

Thermal time constant measurements for Ge doped GaAs thermometers at low temperatures (7/30/03)

K.A. Larson and G.G. Ihas
Physics Department
University of Florida
Gainesville, FL 32611 USA

Abstract

In this experiment, thermal time constant measurements were taken from a system consisting of a heater, He gas, and a sensitive, low temperature resistance thermometer. The resistance thermometer [3] was made of a Ge film deposited on a GaAs substrate. The data from this experiment will be used to design a mass measurement system for hydrogen storage tanks in micro-gravity environments.

INTRODUCTION

NASA would like to develop a more efficient way of determining the mass of hydrogen fuel remaining on board the space shuttle. The hydrogen is stored in a large (2,500L) tank located inside the shuttle. Although the amount of fuel remaining could be determined from history of use, experience has shown this is not practical. The hydrogen inside the tank consists of both liquid and vapor phases. In a micro-gravity environment, the exact liquid/vapor configuration of the hydrogen is not known. Depending on the recent motion of the shuttle, the configuration could range from many small drops, to a single glob. The current method used to determine the amount of hydrogen fuel remaining requires the shuttle to be accelerated for approximately 15 sec, at which point, a standard level meter can be used to detect the single liquid/vapor meniscus.

Four possible methods have been considered to gauge the liquid mass in a tank: optical, sonic, pressurization, and temperature. It is the last approach that we are taking. The temperature approach takes advantage of the large difference in heat capacities of liquid and vapor phases [4]. The heat capacities are independent of the shuttle's motion or gravitational field. By using small, sensitive thermometers and injecting a known quantity of heat, we can calculate the change in temperature (ΔT). Using the volumetric heat capacities of the liquid and vapor states and knowing that the volume of the tank (V) is equal to the sum of the gas and liquid volumes (V_g, V_l), we determine the volume of the liquid state Eq.(1). We then calculate the mass of liquid at 20.4K and 10^5 bar (1atm).

$$\Delta T = \frac{Q}{C_l V_l + C_g V_g}$$
$$V_l = 1.5 \left(\frac{Q_{\text{joules}}}{\Delta T_{\text{Kelvin}}} - 0.017 V_{\text{tank/liters}} \right) \text{liters} \quad (1)$$

There are two considerations for this method: (1) whether a thermometer system can be built with the necessary sensitivity, and (2) whether the measurement can be made fast

enough to avoid interference from the refrigeration system. The minimum sensitivity required can be found from Eq.(1). When the tank is devoid of liquid, $V_l = 0$, and

$$\frac{Q}{\Delta T} = 42.5 \left(\frac{J}{K} \right) = 0.043 \left(\frac{J}{mK} \right)$$

This corresponds to the minimum required sensitivity. It has been shown that the thermometers being used possess this sensitivity. The second consideration is being addressed by this experiment. By measuring the thermal response of our gas/Detector system to different heat inputs, we are helping to determine the needed conditions to create our Ge thermometer system.

OBJECTIVE

For this experiment, we measured the thermal response times (τ) of our system to various heat inputs at various temperatures. The purpose of these measurements was to determine under what conditions (heat input levels) our system responded most rapidly. The various heat inputs and temperatures settings allowed us to observe patterns and get a feel for what sort of “physics” may be going as a result of the changing conditions.

PROCEDURE

The first step in this experiment was to design the cell used in taking measurements inside the liquid helium cryostat (see Appendix A for photo). The cell consisted of a Stycast block (insulating), thick-film heater, doped Ge Detector, and electrical pin connectors for both the heater and Detector. These connectors also served to mount the devices to the block. A small opening was drilled through the center of the Stycast block to allow for heat to flow through the He gas from the small heater to the Detector. Mounted on one side of the block was the thick-film heater, and on the other, the Ge Detector. The Stycast block would eventually be connected to a large heater, used for thermal regulation. Also included was a Ge thermometer, mounted to the large heater. The Stycast block was machined to the appropriate dimensions (approx 1” by 1” by .3”), holes for the connectors and mounts were drilled, and the parts were assembled.

An important consideration for this experiment was the dimensions of the Stycast block. The height of the block, or the length corresponding to the distance between the Ge Detector and the thick-film heater, had to fall within a specific range. For the purposes of this experiment, we wanted to consider only the heat transferred by thermal conduction. If the distance between the Detector and the heater were too small, effects from thermal convection would skew our results. On the other hand, if the distance were too large, heat would be dissipated along the length of the tube as it traveled. An equation involving the [1] specific heat of helium (C_p), [2] thermal conductivity (k) of helium, mass of the He gas ($m = \rho V$), cross-sectional Area (A), and travel Length (L) was used to calculate the heat’s time of propagation (Γ) through the He gas in the opening of the Stycast block:

$$\begin{aligned} \Gamma &= (C_p \rho V) / (kA/L) \\ &= 36000 (L^2 / m^2) \text{ sec} \end{aligned} \tag{2}$$

This calculation shows that for a tube of 0.3” (approx 7mm) in length, the time of propagation falls within the range that minimizes the effects of both thermal convection and dissipative heat loss.

After the Stycast block was assembled with the thick-film heater and Ge Detector, the next step was to attach it to the mounting stick of the dewar; the Ge thermometer and large heater were also attached to the mounting stick. The mounting stick was then placed inside the dewar insert, which, in turn, was placed inside the liquid helium dewar. First, the large heater and Ge thermometer were fitted to the mounting stick. Then the Stycast block was connected to the heater using a connecting pin. The Stycast block and large heater were connected approx 1" apart. After the assembly to the mounting stick, the next step was to solder the electrical leads of the Detector, large heater, thick-film heater, and Ge thermometer to the connecting wires, which lead out from the dewar. These connecting wires came as twisted pairs and were as follows: two pairs for the Detector, one leading from the voltage pins and the other from the current pins; one pair for the larger heater; one pair for the small heater; and a set of 3 wires leading from the thermometer (see Appendix B). Note: After the Stycast block was attached to the mounting stick and before it was placed into the dewar insert, a heat shield was attached. The heat shield was made of a Cu can formed around the Stycast block, Detector, and thick-film heater. The shield was attached to the large heater, where it helped to maintain the experiment at a constant temperature and to insulate the experiment from the walls of the dewar insert. Also, room temperature resistance measurements of the heaters and Detectors were made for future reference.

A critical step for this experiment was writing the computer code for LabView. LabView is a computer program used by scientists to aid in experiments. It is a visual based program that creates virtual front panel displays of many of the commonly used scientific instruments. The basis of the program is that it allows the computer and its software to perform the same tasks previously carried out by instrumentation. At the same time, the computer takes up less space and increases convenience. For this experiment, I had no previous knowledge of LabView. I first reviewed the help files and tutorials, then created a relatively simple Virtual Instrument (VI) program to run the experiment.

Before the installation of the Ge thermometer and Stycast block onto the mounting stick, a determination of the thermometer sensitivity had to be made. More specifically, the thermometer with the greatest sensitivity, or $\partial R / \partial T$, had to be determined. The experiment used resistance thermometers, where the resistance versus temperature of each thermometer was known. We were able to graph the data and determine which thermometer had the highest change in resistance with temperature ($\partial R / \partial T$) at 20K. In addition, we used the resistance vs. temperature data of the thermometer to set our thermal regulation system to the required temperatures.

Most of the devices in our experiment were interfaced to a Dasi board, which was then connected to a computer. The exception to this arrangement was the Ge thermometer. The leads of the Ge thermometer were soldered to connecting wires, which led out from the cryostat. From there, the thermometer was connected directly to a LR110 Resistance Bridge. This device monitors the temperature of the system set by the user. Then, a signal is sent out by the LR110 to the LR130 Temperature Controller. The Temperature Controller was connected to the leads of the large heater. The LR130 sends power to the large heater and works in conjunction with the LR110 monitoring device to maintain a

constant temperature in the system. The resistance settings of the LR110 for the different temperatures of the experiment were 2467Ω for 10K, 1750Ω for 20K and 1467Ω for 30K.

In this experiment, we wanted to determine how quickly the voltage across the Detector changed with a given heat input. The time it took for these voltages to change correlated to the thermal time constants of the gas/Detector system. To measure this voltage change, we placed our Detector into a Wheatstone bridge. This put the Detector in parallel with our decade resistor. We then tuned the decade so that the voltage difference between the decade and the Detector was constant. Finally, we set a voltage measurement at the nodes of the decade resistor and Detector to monitor the voltage difference between the two. This voltage measurement was taken at the voltage input pin of the Dasi board and, from there, sent to the computer where the change in voltage (due to a heat input) was monitored.

RESULTS

Typical data for this experiment at a given power setting and temperature is shown in Fig.1. The purpose of this experiment was to calculate and compare the voltage response time (resulting from heat inputs) of the Detector. To make this calculation, we first graphed the voltage vs. time data we had collected. We then found a point on the graph known as the $1/e$ location, where e is the natural log constant ($e = 2.72$). The method was as follows: The difference between the initial and final voltages (ΔV) of the Detector was determined. The initial voltage corresponded to the time before the thick-film heater was turned on, and the final voltage corresponded to the point of equilibrium where the Detector was no longer changing voltage. After ΔV was determined, the $1/e$ value was used as a fraction to calculate the y-value location that was “ $1/e$ ”% greater than the final voltage value. The corresponding x-value could then be found on the graph, and the time from when the thick-film heater was first turned on to when the $1/e$ location occurred could be calculated. This time was the thermal time constant, or Tau (Γ).

The graphical technique for finding the location of the $1/e$ points will be described: The voltage value of the Detector was measured once every 50ms (approx), via the V_{in} pin on the Dasi board. This value was then sent to a data file, along with the corresponding measurement time. Following this, the data was graphed as voltage vs. time, as in Fig. 1. To smooth the graph, an adjacent averaging was performed. After the averaging, straight line fits were performed on the horizontal upper and lower voltage limits of the data points. The straight line fit gave the average voltage values at these locations. The $1/e$ y-value between the voltage limits was then found as discussed earlier. To find the $1/e$ x-value, a polynomial curve fit was done on the graph. This provided a single line curve, from which the x-value was determined and the Tau value calculated. This process was repeated at a given temperature for voltage settings on the thick-film heater of 1.5V, 2.0V, 3.0V, and 4.0V. The process was repeated for the temperatures 10K, 20K, and 30K. After the Tau (Γ) values were found, Γ vs. P was graphed for the given Temperatures (T). Power was calculated as $P = V^2 / R_h$ where R_h is the resistance of the thick-film heater.

$$R_h = R - 2 * R_{lead} \text{ (where } R = \text{resistance of the small heater circuit)}$$

A straight line fit was then done for the Γ vs. P graphs at each temperature, as shown in Fig. 2-4. From this fit, a Zero Power Tau vs. Temperature graph was made. The Zero Power Tau value indicated the theoretical limit (longest time constant) of the Tau value for a minimal Power input (See Fig. 5)

CONCLUSIONS

For this experiment, we designed a system in which we could apply a controlled heat input to our Detector and measure its response. We used LabView software and a specially design computer board to run our experiment and collect data. We then graphed our data and analyzed it to determine the time constants (Tau) at different Power settings and Temperatures.

Overall, the experiment was a success. The basic aim was to collect voltage vs. time data from our Detector, and this was accomplished. Although the time constant (Tau) vs. Power (∂Q) data points did not follow a truly straight line, their pattern was consistent between the different Temperatures that data was collected. The decrease in the Tau value from 1.5V to 2.0V was not as large as expected. This pattern was seen again in going from 3.0V to 4.0V. However, the straight-line fit of our curve fell within the standard deviation error bars of all of our data points.

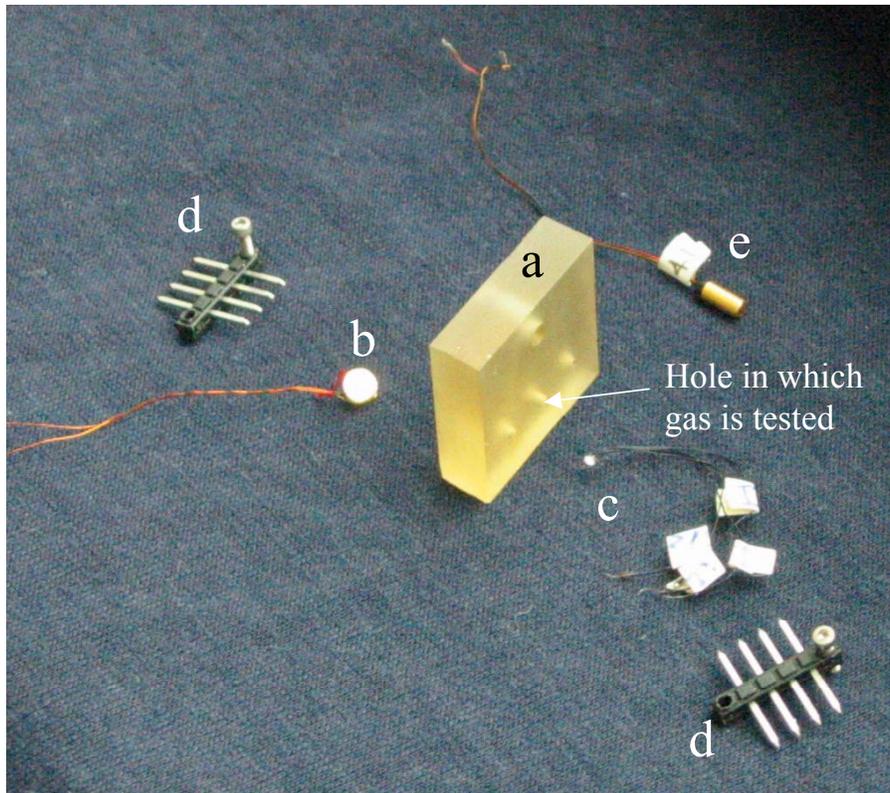
The next step for this experiment would be to look at the cause of the slightly non-linear pattern of our Tau vs. Power graphs. Also, we would like to place multiple Detectors into our cryostat and examine the thermal time constants in this case. Finally, we would like to switch from a liquid helium to a liquid hydrogen dewar in order to gather information on the thermal conductivity of H gas.

REFERENCES

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- [3] Mitin, V., McFarland J., Ihas, G.G., Dugaev, V.K., Physica B, Vol. 284-288, 1996.
- [4] Flynn, Cyrogenic Engineering, Thomas M. Flynn, Dekker, NY (1996).

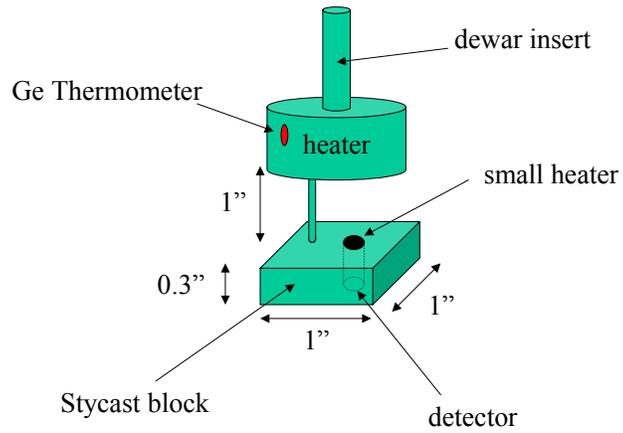
Appendix A

- (a) Stycast block
- (b) Thick-film heater
- (c) Ge doped Detector
- (d) Electrical pin connectors
- (e) Ge thermometer

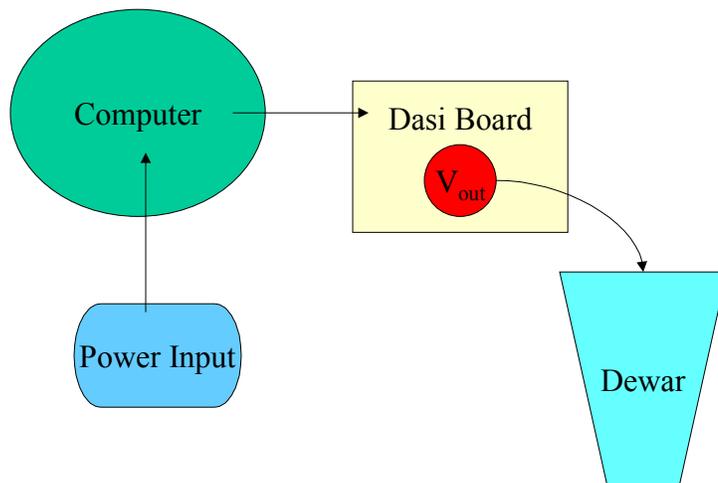


Appendix B

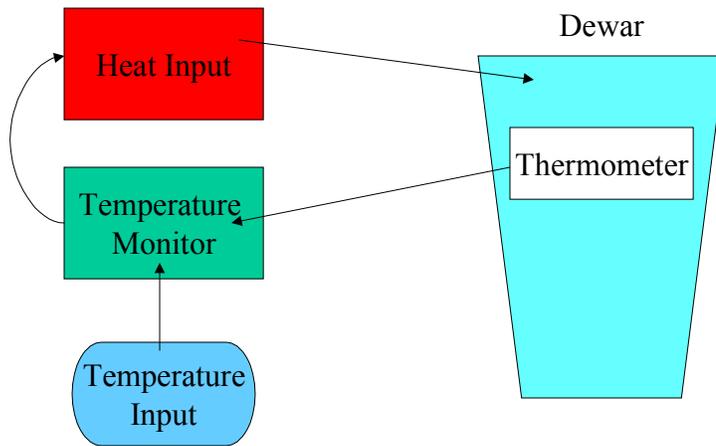
Experiment setup



Small Heater



Large Heater / Thermal Regulator



Data Collection / Wheatstone Bridge

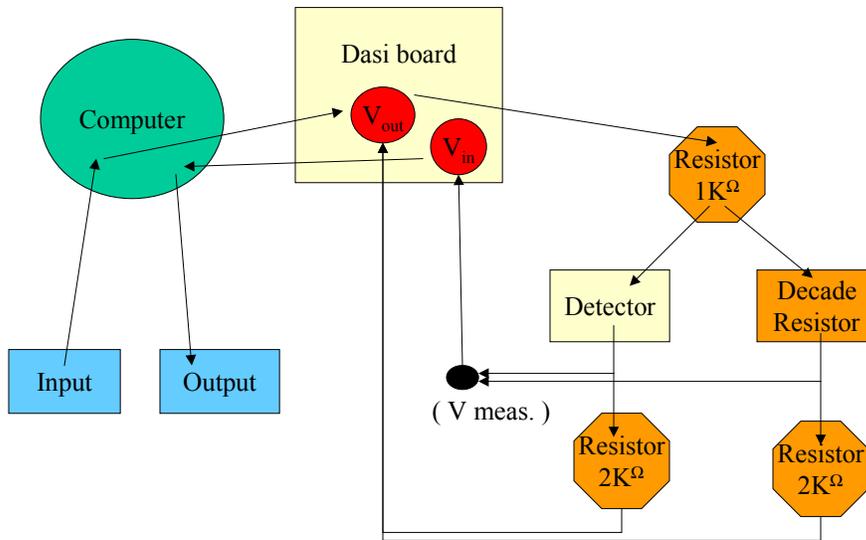


Figure 1

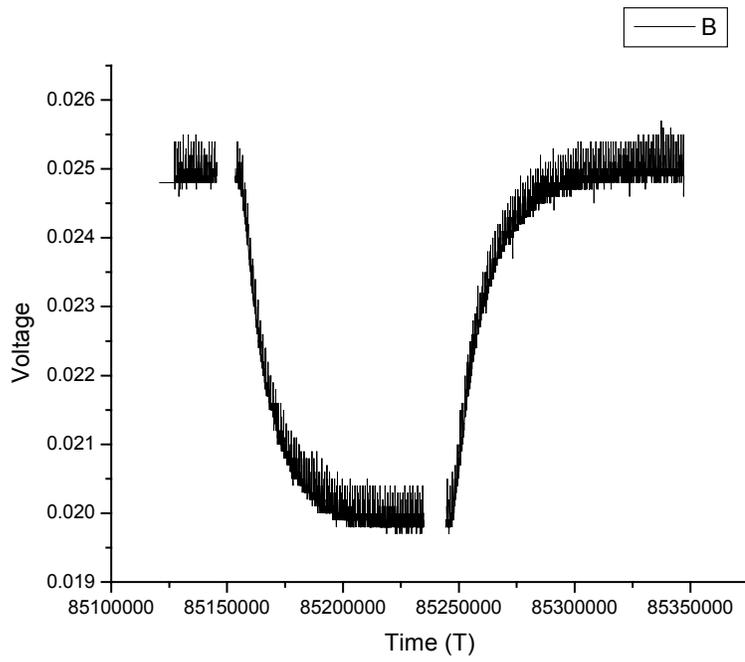


Figure 2

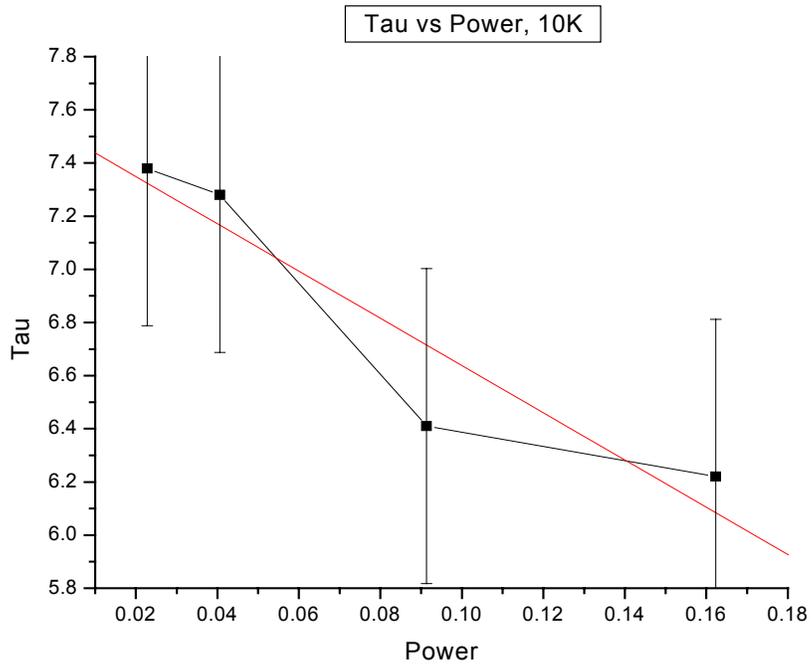


Figure 3

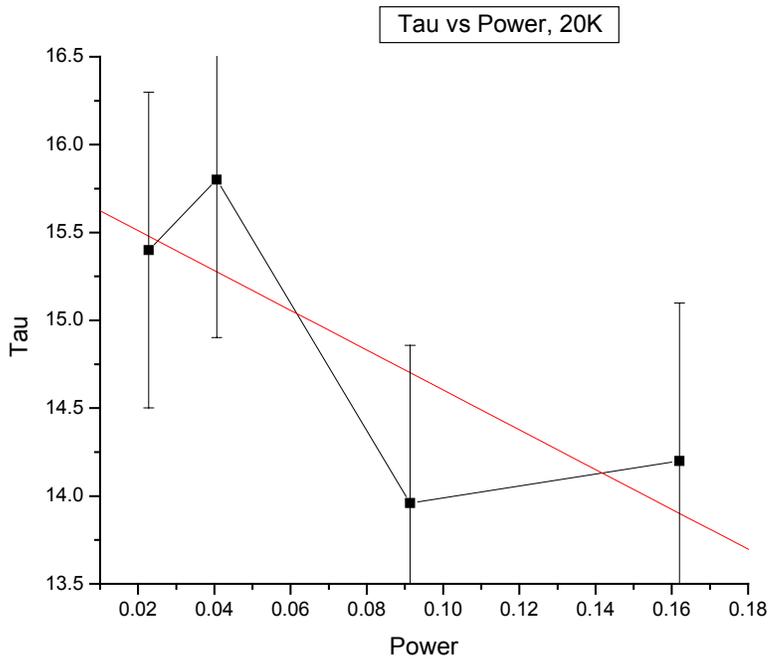


Figure 4

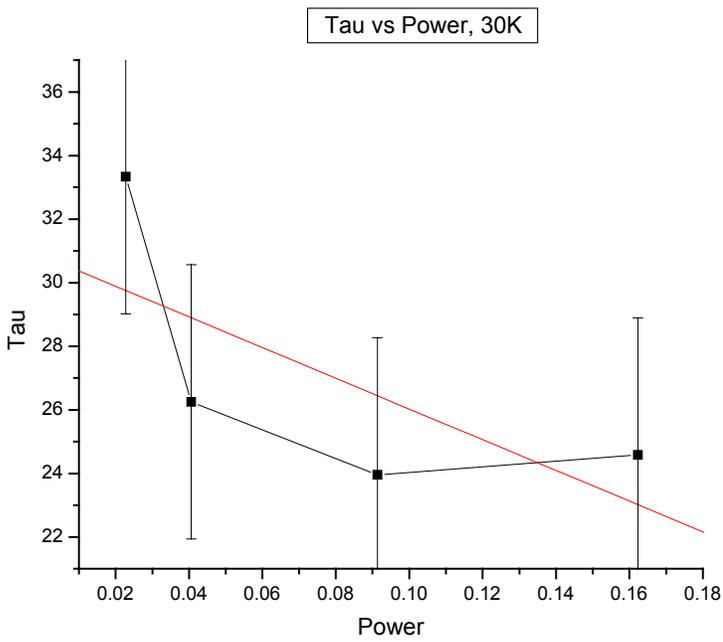


Figure 5

