New High Efficiency Thermoelectric Materials for Thermal Energy Harvesting

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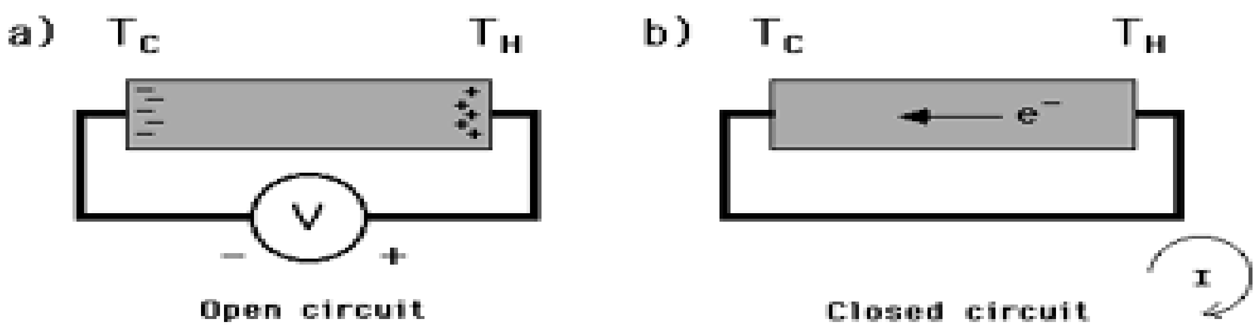
Abstract

Thermoelectric materials are a type of material that produces thermoelectric effects. When a temperature difference causes an electric potential, a thermoelectric effect is created. Alloys, complex crystals, and nanocomposites are three different types of thermoelectric materials. Very often bismuth telluride (Bi2Te3) is used in thermoelectric materials. Materials containing these compounds have been shown to have some of the best performance as near room temperature thermoelectric applications while maintaining temperature independent thermoelectric effect. Thermoelectric efficiency depends in large on the ZT, a dimensionless parameter to evaluate the performance of a thermoelectric material. Our research was aimed using bulk nano-grained p-type bismuth antimony telluride to try and obtain comparable ZT peaks to those that can be achieved and for further improvement. Our research also focused on determining the electrical and thermal conductivity of the thermoelectric material.

Introduction

Thermoelectric effect is the conversion of temperature difference to electric voltage and can also be reversed converting electric voltage to a temperature difference. A thermoelectric device makes a voltage with a different temperature on each side. If a voltage is applied, then a temperature difference is made. The thermoelectric effect can be utilized to create electricity, measure temperature, or change the temperature of a device. The efficiency of a thermoelectric is determined through the figure of merit(ZT). $ZT = (S^2\sigma/k)T$, where S,σ,k, and T are the Seebeck coefficient, electrical conductivity, thermal conductivity, and the absolute temperature, respectively. In 1821, Thomas Seebeck found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, if the junctions of the metals were maintained at two different temperatures.

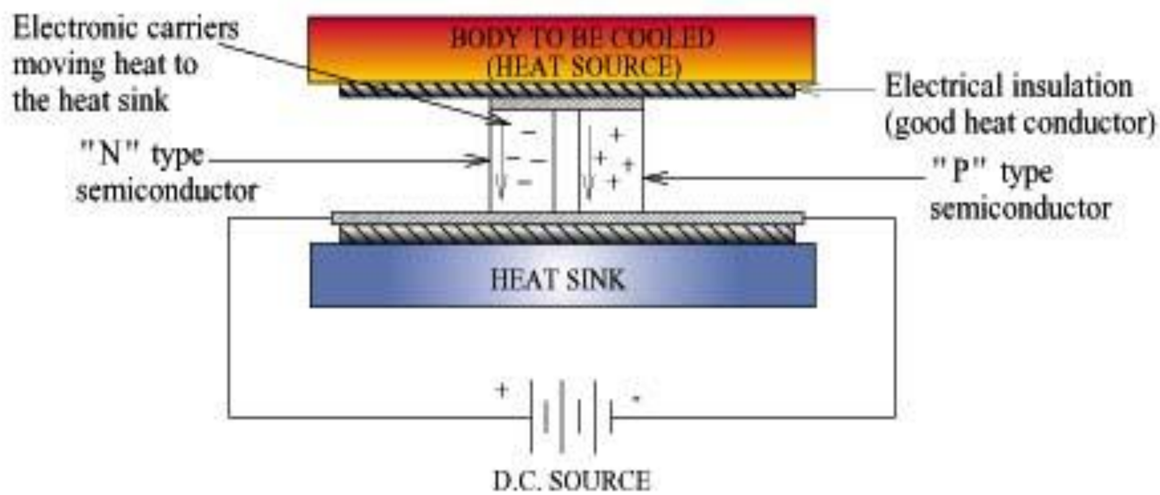


$S = dV / dT$;

S is the Seebeck Coefficient with units of Volts per Kelvin

S is positive when the direction of electric current is same as the direction of thermal current

Since the 1950s, there have been numerous attempts to improve the ZT. High ZT values have been discovered in supperlattice structures. However, it is hard to use them in large scale energy conversion applications. A very large increase in ZT has been found in bulk materials composed of bismuth, antimony and telluride. This has been found to be from the reduction of thermal energy due to phonon scattering. High ZT value make bulk materials feasible for cooling and low grade waste applications. High ZT values are also isotropic in bulk nano materials.



Experimental Set Up and Procedures

To begin the experiment, we first had to sandpaper the metal that held the samples in place. This eliminated the amount of impurities that could be found within the sample. Our sample was a bulk nanograined bismuth antimony telluride powder. Then the following steps were taken:

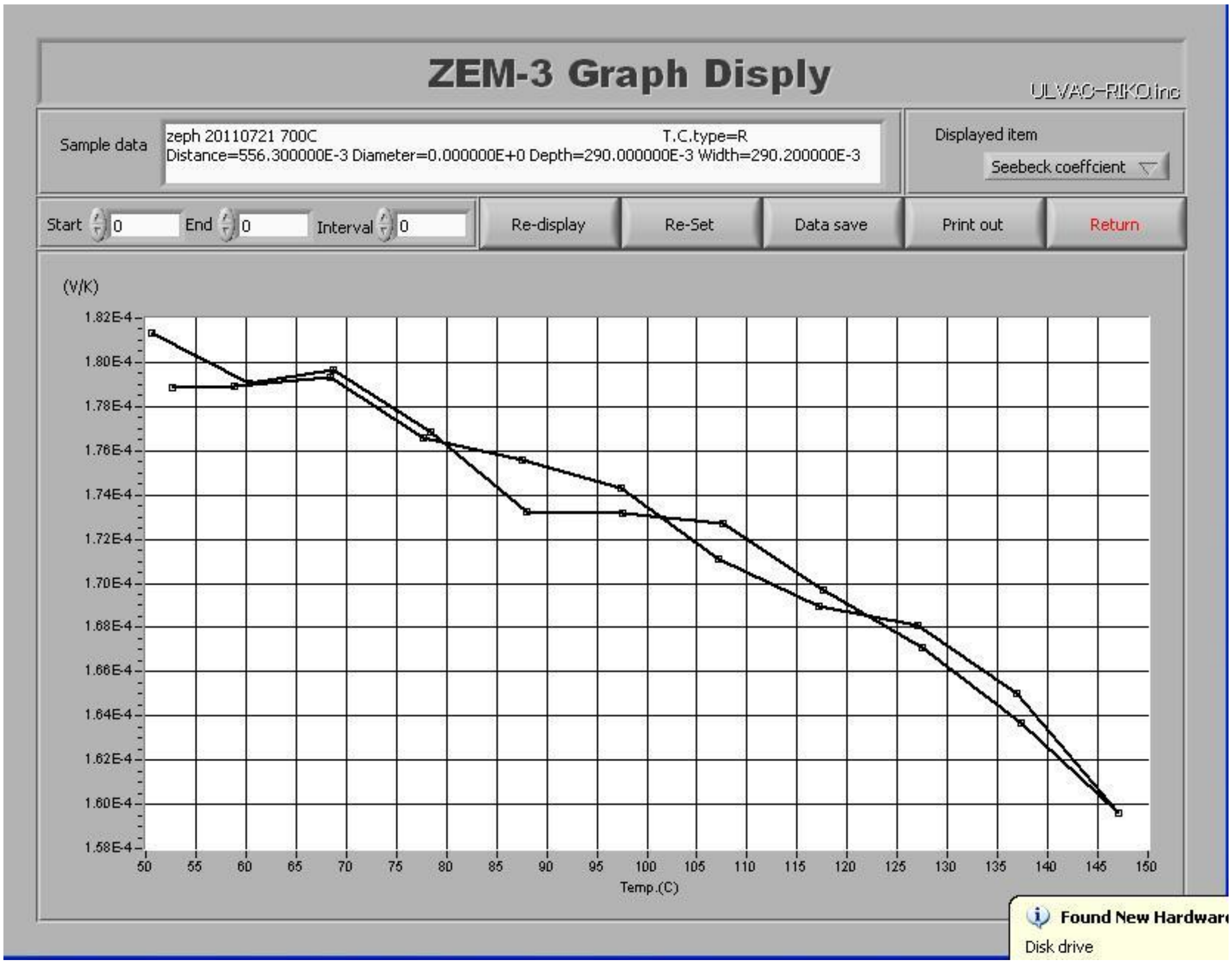
- Nanopowders were created using ball milling of bulk p-type bismuth,antimony,telluride (BiSbTe) alloys.They were placed in a jar with balls inside of an argon filled glove box to prevent oxidation.
- The jar of nanopowders was loaded into the ball mill machine and processed for 18 runs at 90 minutes each.
- The powder was then put through a hydrogen reduction process to prevent further oxidation for 20 hours with a hydrogen flow rate of 30-40 sccm.

Temperature	Time
0°C	140 min
280°C	120 min
280°C	30 min
330°C	120min
330°C	30 min
380°C	300 min
380°C	150 min
-120°C	7000 min

- Once the hydrogen reduction was completed, the nanopowders were loaded into a cold press at 12MPa for one hour to create a disk of 2.25mm.
- The disk was then annealed using the same process as the hydrogen reduction. This was done for 24 hours with the same hydrogen flow rate.
- Once the disk was created, the sample was then cut into bars of 1.6mm by 1.3mm
- The bars were then sandpapered for the Seebeck coefficient, electrical conductivity, and thermal conductivity.

Results

Figure 1. Thermoelectric Seebeck coefficient of nano structured $Bi_{0.5}Sb_{1.5}Te_3$



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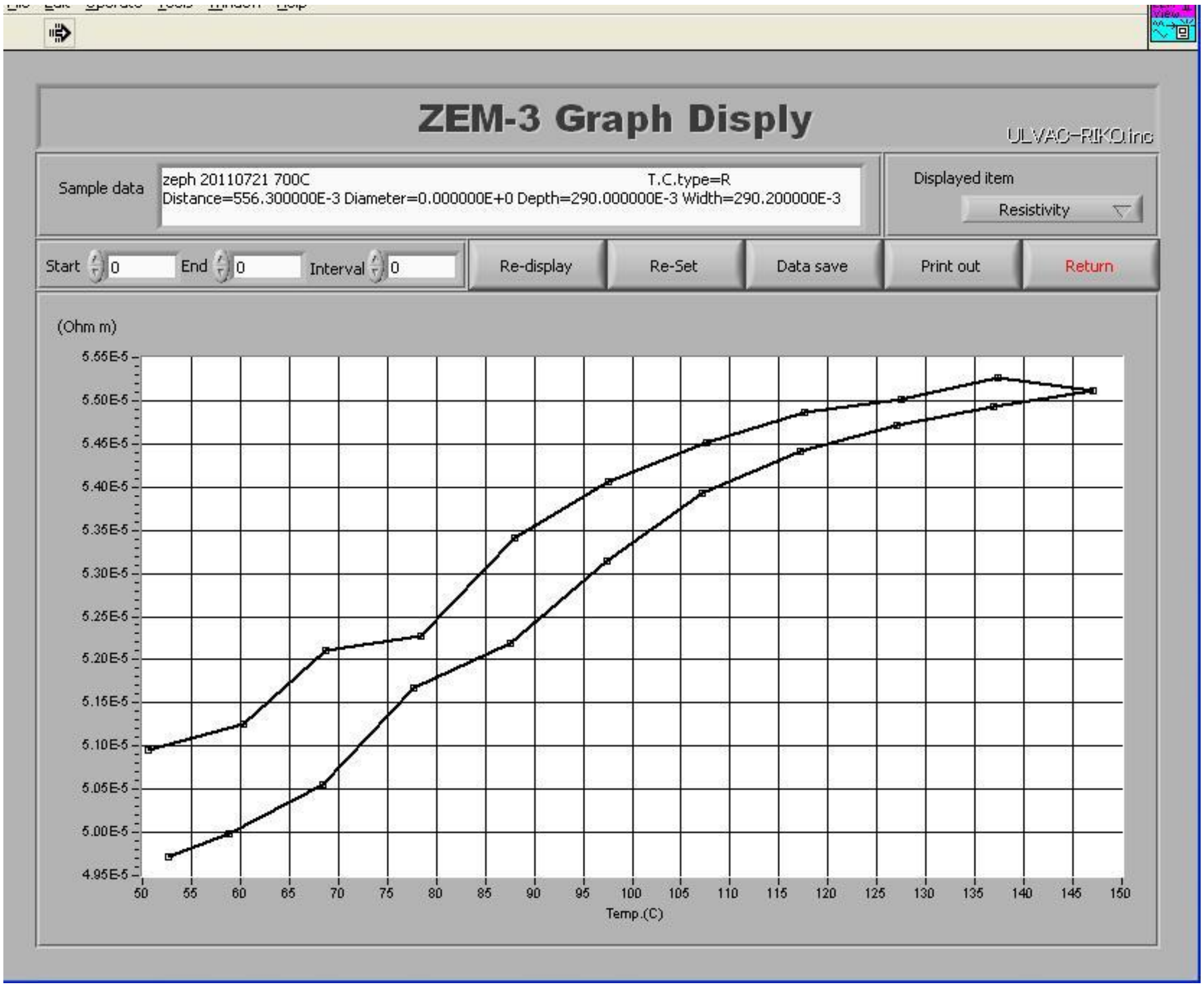

Figure 2. Thermoelectric resistivity of nano- structured $Bi_{0.5}Sb_{1.5}Te_3$

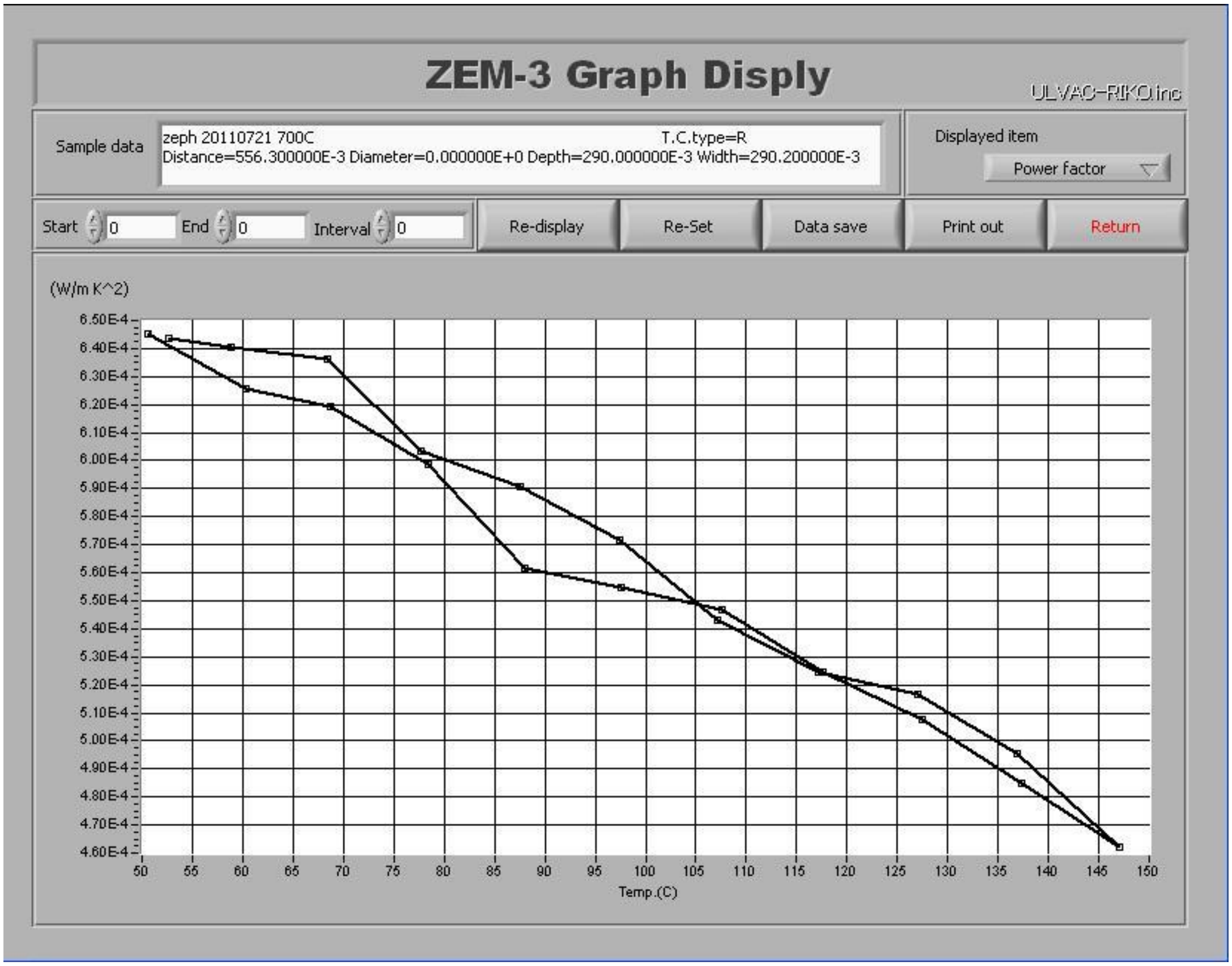

Figure 3. Thermoelectric power factor of nano- structured $Bi_{0.5}Sb_{1.5}Te_3$

Discussion

In order to investigate the thermoelectric properties, the Seeback coefficient, electrical resistivity and power factor dependence of temperature were obtained with the accuracy instrument ZEM-3 system. After doing the average of the data belong to delta temperature 50°C to 75° C respectively, the Seeback coefficient S (Fig.8) of the nanostructured alloyed sample is drawn. The function between S and temperature T shows that the value of Seeback coefficient will decrease along with the increasing temperature. The maximum value which is about 178μV/K to 180 μV/K appears in the range being above 50℃ and below 100℃. The characterization result of the electrical resistivity ρ of the sample is also shown in Fig.9. Being versus temperature, the changing discipline is similar to the one about the Seeback coefficient. However, the value reaches to the highest one of about 4.97×10^{-5} Ωm to 5.13×10^{-5} Ωm from 50 ℃ to 75 ℃. It has been seen clearly that the temperature dependence of the power factor[5] of which value is defined by S^2/ρ (Fig.10). Around 55℃, the power factor is about 6.45×10^{-4}W/mK^2 , which is the extramum of the curve.

Conclusion

From the above results discussions, it can be sure we have applied the ball milling, cold press and heat treatment techniques to make a great progress on the way to synthesize high figure of merit (ZT) nanostructured materials because it closely dependents on the value of power factor. The next work is to do the test and research for the thermal conductivity of the sample. Obtaining high thermoelectric properties materials is foreseeable. The process, by using elemental shots, is significantly simplified in comparison to using Bridgman method[2]. The mechanical way to get the alloy is also economy and environmentally.

References

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