PART II: WHAT MAKES A GOOD THERMOELECTRIC

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Abstract
Successful synthesis of p type single crystal $Bi_2Te_{2.8}Se_{0.2}$ by the Bridgman process obtained at the Serbian Academy of Sciences and Arts (SANU) in Belgrade was performed. A significant scientific contribution has been made in the application field of bismuth telluride as a thermoelectric material and selenium as its dopant. In this way, the conducted research enriched the set of data relevant for further research.

Keywords: *Bridgman technique, Hall and Van der Pauw method, doping*

1. INTRODUCTION

The best thermoelectric materials at temperatures from 300 K to 500 K [1,2,3] are Bi_2Te_3-based solid solutions, including $(Bi, Sb)_2Te_3$ and $Bi_2(Te, Se)_3$.

The commercial Bi_2Te_3-based thermoelectric of p and n type are generally prepared by unidirectional solidification methods, such as zone melting [4], Bridgman [5,6], and Czochralski [7].

Good thermoelectric is defined as:

$$ZT = \frac{\alpha^2 \cdot \sigma \cdot T}{k} = \frac{\alpha^2 \cdot T}{k \cdot \rho} = \frac{\alpha^2 \cdot T}{(k_e + k_l) \cdot \rho} \quad (1)$$

where: α - Sebek coefficient, σ - electrical conductivity, k - thermal conductivity, T - absolute temperature, ρ - electrical resistance.

For almost all typical thermoelectric materials with doping increasing Seebeck coefficient is reduced. It is necessary large Sebek coefficient and small resistivity and thermal conductivity as seen from the equation 1.

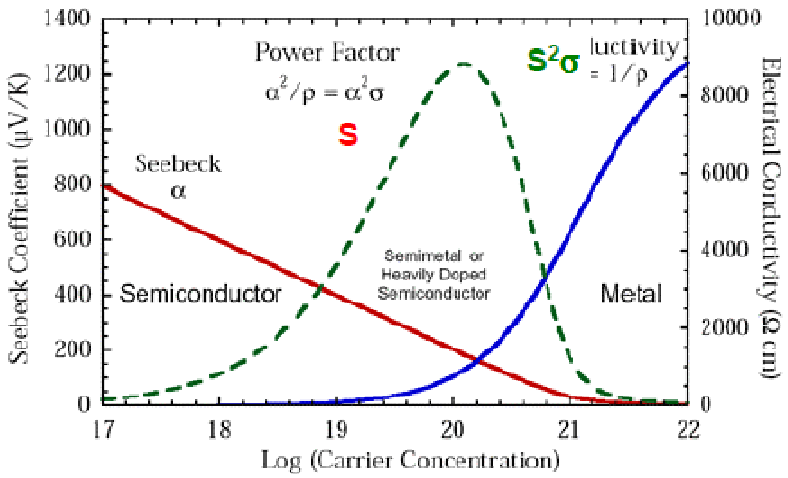

Figure 1. Materials with optimizing power factor[8]

Materials with good properties (Sebek coefficient, electrical conductivity, thermal conductivity, electrical resistance. carrier concentration, power factor) and which can be good thermoelectric are present on the Figure 1.

Best compositions for traditional bulk thermoelectric materials had largely been discovered by 1980[9].

2. EXPERIMENTAL

A monocrystal sample of p - type, $Bi_2Te_{2.8}Se_{0.2}$ was synthesized by the Bridgman method[10] at a temperature of 600°C starting from spectroscopic pure materials. Bismuth (Sigma - Aldrich, 99.999%), Selenium (Alfa Aesar, 99.999%) and Tellurium (Sigma - Aldrich, 99.999%) were taken in a certain proportion and sealed in a quartz ampoule under a pressure of 10^{-5} Pa. According to the stoichiometry of $Bi_2T_{3-x}Se_x$ (x = 0.2) alloy, high purity (5 N) elemental granules of Bi, Te and Se were weighed and then melted.

The lowering speed of the ampoule in the vertical furnace was about 2.2 mm/h. Structural, transport and thermoelectric properties were investigated. XRD analysis confirmed the monocrystal structure of $Bi_2Te_{2.8}Se_{0.2}$. Transport properties have shown that with increasing current, mobility increase. Positive values of Hall coefficient confirm that the material is p - type with high concentrations of charge carriers.

3.RESULTS AND DISCUSSION

The calculated data from the measurement results of the transport quantities for sample 6/4 (⊥) with a Schottky diode at room temperature (25 ° C) and magnetic induction of the permanent magnet B = 0.370 T are given in Table 1 and Table 2. Measurements were performed at currents of 1 and 5 mA.

Table 1. Results for sample 6/4(⊥) at a current of 1 mA

Measured size	**Symbol**	**Result**	**Measuerment unit**
Bulk carrier concentration	n_b	$4.876x10^{19}$	$/cm^3$
Mobility	μ	$1.700x10^1$	cm^2/Vs
Specific resistivity	ρ	$7.529x10^{-3}$	Ωcm
Average Hall Coefficient	R_H	$1.280x10^{-1}$	cm^3/C
A-C Cross Hall Coefficient	R_{H1}	$-4.388x10^{-1}$	cm^3/C
B-D Cross Hall Coefficient	R_{H2}	$6.948x10^{-1}$	cm^3/C
Sheet carrier concentration	n_S	$8.777x10^{18}$	$/cm^2$
Specific conductivity	σ	$1.328x10^2$	1/Ωcm
Magneto resistance	ΔR	$2.123x10^{-3}$	Ω
Vertical/Horizontal ratio of resistivity	α	$9.643x10^{-2}$	

Table 2. Results for sample 6/4(⊥) at a current of 5 mA

Measured size	Symbol	Result	Measuerment unit
Bulk concentration	n_b	$6.640x10^{18}$	$/cm^3$
Mobility	μ	$1.565x10^2$	cm^2/Vs
Specific resistivity	ρ	$6.008x10^{-3}$	Ωcm
Average Hall Coefficient	R_H	$9.401x10^{-1}$	cm^3/C
A-C Cross Hall Coefficient	R_{H1}	$9.863x10^{-1}$	cm^3/C
B-D Cross Hall Coefficient	R_{H2}	$8.940x10^{-1}$	cm^3/C
Sheet concentration	n_S	$1.195x10^{18}$	$/cm^2$
Specific conductivity	σ	$1.664x10^2$	1/Ωcm
Magneto resistance	ΔR	$2.442x10^{-3}$	Ω
Vertical/Horizontal ratio of resistivity	α	$8.606x10^{-2}$	

Mobility increases with increasing current. The Hall coefficient values are positive. This indicates that the samples are of p type and that the charge carriers majority are holes. That the samples are of p type was also confirmed by the hot point method. The mobility of most charge carriers decreases with increasing current, which indicates that the temperature of the samples increases, which affects on the mobility. For our sample the value of μ is increase from μ = $1.700x10^1 cm^2/Vs$at current intensity of 1 mA to μ = $1.565x10^2 cm^2/Vs$ at current intensity of 5 mA.

4. CONCLUSION

Transport properties namely electrical conductivity (σ), Hall Effect (RH), bulk carrier concentration (n_b), sheet carrier concentration (n_S), mobility (μ) and specific resistivity (ρ)have been measured for the ternary system $Bi_2Te_{2.8}Se_{0.2}$as function of current intensity.

RH measurement indicates p-type conduction. The results were analyzed in order to establish the conduction mechanism in these compounds. The aim of our researches is to characterize transport properties and to detect the possibility of using these materials in thermoelectric devices.

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