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Comprehensive analysis of an optimized near-field tandem thermophotovoltaic converter

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ABSTRACT

The electrical power generation of a thermophotovoltaic (TPV) device can be enhanced if the vacuum gap between the thermal emitter and TPV cell is at the nanoscale owing to the photon tunneling of evanescent waves. Multi-junction TPV cells with multiple bandgaps have gained interest as a method of improving their conversion efficiency by selectively absorbing the spectral radiation in each subcell. In this paper, we comprehensively analyze an optimized near-field tandem TPV converter consisting of a tungsten emitter covered by an ITO thin film (at 1500 K) and a GaInAsSb/InAs monolithic interconnected tandem TPV cell (at 300 K). We developed a simulation model by coupling the near-field radiation solved by fluctuational electrodynamics and diffusion-recombination-based charge transport equations. The optimal configuration of the near-field tandem TPV converter obtained using the genetic algorithm achieved an electrical power output of 8.42 W/cm^2 and a conversion efficiency of 35.6% at a vacuum gap of 100 nm. We demonstrated that two resonance modes (i.e., surface plasmon polaritons supported by the ITO-vacuum interface and the confined waveguide mode in the tandem TPV cell) significantly contribute to the enhanced performance of the optimized system. Through loss analysis, we also demonstrate that the near-field tandem TPV converter is superior to the single-cell-based near-field TPV converter in terms of both power output and conversion efficiency. The optimization performed with the objective function of the conversion efficiency resulted in the current matching condition for the tandem TPV converter, regardless of the vacuum gap distance. In addition, the impacts of the additional series resistance and shadowing losses are explored by introducing the front contact grid.

1. Introduction

A thermophotovoltaic (TPV) system consists of a high-temperature emitter and a TPV cell, and it directly converts the radiative energy into electrical energy through the photovoltaic effect [1–4]. One of the advantages of TPV energy conversion is the versatility of the thermal source, enabling it to be utilized wherever the emitter can be heated to high temperatures. For example, when a TPV system is applied in industries, the waste heat can be recovered into electrical energy [1,3–5]. Moreover, the TPV system can also be applied to a full-spectrum solar energy harvesting system called a solar TPV (STPV) system [6–8]. Compared with conventional solar cells, STPV systems can surpass the Shockley–Queisser (SQ) limit of a single-junction solar cell because it can significantly reduce the angular mismatch loss. The STPV system is also available for photonic engineering for both emitter and PV cells, reducing the spectral mismatch loss. In addition, the TPV system retains the advantages of solid-state devices, such as compactness and simplicity in configuration, noise- and vibration-free operation, and potential for miniaturization [1–4].

It is well known that the performance of a TPV converter can be enhanced when the gap between the emitter and TPV cell is smaller than the thermal characteristic wavelength determined by Wien's displacement law [1,3–5,9–26]. In this near-field TPV (NFTPV) converter, thermal radiation exceeding the blackbody limitation can be transferred to the TPV cell owing to the contribution of evanescent waves. To further enhance the electrical power generation and conversion efficiency of the NFTPV converter, several studies have focused on the optical tuning approach, that is, tailoring the spectrum of thermal radiation by modifying the surface of the emitter or the TPV cell

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