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Generation of electricity using InGaAsSb and GaSb TPV cells in combustion-driven radiant sources

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Abstract

Electric power generation using InGaAsSb and GaSb thermophotovoltaic (TPV) cells was investigated in a gas-fired heating furnace. Electric output characteristics of the TPV cells in the combustion-driven radiant sources are presented. For the InGaAsSb cells, open circuit voltage was higher than 300 mV at a short circuit current density above 1 A/cm^2. The short circuit current of the InGaAsSb cells increased more rapidly than that of the GaSb cells in radiator temperature range 930–1215 °C. A mathematical model for the TPV devices was developed to describe the effect of cell bandgap and radiator temperature on electric power output and cell efficiency. Also, the design aspects of the combustion-driven TPV systems are discussed.

Keywords: TPV; Radiator; Combustion; Model

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1. Introduction

Interest is growing in thermophotovoltaic (TPV) cells and TPV power generation systems [1–6]. TPV generation of electricity has application in electric grid-independent or self-powered gas appliances, portable generators, co-generators of electricity and heat, hybrid electric vehicles, recovery systems of waste heat from industrial processes, etc. In TPV power systems, combustion-driven radiant sources are utilized for generation of electricity.

During TPV energy conversion, TPV cells convert part of the thermal radiation emitted by a combustion-heated radiator into electricity. The photon energy of the selected part of radiation should be matched to the bandgap of the cells. Low bandgap TPV cells are preferred, since they utilize a greater portion of radiation from a thermal radiator in the temperature range of interest. Table 1 represents the percentage of radiation energy from a blackbody above the cell bandgap, i.e., below cutoff wavelength and corresponding radiant power density at various temperatures. Clearly lower bandgap cells are capable of utilizing more radiation energy in the temperature range considered. However, the cell efficiency may decline to a certain extent as its bandgap is lowered due to the decrease in open circuit voltage as well as fill factor (5). Thus, for incident radiation with a particular spectrum there is an optimum bandgap for TPV cells.

In recent years, significant progress has been made in the fabrication of low bandgap semiconductor TPV devices, such as InGaAsSb, InGaAs cells and GaSb cells. The binary semiconductor GaSb devices were originally developed for GaAs/GaSb tandem solar cells. GaSb TPV cells can be fabricated with a simple diffusion process in large volume [6]. It is well known that the bandgap of GaSb devices is 0.72 eV. Low bandgap InGaAsSb and InGaAs cells are of considerable interest. The epitaxial growth of the quaternary or the ternary semiconductors on semiconductor substrates has been the subject of various studies [1–3]. Methods of epitaxial growth include organo-metallic vapor-phase epitaxy, molecular beam epitaxy and liquid-phase epitaxy. The diode behavior and electric characteristics of the TPV devices have been reported and discussed extensively [1–3].

Table 1
Blackbody radiant power and the percentage of radiation energy above cell bandgap energy (i.e. below cutoff wavelength) at various temperatures

Blackbody temperature (°C)	Hemispherical radiant power (W/cm^2)	Percentage of radiation energy above the cell bandgap		
		InGaAsSb (bandgap = 0.53 eV)	GaSb (bandgap = 0.72 eV)	Si cells (bandgap = 1.1 eV)
1000	14.9	28%	10%	0.9%
1100	20.1	33%	14%	1.3%
1200	26.7	38%	17%	2.1%
1300	34.7	44%	21%	3.1%