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Research Highlight

The first technology can compete with piezoelectricity to harvest ultrasound energy for powering medical implants

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Sustainable operation of implanted medical devices is essential for clinic applications. However, limited battery capacity is a key challenge for most implantable medical electronics [1]. Higher-capacity battery is not an ideal choice, because battery capacity is usually linearly dependent on battery volume [2]. New energy harvesters have been developed as promising alternative solutions, which extracted energy from the ambient environment and biosystem for powering implantable devices [3]. However, the energy reclaimed from body and ambient environment also have power limitation, such as thermal gradient and bioelectric potential. Delivery ultrasound or RF energy into the body and generate electrical power by a converter is a reliable solution.

Nowadays, ultrasound is widely used to diagnose and monitor diseases. The piezoelectric ultrasonic transducer based on lead zirconate titanate (PZT), PMN-PT and $BaTiO_3$ (BT) [4] etc., can convert ultrasound energy to electricity. Some demonstrations reported piezoelectric ultrasonic energy harvester for enabling self-powered implantable biomedical devices [5].

Triboelectric nanogenerator (TENG) has been developed since 2012 by Prof. Zhong Lin Wang [6]. It is a new technology that can convert mechanical energy into electricity. Implantable TENG [7] and biodegradable TENG [8] were developed to power implanted devices or directly work as a stimulator. TENGs have also been implanted beside rat stomach as a self-powered vagus nerve stimulation device [9] and beside porcine heart as a power source of symbiotic cardiac pacemaker [10]. Fig. 1 shows the research roadmap of implantable triboelectric energy harvester and self-powered implantable medical system based on TENG.

Recently, a significant breakthrough from Prof. Sang-Woo Kim's group in Sungkyunkwan University was reported in *Science*, for overcoming the limitation of present ultrasound energy harvest technology (Fig. 2). They proposed a new device [11] based on TENG, which can effectively harvest the ultrasound mechanical energy *in vivo* and in liquids. The ultrasound can drive the vibrating and implantable triboelectric generator (VI-TEG) to generate electric power. In their work, they recharged a lithium-ion battery at a rate of 166 μC/s in water. The voltage and current generated *ex vivo* by ultrasound energy transfer reached 2.4 V and 156 μA under porcine tissue.

This VI-TEG device achieved the sustainable power generating *in vivo* and in liquids. This work changed the status quo that triboelectric devices can only harvest the limited biomechanical energy *in vivo*. The electric current improves 1000 times by using the ultrasound waves. Lithium ion battery (0.7 mAh) recharged to 4.1 V in 4.5 h by the VI-TEG, with an average charging rate of 166 μC/s. Thus, the triboelectric device can meet the power requirements of most implanted devices. For example, the daily consumption of cardiac pacemakers is 0.2–0.3 mAh. These encouraging findings show that VI-TEG can compete with piezoelectricity, which is the first time, to harvest ultrasound energy for powering medical implants.

With the contribution from worldwide researchers, the triboelectric nanogenerator technology expects to provide more promising method to harvest ultrasound energy *in vivo*, with advantages of wide choice of materials, high outputs, light weight, excellent durability and low cost [12]. Implantable TENG also shown remarkable mechanical durability and cytocompatibility [10], which are determinant for long-term implantable devices.

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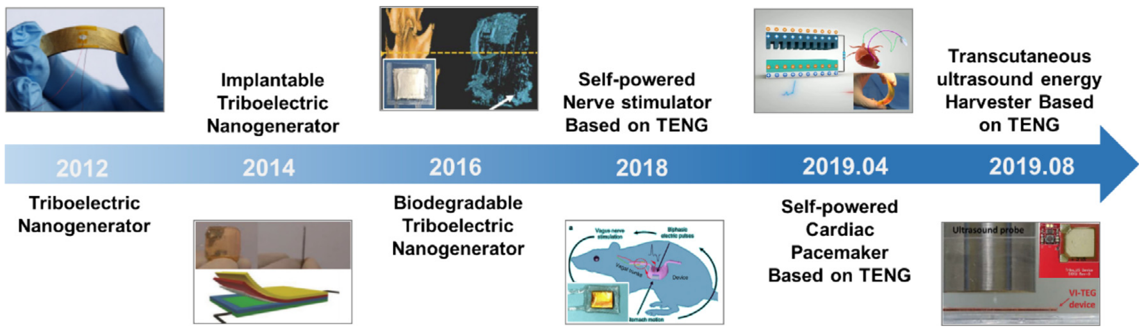

Fig. 1. Research roadmap of implantable triboelectric energy harvester and self-powered implantable medical system based on TENG [6–11]. Copyright © 2014 John Wiley and Sons. Copyright © 2012 Elsevier. Copyright © 2016, 2019 AAAS. Copyright © 2018, 2019 Springer Nature.

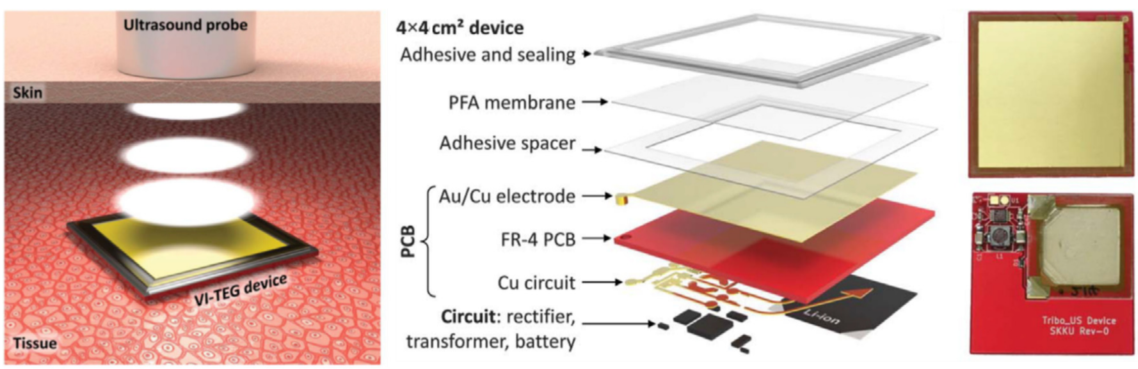

Fig. 2. Illustration and photo of US energy harvesting under skin using the VI-TEG [11]. Copyright © 2019 AAAS.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

[1] Gibney E. The body electric. Nature 2015;528:26.
[2] Dagdeviren C, Li Z, Wang ZL. Energy harvesting from the animal/human body for self-powered electronics. Annl Rev Biomedical Eng 2017;19:85–108.
[3] Dagdeviren C. The future of bionic dynamos. Science 2016;354:1109.
[4] Zhao C, Wu H, Li F, et al. Practical high piezoelectricity in barium titanate ceramics utilizing multiphase convergence with broad structural flexibility. J Am Chem Soc 2018;140:15252–60.
[5] Shi Q, Wang T, Lee C. MEMS based broadband piezoelectric ultrasonic energy harvester (PUEH) for enabling self-powered implantable biomedical devices. Sci Rep 2016;6:24946.
[6] Fan F-R, Tian Z-Q, Wang ZL. Flexible triboelectric generator. Nano Energy 2012;1:328–34.
[7] Zheng Q, Shi B, Fan F, et al. *In vivo* powering of pacemaker by breathing-driven implanted triboelectric nanogenerator. Adv Mater 2014;26:5851–6.
[8] Zheng Q, Zou Y, Zhang Y, et al. Biodegradable triboelectric nanogenerator as a life-time designed implantable power source. Sci Adv 2016;2:e1501478.
[9] Yao G, Kang L, Li J, et al. Effective weight control via an implanted self-powered vagus nerve stimulation device. Nat Commun 2018;9:5349.
[10] Ouyang H, Liu Z, Li N, et al. Symbiotic cardiac pacemaker. Nat Commun 2019;10:1821.
[11] Hinchet R, Yoon H-J, Ryu H, et al. Transcutaneous ultrasound energy harvesting using capacitive triboelectric technology. Science 2019;365:491–4.
[12] Shi B, Li Z, Fan Y. Implantable energy-harvesting devices. Adv Mater 2018;30:1801511.

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