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Supplementary Information

Self-powered Flexible Pressure Sensors with Vertically Well-aligned Piezoelectric Nanowire Arrays for Vital Signs Monitoring

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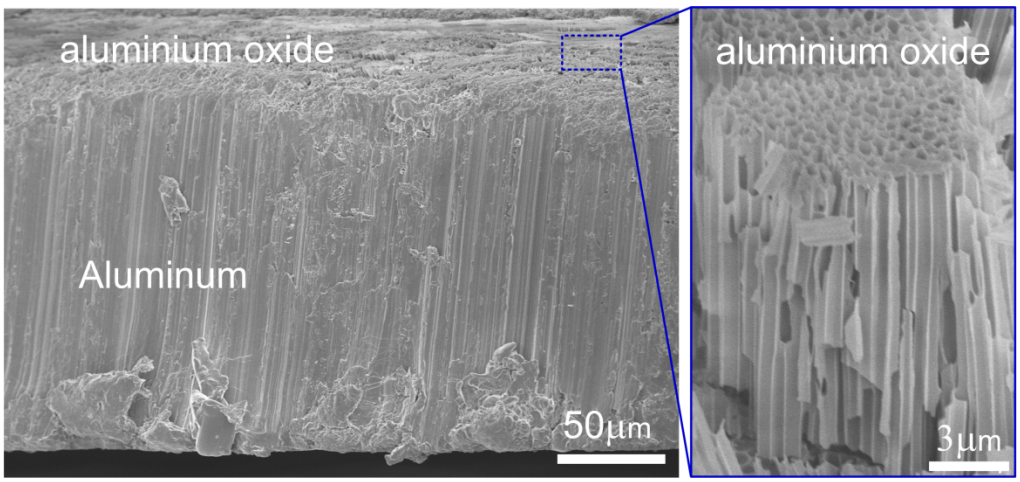

Fig. S1. SEM images of cross section of the anodized aluminium oxide(AAO) template. The conductive Al layer has a thickness of ~200μm. The aluminium oxide layer has a thickness of 10 μm, as shown in the enlarge SEM image in right side.

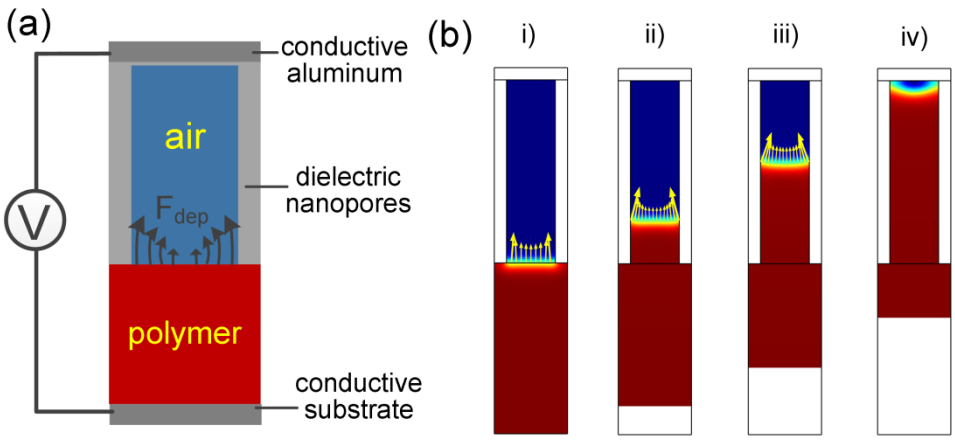

Fig. S2. (a) The geometrical configuration of the finite element method (FEM) simulation model. (b) Progressive evolution of polymer at the beginning i), middle ii-iii) and ending iv) of the EHD process, with the yellow arrows representing the L-DEP force on the polymer surface

In the numerical simulation, the cavity width of the simulated template was modeled as 400nm which reflect actual dimension of the AAO template, the cavity depth of the template was set as 1.5μm to simply the simulation and the thickness of polymer was 1.5μm. Fig. S1-a shows the geometrical configuration of the finite element method (FEM) simulation model. The template consisted of a conductive Al backup and a dielectric nanopores layer. The bottom of the P(VDF-TrFE) film was electrically grounded, and a voltage of 150V was applied between the bottom of the P(VDF-TrFE) film and the Al backup.

The dynamic deformation of P(VDF-TrFE) film within the nanopores of AAO template can be explained by a proportional relationship between the electric field E and the volumetric dielectrophoresis-electrocapillary force (F_{dep}) acting on the polymer surface, as expressed in the following:[1]

$$F_{dep} = -\frac{1}{2} E^2 \nabla \varepsilon \qquad (1)$$

where the polymer and air are assumed to be dielectric media with no volumetric free charge density, and ε is the permittivity of the fluid, comprising air and polymer in the two-phase filled formulation. With a proper voltage, the L-DEP force F_{dep} becomes large enough to drive the polymeric liquid flow upward along the solid wall of template by overcoming the surface tension and viscous resistance. Fig. S1-b shows the progressive evolution of polymer at the beginning i), middle ii-iii) and ending iv) of the EHD process, with the yellow arrows representing the L-DEP force on the polymer surface. The final shape of polymer is determined by a static equilibrium between the hydraulic pressure of trapped air and the L-DEP force.

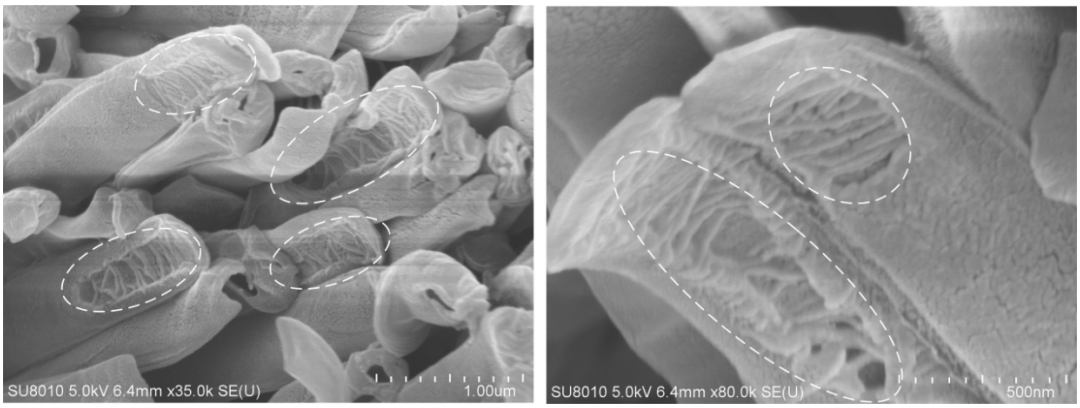

Fig. S3. The amplified SEM images of the nanowires of P(VDF-TrFE). The needlelike grains were observed in the inside of nanowires, as denoted by the dotted line circles. The needle/fiber-like shapes of the grains are typical β phase crystallites，which are composed of multiple stacks of crystalline lamellae along the long axis direction.

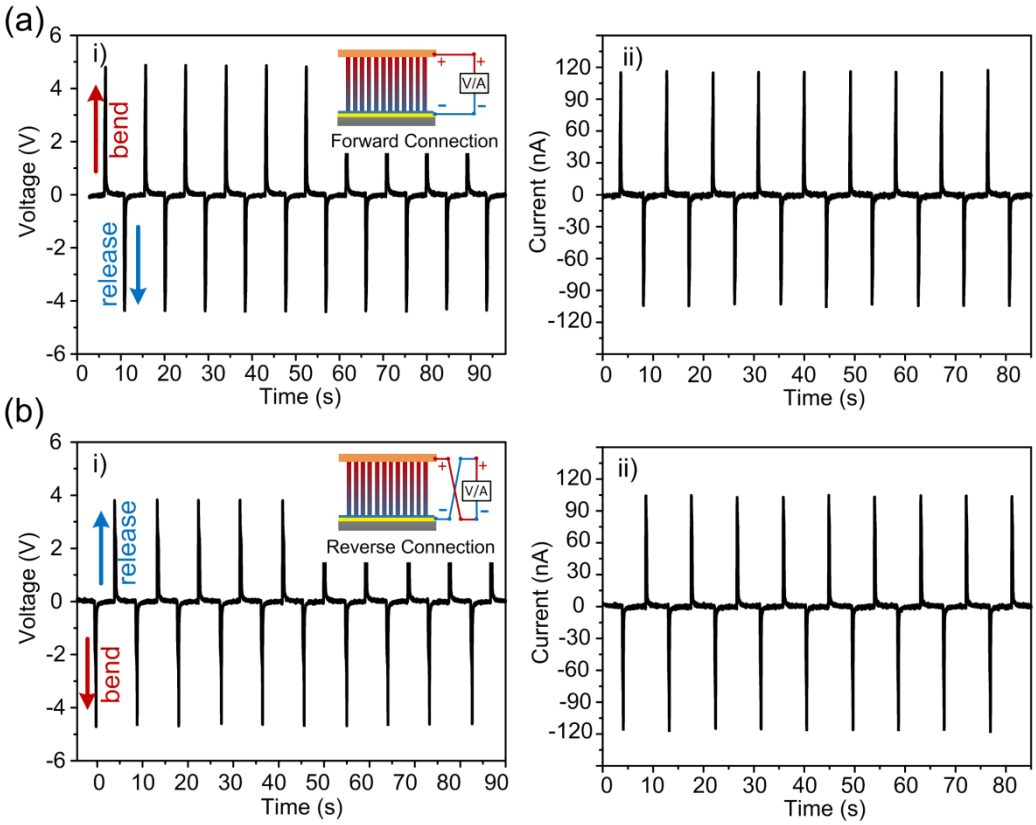

Fig. S4. Upon the repeatedly bending/release motions, the corresponding output voltage/current time curves when forward-connected to the measurement system (a) and when reverse-connected to the measurement system (b).

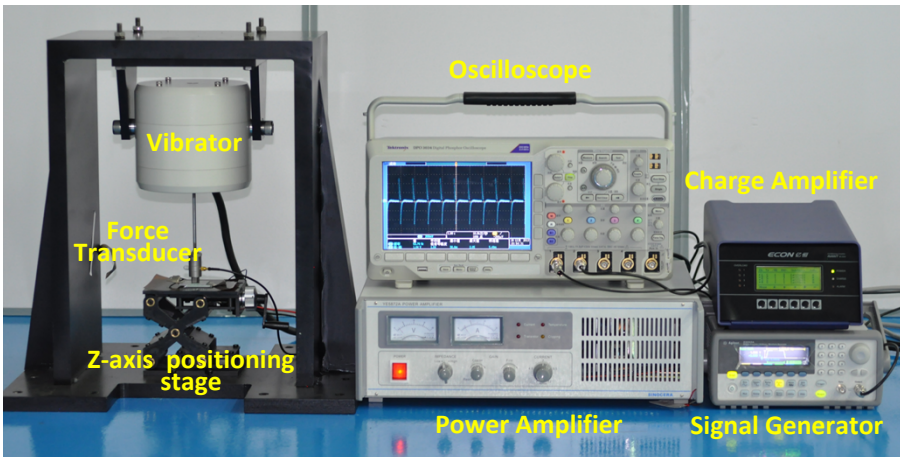

Fig. S5. The experimental setup for the SFPS measurement. The SFPS sample was positioned under a cylindrical probe, which was driven by an electromechanical vibrator (SINOCERA JZK-10). The exciting signal from a function generator (Agilent 33220A) is amplified by a power amplifier (SINOCERA YE5871A) to drive the vibrator. The magnitude of the force input to the SFPS sample was measured by a calibrated piezoelectric force transducer (SINOCERA CL-YD-331) having a sensitivity of 3.37 pC/N, which was placed between the probe and the upper electrode. The output from the force transducer was passed through a charge amplifier (ECON MI-2004-2) before being recorded on an oscilloscope (Tektronix DPO3034). The electrical output signals from the FNSDS devices were recorded by the Tektronix DPO3034 oscilloscope. The output voltage was measured with a 100 MΩ probe and the output current was measured using low-noise current preamplifier (Model No. SR570, Stanford Research Systems, Inc.)

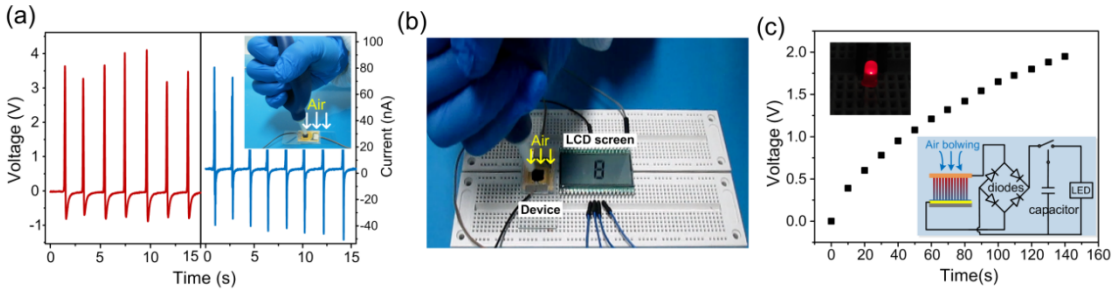

Fig. S6 (a) The output voltage and current of SFPS upon exposure to an air flow which generated by hang-extruding a dust blowing ball. (b) A LCD screen operated by electricity generated by the blowing air flow without external circuits. (c) The voltage across a storage capacitor (1μF) while being charged by air blowing with the full wave bridge rectifier. The lower inset shows circuit for rectifying, charging capacitors and lighting LED. The upper inset depicts digital photography of a lighted LED powered by the charged capacitor.

We further demonstrate the air-pressure-driven power-generating performance of the device. Upon exposure to an air flow which generated by hang-extruding a dust blowing ball, the measured output peak voltage reach up to ~4.0V and the current reached~90nA, as shown in Fig. S4a. The generated electricity output was not quite symmetric because the pressure and rate were different for compressing and releasing of the air. The output was significantly higher than other reported air-driven devices[2, 3] possibly because the high sensitivity of the vertically aligned nanowire array so that the pressure acted directly onto the nanowire structure without being damped by bending the substrate. Additionally, two approaches to prove the electricity generated by the air has also been implemented. We first demonstrated the lit up of a commercial liquid crystal display (LCD) using only the generated energy sources from the device without the energy storage process. As shown in Fig. S4b, the high output electricity can be used to directly drive a LCD (with a display of "8"). More details are shown in Video S1 in the supporting information. In addition, the output electricity can also be rectified by a bridge rectifier and charging the capacitor continuously. The charging curve of the 1μF commercial capacitor is shown in Figure S4c. The capacitor could be charged to 1.98 V in around 140 s, which could light up a red light emitting diode (LED), as shown in the upper inset of Fig. S4c, indicating that the electricity generated by the SFPS can be stored in a storage cell and power commercial electronics.

Reference:

1. H. Tian, J. Shao, Y. Ding, X. Li and H. Liu, *Langmuir*, 2013, **29**, 4703-4714.

2. Z. Li and Z. L. Wang, *Adv Mater*, 2011, **23**, 84-89.

3. R. Zhang, L. Lin, Q. Jing, W. Wu, Y. Zhang, Z. Jiao, L. Yan, R. P. Han and Z. L. Wang, *Energy & Environmental Science*, 2012, **5**, 8528-8533.

Supplementary Videos

Supplementary Videos 1: A LCD screen operated by electricity generated by the blowing air flow without external circuits.

Supplementary Videos 2: A real-time output of the sensor in response to the breathing behavior of human.

Supplementary Videos 3: A real-time output of the sensor to the heart-beating behavior.