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Optimization of the Output Characteristics of Photon Enhanced Thermionic Energy Converter with Heat Transfer System
熱輸送機構を備えた光支援熱電子発電器出力特性の最適化

Takahito Setsuda, Akihisa Ogino
説田貴仁, 荻野明久

Graduate School of Engineering, Shizuoka University
3-5-1, Johoku, Naka-ku, Hamamatsu 432-8561, Japan
静岡大学大学院工学研究科　〒432-8561　浜松市中区城北3-5-1

In photon enhanced thermionic energy converter using solar energy (afterward called as PETEC), higher theoretical efficiency can be obtained at lower operating temperature in comparison with conventional thermionic energy converter. To realize the high performance, optimization of the emitter temperature T_E is important. In this study, numerical analysis of the output characteristics of PETEC with heat transfer system was carried out. As a result, in the case of p-Si emitter and solar flux concentration α=100, the efficiency of PETEC is improved to 22 % from 10 % with heat transfer system.

1. Introduction

TEC is direct electric power generation system using thermionic emission from a metal emitter. There are characteristics of thermionic energy converter (TEC): the output power density per unit area is high, and electric power generation is possible at rather high operating temperature (~2000 K). To decrease the operating temperature (~800 K), a semiconductor material is used as the emitter and photon enhanced thermionic emission (afterward called as PETE[1]) is adopted to TEC. To realize high efficiency in PETEC, optimization of T_E is necessary. However, in the system of PETE that depends only sunlight as power source, the control of T_E is difficult. To optimize T_E, heat transfer system that is able to supply and recover heat is adopted to the emitter. Therefore, numerical analysis of the output characteristics of PETEC with heat transfer system was carried out in this study.

2. Numerical analysis model

As shown in Fig.1, the scheme of PETEC can be described in the next three processes, 1: electrons in the valence band of a semiconductor emitter are excited into the conduction band by photons with the energy higher than band gap E_g, 2: the excited electrons in the conduction band are thermally emitted to the vacuum when the thermally energy overcome the electron affinity energy barrier, 3: the emitted electrons are collected by collector and flow into the emitter through load, and electricity will be brought. In this model, T_E is determined from the Eq.(1) of heat conduction for the emitter,

$$m_E c_E \frac{dT_E}{dt} = Q_{in} + Q_{\sup} - Q_{loss}\left(T_E\right) \qquad (1)$$

where, m_E, c_E, Q_{in}, Q_{sup} and $Q_{loss}(T_E)$ are mass and specific heat of the emitter, the thermal input of sunlight, transfer power (heat recovery or heat supply) and thermal loss, respectively. To emit the electrons excited by internal photoelectric effect effectively, the optimum T_E which is the temperature to give maximum efficiency is determined by a heat equilibrium condition between input to the emitter and thermal loss from the emitter. In the calculation, the surface area S_E and the electron affinity χ of p-Si emitter and the collector work function Φ_C are 1 cm^2, 0.4 eV and 1.0 eV, respectively.

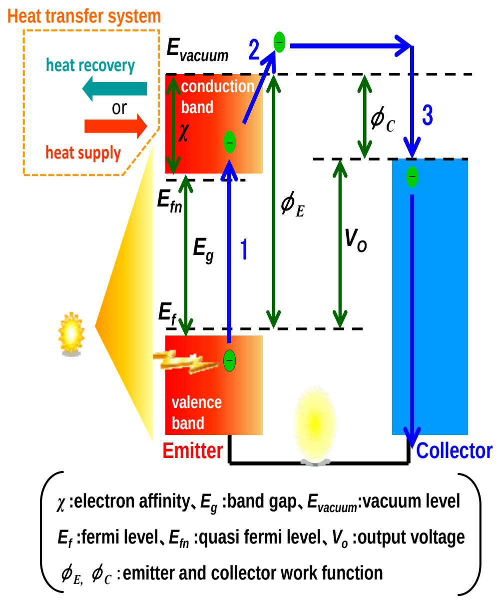

Fig.1. The scheme of PETEC with heat transfer system.

3. Results and discussion

Figure 2 shows the calculated result of the efficiency of electric power generation η at each α. η increases with T_E below the optimum T_E, and decreases with T_E above the optimum T_E because the radiation loss from emitter surface increases largely with increasing temperature. η increases with α, the optimum T_E decreases with increasing α. The optimum T_E at α=1, 10, 100 and 1000 are 1267 K, 1221 K, 771 K and 743 K, respectively.

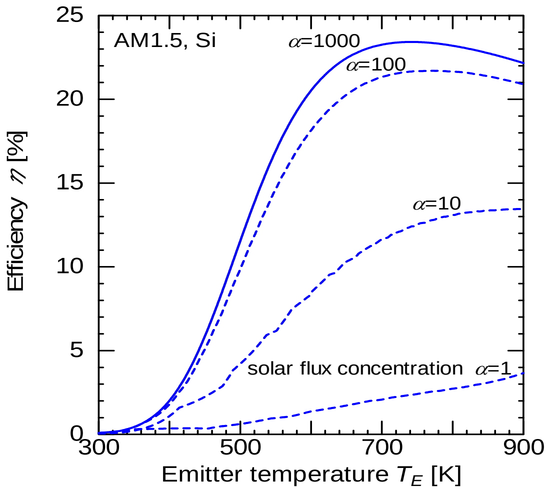

Fig.2. Efficiency as a function of emitter temperature in each solar flux concentration (χ = 0.4 eV, Φ_c = 1.0 eV).

Figure 3 shows the calculated result of T_E and η at α=1 and 1000. T_E increases with heat supply Q_{sup}. At α=1000 in comparison with α=1, higher η can be obtained at lower T_E because the influence of the PETE effect becomes large at higher α.

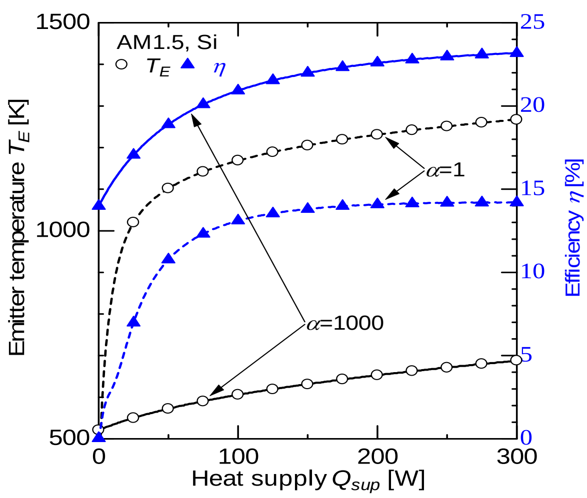

Fig.3. Emitter temperature and efficiency as a function of heat supply at α = 1 and 1000 (χ = 0.4 eV, Φ_c = 1.0 eV).

Figure 4 shows the calculated results of the optimum T_E and η of PETEC with and without heat transfer system. In the case of p-Si emitter, most of the input power of sunlight is consumed for internal photoelectric effect. As the results, the T_E dose not reach optimum T_E enough to emit the excited electrons in the conduction band. However, electron emission will be improved by optimizing T_E using heat transfer system. As shown in Fig.4, the η of PETEC without heat transfer system is 10 % at α=100, on the other hand, the η of PETEC with heat transfer system is 22 % at α=100 and Q_{sup}=70 W.

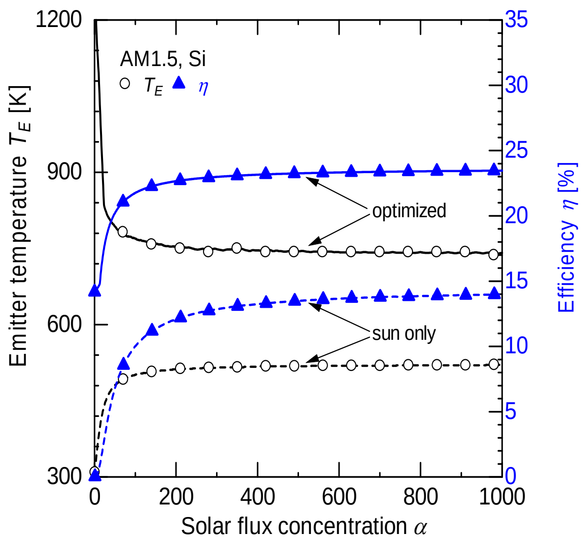

Fig.4. Emitter temperature and efficiency as a function of solar flux concentration (χ = 0.4 eV, Φ_c = 1.0 eV).

4. Conclusion

Optimization of the output characteristics of PETEC with heat transfer system was considered by numerical analysis. Higher η can be obtained at lower T_E because the influence of the PETE effect becomes large at higher α. In the case of p-Si emitter and α=100, the efficiency of PETEC is improved to 22 % from 10 % with heat transfer system. It is thought that PETEC is an effective device to convert the both energy of sunlight and exhaust heat from various engines, boilers, furnaces.

References

[1] J. W. Schwede, I. Bargatin, D. C. Riley, B. E. Hardin, S. J. Rosenthal, Y. Sun, F. Schmitt, P. Pianetta, R. T. Howe, Z.-X. Shen, and N. A. Melosh, Nat. Mater. **9**, (2010) 762.