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Micro-scale energy harvesting devices: Review of methodological performances in the last decade

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ABSTRACT

Power harvesting devices which harness ambient surrounding energies to produce electricity could be a good solution for charging or powering electronic devices. The main advantages of such devices are that they are ecologically safe, portable, wireless, and cost effective and have smaller dimensions. Most of these power harvesting devices are realized by utilizing the microelectromechanical systems (MEMS) fabrication techniques. In this paper, the capabilities and efficiencies of four micro-power harvesting methods including thermoelectric, thermo-photovoltaic, piezoelectric, and microbial fuel cell renewable power generators are thoroughly reviewed and reported. These methods are discussed in terms of their benefits and applications as well as their challenges and constraints. In addition, a methodological performance analysis for the decade from 2005 to 2014 are surveyed in order to discover the methods that delivered high output power for each device. Moreover, the outstanding breakthrough performances of each of the aforementioned micro-power generators within this period are highlighted. From the studies conducted, a maximum energy conversion of 2500 mW cm^{-2} is reached by thermoelectric modules. Meanwhile, thermo-photovoltaic devices achieved a rise in system efficiency of up to 10.9%. Piezoelectricity is potentially able to reach a volumetric power density of up to 10,000 mW cm^{-3}. Significantly in microbial fuel cell systems, the highest power density obtained reached up to 6.86 W m^{-2}. Consequently, the miniaturized energy harvesters are proven to have credibility for the performance of autonomous power generation.

Contents

1. Evolving technology of miniature power harvesters

Miniature power harvesting is the process of generating minute-scale electricity from external energy sources such as solar, thermal, wind, vibration, and chemical sources, human body heat, human movements, and so on. The main motivations for minute power

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harvesting devices are to add simplicity and ease in daily life, lower cost, and respect the nature of ecosystems. Besides, ambient energies and radiation can be a great solution as they are ecologically friendly and renewable. Also, in this way the life-times, capabilities, and reliability of such energy scavenging systems can be upgraded.

Therefore, investigations of small energy harvesting methods are very much welcomed for easy powering of diminutive wireless and mobile electronics such as hand phones, cameras, chargers, watches, laptops, and others. The invention of alternative micro-power generators can augment or substitute for the use of conventional batteries [1]. Such energy harvesters are also applied in self-powered devices and wireless sensor networks [2,3] as they can sustain operation and work independently without requiring an external power supply. Additionally, nowadays the development of portable power harvesting systems is keenly focused toward the advance of microelectromechanical systems (MEMS) technologies.

In this study, attention is focused on four different kinds of minute-scale power machines: thermoelectric, thermo-photovoltaic, piezoelectric, and microbial fuel cell. In the first and second sections of the study, the promising prospects as well as the difficulties and constraints faced by micro-scale energy converters are discussed. Then, the methodological performances analysis and investigations of the highest achievements made during the decade of 2005–2014 years are presented for each device.

2. Positive prospects of micro-scale electricity harvesters

Micro-scale power harvesters such as thermoelectric, thermo-photovoltaic, piezoelectric, and microbial fuel cell are very useful for easy powering or charging of mobile electronics, even in remote areas, without the need for large power storage elements. Besides, such energy scavenging devices also encompass several extra benefits that may attract more attention to their systems viability as described in Fig. 1.

For instance, the thermoelectric generator utilizes unused, ambient, or human body heat energy for direct conversion into potential differences. Nowadays, as an alternative heat source, combustors have also been assimilated into thermoelectric devices. Thomas Johann Seebeck studied the thermoelectric effect back in 1821, and thermopile structuring was later discovered by Leopoldo Nobili and Macedonio Melloni in the middle of the nineteenth century. A thermoelectric generator is a low cost generator with a reliable energy source and has no moving blocks, and it is therefore easily scalable and both heating and cooling processes can be conducted. It can work for longer hours with less noise and low emissions [4]. Moreover, it can be used to recycle wasted heat energy, so it also leads to a healthier atmosphere. This energy conversion method is widely used in several applications such as biometric sensor [5], hydrogen sensors [6,7], vacuum gauge [8], and coolers [9,10].

On the other hand, solar power is one of the cleanest and most reliable energy resources. The first solar or photovoltaic cell was designed by Alexandre-Edmond Becquerel in 1839. In order to elevate the energy conversion level of the photovoltaic cell, collection of solar rays is required, and therefore an emitter and a filter are also used to supply a consistent heat source for the cell. This device is known as a thermo-photovoltaic generator and was first constructed by Henry Kolm in 1956. It is a solar or thermal combustion based electricity generator. It is cheap and simple and contributes to lowering noise and emissions. The thermal-to-photons-to-voltage tri-generation module also has no moving blocks and is easily amalgamated with other devices [4]. Thermo-photovoltaic energy harvesters are employed as energy sources for residential [11,12] and industrial [13] applications and to track maximum power points [14].

Unlike the thermo-photovoltaic power generator, which uses solar energy or a combustor as a heat source to create photon energy and then generate a voltage, the potential of mechanical motion as an energy source was reported in 1880, when Jacques Curie and Pierre Curie identified the piezoelectric effect. This effect delivers a small-dimension kinetic-to-electricity transduction mechanism. A piezoelectric system creates a higher output voltage based on actuations or motions applied to the device. It exhibits a simple mechanism that can be practiced and implemented easily. The device is highly sensitive to the strain applied to it, and gives a higher frequency response as well as having a longer life cycle [15]. Flexible human movements can also produce a minuscule piezoelectric effect. Piezoelectricity has been widely applied in many areas such as micro-pump [16], bio-chemical [17], and bio-medical areas such as health monitor sensor [18], intra-cardiac pacemaker [19], orthopedic implant [20], and drug delivery device [21].

Besides the implementations of waste heat, solar, and mechanical energy resources in thermoelectric, thermo-photovoltaic, and piezoelectric systems, respectively, microbial fuel cell has also become a popular type of energy harvester since initial experimentation on

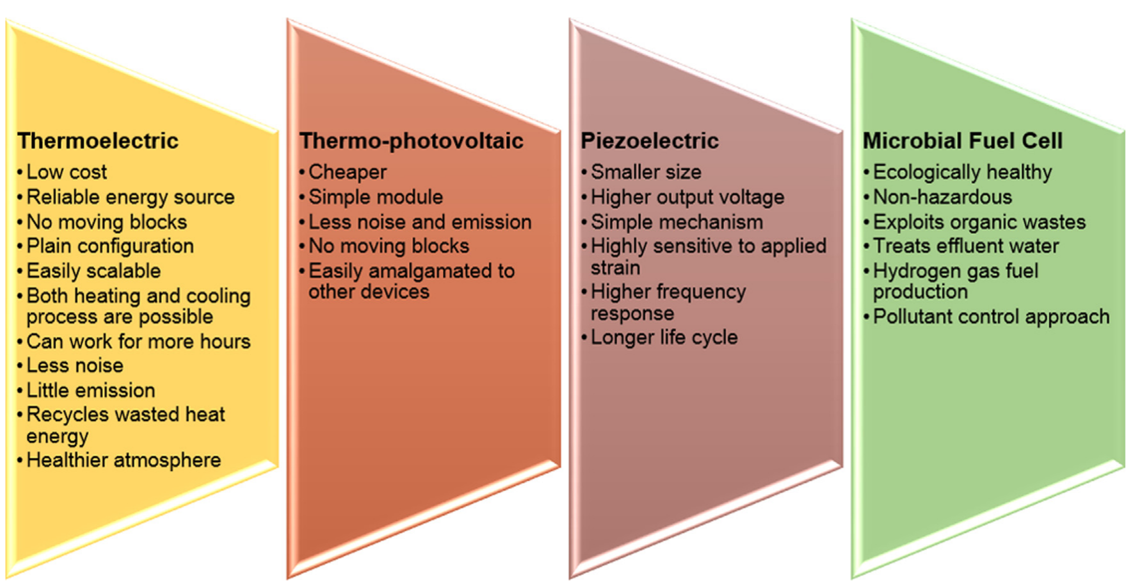

Fig. 1. Positive prospects and benefits of four micro-power devices.