Current Trends in Technology and Science
ISSN : 2279-0535. Volume : 04, Issue : 03 (Apr.- May. 2015)

Ultras TPV Conversion Efficiencies Depending on the Energy Gap of The Materials Used and the Source Emission Temperature

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Abstract — The interest on thermophotovoltaic cells (TPV) is their ability to generate electricity from heat sources. They are made of semiconductor materials which are classified according to the width of their band gap. Those with smaller band gaps, so capable of absorbing large wavelength radiation such as infrared, offer better prospects for greater extension of solar energy, especially in hot countries. This article is a study of the ultras TPV conversion efficiencies depending on the energy gap of the materials used and the source emission temperature. This study focused generally on the cells at high, medium and low band gap.

Keyword — Thermophotovoltaic, cells, efficiency, material, power output, band-gap, emitter, filter.

1. INTRODUCTION

The technology of thermophotovoltaic (TPV) devices will develop a pathway that may be an alternative to fossil energy, as it allows the generation of electricity from thermal energy. This technology was born in the context of the cold War between the United States and Russia. [1] Many researches have concluded that their efficiencies are much higher than those of photovoltaic cells.

2. COMPONENTS OF A TPV DEVICE

A thermo photovoltaic device consists of a heat source, an emitter, an optical filter and suitable photovoltaic cell as shown in Figure 1.

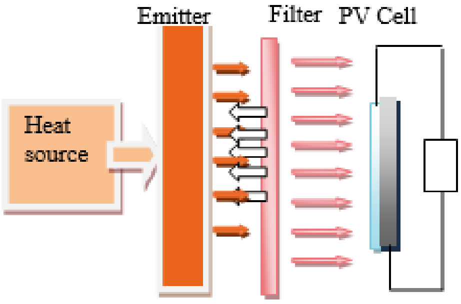

Figure 1: Schematic diagram of a thermal photovoltaic device.

The heat generated may come from solar radiation, from the combustion of a gas and nuclear reaction.

The crucial element of a TPV generator is the emitter. The adaptation of the emission spectrum with the spectral sensitivity of the cell is the major difficulty encountered in the optimal operation of the generator. Bitnar [2] studied the selective emitters based on rare earths. The several types of emitters have emerged.

Filter, placed just after the emitter is operable to select the wavelength of the emission spectrum from the emitter. It allows to increase the efficiency of the TPV cell and reduce the harmful effects of heat on the cell.

The TPV cell plays a key role in the conversion of electromagnetic radiation into electricity. The optimization of these materials with infrared radiation is the major task for satisfactory conversion efficiencies. The materials can be divided into three categories [3] big gap, medium-band gap materials, [4], [5] and low-band gap materials [6], [7], [8].

3. POWER DELIVERED BY THE EMITTER

In the case of black body, the Planck law gives the radiation emitted by a black body. It is a function of the temperature and wavelength [1].

$$P(u,T) = \xi.T^3.\frac{u^3}{e^u - 1} \qquad (1)$$

$$\xi = \frac{2\pi k^3}{(c.h)^2} \qquad (2)$$

$$u = \frac{E}{K_B T} \qquad (3)$$

$K_B = 1.38.10^{-23}\ J.K^{-1}$ is the Boltzmann constant, h is Planck constant, c is the light velocity, and T the temperature of source of the emission and frequency.

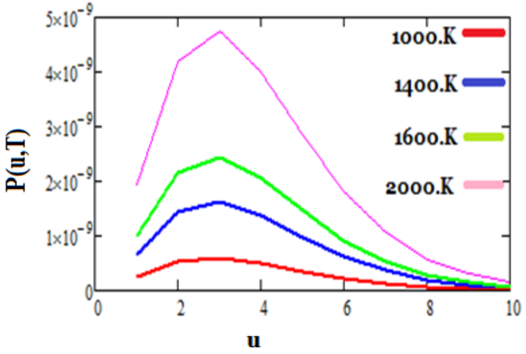

Figure 2. Power emitted by the emitter as a function of u.

For a gray body, the radiation power per unit area per unit photon energy (eV) is:

$$P_{rad}(E,T)=\varepsilon(u)P(E,T) \qquad (4)$$

$\varepsilon(E)$ is the emissivity of the radiator.

4. RESULTS AND DISCUSSION

4.1. Performance of the emitter

$$\eta_E=\left\{1+\gamma\left[\left(b.e^{-a_1\frac{E}{T_E}}.\left[6+6.a_1.\frac{E}{T_E}+3a_2.\left(\frac{E}{T_E}\right)^2+a_3.\left(\frac{E}{T_E}\right)^3\right]\right)^{-1}-1\right]\right\}^{-1} \qquad (5)$$

$$b=\frac{15}{\pi^4},a_1=\frac{1}{k_B},a_2=\frac{1}{k_B{}^2},a_3=\frac{1}{k_B{}^3},\gamma=\frac{\varepsilon_l}{\varepsilon_b}$$

ε_l and ε_b variables.

T_E is the temperature of the emitter,

ε_l is the emittance for the low-energy photon region of the spectrum that can not be converted into electricity,

ε_b is the emittance for the energy of the photons useful in the spectrum region.

Letting $u_E = E/kT_E$, the emitter performance as a function of u_E is displayed on fig.2 for different values of □.

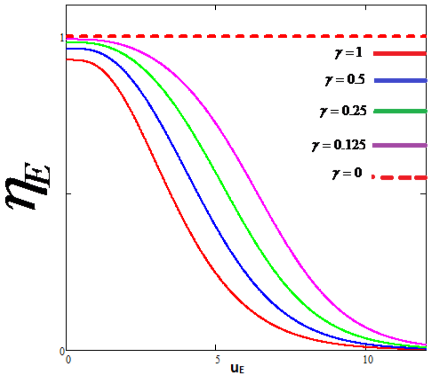

Figure 3. Performance of the emitter based on u_E and γ.

It is clearly seen that η_E essentially depends on γ. The proof is, when its value is zero η_E reaches its maximum and remains constant for all values of u_E. This means that all the radiation coming from the source reaches the emitter without loss. However, when it is not zero, then the curves present two concavities. The first concavity occurs just after a quasi constant shape of the curve corresponding to low photon energies between 1.5 and 2.5 for u_E.

As the photons energy increase, the cell performance decreases abruptly.

The parts of the curves corresponding to the second concavity, shows that the TPV cell performance tends to zero.

4.2. Thermo photovoltaic cell efficiency

The overall performance of TPV device is obtained from the parameters related to the emitter, the filter and the PV cell.

$$\eta=\frac{P_{el}}{Q_{th}} \qquad (6)$$

P_{el} is the electrical output power of the cell, Q_{th} is the input thermal power.

The calculations are developed in ref [1]. The electrical power must be calculated from the potential V and the current density J developed by the cell. Developments have given the following relationship:

$$P_{el}=\frac{A_C}{\lambda_g}\int_0^{\lambda g}\left(-\rho_C\right)q_{iC}P(\lambda)d\lambda \qquad (7)$$

λ_g is the length corresponding to the band gap of the PV cell material, A_c is the cell surface, q_{iC} is the flow of radiation incident on the PV cell per wavelength unit, ρ_c is the reflectance of the emitter and of the cell respectively.

$P(\lambda)$ is the power emission of the black body constituted by the emitter. The maximum electric power is:

$$P_{el\max}=\frac{A_C}{\lambda_g}\int_0^{\lambda_g}\left(-\rho_c\right)q_{ic}\lambda d\lambda \qquad (8)$$

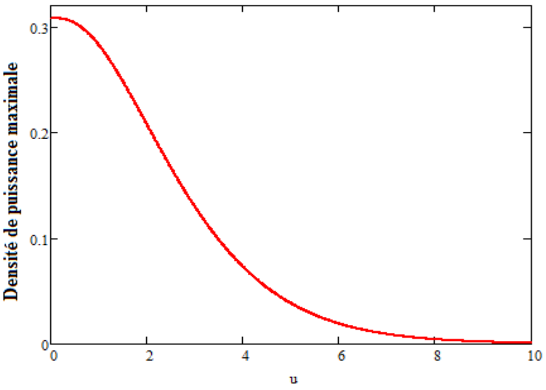

Figure 5: maximum power density as a function of u

The determination of incident thermal power Q_{th} requires to assume that all incidents and outgoing flows of energy are uniform.

$$Q_{th}=A_E\int_0^{\infty}\left(q_{OE}-q_{iE}\right)d\lambda \qquad (9)$$

q_{0E} is the flux of the radiation emitted by the transmitter unit by wavelength.

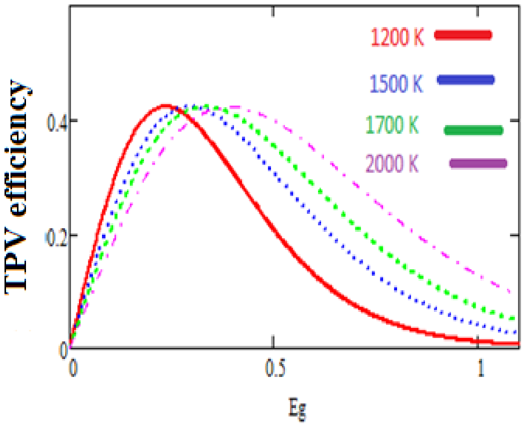

Figure 6: TPV efficiency as a function of E_g (eV) for different temperatures.

The curves present the same profile and have the same maximum value. This maximum moves toward the low values of E_g for lower temperatures.
The emitter's performance R is described in ref [1], it is the ratio of the emittance for low photon energy in the spectrum region that cannot be converted into electricity and the emittance for useful energy photon.

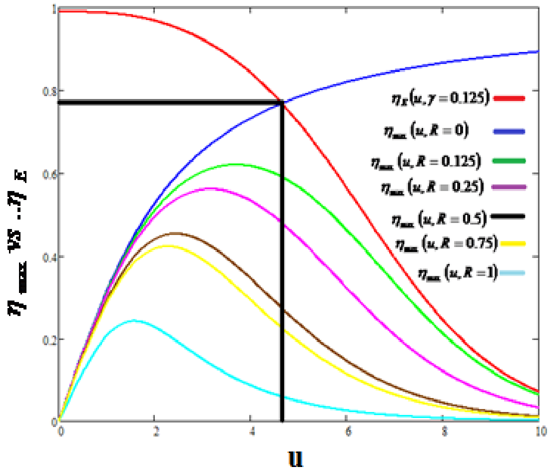

Figure 7. TPV maximum performance and efficiency of the emitter according to u.

he figure 7 reflects the evolutions of TPV maximum performance for different values of R and emitter efficiency (red curve) as a function of photons energy. In this case, T_E is the temperature of the transmitter and □ is the corresponding wavelength. It is observed that higher TPV efficiencies are obtained for low values of u_E. The ideal case is for low values of R (the zero limit) to expect a higher conversion efficiency. With the set parameters of our analysis, the graph shows a very remarkable point: the intersection for the red and blue curves. The maximum TPV conversion efficiency does not correspond to the maximum performance of the emitter. The adequate value of conversion efficiency is obtained for $u = u_g$ which corresponds to this point. The photons from the emitter with an energy that matches u_g will be well absorbed by the PV cell. Those which are lower will warm up the device that would eventually deteriorated. For other photons, their excess energy would have the same effects as those which are lower.

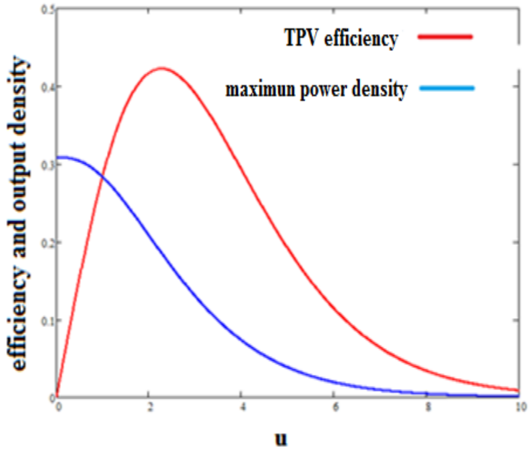

Figure 8. TPV efficiency and maximum power density as a function of u.

4.3. High – gap cells efficiency

Figure 9 shows the efficiency of a TPV as a function of temperature of the emitter silicon-based cell (E_g=1.1 eV). The performance is very low ; this means that silicon is a poor candidate for the TPV industry.

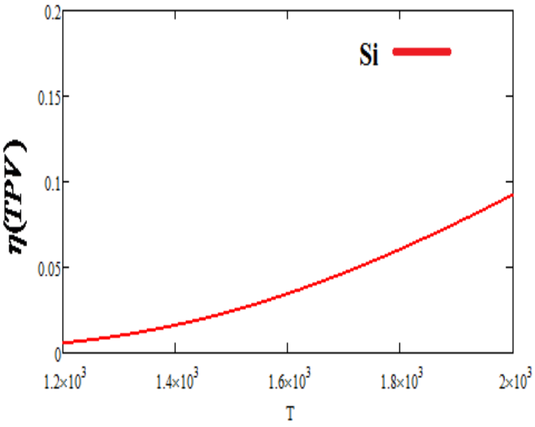

Figure 9: Efficiency the TPV in the function of temperature (K) of the emitter to a silicon-based cell.

4.4. Performance of medium - gap cells.

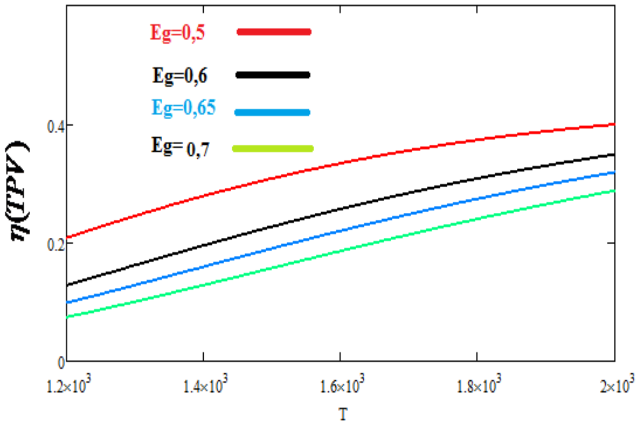

Figure 10: efficiency the TPV in the function of temperature (K) for the cells in gap (eV).

Figure 10 shows a net increase in the efficiency with the temperature for different cells as InPAsSb (E_g =0,76), GaSb (E_g = 0.7 eV), Ge (E_g = 0.66eV eV) and InGaAs (E_g =0,6eV), as the band gap energy decreases.

4.4. Small – gap cells efficiency

The best efficiencies are obtained with the small-gap cells. Researches for best TPV cells efficiencies should focus largely on small – gap materials such as InGaAsSb (E_g =0,53 eV), InPAsSP (E_g =0,5 eV), GaInAsPSb (E_g =0,35 eV). All curves displayed in figure 11 and related to these cells show a efficiency between 20 % and 40 % depending on emitter temperature. This is a proof that the TPV industry is an excellent candidate to replace fossil energy.

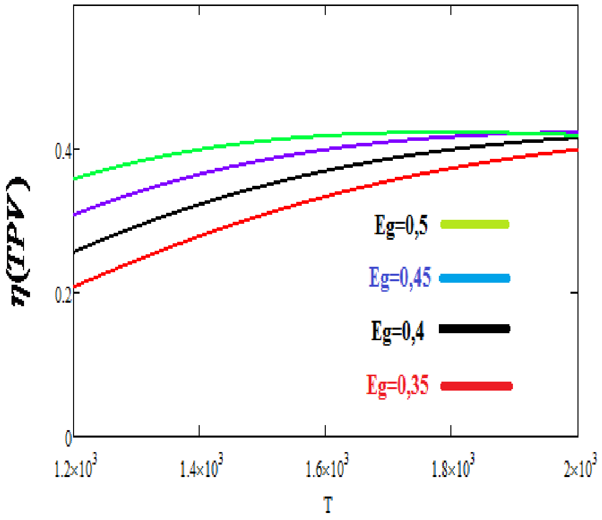

Figure 11: efficiency the TPV in the function of emitter temperature for the cells in gap (eV) low.

5. CONCLUSION

The thermophotovoltaic (TPV) devices potentially have greater efficiencies than photovoltaic cells. But that performance depends on many factors : the emitter, the filter with low absorptivity in some cases can affect proper operation of the cell because the gap of the cell material should be compatible with the radiation spectrum. On the other hand, there are not many materials with very low bandgap, which requires very high temperatures emitters. The maximum efficiency that can be expected from TPV cells is examined according to the emitter temperature and the gap of the material. A comparison between the performance of low, medium and large gaps cells is done. Small gaps cells requires low emitter temperatures at the opposite of large gap cells and offer better performance. The emission temperature plays an important role because because high thermal energy can affect the performance and durability of the unit. Most current researches are focused on the manufacture of several types of TPV cells ranging from ternary to pentanary cells which are small-gap cells.

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