

## Ultrasound generate electricity inside the body

Implantable medical devices (IMDs) are highly beneficial to patient health. Concerning rapidly evolving technologies for IMDs, sustainable and reliable powering methods for IMDs is truly essential. They are generally relying on primary batteries, which are subject to replacement of surgeries that may cause non-negligible risks and costs. Wireless electromagnetic power transmission has been proposed as an alternative powering strategy. However, it generates excessive heat in tissues when transmitting high power, which raises safety concerns.

Nanogenerators (NGs) have been presented to detect/harvest the mechanical energy triggered by human movements. Two types of NGs have been studied in terms of driving principles. Piezoelectric NGs (PENGs) require a cyclic stress, driven by squeezing or bending, in order to generate electricity. Triboelectric NGs (TENGs) are capable of generating electricity as long as physical contact or rubbing is involved. Considering regulatory groups of materials/devices for IMDs to avoid any biological adverse response inside the body, TENGs are benefited from the diversity of materials unlike PENGs that are governed by limited group of noncentrosymmetric materials (e.g., ZnO, Pb(Zr,Ti)O<sub>3</sub> (PZT), BaTiO<sub>3</sub>, and PVDF). From a power capacity standpoint, the power converted by implanted TENGs, operated at low-frequency body movement, may not meet the sufficient level to power the IMDs. Accordingly, as for alternative powering strategy, non-invasive, sustainable, and sufficient power capacity has to be addressed.

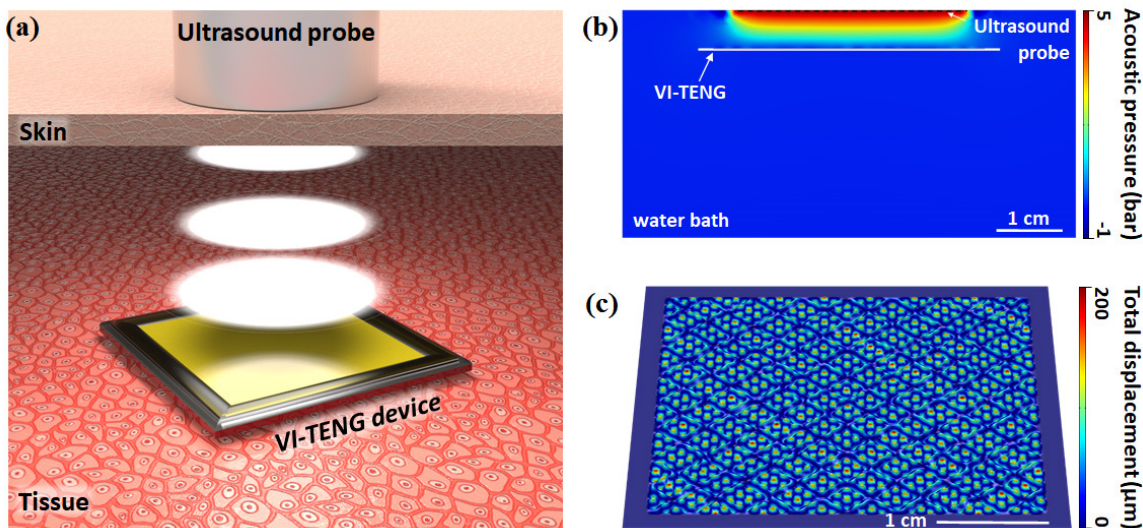


Fig. 1. (a) Schematic of the concept of the operating VI-TENG. Finite element method (FEM) simulation shows (b) acoustic pressure propagation through water and the VI-TENG, and (c) the level of oscillation triggered through the VI-TENG under 20 kHz of US.

Ultrasound (US) has been approved to develop various medical purposes such as therapy for pain relief and appliances for imaging. Since US causes a specific region to oscillate as it travels through biological tissue, piezoelectric US energy receivers have been demonstrated the supply of hundreds of milliwatts of power. However, limitations include the potential toxicity of PZT in the human body concerning long-term periods

and inappropriate thickness to be implanted remain obstacles as being IMDs. TENGs, on the other hand, have been proposed as a promising implantable powering system because their powering capability regardless of materials. Furthermore, TENG can generate electricity in confined space (e.g., human body) as long as there is minimal contact between materials. We reported the use of a high-frequency vibrating and implantable TENG (VI-TENG) designed to harvest US in vivo (Fig. 1a). According to acoustic and mechanical simulations, US cannot go through the VI-TENG but excite the device (Fig. 1b), verifying an oscillation throughout the triboelectric material at a frequency of the applied US (Fig. 1c).

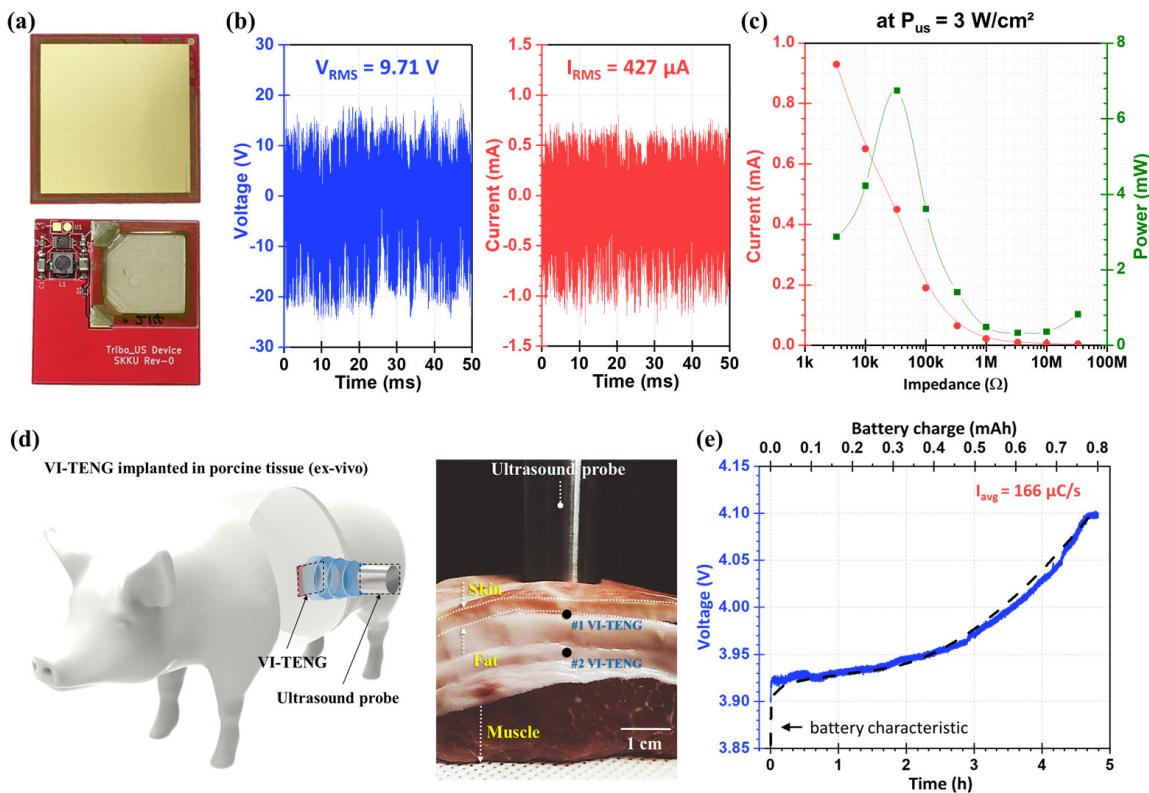


Fig. 2. (a) Front and backside of the VI-TENG. (b) Voltage and current generated by VI-TENG from the US probe setup at 20 kHz and 3 W/cm<sup>2</sup>. (c) Maximum current and thereby power as a function of electrical impedance at 5 mm from the US probe set at a power density of 3 W/cm<sup>2</sup>. (d) Schematic of the porcine ex vivo and the tissue showing the location of the implanted VI-TENG. (e) Charge of a 700- $\mu$ A-hour thin film Li-ion battery.

VI-TENG (Fig. 2a) was developed to harvest US and charge the battery integrated on the backside. First, we characterized VI-TENG under water that acts as an excellent medium for US to propagate. Our findings presented that VI-TENG generates 9.71 V<sub>[root mean square (RMS)]</sub> and 427  $\mu$ A<sub>RMS</sub> as triggered with an applied 20 kHz ultrasound at 3 W/cm<sup>2</sup> (Fig. 2b). To characterize an optimum power generated by TENG, we measured the output current as a function of electrical impedance (Fig. 2c). The VI-TENG generated 450  $\mu$ A at 33 kilohms, supplying a maximum output power of 6.74 mW, which is identical to 0.872 mW of constant average power and a power density of 5.2 W/m<sup>2</sup>. Since the given VI-TENG was aimed to charge the transcutaneous implant batteries, we characterized the VI-TENG under porcine tissue that is comparatively

similar to human skin (Fig. 2d). VI-TENGs implanted at 5 to 10 mm depth generated approximately 2.9 to 4.7 times less than in water (2.4 V/156  $\mu$ A at 5 mm and 1.93 V/98.6  $\mu$ A at 10 mm depth respectively), indicating both the acoustic impedance and attenuation of US governs the performance of VI-TENG. As for a practical standpoint, we recharged a 700- $\mu$ A hour thin-film Li-ion battery (Fig. 2e) that could supply commercial IMDs such as pacemakers, neurostimulators, and nerve stimulators. We recharged the battery to 4.1 V in 4 hours 30 min, at an average charging rate of 166  $\mu$ C/s. It is comparable to the commercial pacemaker KSR701 that typically consume 289  $\mu$ A hour. This result motivates additional studies for the advancement of US-driven TENGs to cope with power issues in IMDs.

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## **Publication**

[Transcutaneous ultrasound energy harvesting using capacitive triboelectric technology](#)

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*Science*. 2019 Aug 2