NEW THERMOELECTRIC MATERIALS

G. Abdurakhmanov
National University of Uzbekistan, Tashkent, Uzbekistan, gulmirzo@mail.ru

K Mukimov
National University of Uzbekistan, Tashkent, Uzbekistan

A Esbergenova
National University of Uzbekistan, Tashkent, Uzbekistan

S. Mamatqulova
Scientific and Technical Centre of JSC Uzbekenergo, Tashkent, Uzbekistan

Follow this and additional works at: https://uzjournals.edu.uz/semiconductors

**Recommended Citation**
Abdurakhmanov, G.; Mukimov, K; Esbergenova, A; and Mamatqulova, S. (2020) "NEW THERMOELECTRIC MATERIALS," *Euroasian Journal of Semiconductors Science and Engineering*: Vol. 2 : Iss. 6 , Article 10. Available at: https://uzjournals.edu.uz/semiconductors/vol2/iss6/10

This Article is brought to you for free and open access by 2030 Uzbekistan Research Online. It has been accepted for inclusion in Euroasian Journal of Semiconductors Science and Engineering by an authorized editor of 2030 Uzbekistan Research Online. For more information, please contact sh.erknov@edu.uz.
NEW THERMOELECTRIC MATERIALS

G. Abdurakhmanov1,2,3, K. Mukimov1, A. Esbergenova1,3, S. Mamatqulova2,3

1National University of Uzbekistan, Tashkent, Uzbekistan
2Tashkent State Technical University, Tashkent, Uzbekistan
3Scientific and Technical Centre of JSC Uzbekenergo, Tashkent, Uzbekistan
e-mail: gulmirzo@mail.ru

Abstract. Recent achievements in developing of thermoelectric materials of higher efficiency are reviewed. It is shown that these achievements are based on decreasing of thermal conductivity down to values typical for materials having disordered or nanoscale structure. On the other hand these achievements demonstrate that there is no any principal limit for efficiency of thermoelectric devices beyond the Carnot formula.

Keywords: thermoelectric devices, thermoelectric materials, nanoscale heterogeneity, phonon scattering, thermal conductivity, thermoelectric figure of merit.

In Uzbekistan, the main alternative source of energy is solar radiation. Therefore, much attention is paid to the conversion of solar radiation into electrical energy, while direct, machineless ones (photoelectric generator - PEG, thermoelectric generator - TEG, their combinations - PTEG, thermionic and thermionic) are considered as the main methods.

Although the physical foundations of these methods have been known for a long time [1-3], their widespread use is currently hindered by the high price of the corresponding devices with insufficient efficiency. An increase in the efficiency of laboratory samples of PEG up to 42.3% [4] was achieved in a triple heterostructure InGaP/GaAs/InGaAs with a radiation concentration of 406 times. The complexity of the technology of such structures and the materials used are unlikely to make them available for widespread use in the near future. In addition, a high concentration of solar radiation causes heating of the active structure, shortening the duration of its operation. However, this issue has not yet been adequately studied. And thin-film PEG produced using a simple technology (even by inkjet printing) have a life cycle of less than 1500 hours, which negates their main advantage - low cost.

To use the heat released in the PEG under the influence of solar radiation (especially concentrated), tandems - PEG + TEG (PTEG) are created, which increases the total efficiency by 10-12% [5]. In this case, problems arise, on the one hand, the consistency of the coefficients of thermal expansion of the PEG and TEG materials, on the other hand, the selection of PEG materials for operation at those temperatures when the TEG operation is effective. Therefore, in such tandem designs, wide-gap semiconductors of the GaAs type are used [5], and the cost of the devices increases dramatically.

TEG is attractive because it can be used not only in solar energy, but also for energy conservation (generating electricity from waste heat). The amount of waste heat in Uzbekistan is more than 200 billion kWh per year, and around the world - about 70% of all generated energy (more than $1.14 \cdot 10^{20}$ kWh).
The widespread use of TEG in the power industry was constrained for many years by their high price (more than USD 9000 per 1 kW of generated power) with low efficiency (3-6%), which was due to the materials used (Bi$_2$Te$_3$, Sb$_2$Te$_3$, PbTe, Si-Ge), the limiting efficiency of which was achieved in the late 50s of the last century, and over the next 40 years, it practically did not change (Fig. 1). The dimensionless thermoelectric figure of merit $ZT$ shown in this figure is related to the efficiency $\eta$ as follows:

$$\eta = \frac{T_H - T_C}{T_H} \frac{\sqrt{ZT + 1} - 1}{\sqrt{ZT + 1} + T_C / T_H}.$$

Here $T_H$ and $T_C$ – hot and cold side temperature TEG, $ZT = S^2 \sigma T / \kappa$, $S$, $\sigma$ and $\kappa$, respectively, are the thermo-EMF coefficient (Zeebeck coefficient), electrical and thermal conductivity of the thermoelectric material, $T = (T_H + T_C)/2$.

Fig. 1. Development stages of thermoelectric materials

And only after 1995, when the theory of "phonon glass, electron crystal" was published [6], the situation changed - nanostructures with $ZT > 2$ were created, and these successes were achieved precisely by reducing the thermal conductivity $\kappa$ due to the enhancement of phonon scattering (phonon glass) by inhomogeneities nanoscale, the dimensions of which are comparable to the phonon wavelength. However, the technology of all these structures is complex, and nanometer-thick layers sharply reduce the life of devices due to diffusion of atoms at elevated (up to 400-500°C) temperatures. Therefore, these studies are only proof of the absence of any physical
restrictions on increasing $ZT$, and the fundamental possibility of creating thermoelectric materials that meet the requirements of widespread use of TEG ($ZT > 2$).

In parallel with this, the $ZT$ was doubled in the classical PbTe material by doping with thallium [7]. It turned out that the dependence of $ZT$ on the doping level has a maximum of about 2 at. % thallium content, and the reason for this is still unclear [8]. Since thallium and its salts are very toxic substances [9] and it belongs to the scattered elements, the use of the PbTe (Tl) system in TEG is questionable.

Apparently, from a practical point of view, the most encouraging are two reports [10, 11], which appeared in 2019. In [10], the combination of nanopowder technology with the selection of alloying additives (P and Fe) made it possible to increase $ZT$ to 3.6 in the Si-Ge solid solution, which corresponds to the TEG efficiency $\eta \approx 23\%$. It is important that this technology makes it possible to produce large quantities of bulk thermoelectric materials that meet the needs of the power industry, where the active volume of the material, in contrast to microelectronics, cannot be arbitrarily reduced due to overheating under the influence of the supplied thermal power.

In [11], the value of $ZT = 5$-$6$ ($\eta \approx 26\%$) was achieved on thin-film samples of the Geislerian alloy, and such microTEG will find application in medicine (pacemakers), in various sensors powered by microTEG (meteorology, environmental protection and hazardous (harmful) substances, prostheses, etc.).

The main thing that follows from these results is that it has been experimentally proven once again that there are no fundamental restrictions on the value of $ZT$, and, in principle, TEG may well compete with traditional methods of generating electricity. It remains only to find a suitable composition and structure of thermoelectric materials, which, if possible, consist of widespread, harmless and cheap initial components. And it is precisely the latter that is the main issue in the development of thermoelectric power engineering - the physics of thermoelectric phenomena in this issue so far cannot help anything [12], and the search has to be carried out by trial and error. Moreover, in the very physics of thermoelectric phenomena there are many internal discrepancies and inconsistencies with experiment [13].

References


