Hybrid Thermoelectric–Thermophotovoltaic Architecture for Improved High-Temperature Energy Conversion

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Thermoelectric generators (TEGs) remain limited to roughly 6–8% efficiency due to material constraints, but their solid-state design enables exceptional reliability. Thermophotovoltaic (TPV) cells can achieve higher efficiencies, but they introduce reliability concerns such as emitter degradation, structural warping, and sensitivity to spectral tuning. This project investigates efficiency improvement through system-level architectural optimization and a hybrid thermoelectric–thermophotovoltaic approach. The proposed design integrates TPV cells, thermoelectric materials, advanced thermal shaping, and high-temperature selective tungsten metasurfaces to direct emission spectra toward TPV bandgaps. A thermal and electrical model was developed to simulate a single thermocouple within this architecture. Boundary conditions were selected to approximate literature-based values for NASA's Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), allowing the modeled thermocouple to be scaled to an equivalent system. Efficiency calculations were then performed using a Python-based analysis incorporating simulation outputs. When scaled to an MMRTG-class configuration of 768 thermocouples, the proposed architecture produced approximately 280 W of electrical output from 2000 W of thermal input, corresponding to an estimated system efficiency of 14%. These results suggest that hybrid thermoelectric–thermophotovoltaic integration and system-level optimization may provide meaningful efficiency improvements in solid-state thermal power systems while preserving long-duration reliability.

Awards Won:

Fourth Award of $600