New High Efficiency Thermoelectric Materials for Thermal Energy Harvesting

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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. 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.

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 (Bi_2Te_3) 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 (figure of merit), a dimensionless parameter to evaluate the performance of a thermoelectric material. Our research was aimed at 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.

Experimental:

- Nanopowders were produced using bulk p-type bismuth, antimony, telluride ($Bi_{0.5}Sb_{1.5}Te_3$) 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 at a temperature of 330°C, a hydrogen flow rate of 30-40 sccm for 20 hours.
- Once the hydrogen reduction was completed, the nanopowders were loaded into a cold press at 12MPa for one hour to create a disk of approximately 2.25 mm in width.
- The disk was then annealed at 280°C, a hydrogen flow rate of 30-40 sccm for 24 hours.
- Once the disk was created, the sample was then cut into bars of 1.6mm by 1.3 mm.
- The bars were then sandpapered for the Seebeck coefficient, electrical conductivity, and thermal conductivity.

Results:

Figure 1. ZEM-3 machine. It's responsible for the results below.

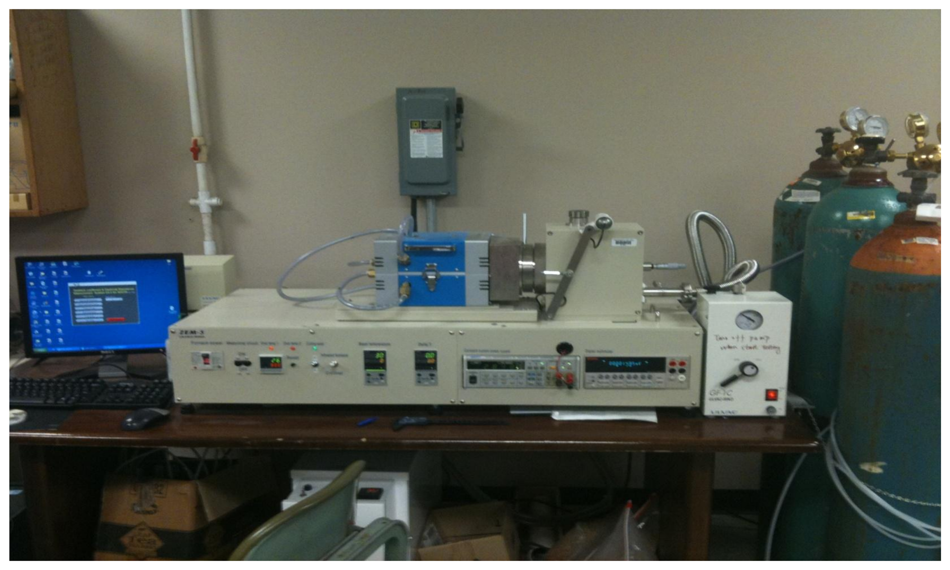


Figure 2. Seeback coefficient dependence of temperature of nanostructured bulk sample made from elemental shots

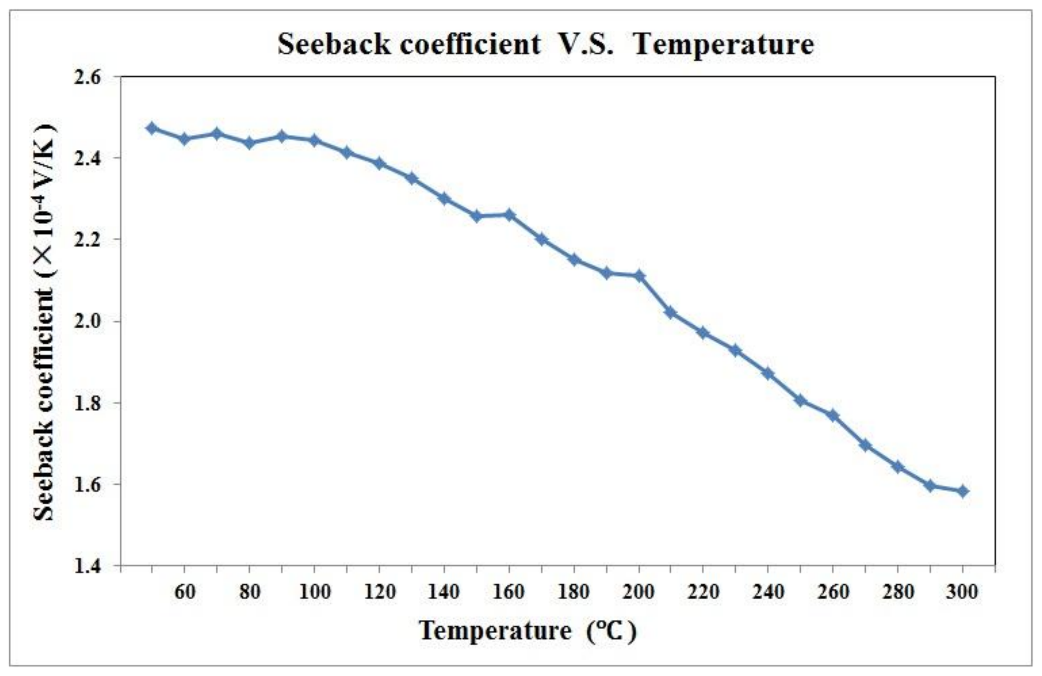


Figure 3. Electrical resistivity dependence of temperature of nanostructured bulk sample made from elemental shots

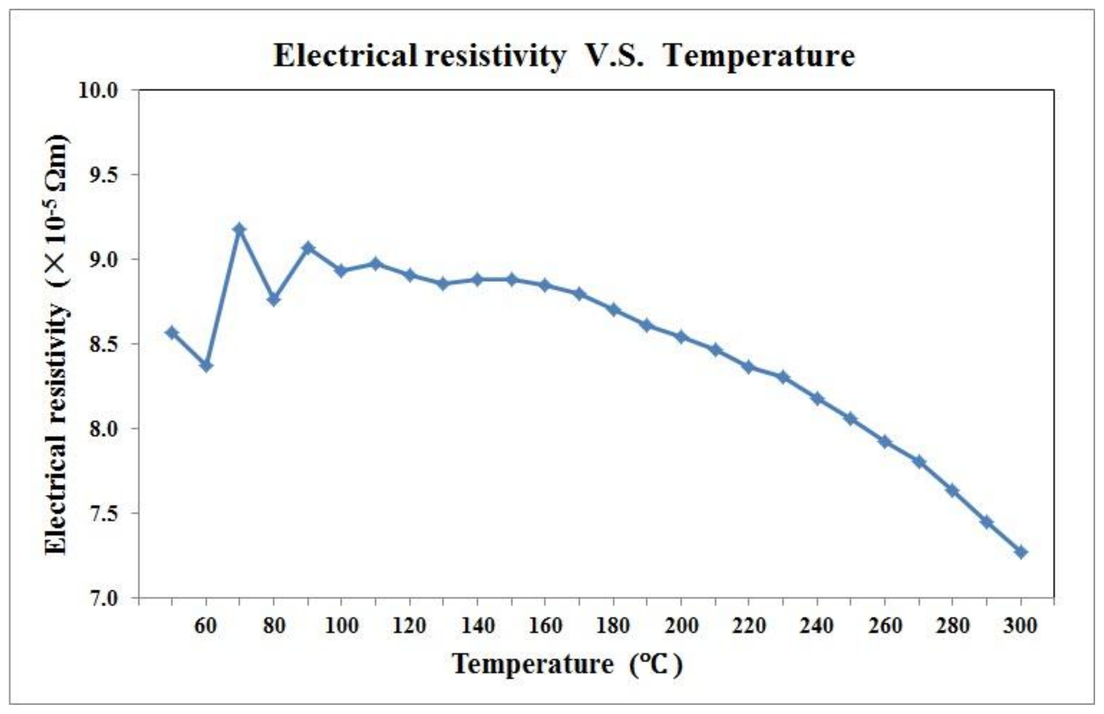
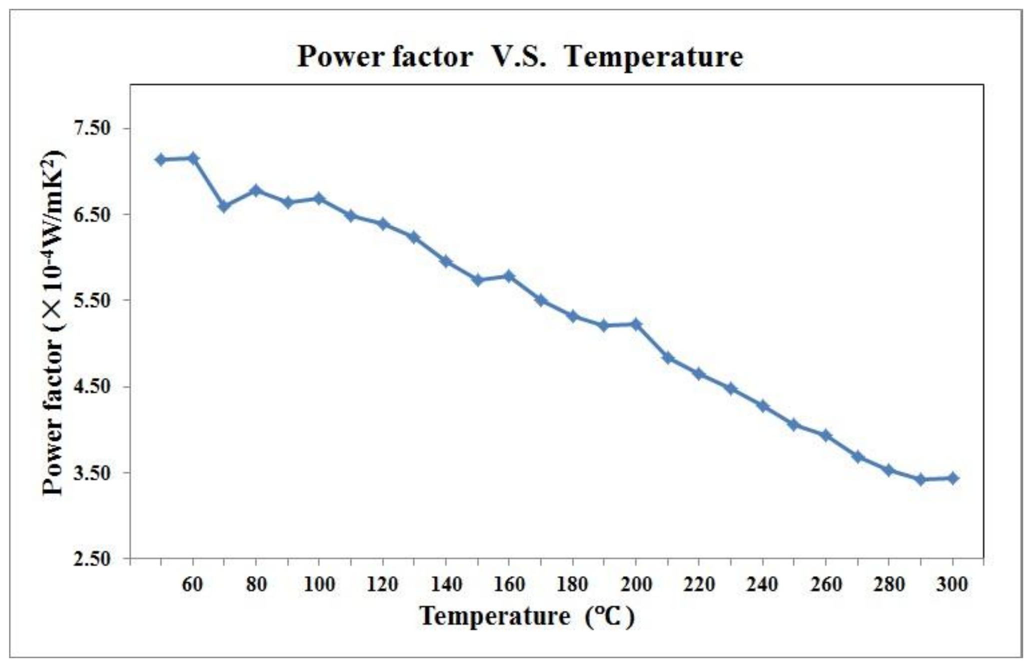


Figure 4. Power factor dependence of temperature of nanostructured bulk sample made from elemental shots



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 belonging to delta temperature 10°, 20° and 30°C, respectively, the Seeback coefficient *S* (Fig.2) of the nanostructured alloyed sample is drawn. The function between *S* and temperature *T* shows that the value of the Seeback coefficient will decrease along with the increasing temperature. The maximum value which is about 250μV/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.3. 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 9.0×10^{-5} Ωm from 80° to 120°C. It has been seen clearly that the temperature dependence of the power factor[5] of which value is defined by S^2/ρ (Fig.4). Obviously, around 55°C, the power factor is about 7.3×10-4W/mK², which is the extramum of the curve.

Conclusion and Future Work:

From the above results and discussions, it can be shown that we have applied the ball milling, cold press and heat treatment techniques to make progression to synthesize high figure of merit (*ZT*) nanostructured materials because it closely depends on the value of the power factor. The future work is to conduct research to find 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 the Bridgman method. The mechanical way to get the bulk p-type bismuth, antimony, telluride ($Bi_{0.5}Sb_{1.5}Te_3$) alloys is also economically and environmentally friendly.

References:

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