ND*nano* Summer Undergraduate Research
2016 Project Summary

1. *Student name*: Peter Hanly

2. *Faculty mentor name*: Prof. Tengfei Luo

3. *Project title*: Fabrication of Polymer Nanofibers with Anomalous Thermal Conductivity

4. *Briefly describe any new skills you acquired during your summer research*:
   While completing my summer research project I learnt many new skills that varied from instrumentation skills to lab safety skills to general research and professional working skills. Throughout the project I learnt how to use and calibrate two different optical microscopes, how to use and wire a DC solid state relay temperature controller and how to manage a very delicate mechanical drawing process. During the summer I feel my lab safety skills have also increased. I learnt how to assess a current experiment and the future plans of an experiment and provide a safe method to proceed. Notre Dame's labs are of world-class quality and so are their safety mechanisms. This environment encouraged me to constantly strive to ensure my work was being done in a safe and effective manner. Finally an important skill I learnt this summer that greatly helped my research was the skill of knowing what resources were available to me and who was willing to lend a hand to help with my research. Quite often people will isolate themselves with a problem affecting their research. Learning how and who to ask for help greatly increased the productivity of the project.

5. *Briefly share a practical application/end use of your research*:
   Currently heat transfer devices which are used in thermal management, energy management and heat exchangers rely on heavy materials such as copper and steel. These materials are used because of their high thermal conductivities despite their significant draw backs, namely their large mass and their susceptibility to corrosion. Polymer nanofibers however, have been shown to have increased thermal conductivity as well as being characteristically lightweight. These properties mean they have the potential to produce lightweight heat transfer devises which have uses in thermal management, energy management and heat exchangers. This application is especially attractive to the electronics industry.

Begin two-paragraph project summary here (~ one type-written page) to describe problem and project goal and your activities / results:

Introduction:

The ever expanding and evolving manufacturing industry requires new light weight and energy efficient materials that have high mechanical strength, stiffness and thermal conductivity. The aim of this project is to explore the possibility of altering the structure of polymers so as to produce polymer nanofibers that exhibit these attractive properties that will have lightweight heat transfer applications.

Polymers which are usually amorphous materials meaning they do not have a repeating periodic crystal structure generally have poor thermal conductivity, stiffness and mechanical strength. These properties can be altered by creating well packed and aligned polymers. These polymers have an altered structure that are not made up of entangled molecular chains but aligned ones. Polymers with such crystal structure have high thermal conductivity and strength and can potentially benefit light weight heat transfer applications.

The overall goal of this project is to study the molecular structure of mechanically drawn polymer nanofibers and explore how this structure affects the thermal properties of the fiber. Before this goal can be achieved a reliable, consistent and simple method of fabricating the nanofibers must be produced. Therefor the goal of my 9 week research project was to work with my fellow REU co-worker Manikandan Suresh and produce a method that would produce these polymer nanofibers in a consistent manor. Previous REU groups had attempted drawing the fibers, this meant that one of the main challenges was to add to their work and reduce the polymer diameter from the previous groups 3 micron diameter down to the nanometer level.

Method & Experimental Detail:

Having set up the experimental equipment and completing sufficient background reading myself and my co-worker decided to focus on finding the optimal initial and secondary draw temperature and rate to produce the most consistent fibers on the nanoscale. Below is the procedure used to conduct the experiment.

Procedure:

1) Gel Prep

The gel is prepared by mixing 0.024 grms of polyethylene powder with 3ml of Decahydronaphthalene and heating the solution for 11 minutes while stirring. Following the mixing process the gel is quenched for 3 minutes.

2) Initial Draw

After the gel is prepared a small sample is placed on slide which is heated to a specific temperature using a temperature controller, a power supply and a flexible heating resistor. When the gel becomes a clear liquid a tungsten tip is inserted into the gel using an automated coordinate machine and is removed at a set rate which is controlled by a computer program. After a fiber measuring 0.5mm in length is drawn the process is stopped and the decalin is allowed to evaporate. To the right is an image of the tip and the gel during initial drawing.

Initial Draw

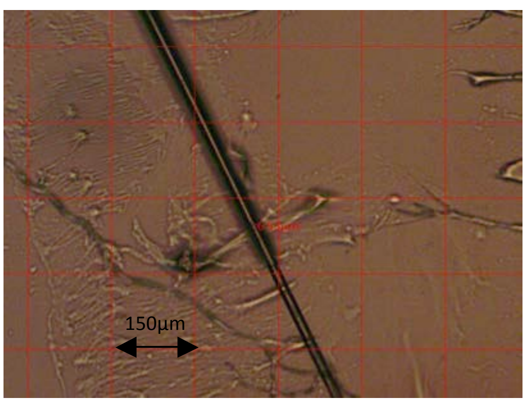
3) Secondary Draw
When the decalin evaporates the temperature is changed to a specific secondary draw temperature and the program is initiated at a specific secondary draw rate. When the fiber reaches a length of 1.5mm the drawing is stopped.

4) Isolation and Viewing
When the secondary draw is stopped a small amount of tension is released within the fiber by manually moving the tip forward by ~ 0.01mm. The fiber is then allowed to cool. Following cooling, further tension is taken from the fiber by manually moving the tip forward until buckling occurs. When the tension is removed from the fiber it is then manually cut with a scissors. The fiber can be viewed using an optical microscope or a low voltage SEM if the diameter is reduced to the nanometer level.

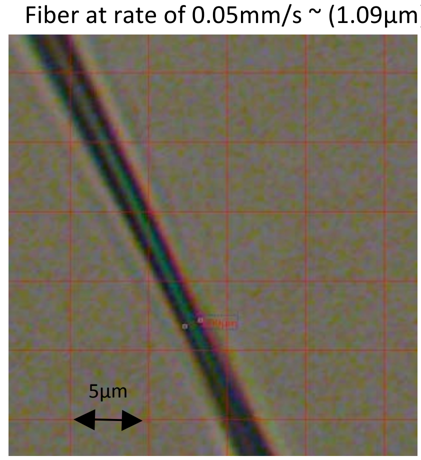
Results

From the experiments completed throughout the research it was found that as the temperature increases during the initial draw the fiber diameters become smaller. However if the temperature of the slide rises to above 135^{o}C the gel begins to become volatile and reduce in size dramatically. This causes inconsistent fiber drawing. The same can be said with regards to the draw rate. It is seen that as the draw rate increases the fiber diameters reduce in size. This is due to the increase in shear stress that is applied to the fibers at higher rates. However above 0.05mm/s the shear stress becomes too large and the fiber breaks prematurely. Below is the variations seen in fiber diameters when the draw rate is varied.

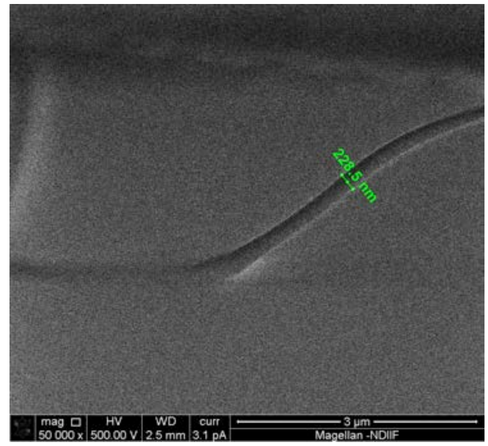
Fiber at rate of 0.01mm/s ~ (6.55µm)



Fiber at rate of 0.05mm/s ~ (1.09µm)



The above results showed that at 135^{o}C and 0.05mm/s we are able to achieve an average initial draw diameter of 1 – 2 microns.
The first round of secondary draw experiments have begun at a temperature of 120^{o}C and a rate of 0.001mm/s. One of the samples produced was measured under an SEM and had a diameter of 228nm. Going forward with further secondary draw experiments at different temperatures and rates I believe the diameter can be reduced further.



Secondary drawn fiber ~ 228nm

Publications (papers/posters/presentations):

Poster: Fabrication of Polymer Nanofibers with Anomalous Thermal Conductivity, Poster Session – 07/27/2016, Jordon Hall of Science Galleria

Presentations: Fabrication of Polymer Nanofibers with Anomalous Thermal Conductivity, Presentation Session – NDnano Nurf Presentation Session, 08/04/16