PHYSICS AND CHEMISTRY OF SOLIDSTATE
V. 18, № 3 (2017) P. 372-375
DOI: 10.15330/pcss.18.3.372-375

ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 18, № 3 (2017) С. 372-375

УДК 621.362+ 621.383

ISSN 1729-4428

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The Thermoelectric Solar Generator

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Developed a comprehensive system for generating of electric energy "Thermoelectric generator – solar collector". The Sb doped PbTe (n-type of conductivity) and triple compound PbSnTe (p-type of conductivity) were synthesized as basic materials for thermocouples.

Keywords: thermoelectric generator, solar collector, lead telluride.

The article came to the editor 23.08.2017; accepted for publication 15.09.2017.

Introduction

Solar energy is the renewable energy sources that are free and available throughout the year. But, we must note, that should distinguish between the energy that can be obtained through solar radiation and solar heat.

Now the spectrum of solar radiation is efficiently converted into electricity through photovoltaic panels (monocrystalline, polycrystalline, or thin film systems). One of the variants of devices that collect the heat into solar energy is the solar collectors, which are used for heating and domestic hot water supply facilities, production processes, household needs.

On the practical use of thermoelectric effect to generate of electricity (effect of Seebeck) it is important that it has place for renewable energy and for non-renewable [1]. In the first case as a source of the heat can be used, for example, the direct solar heat. Focus of solar power (using special surfaces, systems lenses, mirrors) allows to significantly increase the efficiency of the end device – generator.

Thermoelectric effects are describes by many publications. The main issues, that currently stands in front of thermoelectric society are improve of the properties of thermoelectric materials and reduce the cost of modern thermoelectric materials. To improve the properties, there are varieties of ways: creating multicomponent or composite materials [2-4], or transition from the bulk of materials to nanostructures [5, 6].

The authors of this work suggested the constructive solutions with the purpose of use of the solar collector to heating of thermoelectric module and the next generation of electricity. Such installation is relatively small, mobile, and, most importantly, it can work outside of the network systems of power supply to provide electricity to small industrial or household needs.

It should be noted, today the cost of 1 Watt of the generated of thermoelectric energy is approximately 1 USD that is comparably with the cost of electricity generated by photoelectric panels [7, 8]. Though it should be noted that this cost takes into account only generate of thermoelectric energy and its following transfer for load (without batteries). And, the source of heat for generating of thermo-electric energy is exhaust heat, or the heat of the Sun or the Earth entrails, which is free for people. In this case the low efficiency of the industrial thermoelectric device (4-7%) does not become an obstacle to the development thermoelectric in general. Moreover, in modern's hybrid systems are possible to reach a sufficiently high efficiency. So, for complex system "Solar collector – Thermoelectric generator", the authors [7] report about efficiency of 23 %, and in [10] even reaches up to 40 %.

Fig. 1. Photograph solar thermoelectric generator.

I. Experimental installation

Photos of the construction of the solar thermoelectric generator (STAG) show on fig. 1. It combines the vacuum thermal solar collector with thermoelectric generator (TEG) as well as solar panel for possible compare of results.

A test version of the solar collector are consists four vacuum tubes with diameter of 58 mm and length 500 mm (fig. 1). Collected heat through the heat pipe is passed to condenser which incorporated the design of the welded copper plate for placement the thermoelectric module. For drain heat from “cold” surfaces of the thermoelectric module used the radiator with fan (fig. 2). All thermointerfaces are covered with heat conductive paste KPT-8.

Fig. 2. Photo with thermoelectric module occur on the condenser of vacuum collector.

II. Thermoelectric modules

Structurally, the thermoelectric module is made in the form of the matrix of thermocouples of the p- and n-type of conductivity which are connected in series. To ensure of electric contact used copper plates that are soldered to the thermoelement. The thermoelectric module is protected by heat-transfer ceramics on the both sides.

Semiconductor components of thermoelectric modules were received by the method of cold pressing with subsequent annealing. Compaction powder was milled in in ball-mill from synthesized polycrystalline ingots in planetary ball mill Pulverisette 6. The synthesis was carried out in the evacuated quartz ampoules to the residual pressure 10^{-4} Pa. Ampoules were carefully cleaning, including washing by mixture of HNO_3:HCl and repeated alternately washing with rubbing alcohol and distilled water, drying in the furnace at T = (420 - 470) K. On next stage these ampoules filling in starting from the most volatile component. For the synthesis was used the initial materials with content of main component 99.999 %.

For receiving legs of n-type of conductivity using material based on lead telluride doped by antimony, and for p-type of conductivity using materials on the basis of solid solutions lead-tin-telluride. Optimal size fractions was in the range of (50 - 500) µm, under pressing (1 - 2) GPa, the annealing temperature was (300 - 500)$^{\circ}$C.

Each module contains 16 thermoelements with diameter of 8 mm and height of 5 mm. They are placed in square matrix 4x4. Dimensions of the module consists of 45x45 mm. The thickness of the copper circuit plates was 0.3 mm, thickness of ceramics 1 mm.

III. The control system

Electric control system is designed based on the microcontroller ATMega8A. It provides the charging of the built-in battery for thermoelectric modules and solar photovoltaic panels, the work of two USB outputs (5 V, 2 A) for charging of mobile devices or other load. On four-row liquid crystal display can be withdrawn the generated and consumed power, voltage, current, and temperature of “cold” and “hot” surfaces of thermoelectric modules.

The electric circuit diagram of the control unit is shown in Fig. 3. Electrical voltages are measured using the built microcontroller of the 10-bit analog-to-digital converter. The source of the reference voltage selected is precise chip LM4040C30. Currents measured by integral sensor ACS712E. The temperature was measured using two thermocouple and integral sensor DS18B20. Generated energy from photovoltaic panels and four serial connected thermoelectric modules through the DC-DC converter is used to charge the built-in battery and two USB outputs. Maintain stable temperature gradient on thermoelectric modules controller can turn fans for improve heat dissipation from radiators on the “cold” surfaces.

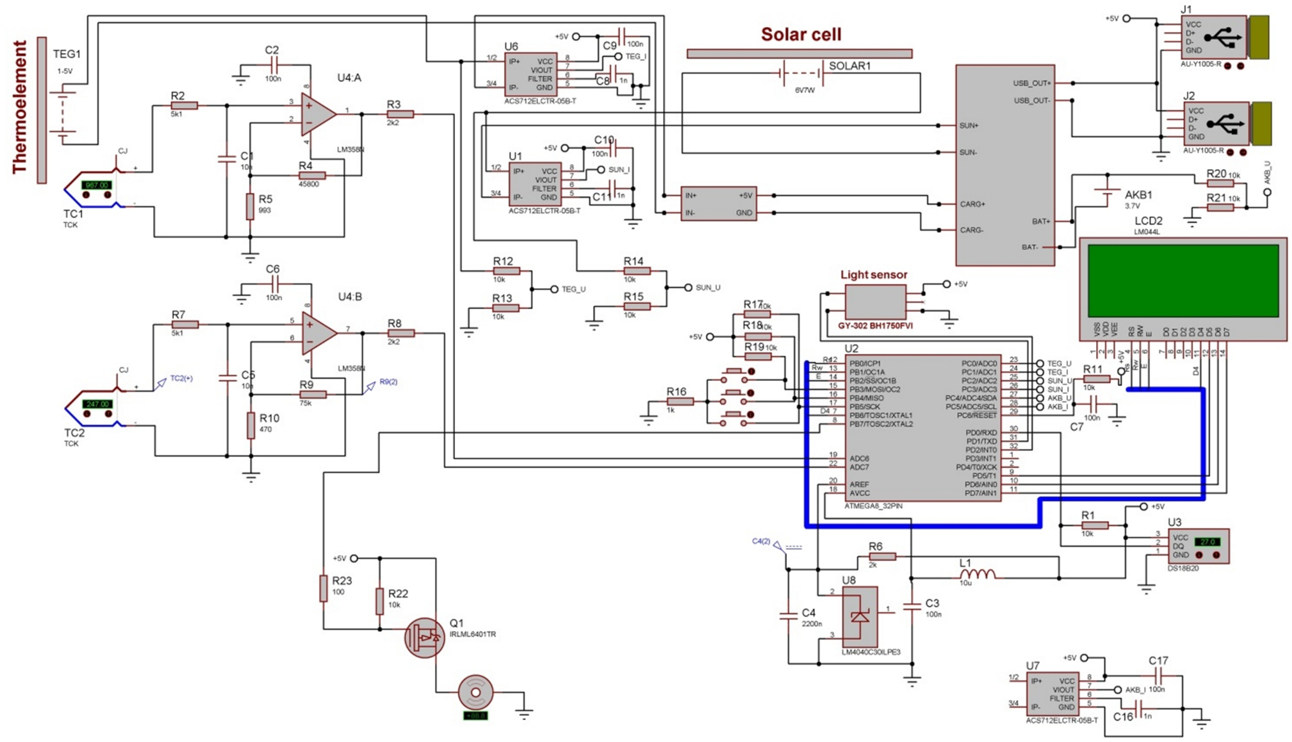

Fig. 3. Electric diagram of the control system.

IV. Experimental results

In table 1 are shown the thermoelectric characteristics of thermoelements.

Model of the photoelectric cell can be represented in the form of schema, shown in Fig. 4, and it provides a source of current, diode and resistance R_P and R_S. Photoelectric cell closes the circle through the diode (if the circle of open), and external load (closed circle). The value of the resistance of the resistor R_P is high, and the resistance of the resistor R_S, by contrast, is very low. Maximum power can be obtained if the resistance of the connected load is equal to the internal resistance of the photovoltaic cell.

Table 1

The value of thermoelectric parameters (coefficient Seebeck S, specific electrical conductivity σ, coefficient of thermal conductivity k, and thermoelectric figure of merit ZT) of received thermoelements.

Material	Type simple	S, μV/K	σ, Om^{-1} cm^{-1}	k, W/(cm K)	ZT
PbTe(Sb)	n	250	250	0.01	0.8
PbSnTe	p	90	350	0.005	0.3

Model of electrical circuit thermoelectric module shown in Fig. 4. This model is similar to electric scheme model of photovoltaic panel. The current increase causes to growth of the power, which is spent on internal load. If between the surfaces of the thermoelectric module creates a temperature difference, then an electric current flows through the load and is fixed with a certain electric power [1].

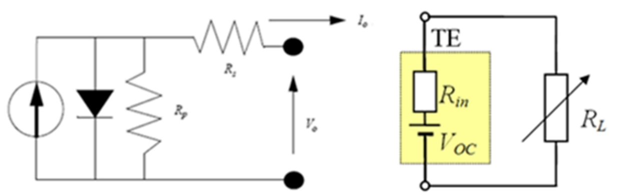

Fig. 4. Equivalent electrical circuit of the photoelectric cell (a) and thermoelectric module (b).

Voltage open circuit, which fix the thermoelectric modules, varies parabolic depending on the temperature difference between the surfaces ($\Delta T = T_H - T_C$). Maximum power for the thermoelectric module is expected when the resistance of the connected load is equal to the internal resistance of the thermoelectric module/generator.

Experimental measurement were carried out at ambient temperature 25°C. Solar radiation flux density was 2 kW/m^2. The maximum capacity of the photovoltaic panel approximately amounted to 6.3 W, resistance load 5 Ohms, the voltage value of the measured current and thus equaled, respectively, 1.1 A and 5.5 V.

Measured temperature difference on thermoelectric modules was $\Delta T = T_H - T_C$ = 115°C – 40°C = 75°C.

Accordingly, recorded in thermoelectric power thermoelectric generator was 0.5 W.

Conclusions

1. Developed the design of the system for direct conversion of solar thermal energy (based on solar collector) into electricity through the use of thermoelectric generator.

2. Received effective thermoelectric materials of the n- and p-types of conductivity for use as active elements for solar thermoelectric generator.

3. Developed the measurement's block of initial parameters and automated control for solar thermoelectric generator.

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Розроблено комплексну систему генерування електричної енергії «Термоелектричний генератор – сонячний колектор». У якості матеріалів вихідних термоелементів синтезовано легований стибієм PbTe (n-тип провідності) та потрійна сполука PbSnTe (p-тип).

Ключові слова: термоелектричний генератор, сонячний колектор, плюмбум телурид.