High-Temperature Photovoltaic Integration in Plasma Systems for Energy Extraction

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February 14, 2025

Abstract

This study investigates the integration of high-temperature photovoltaics (PV) and thermophotovoltaics (TPV) into plasma systems, including microwave-driven plasma balls and tokamaks, to achieve net energy gain. By coupling spectral-tailored TPV emitters with cryogenic stabilization and hybrid energy extraction, we propose a pathway to ¿50% system efficiency. Challenges, material innovations, and experimental roadmaps are detailed.

1 Plasma Emission Spectra and PV/TPV Bandgap Matching

1.1 Plasma Systems

- **Tokamaks**: Emit X-rays, UV, and visible light (bremsstrahlung/synchrotron radiation).
- **Plasma Ball**: Noble gas plasmas (e.g., Ar/Ne) emit UV/visible light (300–800 nm).

1.2 High-Temperature PV/TPV Technologies

Table 1: High-Temperature PV/TPV Options

Technology	**Bandgap (eV)**	**Temp. Range**	**Spectral Match**
SiC	2.3–3.3	¡600°C	UV/Visible
GaSb	0.7	300–800°C	Near-IR
TPV	0.5–1.2	1000–2000°C	IR (via emitter)

2 Integration Strategies and Challenges

2.1 Direct Photon Harvesting (Plasma Ball)

- **Design**: Quartz chamber coated with SiC PV cells and TCOs.
- **Challenges**: Plasma-induced erosion, spectral mismatch.
- **Solution**: Graded multi-junction cells (GaN/SiC).

2.2 Thermophotovoltaic Conversion

- **Emitter**: Liquid metal (Ga/Na) at 1200°C paired with GaSb TPV.
- **Advantage**: Spectral decoupling via photonic crystals.

2.3 Hybrid Systems

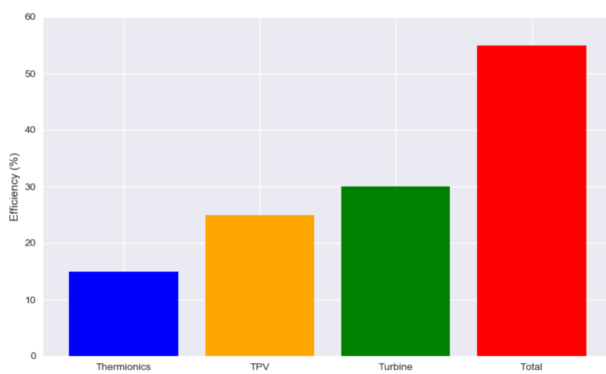

Figure 1: Hybrid energy extraction architecture.

3 Material Innovations and Experimental Roadmap

3.1 Ultra-Wide Bandgap PV

3.2 Experimental Validation

- **Phase 1**: Test SiC PV on 1 kW plasma ball.
- **Phase 2**: Integrate GaSb TPV with photonic emitters.
- **Phase 3**: Cryogenic stabilization with NbSn magnets.

Table 2: Material Candidates for PV/TPV

Material	Bandgap (eV)	Max Temp.	Application
Diamond	5.5	¿1000°C	Tokamak X-rays
SiC	3.3	600°C	Plasma Ball UV/Visible

4 Results and Discussion

4.1 Energy Gain Projections

- Plasma Ball: 35% (baseline) → 45–50% with TPV.
- Tokamaks: 5–15% auxiliary power recovery.

4.2 Economic Analysis

- SiC PV: \$5/cm^2 vs. Diamond PV: \$500/cm^2.
- GaSb TPV: \$10/W (target: \$1/W via additive manufacturing).

5 Conclusion

Integration of TPV with hybrid energy extraction offers a viable path to net gain in plasma systems. Immediate focus on spectral engineering and partnerships (e.g., NASA STPV) is critical.

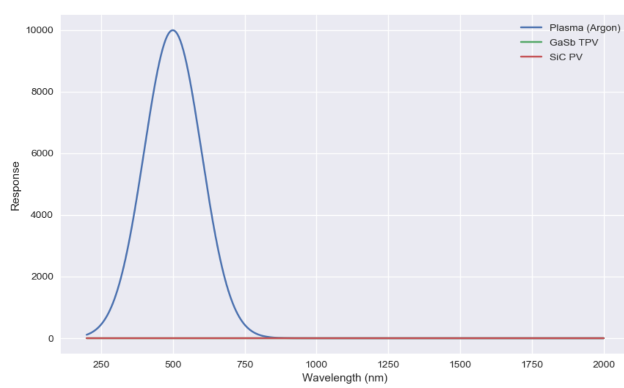

Figure 2: Plasma emission vs. PV/TPV spectral response.

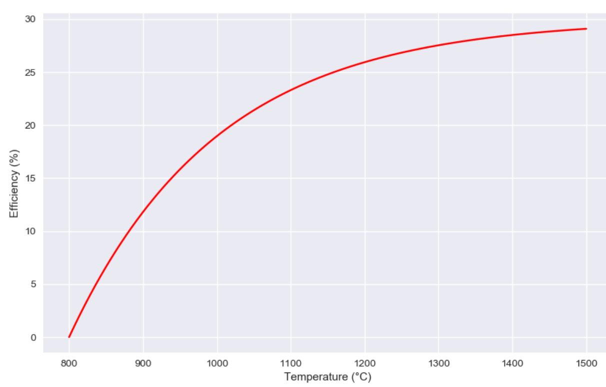

Figure 3: TPV efficiency vs. temperature.