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Optimization and improvement of thermal energy harvesting by using pyroelectric materials

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ABSTRACT

We deal with the thermal energy which is one of the ambient energy sources surely exploitable, but it has not been much interest as the mechanical energy. In this paper, our aim is to use thermal energy and show that it's an important source for producing the electrical energy through pyroelectric effect which is the property of some dielectric materials to show a spontaneous electrical polarization versus temperature. In this context, we present a concept to harvest a thermal energy using infrared rays and pyroelectric effect.

The pyroelectric material used in this work can generate an electrical voltage when it subjected to a temperature change which will be ensured by the use of infrared lamp. Our experimental results show that the electrical voltage, current and harvested power increased significantly when increasing the area of the pyroelectric element. The experimental results show also that with this simple concept we harvested a heavy amount value of power which will certainly be useful in an extensive range of applications, including sensors and infrared detection. These results shed light on the thermoelectric energy conversion by Ceramic lead zirconate titanate (PZT) buzzer having the pyroelectric property.

1. Introduction

The generalization of the wireless sensor networks in markets such as industry, infrastructure, transport and habitat… is intimately related to the availability of ambient energy recovery solutions efficient and economical. The energy harvesting, technique according to which the useful electrical energy is generated by the available free sources such as vibration [1,2], heat [3,4] or light [5,6], is an essential characteristic of self-powered wireless sensors that do not require any battery maintenance. However, these sensor networks are increasingly used, especially in applications such as process automation [7] or intelligent buildings [8]. The replacement of the power supply or batteries with energy recovery sensors depends on the performance of the power management circuits with which they are interfaced. But today, the advances that have been made allow the emergence of economically viable products and energy recovery systems.

The devices able to harvest ambient energy and convert it into useful energy arrive more and more often to give us the illusion. The sensors that generate electrical energy from a natural source, such as the temperature difference [9] (thermoelectric generators, thermal cells), vibration or mechanical stress [10] (piezoelectric and electromechanical sensors) or light (photovoltaic cells) [11] became viable for many applications, supplementing and, in many cases, replacing the power supply and batteries. Increase the accessibility, reduce the maintenance costs, improve the energy efficiency and system flexibility… these are some of the benefits that can be drawn from the recovery of energy. This technology supplies a wide variety of measurement systems, control and monitoring deported, autonomous and wireless.

Our work consists in using the thermal energy and the pyroelectric effect to produce electrical energy which is necessary to power the electronic device. In fact the lost heat can be perceived as the heat rejected by the facilities in the environment. So the recovery and reuse of this heat offer the possibility of reducing energy costs. The thermal energy recovery systems include thermal transmission which can be made by three different mechanisms: Radiation, Conduction, and Convection.

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The kind of material used in this study presents a pyroelectric properties i.e. can generate an electrical voltage when it is excited by a temperature variation so it is able to convert thermal energy to electrical energy. For this study, a commercial PZT ceramic was used, heating and cooling are provided by infrared rays. Our work aims also to improve the harvesting energy by increasing the area of the pyroelectric element.

This paper is organized as follows. In Section 2, we describe briefly the modeling of pyroelectric effect. The Section 3 is devoted to the experimental system of our study, while the obtained experimental results and their discussion are given in Section 4. Finally, the last section briefly concludes the paper, recalling the main findings of this experimental study.

1.1. Simple model

Pyroelectricity is the property of a material wherein a temperature change causes a change in electrical polarization. This polarization variation creates a temporary difference in potential and it disappears after the dielectric relaxation time. This variation can generate an electrical current, which makes the pyroelectric materials useful for detecting radiation or electricity production. They are particularly used in some infrared detectors [12]. The pyroelectric effect should not be confused with the thermoelectric effect, where a temperature gradient set gives birth to a permanent tension.

We present here a modeling of the conversion of heat to electric energy using a pyroelectric material. By considering low temperature fluctuations, reflecting a linear behavior, the constitutive equations of pyroelectric effects are given by:

$$\begin{aligned} dD &= \varepsilon_{33}^{T} dE + \rho dT \\ d\sigma &= \rho dE + \frac{C}{T} dT \end{aligned} \quad (1)$$

where $D, E, T, \rho, \sigma, \varepsilon$ and C are the electric displacement, electric field, temperature, pyroelectric coefficient, entropy, dielectric permittivity, and heat capacity, respectively.

The pyroelectric element is modeled as a current source in parallel with the internal resistance R_P and the capacitance C_P, V_P is the output voltage as shown in Fig. 1.

The electric current I_P generated by the pyroelectric material is given by

$$I_p = \rho A \frac{dT}{dt}, \quad (2)$$

where A is area of the pyroelectric material, $\frac{dT}{dt}$ is the heating or cooling rate and ρ represents the pyroelectric coefficient given by the following expression:

$$\rho = \frac{\partial P_t}{\partial T}, \quad (3)$$

where P_t represents the polarization of pyroelectric material

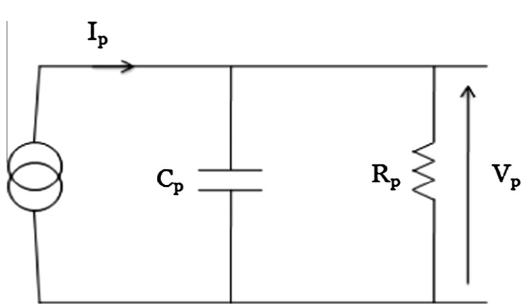

Fig. 1. Equivalent circuit of a pyroelectric material.

Theoretically, the Eq. (2) allows us to predict an increase in current as a function of the surface of the material denoted A, if the surface is increased from A to αA, the current will be increased by the same factor α.

In order to determine the output voltage and the generated power, the pyroelectric element is connected in parallel with an external resistor R as shown in Fig. 2. The instantaneous power dissipated by the resistor can be determined by measuring the output voltage using the usual relation:

$$\mathrm{P}(t) = \frac{V_p^2(t)}{R}. \quad (4)$$

2. Experimental setup and procedures

2.1. Ceramic buzzer

A piezoelectric diaphragm or buzzer is an electromechanical or piezoelectric element which produces a characteristic sound when a voltage is applied to it. The base material of this diaphragm is the ceramic which presents piezoelectricity property, so it is generally used for the electromechanical energy conversion [13] that is to say an electrical current is produced when the buzzer is deformed, conversely, when a voltage is placed on the buzzer, a deformation takes place. In the work presented in this paper, we have shown that the piezoelectric diaphragm can be a thermoelectric converter of energy, because the ceramic, in addition to piezoelectricity, presents the pyroelectric effect [14], i.e. the buzzer is able to generate an electrical voltage when it is subjected to a temperature variation. The kind of buzzer used in this study, is a commercial PZT ceramic buzzer, composed mainly of a piezoelectric lamella (ceramic) bonded to a brass substrate as is shown in Fig. 3. The characteristics of the buzzer are summarized in Table 1.

2.2. Experimental setup

The main purpose of our work is to convert thermal energy into electrical energy through the buzzer which represents the pyroelectric property. As is presented in the introduction of this paper, there are three heat transfer mechanisms. In our work we are interested in the harvesting of thermal energy generated by infrared rays. These rays create temperature changes that allow the buzzer to generate an electrical voltage by pyroelectric effect. Fig. 4 presents an actual picture of the setup developed for the pyroelectric conversion of thermal into electrical energy by the ceramic buzzer.

For our experiment, we used an oscilloscope Agilent Megazoom DSO7034A to visualize the electric voltage generated by the ceramic buzzer and a Philips HP3631/01 InfraCare infrared lamp, with a power of 300 W, to emit infrared radiation to heating (ON) and cooling (OFF) the buzzer. When the ceramic buzzer is subjected

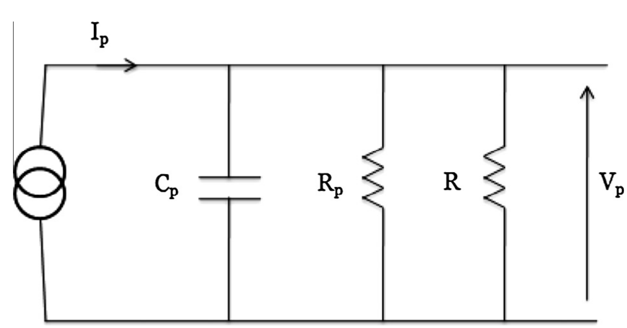

Fig. 2. Equivalent thermoelectrical circuit of a pyroelectric converter.