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Supplementary Information for

"Selective Current Collecting Design for Spring-type Energy Harvesters"

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Finite Element Analysis on a spring coated with P(VDF-TrFE) film

We conducted Finite Element Analysis (FEA) using ABAQUS 6.13 to calculate the stress distributions on P(VDF-TrFE) film coated on a spring. First, we choose a stainless steel spring available in the market. As shown in Figure S1, the spring has a coil diameter of 0.89 mm, an outer spring diameter of 15.03 mm, and a length of 40.28 mm. The spring has 6 turns in total. We created FE model of the spring with P(VDF-TrFE) film on the surface. Due to the thin thickness of the film, shell elements were used for the P(VDF-TrFE) film and solid elements were used for the spring. The FE model adopted fine mesh sizes of 0.1 x 0.1 mm^2 for the P(VDF-TrFE) shell elements in order to satisfy the convergence of numerical analyses. When the spring was subjected to compression load, one end of the spring was fixed and the other was only allowed to move vertically along the loading direction. TIE option was assigned to the interface between the spring and the film.

After numerical analyses, we only obtain in-plane stresses, σ_{11}, σ_{22}, and σ_{12} but ignored stresses in thickness direction from P(VDF-TrFE) film. In addition, it is well known that piezoelectric materials generate electric voltages in response to applied mechanical loads. In case of thin P(VDF-TrFE) film, only σ_{11} and σ_{22} are related to the generation of voltages, where 11- and 22- directions indicate axial and circumferential directions of spring wire, respectively.

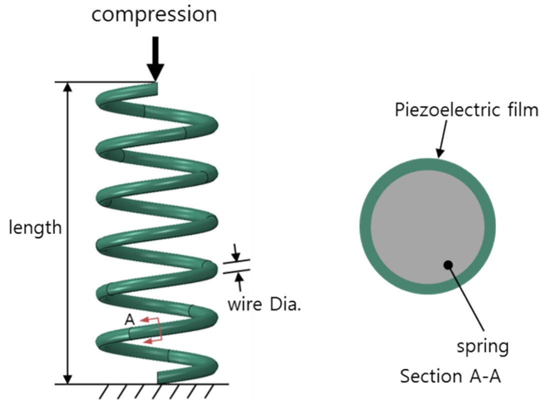

Figure S1. Finite element model for the SPEH.

Output power measurement on a cyclic displacement condition for the SPEH

In Figure S2a, the average amplitude of displacement wave was 5.48 mm (standard deviation (SD) = 0.07 mm) under applied vertical force of up to 3.70 N (spring constant was 337.9 N/m) while the frequency of the wave was 2.43 Hz. Figure S2b shows the output voltage signal from the SPEH under the applied cyclical vertical force and the load resistance of 6.0 MΩ. We were able to collect the output voltage signals from the SPEH using a digital oscilloscope. The average high and low peak voltages were 0.177 V (SD = 0.030 V) and -0.221 V (SD = 0.021 V), respectively. The average peak-to-peak voltage was 0.398 V (SD = 0.0032 V). The SPEH generated maximum peak power of 26.4 nW under impulsive load of 3.70 N when the load resistance was 6.0 MΩ.

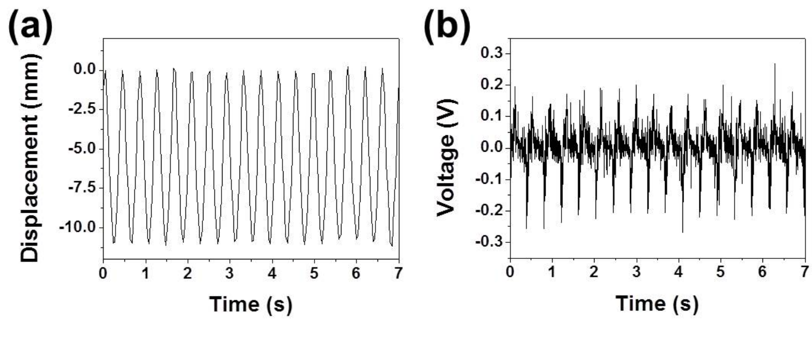

Figure S2. Plots of (a) vertical displacement of the SPEH under cyclical compression stress, and (b) output voltage signal generated from the energy harvester as a function of elapsed time. The average peak to peak voltage was 0.398 V (SD = 0.032 V) under a compressive force of 3.70 N at the load resistance of 6.0 MΩ. The SPEH generated peak power of 26.4 nW under impulsive load of 3.7 N when the load resistance was 6.0 MΩ.

Capacitance measurement of insulating film

In new design of SPEH we should consider the screening effect induced by the insulating film. The insulating layer is analogous to putting a dead layer to a ferroelectric capacitor, so our nail polish can be considered as the low capacitance capacitor connected to the piezoelectric outer layer in series as shown in Figure S3.

To calculate the value of capacitance of our insulating film, we prepared Si/SiO_2/Au/Nail polish/Pt multilayer film. The thickness of the nail polish was 22 μm, and the diameter of Pt dot electrode was 1 mm (0.7854 mm^2). We measured P-V curve of the multilayer film using RT 66A (RADIENT Technology Inc.) as shown in Figure S4. From P-V curve measurement, we calculated the capacitance of the nail polish, of which value was 3.4 pF. If we assume that the relative permittivity of P(VDF-TrFE) film is 11, then the capacitance of the outer part piezoelectric layer with the same area top electrode will be 15.3 pF. Then the total capacitance of the outer part will be 2.78 pF, which will give a ratio of 0.18 when compared with a pure piezoelectric film on the outer part. Therefore, the net effect is to reduce the charge induced on the outer part down to 18 % of the total charge induced without the nail polish layer as listed Table S1.If we take this effect into account, the net effect will lead to 7.92 times higher output voltage in our newly designed SPEH when compared with the original design. 7.92 is much closer to 8.22 times of improvement measured by our experiment.

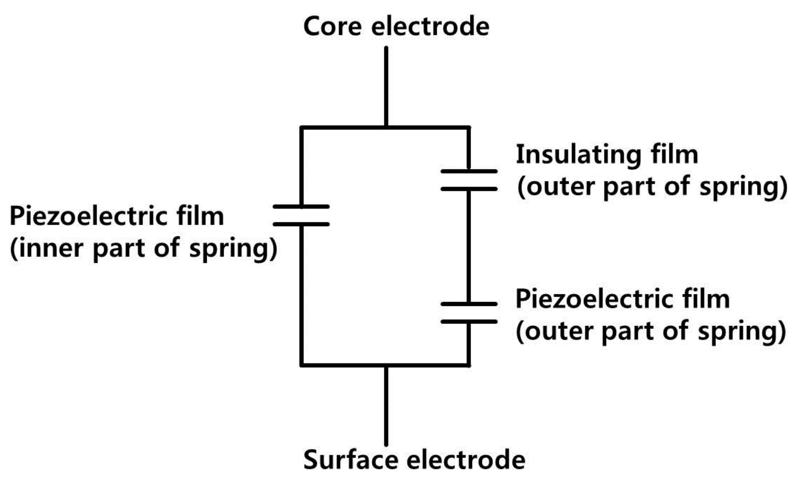

Figure S3. Schematics of electric circuit for the new designed SPEH

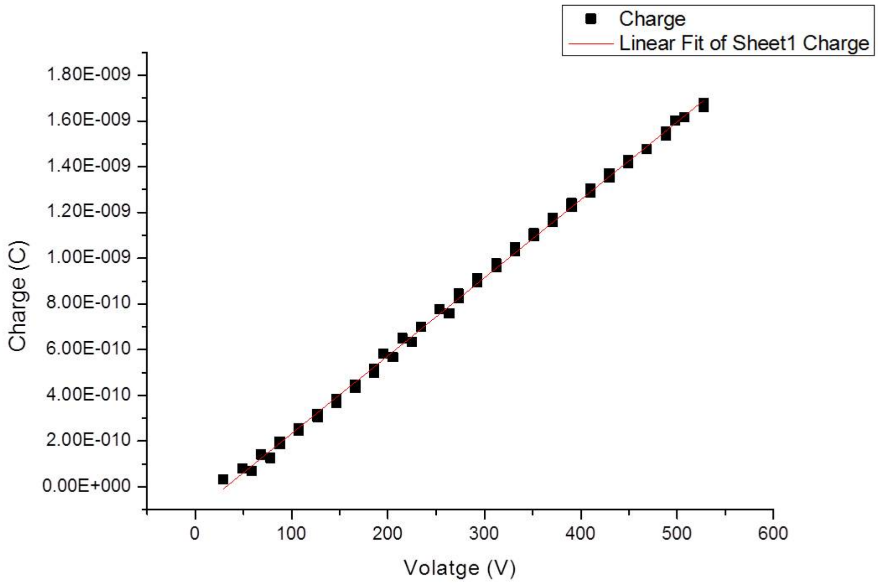

Figure S4. Plots of surface charge of the nail polish as a function of applied voltages.