Photon-enhanced thermionic emission for space power systems

Study reference number: 14-2101
Type of activity: Standard study (25k€)

Project Summary

Objective

This project will study the efficiency of photon-enhanced thermionic emission (PETE) and the feasibility for use in space applications.

Target university partner competences

Applied Physics, Electrodynamics, Electronics, Plasma Physics

ACT provided competences

Space energy systems, space system engineering, thermal management

Keywords

PETE, thermionic emission, efficiency, solar cell, photovoltaic, solar dynamic

Study Objective

This study will determine if photon-enhanced thermionic emission (PETE) is a feasible technology for space applications by developing a mathematically model of the cell performance under relevant conditions.

Background and Study Motivation

By combining the internal photoelectric effect in semiconductors and thermionic emission, scientists have developed a new type of solar energy converter, photon-enhanced thermionic emission (PETE) [1,2]. PETE combines photovoltaic and thermionic effects in a single process to take advantage of the high per-quanta energy of photons and the available thermal energy due to thermalisation and absorption (up to 50% of incident solar energy in silicon solar cells) (see figure 1).

The PETE cell could theoretically achieve the same efficiency as current photovoltaic systems, possibly even higher, with the benefit of working at much higher temperatures. For example, the maximum efficiency predicted in a default terrestrial cell is approximately 42% at an emitter temperature of T_e=1400ºC and T_c=200ºC [1].

Thermionic space power systems have been developed for space applications since several decades [10] mainly in combination with radioisotope generators. Although the conversion efficiency is higher compared to photovoltaic, the overall efficiency ranges between 7-15% with a relatively low practical power limit. Due to the high operating temperature, severe limits are also placed on the material choice and lifetime, while the low bus voltage leads to power conditioning losses.

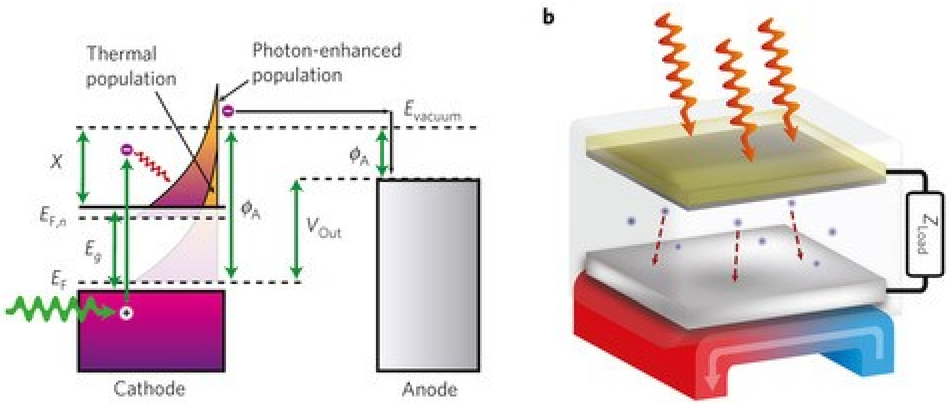

Figure 1: Schematic representation of a PETE cell [3]. Electrons in the PETE cathode are excited by solar radiation into the conduction band. After thermalization in the conduction band, these electrons diffuse to the surface. Electrons with energies above the electron affinity can emit directly into vacuum and collected at the anode, thereby generating a current. [2]

At this moment, the main challenges for thermoelectric systems are related to the high operating temperature and the substantial current densities required for efficient operation. For the latter, various techniques are being investigated to counteract the charge cloud problem. These include Cs-ion injection [5], external magnetic/electric fields [4], material selection and geometry optimization [7,8]. It has been shown that by tuning the electric potential in the converter, the space-charge cloud can be used to contribute to the output current, thereby significantly enhancing the cell efficiency [1]. In addition, nano-structuring of the surface can be used to further improve the photon absorption [7]. To assure the high performance, the device must be thermally optimized to minimize heat losses to keep the converter at the optimal operating conditions.

In the context of space, a PETE device could be useful for near-sun missions where, due to high temperatures, photo-voltaic applications experience a decrease in efficiency. In addition, it could also lend itself for use in concentrated solar power (CSP) systems [3], as reflectors are generally cheaper and less complex than PV solar arrays, thereby reducing the overall power system cost. A further enhancement in efficiency can be obtained by combining a PETE converter with a heat engine cycle [9]. This would have the added benefit that thermoelectric generators can be used to avoid mechanical vibrations of the spacecraft.

Proposed Methodology

The following methodology is proposed for this study, though applicants are invited to propose different approaches which they see fitting better within the scope of this work.

- Develop a mathematical model for assessing the PETE cell efficiency as a function of relevant operating conditions (e.g. surface temperature, solar flux, power requirements, thermal balance and control)
- Model and investigate charge cloud behaviour in PETE cells towards high-current density applications and investigate different mitigation strategies on their feasibility
- Assess the feasibility of PETE design(s) and operating conditions compared to alternative solar conversion techniques; in particular to assess the additional trade-offs related to space applications and, in case of favourable preliminary conclusions, construct a roadmap for future activities

ACT Contribution

The project will be conducted in close scientific collaboration with ESA researchers. In particular ESA researchers will provide technical expertise in space system engineering, satellite power and thermal management and photo-voltaic applications.

Bibliography

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