Semiconductors, 2022, Vol. 56, No. 2

Strip thermoelectric generator made of carbon fiber

© D.K. Ivanov[1], K.G. Ivanov[1], O.N. Uryupin[2]

[1] St. Petersburg State University of Industrial Technologies and Design,
191186 St. Petersburg, Russia
[2] Ioffe Institute,
194021 St. Petersburg, Russia
E-mail: Kivanov@mail.ru

Received September 19, 2021
Revised September 24, 2021
Accepted September 24, 2021

A prototype of a thermoelectric generator based on $p-n$ junctions of a strip carbon fiber modified by a pulsed current was created.

Keywords: carbon fiber, thermoelectric Q-factor, $p-n$ junction.

DOI: 10.21883/SC.2022.02.53035.21

1. Introduction

Due to climate global warming there is a growing need to reduce heat production and its use optimization. One of the possible ways to solve the problem is the thermal waste recovery of industrial and domestic production by direct conversion of thermal energy into electrical energy. At the same time, it is necessary to take into account the environmental friendliness of such a converter to prevent additional use of heat after its decommissioning during disposal. One of the most environmental materials available to mankind is carbon. Therefore, our study relates to studying the possibility of creating a thermoelectric generator (TEG) from carbon fiber (CF), and measuring its thermoelectric properties.

2. Experiment and discussion

Previously, in the paper [1] it was found that carbon fiber subjected to the pulsed current changes the sign of the thermoelectric EMF from negative to positive. It was decided to use this unique CF property to create a sequence of several $p-n$ junctions along the strip CF. To do this, a section of CF strip with a length of ~ 2 cm was subjected to the action of the pulsed current with an amplitude of thousands of Amperes and a half-cycle duration of $100\,\mu$s. The next two-centimeter section of the strip CF was not modified by the electric current, and after it the next 2 cm were again subjected to the action of the pulsed current. Sections of the strip CF modified by the pulsed current have *p*-conductivity type and are easily identified in Fig. 1 as expended regions of CF. Unmodified sections of CF keep their original structure, have *n*-conductivity, and are visible in Fig. 1 as unexpended regions.

Such strip with alternating sections became the basis for creating a prototype of the thermoelectric generator (TEG) on $p-n$ junctions.

The operating TEG model was made from CF strip modified by pulsed current, wound and fixed with glass fiber on a quartz tube with a diameter of 1 cm (Fig. 2).

The device obtained in this way was called a strip carbon fiber thermoelectric generator of carbon fiber (SCFTG).

Fig. 3 shows a diagram explaining the operation of SCFTG (Fig. 2) made during the work. CF with a set of four $p-n$ junctions was wound onto the quartz glass tube, which can withstand large temperature differences. The *p*-type regions are depicted by thicker lines (in Fig. 2 these are expended sections of CF). Areas of *n*-type are shown with thinner lines. The fiber with $p-n$ junctions was wound around the quartz tube so that one part of $p-n$ junctions was opposite to the other one, as shown schematically in Fig. 3. One of the sides was heated by a propane burner flame, the other side was at room temperature (Fig. 3). The readings of the thermoelectric EMF were recorded at the moment when, upon heating, their maximum value began to decrease. This meant that the temperature of cold $p-n$ junctions began to rise, and the temperature difference decreased. The heating process took place within 5–7 s. The temperature was measured by a thermocouple fixed under one of the $p-n$ junctions. The temperature of hot $p-n$ junctions varied by changing the distance between the burner flame and the quartz tube. Thus, the dependencies shown in Fig. 4 were obtained.

As can be seen from Fig. 4, the smallest change in the thermoelectric EMF with the temperature difference increasing from 150 to 500 K has *n*-type CF (dotted line), then a more noticeable increasing of the limit of this change in temperature difference belongs to one $p-n$ junction (dashed curve), and the strip of four $p-n$ junctions reaches the maximum value ~ 12 mV at the difference of 500 K (solid curve), i.e. the temperature of hot $p-n$ junctions reaches 800 K. The temperature of the cold $p-n$ junctions remained at room temperature level. The noticeable nonlinearity of the two curves in Fig. 4 can be explained by the different temperature dependence of the thermoelectric

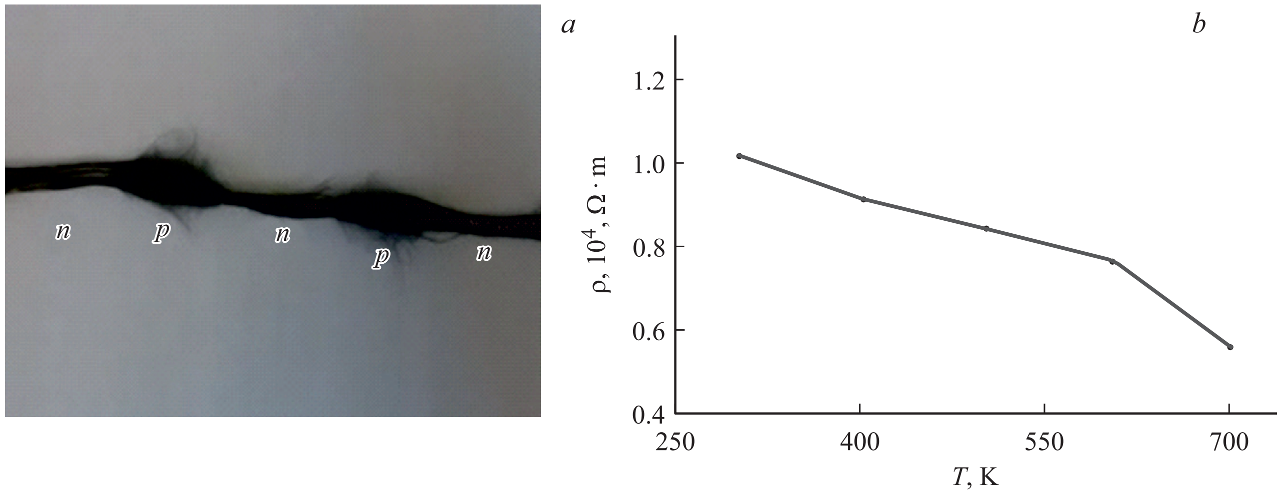

Figure 1. *a* is strip carbon fiber after modification by pulsed current. *b* is dependence of the resistivity of SCFTG made of four $p-n$ junctions on quartz glass tube.

EMF for CF of different types of conductivity, established in the paper [1].

For carbon fibers the thermal conductivity κ lies in the range $0.8-1.6\,\mathrm{W/m\cdot K}$, which was not measured in the paper. Thermoelectric Q-factor $Z = S^2/\rho \cdot \kappa$ according to electrical resistivity ρ, thermoelectric EMF S taken respectively from Fig. 1, *b* and 4 (solid line) for the temperature difference of 500 K and thermal conductivity

Figure 2. The operating model of thermoelectric generator on $p-n$ junctions of strip CF on a quartz glass tube.

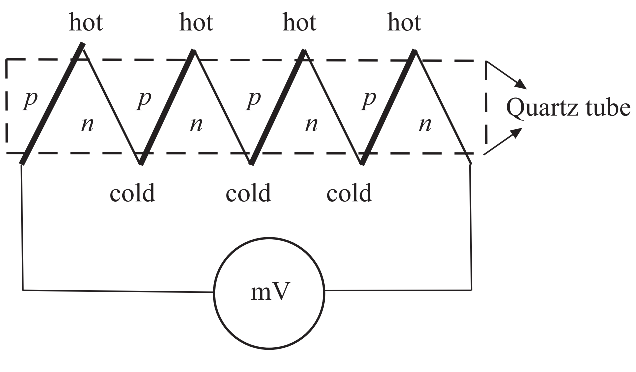

Figure 3. SCFTG diagram, explaining its work.

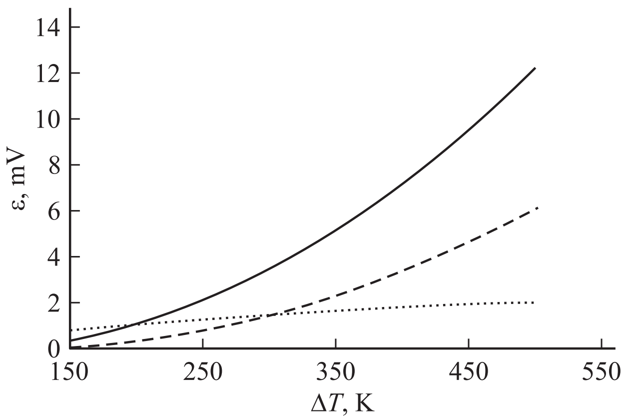

Figure 4. Thermoelectric EMF ε in mV vs. temperature difference: dotted curve is for *n*-type CF, dashed curve is for one $p-n$ junction and a solid curve is for four$p-n$ junctions.

set equal to $\kappa = 1\,\mathrm{W/m\cdot K}$, when calculation gives the values $Z \sim 10^{-5}\,\mathrm{K}^{-1}$.

Carbon fiber can withstand in vacuum the heating up to 3000 K and higher, which allows creation of the large temperature difference between hot and cold $p-n$ junctions. From Fig. 4 it follows that at temperature difference of 500 K, the thermoelectric EMF of one $p-n$ junction (Fig. 4, dashed curve) is by ~ 5 times greater than this value at difference of 300 K Fig. 4. The number of $p-n$ junctions increasing gives an even greater increasing of the thermoelectric EMF (solid curve Fig. 4).

3. Conclusion

The prototype of a thermoelectric generator based on $p-n$ junctions of the strip carbon fiber modified by a pulsed current was created and tested. The ability to create a large number of $p-n$ junctions and high temperature differences between them can be used in certain technical problems. For example, heat-resistant fabrics pierced with thousands of carbon fibers with $p-n$ junctions can simultaneously be heat insulators and generators like solar panels.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] D.K. Ivanov, K.G. Ivanov, O.N. Uryupin. FTP, **51**, 7 (2017) (in Russian).