Enhanced Radiative Heat Transfer for High Performance Thermophotovoltaics

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The relentless quest for advancing combined heat and power (CHP) systems is a cornerstone in the energy sector, particularly for applications demanding high efficiency and compactness. This study introduces a groundbreaking thermophotovoltaic (TPV) system designed to significantly uplift the performance of CHP systems through enhanced radiative heat transfer. The cornerstone of this novel system is the zero-gap TPV (zTPV) architecture, which integrates an infrared-transparent intermediate solid layer, thereby obviating the need for the conventional vacuum or gas-filled gap. Our research emphasizes the pivotal optical and thermal radiative properties that underpin the superior performance of zTPV. By facilitating the transport of low-loss high-wavevector electromagnetic modes, the zTPV system exploits the full spectrum of radiative heat transfer mechanisms. These modes, typically confined in conventional TPVs, are now harnessed to contribute to energy conversion, resulting in an over tenfold increase in power density and nearly 25% improvement in power conversion efficiency. Furthering the innovation, we propose an ultra-compact hybrid CHP design that integrates zTPV with thermoelectric (TE) arrays. This hybridization not only augments electrical power output but also enhances thermal power generation with adjustable high grade, broadening the potential applications of CHP systems. The hybrid system’s integration directly interfaces TE cell arrays with the solid layer between the TPV emitter and receiver, culminating in a highly efficient and compact CHP module with exceptional kWh per volume generation capabilities. Our analysis, informed by a detailed fluctuation electrodynamics model, establishes the zTPV system's potential in achieving high refractive indices and low thermal conductivities, essential for maintaining the integrity of the thermal emitter at elevated temperatures. We address the economic aspects by considering alternative materials to the traditionally expensive III-V semiconductors, highlighting the versatility and cost-effectiveness of the zTPV system. In conclusion, the optical and thermal radiative properties of the zTPV system unveil a new horizon for CHP applications, offering a path to silent, maintenance-free operations with a substantial leap in energy conversion performance. The insights presented here could serve as a guiding principle for developing next-generation CHP systems that are more efficient, compact, and suitable for diverse applications ranging from residential energy to aerospace and beyond.

References

1. Mohammad Habibi, Longji Cui, Modelling and performance analysis of a novel thermophotovoltaic system with enhanced radiative heat transfer for combined heat and power generation, Applied Energy, 343, 2023.