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DIRECT CONVERSION OF SOLAR ENERGY TO ELECTRIC ENERGY

Thermophotoelements with *p–n* and Double Heterostructure

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Abstract—Details of thermal generation and thermocurrent variation depending on the character of electronic heating of narrow-band layers of thermophotoelements with [p-n] and double heterostructures are discussed.

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INTRODUCTION

From 1954 on [1], studies in the area of photovoltaics have been carried out [2], resulting in establishment of Si, $CuInSe_2$, and CdTe solar cell (SC) production. However, the price of photoelectric solar cells is still unacceptable for the mass consumer, maintaining motivation for investigations and developments in this area. The idea of thermophotoelements (TPE) and the establishment of thermophotovoltaics (TPV), which is a new direction in renewable energetics [4, 5], was proposed in [3, 4] with regard to the possibility of reaching appreciable thermocurrent due to the photoelectronic heating and enhancing the efficiency of SCs. It is obvious that the TPV development requires investigations to be carried out over decades. The success of theoretical calculations and experimental works is largely associated with a right formulation of the problem based on reasonable ideas on physicotechnical processes involved. The idea of a Si SC–TPE cascade was proposed in [6].

FORMULATION OF THE PROBLEM

In this paper, the idea of TPE with [p-n] structure and heterostructure is proposed and discussed in order to promote the projecting of task-oriented TPV studies.

Similar to a photocell, a TPE is composed of *p–n* structure, where the heating is due to photoelectrons in contrast to thermoelements. A possible open-circuit voltage (V_{oc}) is reached in TPEs as a result of photogeneration of electron–hole (e–h) pairs and their separation due to the p-n junction field. The TPE short-circuit current (I_{sc}) is composed of the photo (I_{sc}) and thermo (I_{sc}) parts. To develop TPEs with an efficiency of 25–35%, the thermoelectron concentration due to intrinsic carriers should be higher than $(1–2) \times 10^{15}$ cm^{-3} in a narrow-band layer. For this purpose, an operational temperature is chosen for TPEs with allowance for the width of a forbidden band (E_g) of the semiconductor.

It is clear that, in the same way as thermoelements, TPEs should be divided into three kinds depending on the semiconductor E_g: low-temperature ($E_g = 0.2–0.3$ eV), mean-temperature ($E_g = 0.4–0.5$ eV), and high-temperature ones ($E_g = 0.6–1.0$ eV).

Different layers of p-n structure have different temperatures in a TPE that is heated photoelectronically. The temperature gradient in TPEs is expected to be much greater than that in thermoelements, which is 0.03 deg/μm. The temperature difference between the hot and cold ends is ~200°C, since the branch length of the thermoelement is approximately 6 mm. The heat is removed in TPEs in front and rear directions. It is possible to determine the effect of the temperature gradient and the character of heat removal based on thoroughly performed experiments. Therefore, the accumulation of experimental data to clarify the mechanism of solar energy conversion into electricity using TPEs is an important task in the current stage of TPV establishment.

It is obvious that the study of the V_{oc}–I_{sc} relationship for TPEs with heterostructures can provide additional helpful information along with the studies and development of TPEs with homo p-n structure.

In regards to the formulation of the problem, it reduces to the following aspects:

(1) Considerations of low-temperature TPEs.

(2) Separate studies of p and n layers in TPEs.

(3) The estimation of V_{oc} and I_{sc} depending on the illumination of front and rear TPE surfaces.

(4) The determination of V_{oc} and I_{sc} depending on the choice of semiconductor heterostructure materials and the thicknesses and doping levels of p and n narrow-band layers.

(5) The adjustment of heat removal in both directions from a TPE with double heterostructure.

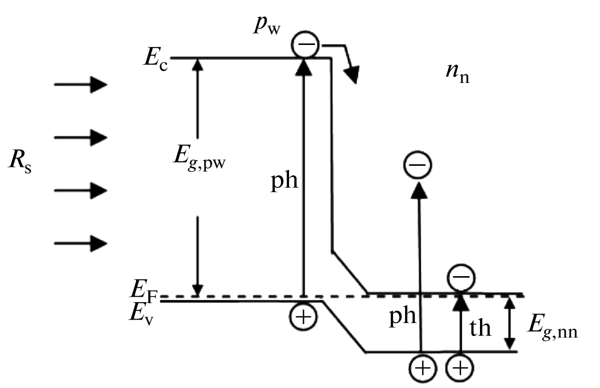

Fig. 1. Band diagram of p_w–n_n heterostructure. $E_{g,pw}$ and $E_{g,nn}$ are the widths of forbidden bands for the wide-band (p_w) and narrow-band (n_n) layers, respectively; ph and th mean the photo and thermal generation of electron–hole pairs, respectively; R_s is the solar radiation.

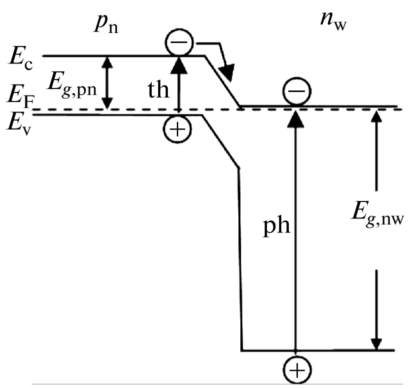

Fig. 2. Band diagram of p_n–n_w heterostructure. $E_{g,pn}$ and $E_{g,nw}$ are the widths of forbidden bands for the narrow-band (p_n) and wide-band (n_w) layers, respectively; ph and th mean the photo and thermal generation of electron–hole pairs, respectively.

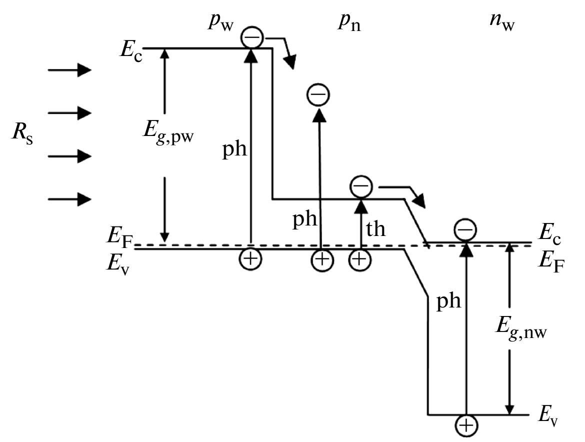

Fig. 3. Band diagram of p_w–p_n–n_w heterostructure. $E_{g,pw}$ and $E_{g,nw}$ are the widths of forbidden bands for the wide-band (p_w and n_w) layers, respectively; ph and th mean the photo and thermal generation of electron–hole pairs, respectively; R_s is the solar radiation.

EXPERIMENTAL

The wide-band and narrow-band layers of the structure are designated using the "w" and "n" subindices, respectively. We will not take into account the band discontinuity effect in *p*–*n* heterojunctions. For a narrow-band layer, it is advisable to use a direct semiconductor, such as PbS, InAs, or $(BiTe_3)_{1-x}(Se_3)_x$ with $E_g \approx 0.2$–0.3 eV and a thickness of 2–6 μm. The recombination of photo- and thermoelectrons is assumed to be radiationless, resulting in TPE heating. Short lifetimes of photo and thermo carriers do not appreciably affect the thermocurrent T_{sc}. In this connection, polycristallic p and n layers doped with a concentration of 10^{18}–10^{19} cm^{-3} can be used in TPEs with heterostructure.

Materials for wide-band layers may be chosen considering their accessibility and simplicity of doping technology, for example, Si, ZnSe, etc. It is of interest to produce and study TPEs with p_w–p_n–n_w and p_w–n_n–n_w heterostructures. We present the band diagrams of p_w–n_n and p_n–n_w structures (Figs. 1 and 2, respectively), whose front and rear surfaces are coated with grid ohmic contacts. If the p_w–n_n structure of the TPE is illuminated on the side of p_w, both layers are heated in different ways depending on E_g and the thickness of the p_w layer. If the n_n side is illuminated, only this layer is heated since it absorbs the whole spectrum of solar radiation, with the heat being removed in both directions. The rear TPE surface can have indiscrete ohmic contact and thermal insulation layer for controlling the heat removal and temperature distribution. The front surface can be covered with a transparent layer whose thickness may be varied.

While studying experimentally TPEs with p_n–n_w structure under similar conditions, we can estimate the difference between photo and thermal generation of eh pairs, the contribution of the p_n layer to V_{oc} and I_{sc}, and the efficiency of solar-into-electrical energy conversion. Note, in particular, that photo V_{oc} and photo I_{sc} can be determined at the moment of illumination, when the TPE heating is almost absent. When the illumination ceases, the observed values of V_{oc} and I_{sc} correspond to the contribution of eh-pair thermal generation to thermal V_{oc} and thermal I_{sc}.

Figures 3 and 4 show the band diagrams of TPEs with the double heterostructures p_w–p_n–n_w and p_w–n_n–n_w, respectively. In these cases, different temperature distributions over the TPE thickness can also be reached depending on E_g, and the thicknesses and doping levels of wide-band layers. Comprehensive investigations of double-heterostructure TPEs lead to the accumulation of interesting and helpful experimental data that are required for clarifying the outlooks for thermophotoelements. One important feature of double-heterostructure TPEs is the fact that the narrow-band p_n (Fig. 3) and n_n (Fig. 4) layers are

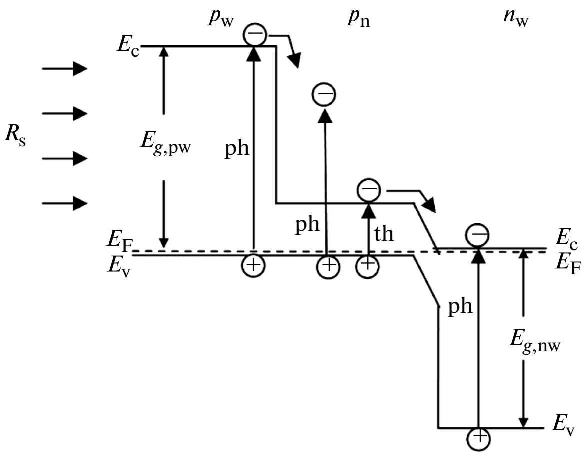

Fig. 4. Band diagram of p_w–n_n–n_w heterostructure. $E_{g,pw}$ and $E_{g,nw}$ are the widths of forbidden bands for the wide-band (p_w and n_w) layers, respectively; ph and th mean the photo and thermal generation of electron–hole pairs, respectively; R_s is the solar radiation.

bounded by energy barriers exceeding E_g from both sides. Therefore, an increase in intensity of incident solar radiation can enhance the temperature of photo and thermal electrons and holes in p_n and n_n layers, enabling us to understand how this process can affect V_{oc} of TPEs.

We hope that the above stated proposal will attract notice of specialists in the area of photovoltaics and thermoelectricity.

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