Supporting Information

Implanted Battery-Free Direct-Current Micro-Power Supply from in vivo Breath Energy Harvesting

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S1. Figures and Captions

Figure S1. Preparation of NGs and i-NGs. (i) Chromium/Copper deposition on PET film and PTFE/PET/PTFE film by metal evaporation. (ii) Assembly of NG with multi-layers. (iii) As-prepared NG. (iv) Fabrication of package layer with cavity pattern by using a PET mask. (v) Package of NG by lamination and curing at 60°C for 1 hour. (vi) A final packaged i-NG configuration.
**Figure S2.** Digital photos of interdigital electrodes with four different electrode size configurations. In the images, $a_1$ is the width of electrode finger, $a_3$ is the gap between different electrode fingers. In all the electrode designs, $a_3$ was remained at a constant 100 $\mu$m, while $a_1$ was varied from 100, 200, 400 to 900 (images from top to bottom, respectively). Scale bar is: 1 cm.
**Figure S3. Voltage generation mechanism.** Schematic image showing how open-circuit voltage was generated in the sliding i-TENG. (i) The initial stage when metal strips were aligned to electrode A which induces the highest potential in electrode A and the lowest potential in the electrode B. (ii) The intermediate stage where there is no potential difference between two electrodes. (iii) The final stage when metal strips were aligned to electrode B, which induces the highest potential in electrode B but the lowest potential in electrode A.
**Figure S4.** Equivalent circuit that was used in the in vitro and in vivo experiments for charging the capacitor by i-TNGE. Circuit in the red box is the equivalent circuit of the i-TENG device.
**Figure S5. In vitro electrical characterization.** (a) Schematic image of an i-NG assembled by integrating two central triboelectric units to boost the electrical output. The left panel is a 3D illustration of the NG assembly; the right panel is the cross-section of this device. (b) The *in vitro* voltage output of i-NGs consists of one (red curves) and two (black curves) triboelectric units driven by a linear motor at a frequency of 1 Hz.
Figure S6. More mechanical characterizations of as-fabricated i-NG. Tensile test of Ecoflex (a) and device (b). (c). Three-point-bending test of PET/PTFE, PET/PTFE packaged by Ecoflex and device. (d). Digital image of bending device under three-point-bending test.
Figure S7. **3T3 fibroblast cells culture.** Optical microscope images of 3T3 fibroblast cells that were cultured on the Ecoflex film (top row) and a standard tissue culture plates (bottom row) for 4 days.
Figure S8. Surgical process for i-NG implantation. (i) The abdomen of rat was shaved and scrubbed with iodine scrub and alcohol. An incision was made on the area marked with red dashed line. (ii) The upper end of i-NG was sutured on both sides of diaphragm central tendon with 2-4 stitches. (iii) The bottom end of i-NG was further sutured on the abdominal wall of rat to secure the i-NG.
Figure S9. **In vivo output of i-NG.** The voltage outputs of i-NG (consisting of 1 triboelectric unit) driven by the diaphragm motion of rat at difference breathing frequency achieved by controlling the depth of anesthesia.
**Figure S10. Warping and i-NG.** (i) i-NG without warping. (ii) Warping of iNG. The inset is a side view of warped device. The relatively rigid nature of i-NG will keep it flat while package layer is warped. (iii) I-NG stretched with warping. (iv) I-NG relaxed with warping.
**Figure S11. Stable in vivo output.** A 1000-cycle operation record of i-NG under in vivo, which indicate the good stability of device.
Figure S12. The evaluation of stability of i-NG in 0.9% NaCl saline solution Voltage output of i-NG (i) before immersed and after immersed (ii) 4h; (iii) 12 h; and (iv) 24 h in saline solution

Video S1. Continuously lighting LED by i-NG under stretching motion.

Video S2. I-NG activated within rat abdominal cavity by up and down movement of diaphragm.

Video S3. In vivo output of single-unit i-NG.

Video S4. In vivo direct lighting of LED with blinking.

Video S5. Consistent operation of the LED driven by the rat breath
### S2. Tables and Captions

#### Table S1. Power consumption of five typical IMD\textsuperscript{[1]}

<table>
<thead>
<tr>
<th>Implants</th>
<th>Power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacemaker</td>
<td>5-10 μW</td>
</tr>
<tr>
<td>Cochlear implant</td>
<td>100-2000 μW</td>
</tr>
<tr>
<td>Drug pump</td>
<td>400 μW</td>
</tr>
<tr>
<td>Retinal stimulator</td>
<td>250 mW</td>
</tr>
<tr>
<td>Neural recording</td>
<td>1-10 mW</td>
</tr>
</tbody>
</table>

#### Table S2. Summary of reported i-NG

<table>
<thead>
<tr>
<th>NG Configuration</th>
<th>Electrical Output</th>
<th>Animal Model</th>
<th>Implantation site</th>
<th>Ref.</th>
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</thead>
<tbody>
<tr>
<td>ZnO nanowire</td>
<td>$V_{oc}$ of 1-2 mV, $I_{sc}$ of 1-4 μA</td>
<td>Rat</td>
<td>Heart and diaphragm</td>
<td>2</td>
</tr>
<tr>
<td>Contact mode TENG</td>
<td>$V_{oc}$ of 3.74 V, $I_{sc}$ of 0.14 μA</td>
<td>Rat</td>
<td>Chest</td>
<td>3</td>
</tr>
<tr>
<td>Pb[Zr$<em>x$Ti$</em>{1-x}$]O$_3$ ribbons</td>
<td>$V_{oc}$ of ~ 4 V</td>
<td>Bovine, ovine, pig</td>
<td>Heart, lung and diaphragm</td>
<td>4</td>
</tr>
<tr>
<td>PVDF film</td>
<td>$V$ of 0.3 V, $I_{sc}$ of 0.3 μA</td>
<td>Rat</td>
<td>Back region</td>
<td>5</td>
</tr>
<tr>
<td>PVDF film</td>
<td>$V_{oc}$ of 1.5 V, $I_{sc}$ of 300 nA</td>
<td>Pig</td>
<td>Aorta</td>
<td>6</td>
</tr>
<tr>
<td>Contact mode TENG</td>
<td>$V_{oc}$ of 14 V, $I_{sc}$ of 5 μA</td>
<td>Pig</td>
<td>Heart</td>
<td>7</td>
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<tr>
<td>Contact mode TENG</td>
<td>$V_{oc}$ of 4-8 V</td>
<td>Pig</td>
<td>Heart</td>
<td>8</td>
</tr>
<tr>
<td>PMN-PT film</td>
<td>$V_{oc}$ of 17.8 V, $I_{sc}$ of 1.75 μA</td>
<td>Pig</td>
<td>Heart</td>
<td>9</td>
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<td>Biodegradable contact mode TENG</td>
<td>$V_{oc}$ of 4 V</td>
<td>Rat</td>
<td>Subdermal region</td>
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</tr>
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<td>This work (micro-grating sliding mode TENG)</td>
<td>$V$ of 0.8 V, $I_{sc}$ of 0.8 μA</td>
<td>Rat</td>
<td>Abdominal cavity</td>
<td>/</td>
</tr>
</tbody>
</table>
S3. Calculation of equivalent battery capacity

Provided that the energy density of fat is 39 kJ/g, while body fat percentage of average person is 25%, the energy stored in fat of an average-weight person (60 kg) is approximately:

\[ 60 \times 25\% \times 10^3 \times 39 \times 10^3 = 5.9 \times 10^8 \text{ J} \]

If a battery has a 3V operating voltage, the capacity is estimated to be:

\[ 5.9 \times 10^8 \div 3 \div 3600 = 54629 \text{ A} \cdot \text{h} \]

S4. Calculation of DC output power

The DC output from i-NG micro-power supply could be calculated from the charging and discharging curve presented in Fig. 4b. Figure S10 shows the charging and discharging curve in details. Specifically, when i-NG was stretched and relaxed, the generated electricity will charge capacitor (the capacitor discharges through LED at the same time), subsequently, the open-circuit voltage of capacitor rises from 2.12 V at 747.3 s to 2.25 V at 747.5 s. At the interval of i-NG, no electricity from i-NG would be yielded, and the capacitor only discharges through LED. Correspondingly, open-circuit voltage at capacitor drops from 2.25 V at 747.5 s to 2.12 V at 748.3 s. The output power is calculated based on the information as following:

Since the potential drop on capacitor is known, the change of surface charge can be obtained by equation (1):

\[ \Delta Q = C \Delta V \quad (1) \]

When C is 0.33 μF and potential drop is 0.13 V, the \( \Delta Q \) is 0.043 μC. Thus, current flow through LED is estimated by equation (2):

\[ I = \frac{\Delta Q}{\Delta t} \quad (2) \]
Δt is 0.8 s in Fig. S6, and then, I is **0.055 μA**. The product of current and average potential gives the estimated output:

\[ W = I \cdot V_{\text{average}} \]  

Therefore, \( W = 0.054 \times 2.185 = 0.118 \mu W \)

**Figure S13.** Potential profile extrapolated from the fully charged capacitor when connected to the LED load. Potential variation of capacitor.
References