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THERMOELECTRICAL CHARACTERIZATION OF $Bi_2Te_{3-x}Se_x$ SINGLE CRYSTALS

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The results of experimental investigation of n-type semiconductor based on Bi_2Te_3 alloy are presented. The behavior of the semiconductor when heated was studied using DTA technique. Changes in physical and chemical properties of materials are measured as a function of increasing temperature by TGA. The specific electrical conductivity, Seebeck coefficient and thermal conductivity were measured. Thermovision imaging was also carried out. Dependence of thermoelectric module output voltage from temperature difference of hot and cold sides was also investigated.

Keywords: semiconductors, thermoelectrical properties, thermovision imaging.

1. Introduction

Tellurium (Te) and selenium (Se) belong to twelve elementary semiconductors. Elementary semiconductors are those in which the properties are dependent on the semiconductor electronic structure. The presence of impurities even in very small proportions can have large effects on the properties of the thermoelectric material [1]. Therefore the conductivity of semiconductors may easily be modified by introducing dopants into their crystal structure.

The *n*-type $Bi_2Te_{3-x}Se_x$ semiconductors are well known to have excellent thermoelectric properties near room temperature and are used in thermoelectric cooling devices and electrical power generation devices. Many studies on these materials have been performed in order to increase the figure of merit, *Z*, the parameter which evaluates the quality of thermoelectric material [2].

2. Experimental procedures

$Bi_2(Te_{2.88}Se_{0.12})$ single crystals of 20 mm in length and 8 mm in diameter were examined using four probe method for specific electrical conductivity measurement, Hartman method for specific thermal conductivity measurement, differential thermal analysis, thermal gravimetry analysis and thermovision imaging.

3. Results and discussion

3.3. Thermoelectric properties

Electrical conductivity σ, Seebeck coefficient α and thermal conductivity λ have been measured to define quality. These properties strongly depend on carrier concentration, mobility, crystal structure and defects in the crystal structure. Values of $Bi_2(Te_{2.88}Se_{0.12})$ crystal for electrical conductivity (σ), the Seebeck coefficient (*S*) and thermal conductivity (λ) at 298 K are:

$\sigma = 1.03 \times 10^5$ Sm^{-1}
$S = 207 \times 10^{-6}$ VK^{-1}
$\lambda = 1.77$ Wm^{-1} K^{-1}

3.4. Differential thermal analysis and thermal gravimetry analysis

Differential thermal analysis (DTA) was carried out under following conditions: air atmosphere, heating rate 10 °C/min^{-1}, and T_{max} = 650°C. The precision of the measurement in the investigated temperature interval was ±1°C. The total mass of the material was 200 mg.

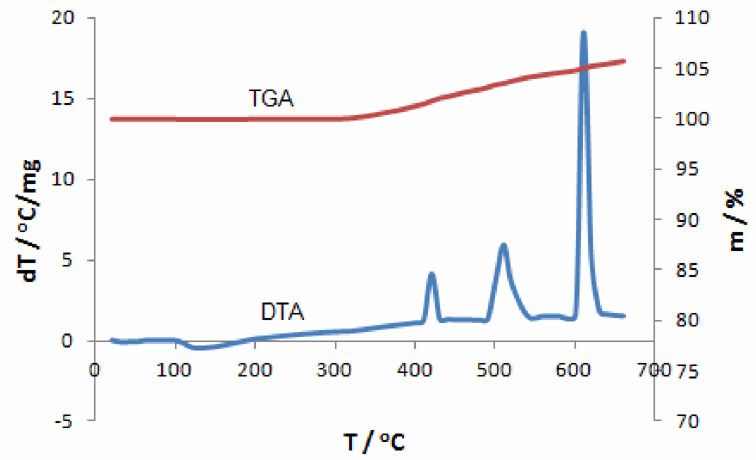

Fig. 1. DTA and TGA curves of $Bi_2(Te_{2.88}Se_{0.12})$ crystal

Obtained liquidus temperature (613.7°C) on Fig. 1 is close to melting temperature of Bi_2Te_3 compound, but slightly increased, which can be contributed to the presence of Se. The obtained DTA results imply that the tested material is stable to about 400°C. The first endothermic reaction at 409.7°C corresponds to the formation of γ phase (Bi_2Te_2Se) [3, 4]. The second reaction obtained at temperature of 491.3°C does not correspond to any phase transformation which may be related to the binary phase diagram of Bi-Te or with phase transformations on binary diagram Bi-Se. We assumed that the second obtained temperature on the DTA curve refers to reaction of two phases: Bi_2Te_3 - based (β_1) and a Bi_2Te_2Se - based (γ) solid solutions [3].

Thermal gravimetry analysis (TGA) was carried out under following conditions: heating rate 10 °C/min^{-1}, sample mass 0.182 g, T_{max} = 650°C in air medium.

The TGA curve shows the sample's change in mass depending on temperature (Fig. 1). The compound is stable up to 350°C and after that its mass increases which may be due to the undergoing reaction of an intermediate product with nitrogen [5].

3.6. Thermovision imaging of termoelectric module

In order to test the efficiency of thermoelectric (TE) elements based on Bi_2Te_3, a module was formed with 27 *p*-type elements measuring of 3×3×5 mm and 27 *n*-type elements of the same size. Thermoelectric material of the *p*-type for the TE module is $(Bi_{0.5}Sb_{1.50})$ $(Te_{2.98}Se_{0.02})$ doped with zirconium.

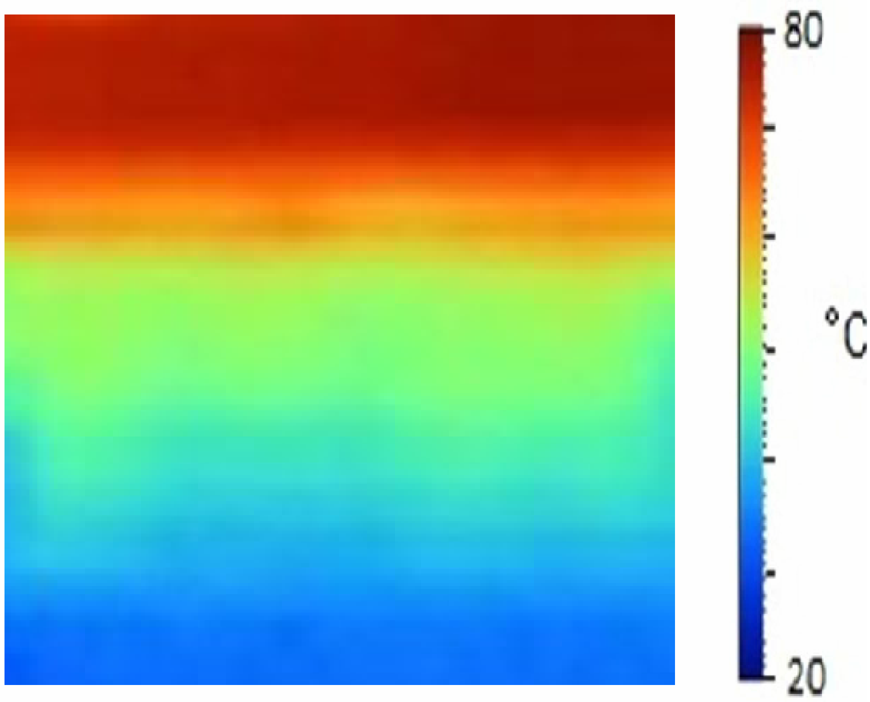

Fig. 2. Thermovision image of thermoelectric module

Thermovision image of the module is shown on Fig. 2. One side of the module is heated up to 80°C and then allowed to naturally cool down. The other side is passively cooled to about 22°C. The resulting dependence of the output voltage on the temperature difference at the hot and cold side is shown on Fig. 3.

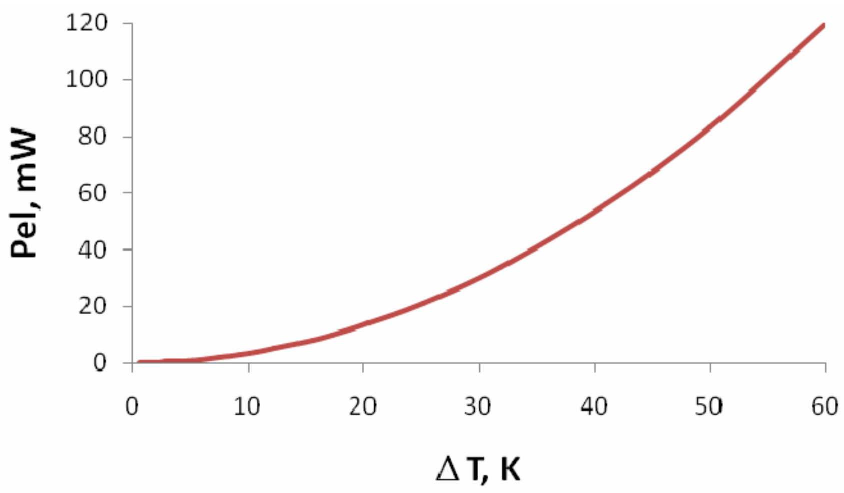

Fig. 3. Dependence of the thermoelectric module output power on temperature difference of hot and cold sides

4. Conclusion

Thermoelectric materials are of interest for applications in solid state cooling and electrical power generation devices due to many attractive features, such as long life, no moving parts, no emission of toxic gases, low maintenance and high reliability.

$Bi_2(Te_{2.88}Se_{0.12})$ single crystal has been investigated using different experimental methods (measuring of specific electrical conductivity, measuring of specific thermal conductivity, DTA, TGA and thermovision imaging). In order to test the efficiency of thermoelectric elements based on Bi_2Te_3 module, thermovision imaging is done. It is shown that thermal imaging research can be a simple tool for analyzing the heating uniformity of thermoelectric module.

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REFERENCES

1. C. Grovenor, Microelectronic materials, CRC Press, NW, USA, 1989.
2. L. Berger, Semiconductor materials, CRC Press, NW, USA, 1997.
3. O.B. Sokolov, SKIPIDAROV S YA, DUVANKOV N I, SHABUNINA G G. Phase relations and thermoelectric properties of alloys in the Bi_2Te_3-Bi_2Se_3 system, Inorganic Materials, 2007, 43: 8—11.
4. G.C. Lahalle, Scherrer H, Scherrer S. Growth of n-type $Bi_2Te_{2.55}Se_{0.45}$ single crystal solid solution by the travelling heater method, Journal of Physics and Chemistry of Solids,1996, 57: 1713—1717.
5. J. Dheepa, Sathyamoorthy R., Velumani S, Subbarayan A, Natarajan K, Sebastian P J. Electrical resistivity of thermally evaporated bismuth telluride thin films, Solar Energy & Materials Solar Cells, 2004, 81: 305—312.

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Термоэлектрическая характеризация монокристалла $Bi_2Te_{3-x}Se_x$.

В докладе представлены результаты экспериментального исследования *n*-типа полупроводника на основе сплава Bi_2Te_3. Поведение при нагревании изучали с использованием дифференциального термографического анализа. Физико-химические свойства материалов измеряли в зависимости от температуры методом термогравиметрического анализа. Были измерены удельная электропроводность, коэффициент Зеебека и теплопроводность, а также проведены тепловизионные исследования. Также была исследована зависимость термоэлектрической выходной мощности модуля от разности температур между горячей и холодной сторонами.

Ключевые слова: *полупроводники, термоэлектрические свойства, тепловидение*.