Portable energy storage technology

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A self-powered system based on energy harvesting technology can be a potential candidate for solving the problem of supplying power to electronic devices. In this review, we focus on portable and wearable self-powered systems, starting with typical energy harvesting technology, and introduce portable and wearable self-powered systems with sensing functions. In addition, we demonstrate the potential of self-powered systems in actuation functions and the development of self-powered systems toward intelligent functions under the support of information processing and artificial intelligence technologies.

In recent years, portable and wearable electronic devices have been in a stage of rapid development1,2. Personalized electronic devices such as smart watches and smart glasses have sprung up, bringing much convenience to people''s life3,4. At the same time, with the promotion of flexible electronic technology5, big data technology6,7 and artificial intelligence technology8, portable and wearable electronic devices have shown the development trend of flexibility, integration, and intellectualization, which have also facilitated rich applications such as health monitoring9,10, human-machine interaction11,12, and the Internet of Things13,14.

For portable and wearable electronic devices, the energy supply is a major obstacle to its flexible and integrated application. Replaceable batteries are now the common energy source of electronic devices. However, the rigid characteristics of these batteries limit the overall flexibility of electronic devices. The limited life of batteries and potential environmental pollution problems also do not conform to the principles of sustainable development. As a result, many efforts have been made to explore new environmentally friendly, renewable energy sources to power electronic devices.

Self-powered technology provides a solution for the sustainable energy supply of portable and wearable systems. Self-powered technology means that the device can maintain its own operation by collecting energy in the working environment without an external energy supply. The effective collection of various forms of energy in the working environment is the basis of self-powered technology.

Electronic devices such as actuators can assist humans in completing diverse and complex operations in specific scenarios. The development of self-powered technology makes it possible to realize various actuation functions without an external energy supply. For example, many researchers use electrical energy converted from other forms of energy as an excitation signal to realize the functions of automatic control41,42, microfluidics43,44, drug delivery and release45, and adjuvant therapy46,47.

From a long-term point of view, we will eventually witness human society entering the age of intelligence. The Internet of Things, artificial intelligence, and big data technology change our lives with each passing day. The relationship between human beings and electronic devices has also presented an unprecedented state. Electronic devices with a single function will no longer meet the functional requirements of portable electronic devices in the intelligent era. Portable and wearable self-powered intelligent systems are gradually replacing bulky computers as the interface of a new generation of intelligent human-machine interactions and playing an important role in intelligent identification48, intelligent control49, and other fields.

Energy harvesting is the basis of a self-powered system. Additionally, for consideration of convenience and environmental protection, we need sustainable, clean, and renewable energy to power portable and wearable devices. There are various forms of energy in the environment, including not only the energy produced by the human body itself but also the energy provided by the external environment. In daily life, human mechanical movements such as finger movement, walking, and running can produce considerable mechanical energy. However, due to the multimode and low-frequency characteristics of human mechanical movement, it is not easy to collect the mechanical energy of the human body effectively.

Triboelectric and piezoelectric generators are the two most common ways to collect mechanical energy generated by human motion. Triboelectric energy harvesting is based on the well-known principle of friction electrification. The contact of two different objects will induce static charges on the surface of the objects. Subsequently, the relative motion between the two charged objects will produce a potential difference, thus driving the flow of charges. Due to the advantages of a wide selection of materials, low operating frequency and high output power, TENGs have become the most common ways of collecting the mechanical energy of human motion.

In Fig. 1a, an arch-shaped TENG was proposed by Z. L. Wang''s research group in 201254. The pyramid patterns on the surface of the TENG help increase the output of the TENG by increasing the contact area of the two triboelectric layers. The output voltage, current density, and energy volume density of the TENG reached 230 V, 15.5 mA cm-2 and 128 mW cm-3, respectively. The energy conversion efficiency is as high as 10-39% and meets the demands of wireless sensor systems and mobile phones. This work demonstrates for the first time the potential of TENGs for driving personal mobile electronic devices and shows how TENGs can affect lifestyle.

a Arch-shaped TENG as a power supply for mobile phones. Reprinted from ref. 54 with permission. b Hybrid nanocomposite generator (hNCG) for hand movement energy harvesting. Reprinted from ref. 68 with permission. c Flexible thermoelectric generator (f-TEG) for harvesting human thermal energy. Reprinted from ref. 73 with permission. d Wearable textile-based hybrid supercapacitor-biofuel cell (SC-BFC) system as a biochemical energy harvester. Reprinted from ref. 77 with permission.

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