Flexible and Wearable Composite Thermoelectric Fabrics Utilizing Bi_2Te_3 Nanoparticles in a Conducting Matrix

Donald Swen[1] and D. P. Young[2]

[1]Department of Physics, Willamette University and [2]Department of Physics and Astronomy, Louisiana State University

What are Thermoelectrics?

Certain materials in this world display remarkable magnetic, electronic, and thermal properties. Many, such as in our computers and cell phones, make them extraordinarily fast. Thermoelectric materials are one such material. If you imagine a cylindrical rod of material with a flame underneath one end of it, this side will be hotter than the other. On average, the electrons at this end of the rod will have a higher kinetic energy than those at the cold end. This leads to a diffusion of the charge carriers from the hot to cold side and the creation of a voltage across the sample due to the temperature gradient. This is the Seebeck effect.

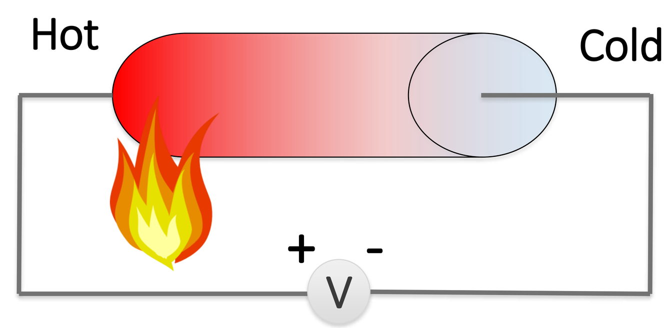


Figure 1: Diagram of the Seebeck Effect. The thermal gradient causes electrons to move toward the cold side, creating a voltage. We measure how good a material is at creating such a voltage with the Seebeck coefficient S, which is defined by change in voltage over the change in temperature.

One such material with this unique property is Bi_2Te_3. However, thermoelectrics are usually solid, inflexible metals. Our project is to make a flexible thermoelectric material. To do this, we will attempt to incorporate Bi_2Te_3 nanoparticles into a graphene and polymer matrix.

Figure of Merit

To determine how good a thermoelectric material is, we need the ZT value, also known as the Figure of Merit.

$$ZT = \frac{S^2\sigma}{\kappa}T$$

Figure 2: Figure of Merit Equation: σ stands for conductivity, κ for thermal conductivity, S for Seebeck coefficient, and T for temperature.

The primary goal is to optimize the variables on the right to achieve the largest possible value for ZT. Ideally, we want the conductivity of a superconductor, thermal conductivity of quartz, and a very large Seebeck coefficient.

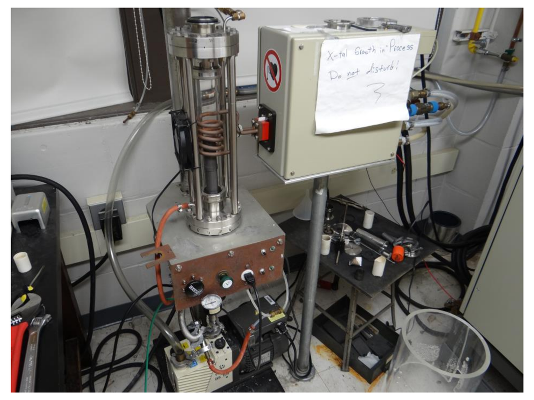
Applications

Thermoelectrics can be used to power a host of environmentally friendly technologies:

- Thermoelectric Shingles
- Flexible and wearable technology
- Refrigeration
- Space Travel
- Power Generation

Synthesis of Bi_2Te_3 Nanoparticles

- To synthesize bulk Bi_2Te_3, we used an RF Furnace which uses an AC magnetic field to inductively melt the Bi and Te metals.



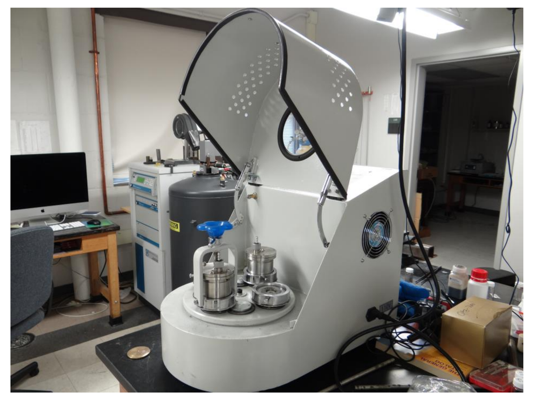
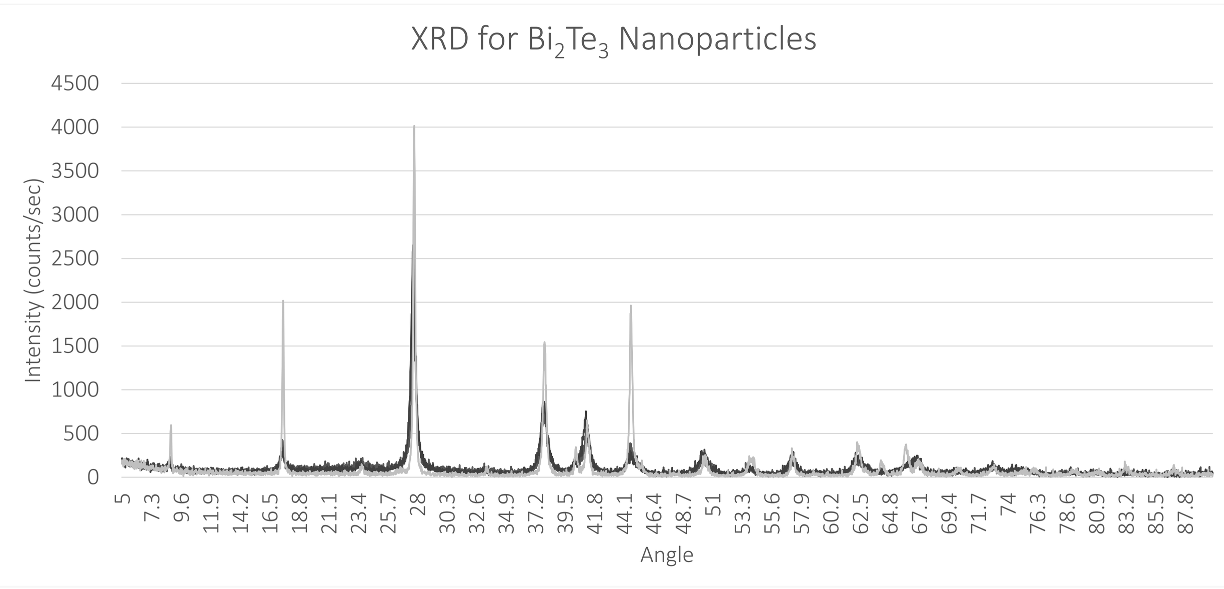


Figure 3 and 4: Images of the RF Furance and the Planetary Ball Mill respectively

- After we obtained the polycrystalline material, we put the Bi_2Te_3 in a Planetary Ball Mill and milled for 30 hours.



To confirm we had Bi_2Te_3, we used x-ray diffraction and SEM to confirm nanoparticle size.

Incorporation into the Graphene Matrix

Lightscribe Technique:

- Researchers at UCLA discovered a novel synthesis approach to synthesizing graphene from Graphene Oxide (GO).
- This works by laser irradiating drop-casted GO onto a Lightscribe CD, which removes the oxygen groups that previously made it non-conductive.

Experimental Procedure:

- We combined Bi_2Te_3 nanoparticles into 10 mL of GO
- To prevent agglomeration of nanoparticles, we added a surfactant
- Drop-cast with a syringe onto transparency substrate and air-dry for 48 hours
- Insert into Lightscribe DVD drive 3 to 4 times, measuring contact resistance each time

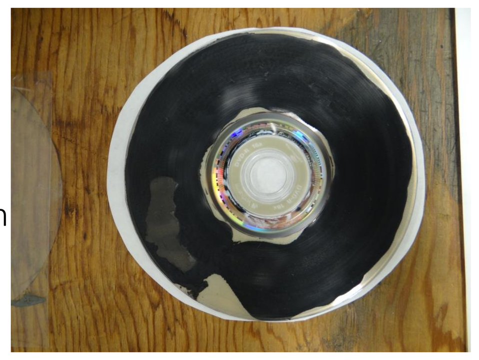
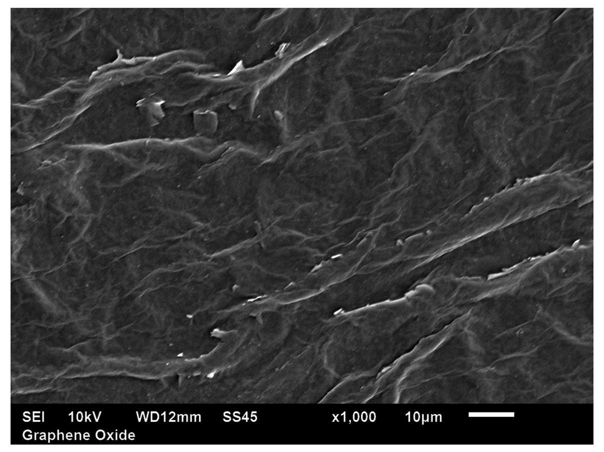
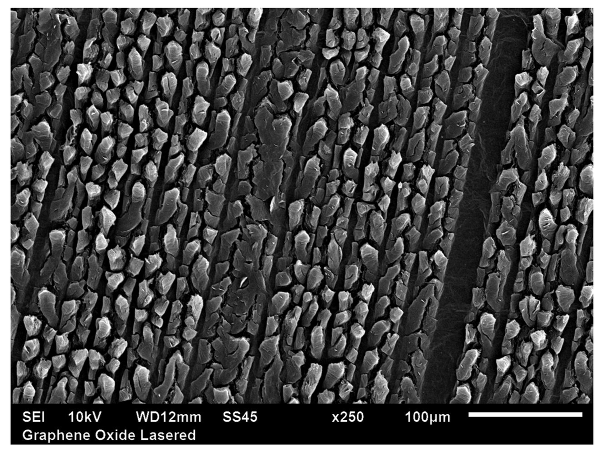
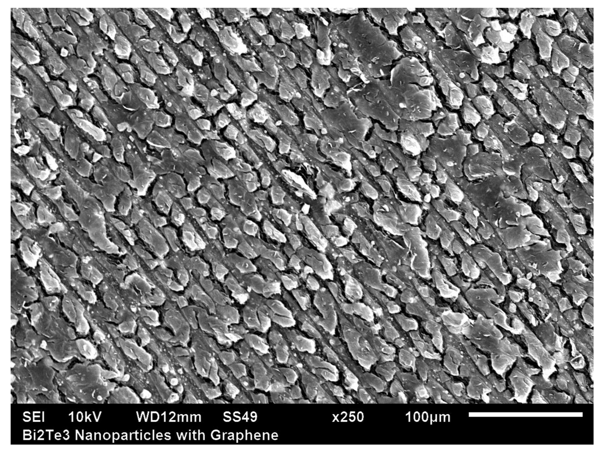


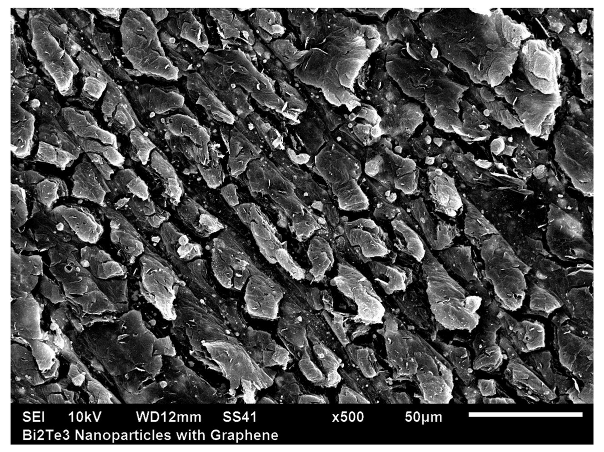
Figure 5 and 6: Air dried drop-casted GO with Bi_2Te_3 nanoparticles, Lightscribe Machine

SEM Pictures of Bi_2Te_3 in GO Before and After Lasing









Incorporation into PVDF Polymer Matrix

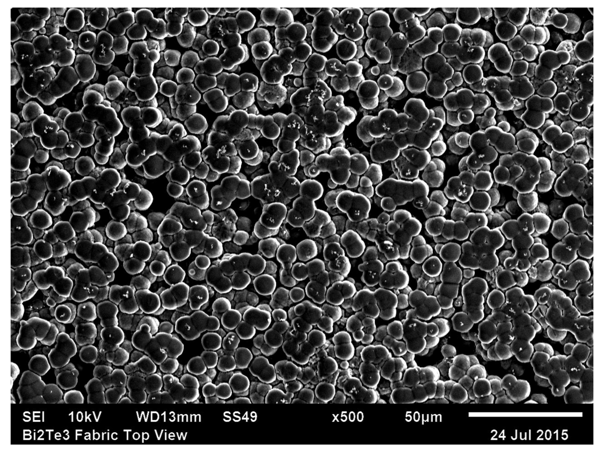
PVDF is a cheap insulating polymer used for fabrics.

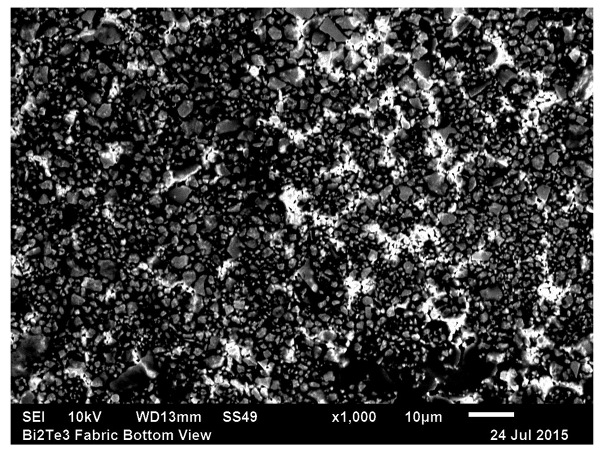
Synthesis Technique:

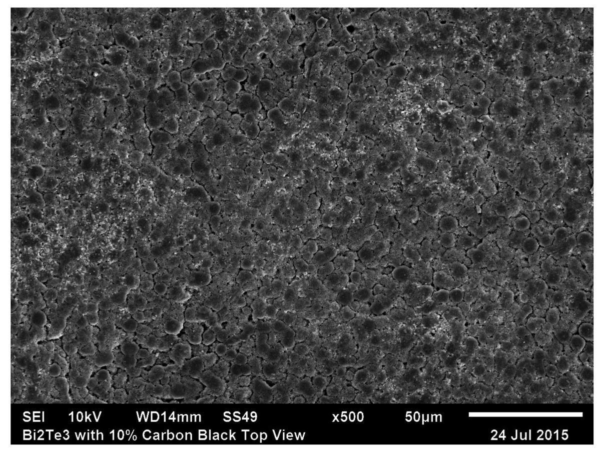
- Dissolve PVDF Pellets with Bi_2Te_3 nanoparticles and Carbon Black in DMF solvent
- Sonicate for 3 hours, drop cast onto glass substrates, and bake at 60 ^{o}C overnight

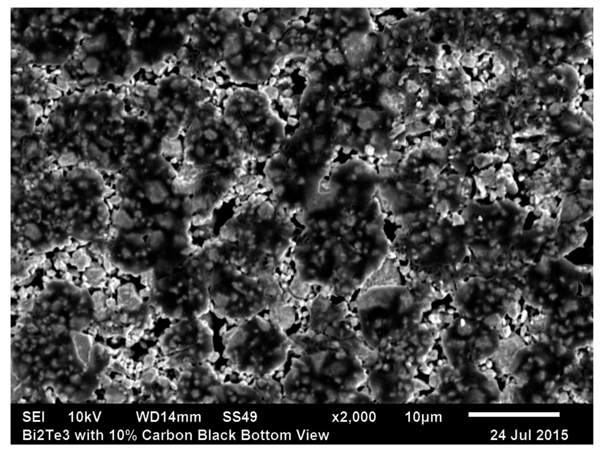
Figure 7 and 8: Picture of Sonicator and hot plate with fabrics being baked on glass substrates, respectively.

SEM Pictures of Bi_2Te_3 Fabric and Bi_2Te_3 with 10% Carbon Black Fabric







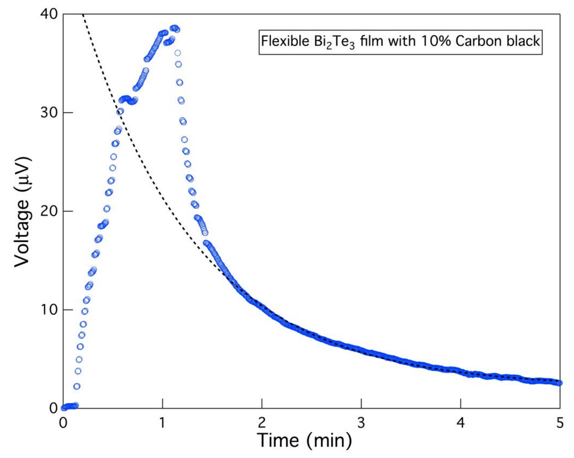


Results and Discussion

Graphene Matrix

Solution	Seebeck Coefficient	Contact Resistance
Graphene with 60 mg/ml Bi_2Te_3 and Pluronic* Lased	2.3 Vµ/K	300-500 Ω
Graphene with 100 mg/ml Bi_2Te_3 and Pluronic Lased	0.53 Vµ/K	1800 Ω

PVDF Matrix



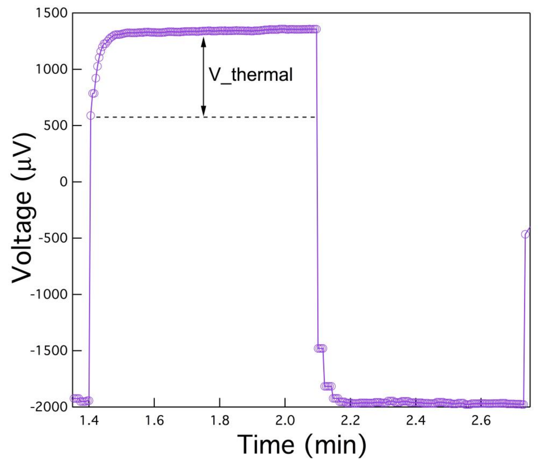


Figure 9: The figure above shows the voltage created as a function of time across a flexible thin film of Bi_2Te_3 with 10% Carbon black at room temperature. The film thickness is approximately 30 microns. The temperature gradient was created with body heat by touching one end of the film, as shown in Figure 11. The film was released after 1 minute, and the resulting thermal voltage decays slowly, due to the low thermal conductivity of the film. The dashed line is an exponential fit to the data, which is well described by thermal decay after approximately 1.5 minutes.

Figure 10: Portion of the voltage versus time plot for a flexible thin film of Bi_2Te_3 with 10% Carbon black at room temperature. A constant DC current was applied to the sample in vacuum and monitored with a 4-probe Harman's method. In addition to the normal Ohm's Law resistive voltage, a thermal voltage is clearly identified in the figure. The thermoelectric figure of merit (ZT) for this particular film is estimated to be 0.2.

Summary Statement

The graphene matrix did not serve as a good conductive matrix. The Seebeck coefficient is too low compared with bulk Bi_2Te_3 (181 Vµ/K). On the other hand, the polymer matrix shows promise. Further work to optimize the ratio of PVDF to nanoparticles should yield a higher Seebeck coefficient, and thus better performance.

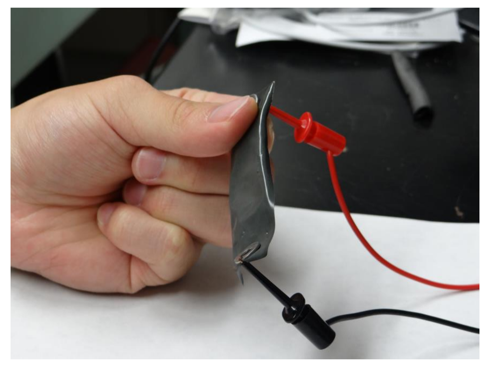


Figure 11: Corresponds to Figure 9: The flexible thermoelectric fabric is being held at one end, which creates a voltage, thus demonstrating the Seebeck effect via body heat.

Future Work

Toward the end of the summer, we began experimenting with Liquion in our solutions, and using PbTe nanoparticles (another good thermoelectric material) to compare with Bi_2Te_3. Future work includes solving the problem of high contact resistance of the drop-cast films and optimizing ratios to achieve higher values of the Seebeck coefficient.

Literature Cited:

1. Kady, et al. Science V. 335. 2012
2. Hewitt, et al. Nano Lett. 2012
3. Dun, et al. Phys. Chem. Chem. Phys., 2015
4. Du, Y. et al. Sci. Rep. 5, 6411 2015.

Acknowledgment: We thank the National Science Foundation for supporting this work through the REU Site in Physics & Astronomy (NSF grant #1262890) at Louisiana State University. We also thank the LSU Department of Physics & Astronomy for additional support. We also thank Mojammel Khan for helping out when needed.