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A pyroelectric generator as a self-powered temperature sensor for sustainable thermal energy harvesting from waste heat and human body heat

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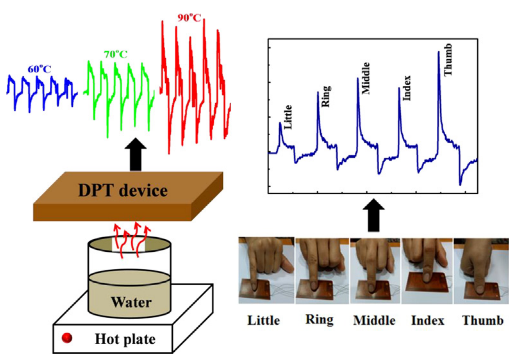
HIGHLIGHTS

- A pyroelectric generator as a self-powered temperature sensor has been demonstrated.
- A self-sustaining pyroelectric generator has been realized.
- It harvests heat dissipation from human body surface.
- It has the potential to use as self-powered breathing sensor.
- The possibility of non-invasive human healthcare monitoring has been shown.

GRAPHICAL ABSTRACT

A pyroelectric generator driven by water vapour and human body heat that can serve as a self-powered temperature sensor is presented.



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ABSTRACT

Conversion of temperature fluctuations to useable electrical energy is rendered by the pyroelectric effect. Waste of heat in our day to day environment and in industrial sector constitutes an abundant source of energy. Herein, we report a pyroelectric generator (PyG) that produces pyroelectric output up to 1.5 V and 1.5 µA. Its power density is 0.034 µW/cm^2 upon exposure to heat-cool condition for a temperature variation from 310 K to 340 K. Due to the fast response time (121 ms) of the PyG, it is expected to be use as a self-powered temperature sensor. The generated electricity could also be stored in a capacitor up to 0.8 V in three heating–cooling cycles. It has been also demonstrated that PyG is possible to drive by water vapour where energy-consuming alternating devices is not necessary. The temperature oscillation achieved by spontaneous water condensation and evaporation from the surface of the PyG that produces open-circuit voltage of 1.6 V for a temperature variation from 303 K to 333 K. Thus the PyG driven by water vapour supports an efficient retrieval of energy from hot water vapour, which is wasted mostly. The linear increment of voltage as a function of temperature indicates PyG is also suitable to use a temperature sensor that may also work in self-powered mode. In addition, the PyG can also harvest the waste body heat, i.e., heat dissipation from human body surface and from the process of respiration. That promises an effective self-powered temperature sensor that might be useful in healthcare monitoring, safety and security sectors.

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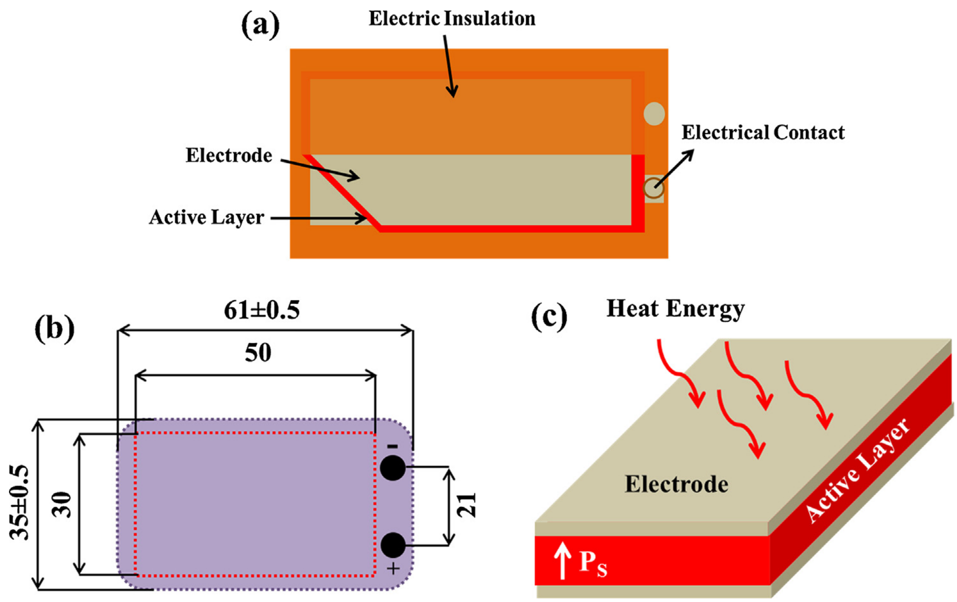

Fig. 1. (a) Schematic design, (b) dimensions (in mm) and (c) thermal radiation heating principle of the PyG.

1. Introduction

Scavenging energy is presently a topic of extreme interest because of the increasing greenhouse gas emission from conventional fossil, fuels and the growing energy demands of society. It provides a mechanism to create autonomous and self-powered systems. That's why intense efforts are employed to the development and usage of renewable and green energy resources, such as solar [1], biomass [2], geothermal [3], wind [4], hydrogen [5], etc. These methods of renewable energy harvesting have been considered as attractive possibilities over the traditional rechargeable batteries because the energy harvesting devices allow battery free operation of wireless sensor networks. Various methods to scavenge energy from mechanical vibration, friction, rotary motion, etc. to generate electrical power have been considered by many researchers. This has led to the development of piezoelectric and triboelectric generators [6–10].

Waste heat obtained from industrial process and natural environment boosters its candidature as an efficient source for thermal energy harvesting. Waste heat can be derived from hot water in industrial cooling process, combustion engines in cars, solar photo thermal energy, etc. This heat can be harvested using different solid state energy conversion methods such as thermoelectric and pyroelectric materials. Thermoelectric generators and pyroelectric generators (PyGs) have been used to transform waste heat into electrical energy using Seebeck effect and pyroelectric effect [11–15]. Thermoelectric generators are based on creating a spatial temperature gradient between the two ends of a thermocouple formed by two different metals for the conversion of heat into electrical energy [16]. But, such steady spatial temperature gradient is very rare in natural environment. In contrast, devices based on the pyroelectric effect have been investigated as an alternative method for thermal energy harvesting, because they do not require a spatial temperature gradient. However, PyG needs a temporal temperature oscillation to stimulate the energy conversion process [14,17]. Fatuzzo et al. and Van der Ziel et al. had considered the potential utility of pyroelectric effect to convert thermal energy into electrical energy in the 1960′s and 1970′s [18,19]. Pyroelectric materials are the subclass of piezoelectric materials that have non-centrosymmetry in crystal structures. Majority of the piezoelectric materials are also pyroelectric. They show change in polarization with temperature fluctuation [20,21]. Several pyroelectric nanogenerators have already been reported with pyroelectric materials that are also well known as a piezoelectric material. These include ZnO [14], PZT [22], $KNbO_3$ [23] and PVDF [24,25].

It is well known that there is a noticeable temperature difference between the human body and the ambient environment (the average human body temperature being 37 °C). Therefore, there is always a heat loss from human body to the ambient environment, mainly through skin and through the process of respiration. This waste heat can be converted into electric energy using pyroelectric effect. Furthermore, among the physiological signals, respiration is considered as an important signal for monitoring human health in real-time. Different human health conditions can be monitored and disease diagnosis can be done by analysing different stages of respiration. Recently, the potential of piezoelectric energy harvesting of commercial DuraAct Patch Transducer (DPT) has been reported [26]. Thus, it could also be a promising device for thermal energy harvesting. To the best of our knowledge no attempt has been made so far where pyroelectric energy harvesting possibilities are studied by using DPT.

In this study, the potential of pyroelectric energy harvesting using commercial DPT, viz., PyG has been investigated. The performance of the PyG presents a promising pyroelectric energy harvester in terms of the output power. The device can also be employed to store the harvested energy in a capacitor. It can also harvest thermal energy from water vapour. Changing the temperature fluctuation, an open-circuit voltage of 1.6 V can be harvested from water vapour and that demonstrates an outstanding performance by the PyG as a temperature sensor. Also the output can be regulated by changing the effective working area of the device. Thus, the PyG driven by ordinarily available water vapour in our daily life can provide a promising application for expeditiously harvesting heat energy from water vapour. The temperature sensor, which can be used to detect human body heat (like temperature of finger surfaces) and monitor respiratory process, has the capability of sustainable energy harvesting as well as self-powered respiration monitoring.

2. Experimental section

A commercial transducer (P-876.A11 DuraAct Patch Transducer) (weight ~2.2 gm) has been used as the thermal energy harvester, i.e., PyG. It is composed of bendable piezo-composite patch transducer that can bear bending radii of 12 mm.

The transducer has been developed by placing a piezoceramic foil, which is also an active pyroelectric layer between two conductive electrodes. The entire structure is laminated that improve the