Applied Thermal Engineering 37 (2012) 30–37

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Pyroelectric waste heat energy harvesting using heat conduction

Felix Y. Lee, Ashcon Navid, Laurent Pilon*

Mechanical and Aerospace Engineering Department, Henry Samueli School of Engineering and Applied Science, University of California, Los Angeles, CA 90095, USA

A R T I C L E I N F O

Article history:
Received 21 September 2011
Accepted 20 December 2011
Available online 30 December 2011

Keywords:
Pyroelectric materials
Ferroelectric materials
Direct energy conversion
Heat conduction
Waste heat harvesting
Olsen cycle

A B S T R A C T

Waste heat can be directly converted into electrical energy by performing the Olsen cycle on pyroelectric materials. The Olsen cycle consists of two isothermal and two isoelectric field processes in the displacement versus electric field diagram. This paper reports, for the first time, a procedure to implement the Olsen cycle by alternatively placing a pyroelectric material in thermal contact with a cold and a hot source. Poly(vinylidene fluoride–trifluoroethylene) [P(VDF–TrFE)] copolymer thin films with 60/40 VDF/TrFE mole fraction were used. A maximum energy density of 155 J/L per cycle was achieved at 0.066 Hz between 25 and 110 °C and electric fields cycled between 200 and 350 kV/cm. This energy density was larger than that achieved by our previous prototypical device using oscillatory laminar convective heat transfer. However, it was lower than the energy density obtained in previous "dipping experiments" consisting of alternatively dipping the samples in cold and hot silicone oil baths. This was attributed to (1) the lower operating temperatures due to the slow thermal response achieved using heat conduction and (2) the smaller electric field spans imposed which was limited by the smaller dielectric strength of air. However, the proposed procedure can readily be implemented into devices.

1. Introduction

Large amounts of waste heat are released as a by-product of power, refrigeration, or heat pump cycles according to the second law of thermodynamics [1]. In 2009, over 55% of the energy consumed in the United States was lost as low temperature waste heat typically discharged to the environment [1]. Opportunities exist to recycle this free source of waste heat into usable energy [2]. For example, Stirling engines directly convert thermal energy into mechanical energy for heat pump, cryogenic refrigeration, and air liquefaction applications [3]. Organic Rankine cycles use refrigerants and hydrocarbons to harvest waste heat up to 200–300 °C [4,5]. However, their performance is limited by heat losses and they cannot function well below 80 °C. Moreover, direct energy conversion using thermoelectric devices have been studied intensively. They make use of the Seebeck effect to convert a steady-state temperature difference at the junction of two dissimilar metals or semiconductors into an electromagnetic force (emf) or electrical energy [6]. Alternatively, pyroelectric energy devices directly convert time-dependent temperature oscillations into electricity [5,7–26]. In practice, the generated energy can be harvested by delivering it to an external load or storage unit [23,26]. Pyroelectric energy conversion devices require thermal cycling of a pyroelectric element (PE) between a hot and a cold temperature source to produce electricity. Various modes of heat transfer can be used to create the desired temperature oscillations [16,21,22,27]. The present study investigates the use of heat conduction in pyroelectric energy conversion using commercial 60/40 mol% poly(vinylidene fluoride–trifluoroethylene) [P(VDF–TrFE)] copolymer thin films.

2. Background

2.1. Pyroelectric materials

Pyroelectric materials possess a spontaneous polarization defined as the average electric dipole moment per unit volume in absence of an applied electric field [28]. A subclass of pyroelectric materials known as ferroelectric materials have the ability to switch the direction and magnitude of the spontaneous polarization by reversing the applied coercive electric field [29]. Note that all ferroelectric materials are pyroelectric and all pyroelectric materials are piezoelectric. However, the converse is not true.

Fig. 1 shows the unipolar hysteresis curves between electric displacement D and electric field E exhibited by ferroelectric materials at two different temperatures T_{cold} and T_{hot}. The curves travel in a counter-clockwise direction upon isothermal cycling of electric field applied across the sample. When a ferroelectric material is heated above its Curie temperature T_{Curie} it undergoes

* Corresponding author. Tel.: +1 310 206 5598; fax: +1 310 206 4830.
E-mail address: pilon@seas.ucla.edu (L. Pilon).
URL: http://www.seas.ucla.edu/~pilon

1359-4311/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2011.12.034