NDnano
Center for Nano Science and Technology

ND*nano* Summer Undergraduate Research
2017 Project Summary

1. Student name & university: Raul Lema Galindo – University of Notre Dame

2. ND faculty name & department: Prof. Tengfei Luo – Aerospace and Mechanical Engineering

3. Project title: Analysis and Experimental Demonstration of Thermal Diodes with a Phase-Change and Phase-Invariant Material Junctions

4. Briefly describe new skills you acquired during your summer research:

Throughout the ten weeks I was working in Lab I learned how to use scientific equipment and its associated software packages to run tests and obtain the necessary results. Furthermore, I learned how to handle chemicals, prepare and test samples effectively to reduce the incidence errors. In the process, I also learned how to distinguish significant results from anomalies and wrong results, strengthened my analytical skills and learned how to report my findings through written work in a clear and concise manner.

5. Briefly share a practical application/end use of your research:

The objective of our research was to prove the feasibility of a thermal diode and with that show that there is a possibility of moving towards phononic computing **--** a field that would allow for data and information transfer using phonons, or heat, instead of electronic devices used nowadays.

6. 50- to 75-word abstract of your project:

My main task during research was to test a thermal diode composed of a junction of two materials, one of which was phase-invariant, and the other underwent phase transition at a known temperature. Using a thermal conductivity testing instrument, it was possible to demonstrate that an appreciable thermal rectification could be obtained when comparing the sample thermal conductivity under forward and reverse temperature bias, where the phase change material was present in one of two phases depending on the direction of heat flow, i.e. which side of the sample (phase-invariant or phase-change material side) was exposed to higher temperature.

7. References for papers, posters, or presentations of your research:

Project Presentation on Thermal Diode Results, July 20th, 2017

As technology moves forward, the demand for small, fast and reliable methods of data and information transmission increases. However, there exists a tradeoff between size, speed and cooling capacity of microelectronic devices. Additionally, heat that is removed from processes is often considered waste energy, regardless of the amount. To circumvent or solve this cooling issue, efforts have been directed at exploring and developing the study of phononics. The idea behind this novel field is to use phonons, the quasi-particles responsible for carrying heat, to aid in information and data transmission using thermal devices. These can be considered analogous to electronic devices used nowadays, but they operate by shuffling heat instead of electrons.

To this end, theoretical and experimental research have taken place in recent years. Articles and letters have been published among the scientific community outlining possible designs and practical applications of these thermal devices. The first step, adopted by many researchers, us included, was to build a thermal diode. Ideally this device could be used at near-room temperatures and bring both significant, reliable and repeatable values of thermal rectification. A thermal diode, or thermal rectifier, operates similarly to its electronic equivalent. It exhibits asymmetric heat flow. In other words, heat transfer in one direction rather than the opposite under equal temperature gradients and biases – i.e. equal but opposite temperatures at the ends of the diode for the forward and reverse gradients – is favored by the device. To accomplish this goal, it has proven necessary to take advantage of certain material properties, which in our case were phase-dependent thermal conductivities. The diode we built and tested with was composed of a two material (A and B) junction inside a plexiglass sampling disk with top and bottom copper caps. This design ensured that the bulk of heat flow went through the diode with minimal losses to the environment given the high thermal conductivity of copper and low conductivity of plexiglass. Material A was a compound with a known solid-liquid phase transition temperature and a phase-dependent thermal conductivity where the solid-phase conductivity was much larger than the liquid-phase. Material B was a phase-invariant compound and it remained solid throughout the length of the test. Together, these two materials had an overall thermal conductivity which varied depending on the sample's thermal bias.

To take advantage of the phase-dependent thermal conductivities, the test had to be made close to the phase-transition temperature of the Material A such that the higher temperature end was at a above and the low temperature end was below this transition point. Thus, when the diode was placed such that Material A faced the hot side, we had a solid-liquid junction with a given thermal conductivity, and when the diode was flipped and Material A solidified due to the temperature it was in contact with, the thermal conductivity changed. Because sample thickness and temperature gradient was the same throughout any given test, it was possible to compute the thermal rectification ratio through dividing the solid-solid junction thermal conductivity by the solid-liquid junction value. If the test was setup correctly, this ratio was greater than one.

In Lab we used Hexadecane, which has a phase transition temperature of 18°C, for material A, and Paraffin Wax and/or PDMS for material B, which have phase transition temperatures (>55 °C) well above the testing temperature. My task was to prepare samples with different thicknesses of either of the materials and test them under different mean sample temperatures to determine an optimum thickness-temperature combination which yielded a high thermal rectification over several trials. By the results obtained it seems like thermal rectification using this type of diode is not only feasible but gives results which are repeatable and significant. Furthermore, rectification values for the Paraffin-Hexadecane junction seem to be more reliable according to the information obtained to date. Further testing needs to be conducted to validate the results obtained, but overall this project seems to be an important success towards the emerging field of phononics.