NEW DEVELOPMENTS IN THERMOPHOTOVOLTAICS

Bernd Bitnar, Günther Palfinger, Wilhelm Durisch, Fritz von Roth, Jana Lehmann

Paul Scherrer Institut,CH-5232 Villigen PSI
phone: 0041 56 310 4085, fax: 0041 56 310 2646
email: bernd.bitnar@psi.ch, http://lmn.web.psi.ch

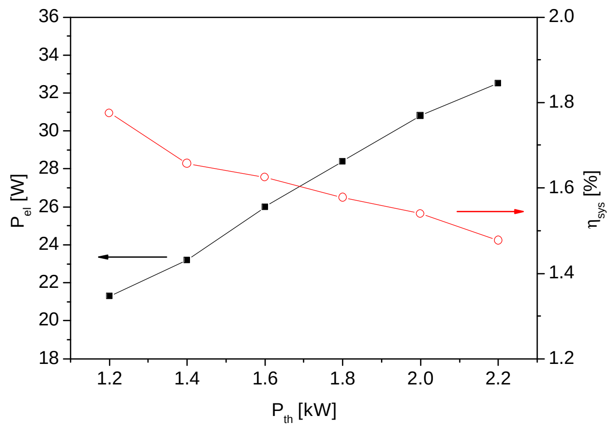
In thermophotovoltaics the radiation emitted from a hot artificial light source (emitter) is converted into electricity by photocells [1]. A technical challenge in TPV is the match between the emitter spectrum and the photocell band gap. For a given photocell, this match can be achieved by using a selective emitter or a selective filter between emitter and photocell. Such a filter transmits convertible radiation to the photocell and reflects sub band gap radiation back to the emitter. The heat source of a thermophotovoltaic (TPV) system can either be a combustion flame (gas-fired TPV system) or concentrated sunlight (solar TPV system).

Experimental results with a small gas-fired TPV system

A small gas-fired TPV system was developed, which is the successor of the prototype system described in [1]. The system is working with Si photocells [2] and an Yb_2O_3 emitter. It consists of the following components:

- A methane burner with a thermal power of 1.0 – 2.4 kW was used as a heat source. The thermal power as well as the amount of combustion air can precisely be adjusted by flow controllers.
- A selective Yb_2O_3 mantle emitter was used [3].
- The photocells were protected from a direct contact with the hot combustion gas by a quartz tube.
- A special photocell optimised for the application in a TPV system was developed. This features by a relatively simple design, an antireflection coating adapted to the emitter spectrum and an aluminium rear side mirror for the back reflection of sub band gap radiation.
- To keep the cell temperature below 30°C during operation, the photocells were glued onto water cooled aluminium blocks.
- The system is cylindrically in shape. Gold coated reflectors close it in axial direction to reduce radiation losses. A slit in the upper reflector allows the escape of the exhaust gas.

The subsequent figure gives experimental results of this system. The electrical output power P_{el} (squares) and the system efficiency η_{sys} (open circles), which is defined as P_{el} divided by the thermal input power P_{th}, are shown. The system produced more than 32 W electrical power. The slight decrease of η_{sys} with P_{th} is caused by the series resistance of the photocells.



Calculations showed that η_{sys} is limited by:

- Radiation losses through the slit in the upper reflector and chinks between the cells.
- Absorption of sub band gap radiation by free carrier absorption (FC) in the photocells. This loss might be reduced by the development of thinner cells with a decreased doping concentration of the base material.

Simulation results of a solar thermophotovoltaic system

A simulation model [4] was used to calculate η_{sys} of this TPV system, if the methane burner is replaced by concentrated sun light. It was studied, whether a solar TPV system operating with an Yb_2O_3 emitter and Si photocells is able to surpass the efficiency of conventional high quality solar cells. For the simulation, the existing system was taken as a reference. The concentrated sunlight was coupled into the system by a hole in the top reflector. The reflectivity of the emitter was assumed being 10% independent of the wavelength presuming light trapping in a rough emitter surface. The area of the concentrator was 5000 cm^2 for all simulations.

The following table gives the result of these simulations. PSI is the existing TPV adapted Si photocell, c means the concentration factor of the sun radiation and T_{em} the resulting emitter temperature.

Photocell	Filter	c	T_{em}[K]	P_{el} [W]	η_{sys} [%]
PSI	Quartz	1000	1750	17	4.0
PSI no FC	Quartz	1000	1850	25	5.9
PSI no FC	Ideal	2000	2000	44	10
Optimised	Ideal	2000	1960	67	16
Optimised	Ideal	5000	2340	120	29

The first line shows that η_{sys} expected for a system with the existing technology is too low to compete with conventional solar cells. The subsequent simulations show, how different optimisations affect η_{sys}:

- Avoidance of FC in the photocell
- Replacement of the quartz tube by an idealised selective filter with 99% transmittance for convertible radiation and 99% reflectance for sub band gap radiation.
- Increase of the concentration factor of the sun radiation and reduction of the opening in the top reflector
- Use of an optimised photocell with an efficiency of 46% for illumination with monochromatic radiation.

A solar TPV system operating with an Yb_2O_3 emitter and Si photocells has in principle the potential to achieve a system efficiency around 30 %. The assumptions needed for such a high efficiency don't seem to be unachievable. Highly efficient solar cells from the University of New South Wales show already a monochromatic efficiency of 46%. The idealised filter is not needed with a rear surface reflector and a sufficiently low FC. A sun concentration factor of 5000 is already achieved in large solar concentrators.

The experimental study of solar TPV systems is planned to be part of the European research project FULLSPECTRUM.

References

[1] B. Bitnar, G. Palfinger, W. Durisch, J.-C. Mayor, D. Grützmacher, H. Sigg, J. Gobrecht, „Simulation- and demonstration model of a high efficiency thermophotovoltaic system", Proc. 14th Quantsol Workshop 2002, editors: DeCola/Königstein/Vanmaekelbergh, pp. 69 - 70.

[2] B. Bitnar, „Silicon-, germanium- and silicon/germanium photocells for TPV applications", Semicond. Sci. Technol. 18 (2003), Special Ed. Thermophotovoltaics, pp. 221 - 227.

[3] B. Bitnar, W. Durisch, J.-C. Mayor, H. Sigg, H.R. Tschudi, "Characterisation of rare earth selective emitters for thermophotovoltaic applications", Solar Energy Mat. and Solar Cells 73/3 (2002), pp. 221 - 234.

[4] B. Bitnar, J.-C. Mayor, W. Durisch, A. Meyer, G. Palfinger, F. von Roth, H. Sigg, "Record electricity-to-gas power efficiency of a silicon solar cell based TPV system", Thermophotovoltaic Generation of Electricity: Fifth Conf. on Thermophotovoltaic Gen. of Electr. (AIP Conf. Proc. 653) ed Coutts, Guazzoni, Luther (2003), pp. 18 - 28.

Acknowledgement

The work was funded by the Swiss Commission of Technology and Innovation CTI, contr. No. 5692.2 EBS.