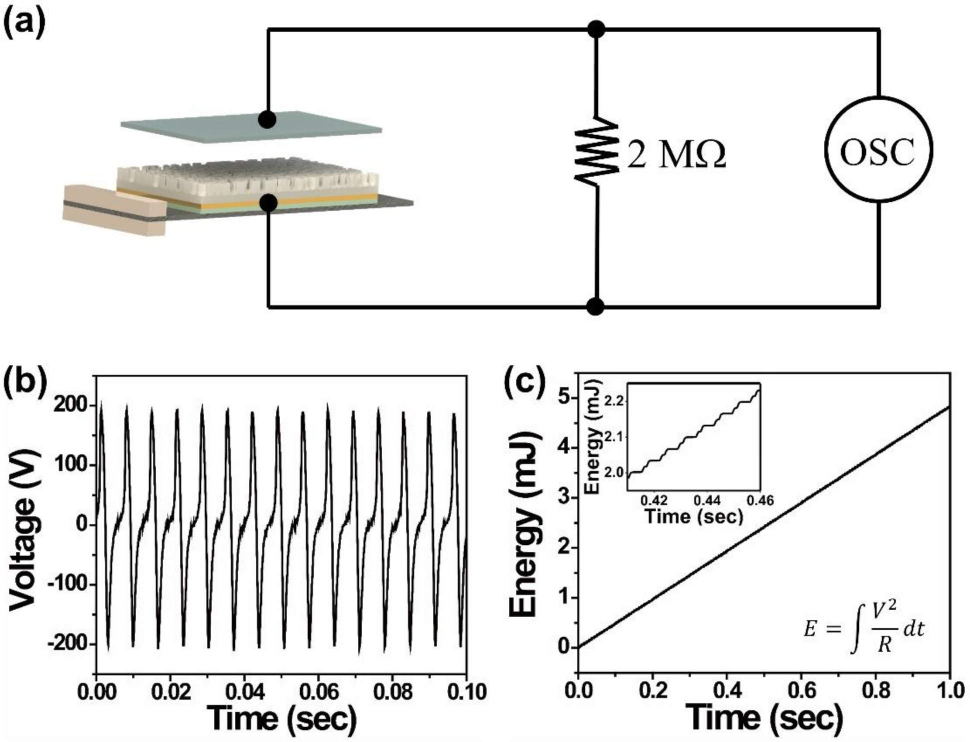


Fig. S8. (a) Circuit diagram for the measurement of continuous AC output power with the MMTEG, 2 MΩ load resistance, and oscilloscope under an AC magnetic field of 7 Oe at 143.2 Hz. (b) The output voltage produced from the MMTEG with a resistance of 2 MΩ. (c) Electric energy generated from the MMTEG for 1 second. The triboelectric device can continuously generate AC power of 4.8 mW (4.8 mJ for 1 second).

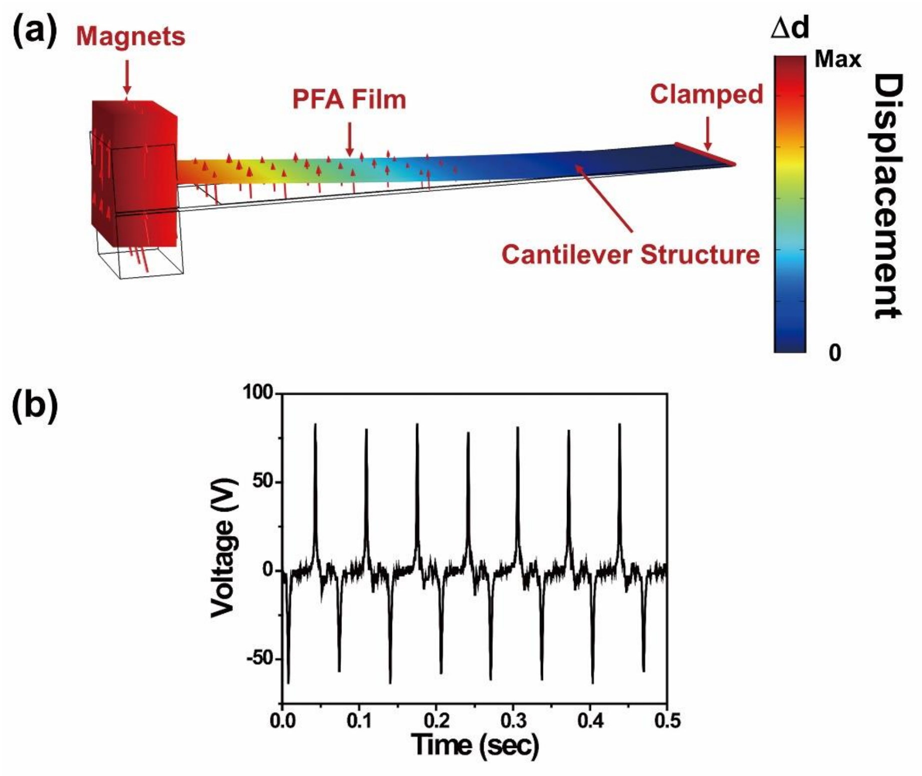


Fig. S9. (a) Eigenfrequency analysis of the bending mode at the first resonance frequency for the MMTEG cantilever using simulation tool. (b) Output open-circuit voltage of the first eigenfrequency-bending mode at 15.1 Hz with AC magnetic field of 7 Oe by real experimental measurement.

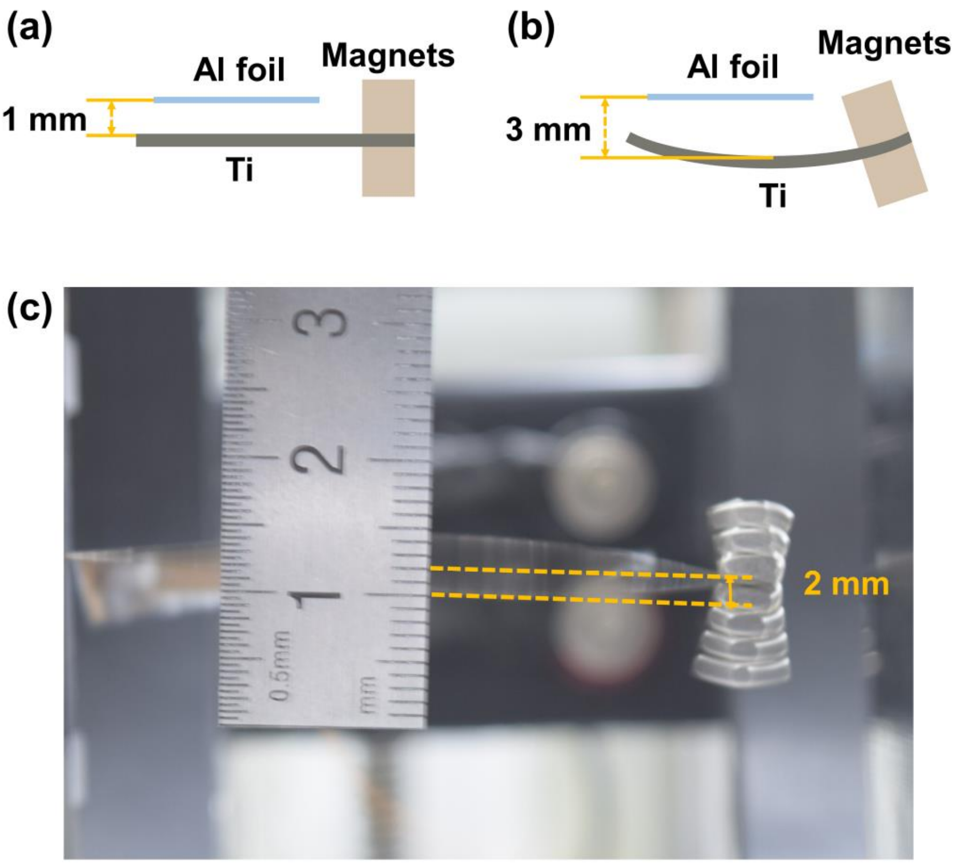


Fig. S10. Schematics of MMTEG at original state (a) and bending state (b), (c) Captured side view of MMTEG on operation to verify the moving displacement of cantilever structure.

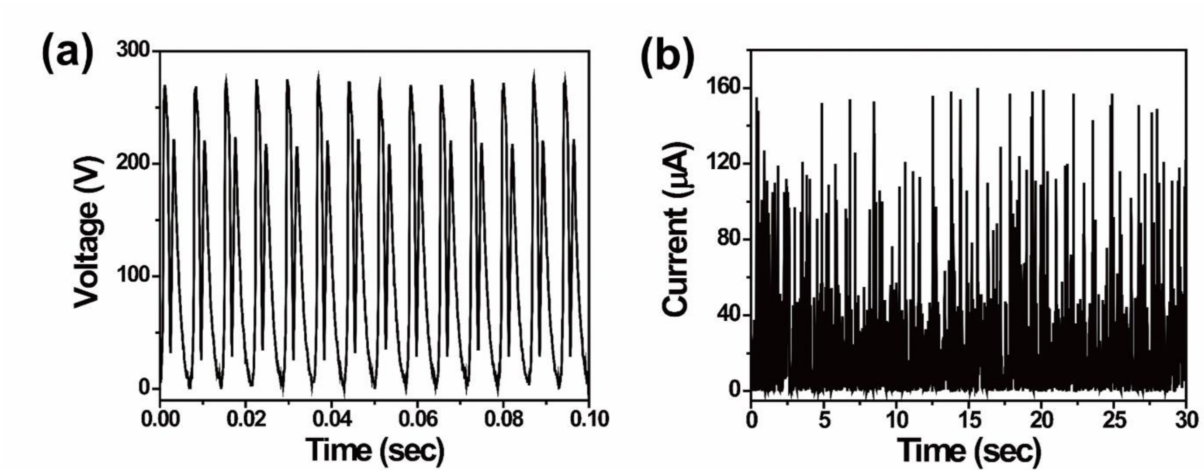


Fig. S11. A rectified open-circuit output voltage (a) and short-circuit current (b) from MMTEG under AC magnetic field of 7 Oe.

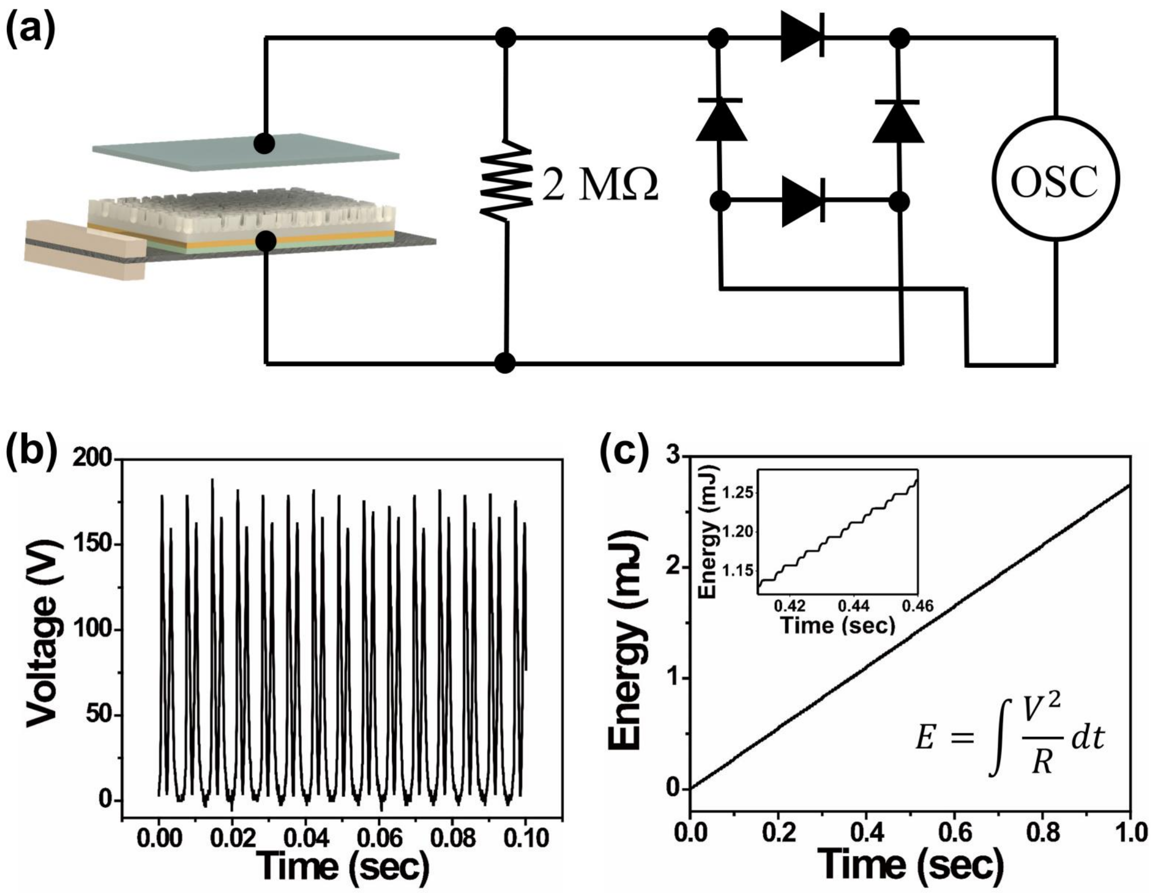


Fig. S12. (a) Circuit diagram for the measurement of continuous DC output power after rectifying (by utilizing a commercial W06 bridge rectifier that has limited input of 600 V and 1.5 A) the output of MMTEG with 2 MΩ load resistance under an AC magnetic field of 7 Oe at 143.2 Hz. (b) The rectified voltage produced from the MMTEG with a resistance of 2 MΩ. (c) Electric energy generated from the MMTEG for 1 second after the rectification. The triboelectric device can continuously generate DC power of 2.7 mW (2.7 mJ for 1 second). The rectifying process caused a huge energy loss of 2.1 mW compared to the initial AC output power of 4.8 mW at resistance of 2MΩ (energy loss of ~44% during the rectification).

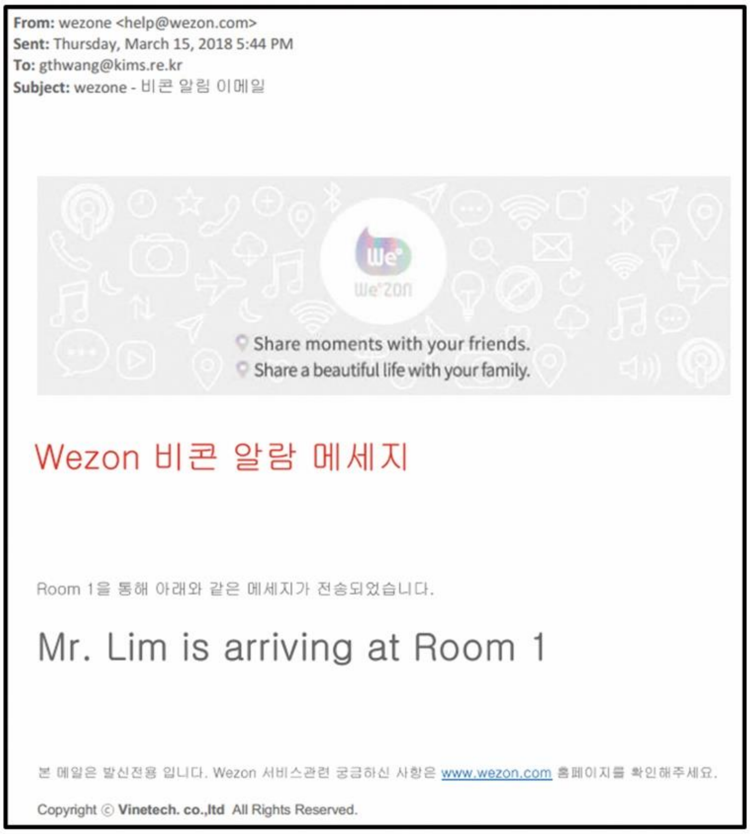


Fig. S13. A message including accurate indoor position of a user who closely approached the self-powered IoT beacon system, which was transmitted from a portable smart pad to the main monitoring computer by wireless internet service.

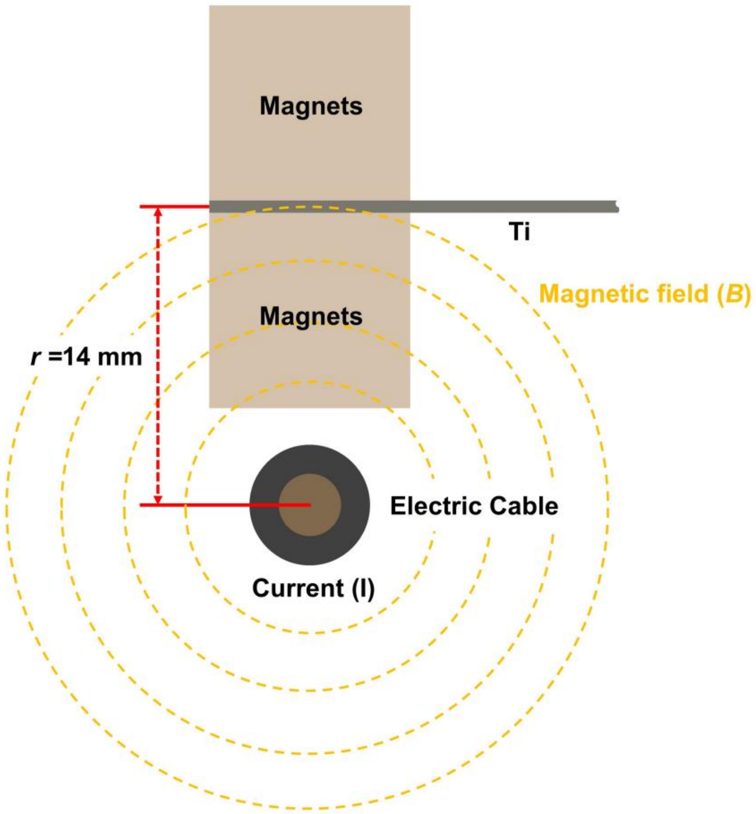


Fig. S14. Schematic illustration of the MMTEG on a 60 Hz electric power cable with current flow (I) to calculate the applied magnetic field (B) on the centre point of magnets located at the end part of cantilever structure using Ampère's law.

Ampère's law $\oint \vec{B} \cdot d\vec{s} = \mu_0 I$

$$2\pi r B = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r}$$

(B: magnetic field, μ_0: permeability of free space, r: radius or distance from the centre of electric cable, I: flowing current on the electric cable)

I_{rms} = 9.2 A, $B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7}\,\mathrm{H}/m \times 9.2\ A}{2\pi \times 0.014\ \ m} = 1.31 \times 10^{-4}\ \mathrm{T} = 131\ \mu\mathrm{T} = 1.31\ \mathrm{Oe}$

I_{rms}= 5.0 A, $B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7}\,\mathrm{H}/m \times 5\ A}{2\pi \times 0.014\ m} = 7.14 \times 10^{-5}\mathrm{T} = 71.4\ \mu\mathrm{T} = 0.71\ \mathrm{Oe}$

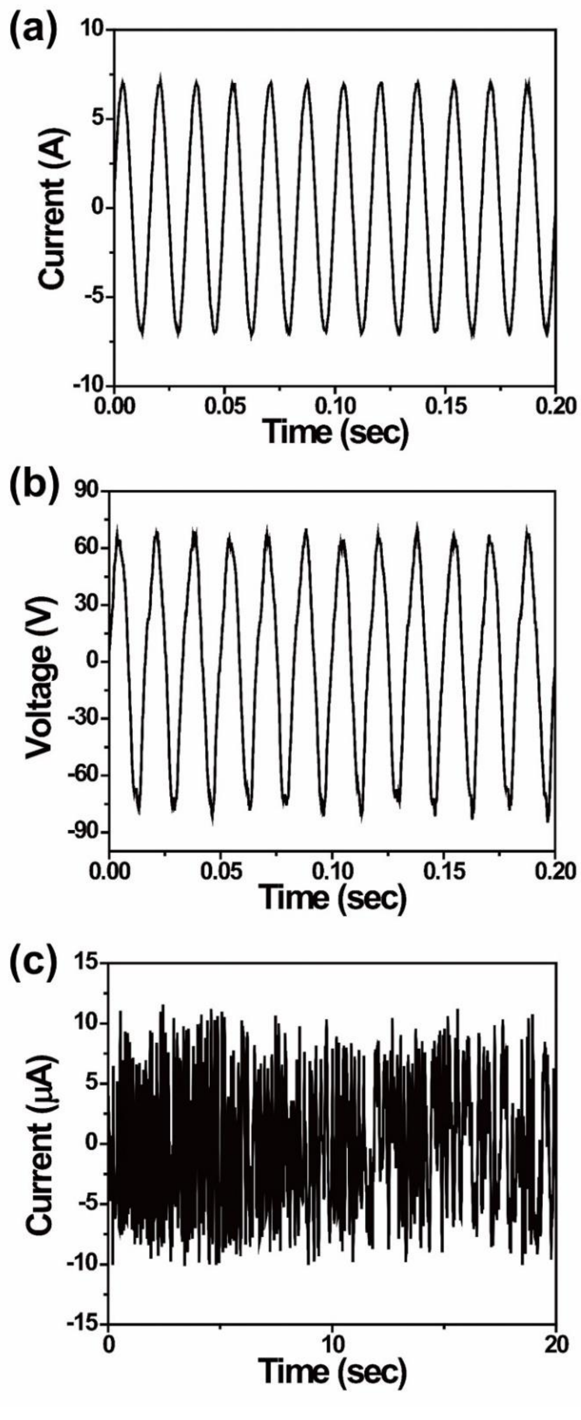
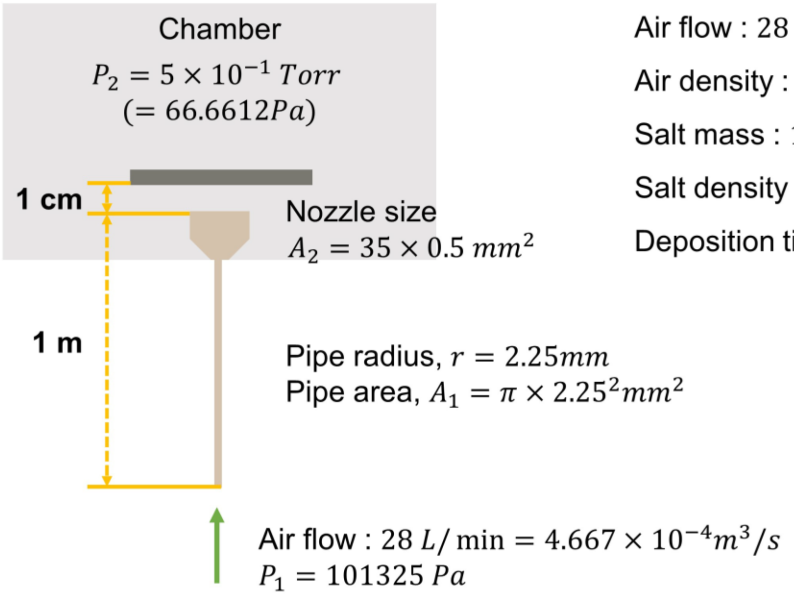


Fig. S15. (a) Measured AC current on the power cable with operation of one hair dryer. (b), (c) Open-circuit voltage and short-circuit current from the MMTEG under noise AC magnetic field generated from the power cable.

Calculation of acceleration speed for NaCl particles on the AD process inside vacuum chamber.



Air flow : $28\ L/min$

Air density : $1.293\ kg/m^3$

Salt mass : $10\ g$

Salt density : $2160\ kg/m^3$

Deposition time : $16\ s$

1. Calculation of Air velocity (Q: rate of flow, A: area, V: velocity)

$$Q = A_1 v_1, \quad v_1 = \frac{Q}{A_1} = \frac{4.667 \times 10^{-4} m^3/s}{\pi \times 2.25^2\ mm^2} = 92.187\ m/s$$

2. Calculation of the volume ratio of air and salt

Air : $4.667 \times 10^{-4}\ m^3/s \times 16\ s = 7.4672 \times 10^{-3} m^3 \rightarrow 99.9381\ \%$

Salt : $10\ g \div 2160\ kg/m^3 = 4.6296 \times 10^{-6} m^3 \rightarrow 0.0619\%$

3. Bernoulli's equation[1] (P: pressure, ρ: density, g: gravitational acceleration, h: height)

$$P_1 + \frac{1}{2}(\rho_1 + \rho_2)v_1^2 + (\rho_1 + \rho_2)gh_1 = P_2 + \frac{1}{2}(\rho_1 + \rho_2)v_2^2 + (\rho_1 + \rho_2)gh_2$$

$$101325\ Pa + \frac{1}{2}(\rho_1 + \rho_2) \times (92.187 m/s)^2 + (\rho_1 + \rho_2) \times g \times 0\ m$$

$$= 66.6612\ Pa + \frac{1}{2}(\rho_1 + \rho_2)v_2^2 + (\rho_1 + \rho_2) \times g \times 1.01\ m$$

$$v_2 = \sqrt{\frac{2(101325 - 66.6612)}{1.293 \times 0.999381 + 2160 \times 0.0619} + 92.187^2 - 2 \times 9.8 \times 1.01} = 292.4\ m/s$$

Reference 1. R. W. Johnson, *The Handbook of Fluid Dynamics*, Springer Berlin Heidelberg, 1998.

Table S1. The measured ΔV and peak power values from nanostructured and non-structured MMTEG devices for all measured load resistances. This data is plotted in Fig. 2c and 2d.

	w/o Nanostructures		**w/ Nanostructures**	
Resistance (Ω)	Voltage (ΔV)	Peak Power (mW)	Voltage (ΔV)	Peak Power (mW)
1 k	0.09	0.0081	0.186	0.0346
5 k	0.448	0.0401	0.954	0.1820
10 k	0.896	0.0803	1.9	0.361
20 k	1.7	0.1445	4.11	0.8446
50 k	4.29	0.3681	9.3	1.7298
100 k	8.2	0.6724	18	3.24
200 k	15.4	1.1858	33.1	5.4781
500 k	32	2.048	66.8	8.9245
700 k	40.3	2.3201	89	11.3157
1 M	56.3	3.1697	131	17.161
2 M	85	3.6125	208.8	21.7987
3 M	106.8	3.8021	243	19.683
5 M	128	3.2768	263	13.8338
10 M	150	2.25	303	9.1809
30 M	176	1.0325	355	4.2008
100 M	189	0.3572	377	1.4213
200 M	192	0.1843	386	0.7450
1 G	192	0.0369	398	0.1584