LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Technical Note **LIGO-Tv-**
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2017/08/04

Second Interim Report: In-Vacuum Heat Switch

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1 Introduction

LIGO Voyager is a design concept for a next generation gravitational wave (GW) detector that is currently being developed with the aims of reaching the limits of the current LIGO facilities. One of the major upgrades is switching the fused silica mirrors to crystalline silicon, along with new, optimized coatings and operating the system at a temperature of 124K. Coating research and development is ongoing with the goal to reduce thermal noise in the experiment. This improvement along with other changes will increase the sensitivity of the LIGO Voyager by a factor of two or three compared to Advanced LIGO [1].

There are two important qualities of crystalline silicon that make it an appealing material for the LIGO Voyager mirrors. Unlike in fused silica, the mechanical losses in crystalline silicon decrease with temperature, and the thermal expansion coefficient of silicon reaches zero at 124 K [2]. This means that the thermoelastic component of thermal noise is eliminated, and thus a quieter system can be achieved. The second advantageous quality of silicon is that it has a much higher thermal conductivity than fused silica. This means that a higher power laser can be used because it is easier for the mirrors to dissipate the heat from the laser and the effects of thermal lensing are reduced [2], [3].

In operation mode, Voyager will only use radiative cooling to maintain cryogenic temperatures, but other methods of heat transfer are being considered to accelerate the initial cooldown. Because there are strict requirements on the vacuum levels in LIGO, using an exchange gas for convective cooling is not an option. Developing a heat switch and cooling the mirrors through thermal conduction is a viable solution for an accelerated cooldown. My research for this summer will be focused around studying the efficiency of heat flow across sample interfaces for different switch mechanisms. Additionally, I can use the study of heat flow to characterize the quality and strength of optically contacted samples. Optical contacting is a form of bonding where two super-polished surfaces get so close to each other that they are joined and held together by intermolecular forces [4]. Heat flow is an indicator for the effective contact area, and so it can be used to assess different switch geometries and bond qualities.

2 Overview of Progress

2.1 Weeks 1 - 3

My experiments this summer are focused on measuring the heat flow across different samples using a small cryostat that has a work plate at the bottom of the in-vacuum reservoir for liquid nitrogen. It is possible to create temperature gradient across the sample by placing two temperature sensors on either side of the sample and then connecting one sensor to the cold plate and the other sensor to a heating element. The heater and sensor elements were placed in custom made aluminum plates in order to achieve an even distribution of heating. The aluminum plates that we ordered had a rough texture to them, so I sanded each of them down to ensure the best thermal contact between the pieces. The next step was to solder four leads to each of the temperature sensors to monitor voltage and current and then glue the RTDs into their aluminum plates. I used a Lakeshore 7031 varnish, which is thermally

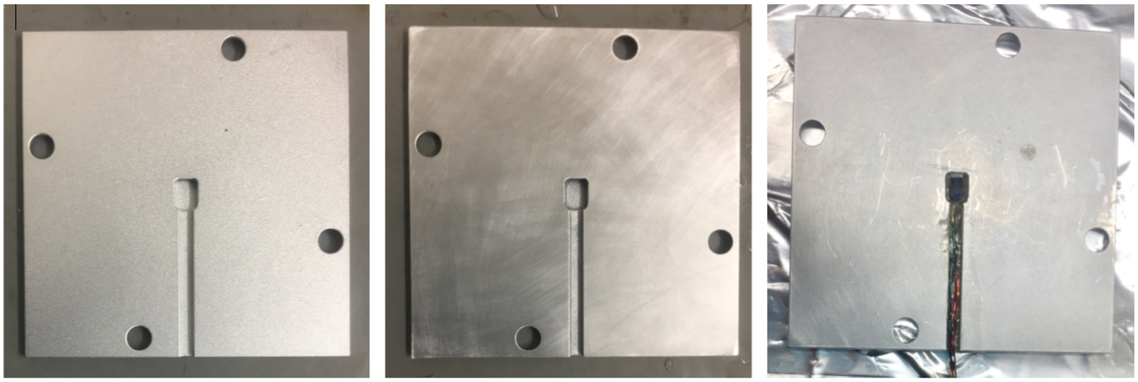

Figure 1: Left: temperature sensor plate before the sanding process. Middle: temperature sensor plate after sanding process. Right: temperature sensor glued into the plate with Lakeshore 7031 varnish.

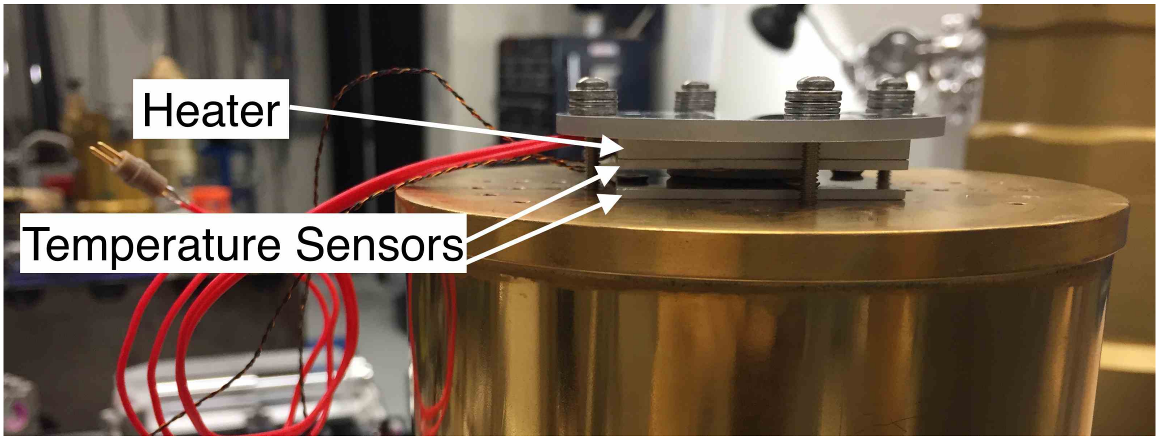

Figure 2: Assembly of the temperature sensors and heater on the workplate of the cryostat.

conductive and electrically insulating. See Figure 1. It was challenging to glue the sensors into the plates without having the leads touch, so new aluminum plates were ordered with deeper channels.

To test that the temperature sensors worked properly, I assembled the plates in the cryostat as shown in Figure 2. I used a small steel disc as a spacer between the temperature sensors because the silicon samples have not arrived yet. Once the crystat was under vacuum, I poured liquid nitrogen into the vessel and recorded how the voltage of the RTD changed as a function of time. The applied current was 50mA, so the initial voltage and resistance of the RTD was 6V and 100 Ω respectively, and this decreased exponentially until bottoming out at 1.2V and 24 Ω. This was a fairly low resistance, and so for future experiments I decided switching to 500 Ω RTDs.

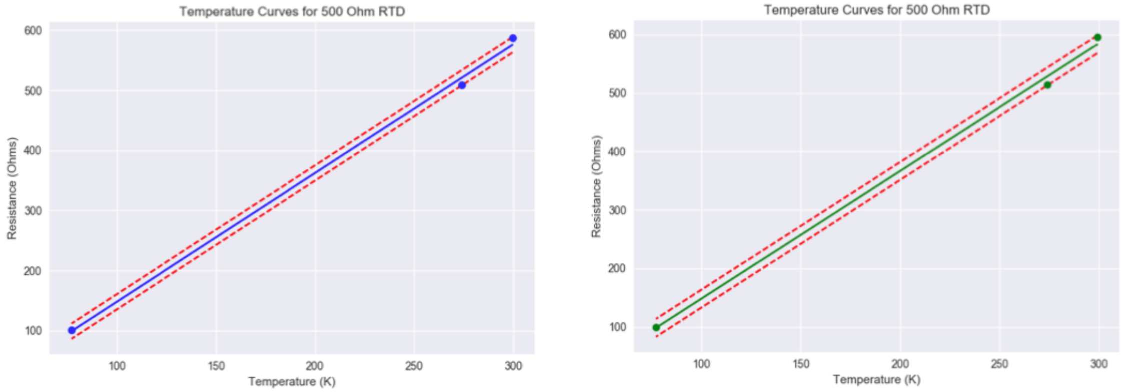

Figure 3: Temperature vs. Resistance of the two 500 Ω RTDs used in the cryostat. Dashed red lines represent 95% confidence interval of the best fit line.

2.2 Weeks 4 - 7

- **RTD Calibration:** I soldered leads onto the 500 Ω RTDs and then glued them into the new aluminum plates that had deeper channels. Since these RTDs were not rated for cryogenic temperatures, I had to calibrate them manually. I did this by applying a constant current of 15 mA across each of the RTDs and measuring an output voltage at three different temperatures: room temperature (299.25 K), freezing point of water (273.95 K), and boiling point of liquid nitrogen (77.35 K). The temperature - resistance relationship of platinum RTDs is know to be linear [7], and so I created a best fit line as shown in Figure 3.

- **Optical Contacting:** Over the last several weeks, I have been learning and improving the process of optically bonding silicon wafers. The wafers are 500 μm thick and come in squares of either 4 cm^2 or 1 cm^2. We cleaned and contacted these samples using the following process:

  1. Use the ion gun to blow off any large particles from the surface.
  2. Drag wipe the pieces down with acetone three times.
  3. Scrub and then drag wipe the pieces with methenol three times.
  4. Once the surfaces are clean, make a right angle with two blocks and put one silicon piece flush against the corner.
  5. Place the second piece (clean side down) on top of the first piece, as shown in Figure 4, and push down to form the bond.

  The first attempt of optically bonding two wafers went well and the pieces were aligned and had a strong bond. In the second attempt the wafers became misaligned during the bonding process and we decided to break the initial bond and re-try. We also noticed that there were some chipped material on the edge of these wafers, possibly from when we were extracting them from the packaging. A second test we performed was if the residue on the back of the wafers from the sticky tape surface they were delivered on could be removed without compromising the surface quality, such that we

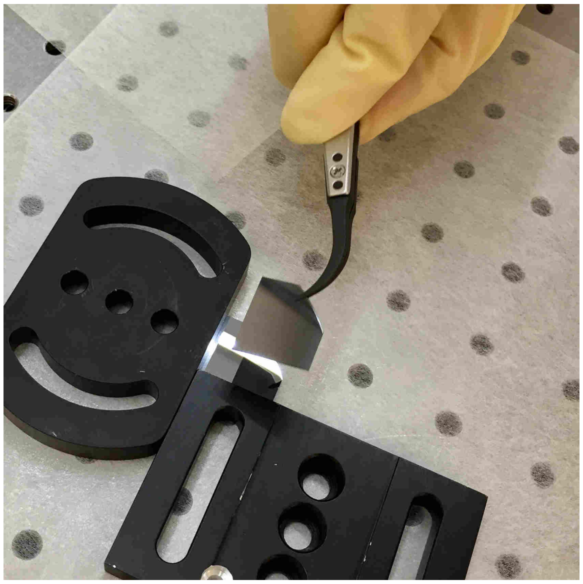

Figure 4: Process of optically contacting two silicon wafers.

Figure 5: Three optically bonded silicon wafers.

may produce stacks of multiple bonded wafers. See Figure 5. This test was successful, and so we know that we can use either side of a wafer to use as a contact surface.

During the next attempt at optical contacting, we used the commercial cleaning product 'First Contact', which is used in LIGO to clean the sensitive interferometer optics. First Contact is a blend of polymers and solvents that is applied as a liquid by brush or spraying and leaves a polymer film behind that can be peeled off, removing contaminants from optical surfaces [6]. This was significantly more effective and faster at cleaning the 4 cm^2 silicon samples. We created two bonded samples and placed one sample on a hotplate for twelve hours and the other sample under a weight of 2.977 kg. I will use the experimental setup in my cryostat to measure the respective rates of heat transfer for each of the samples and compare how their curing methods impacted the strength of their bond.

- **Copper - Silicon Interface:** I am currently conducting an experiment that is investigating the interface between copper and silicon, which models the interface that the

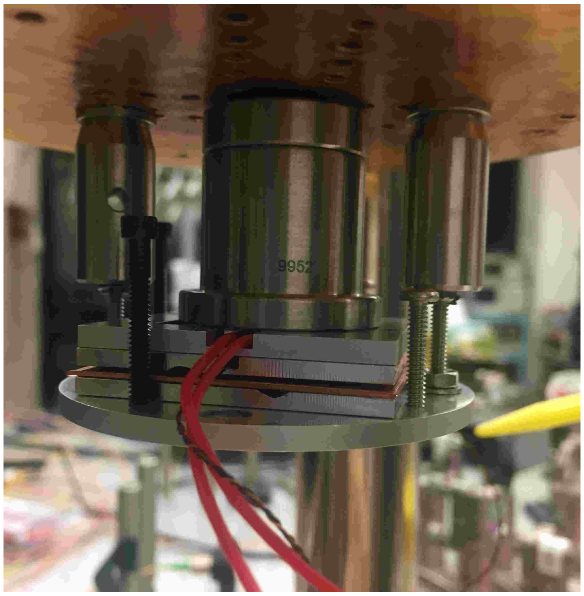

Figure 6: Assembly of temperature sensors, heater and samples on the cryostat cold plate. There is a stainless steel cylinder and a piece of PEEK on top of the assembly to keep stack in place and to limit the amount of heat exchange through radiation.

LIGO Voyager clamping mechanism might see. We obtained copper plates with three sample finishes: mirror, polish, and brush. My first experiment is to determine if the type of finish impacts the efficiency of heat transfer between the copper and silicon samples. I assembled the temperature sensors, heater, and samples on the work plate as shown in Figure 6. I will cool the cryostat down to liquid nitrogen temperatures before turning on the heater and measuring the temperature gradient across the interface. This experiment will be performed for each of the three copper samples.

- **Clamping Mechanism:** I am in the process of developing a clamping mechanism that can grab onto a silicon sample and then be disengaged after the sample is cooled. I completed a first prototype of my design and made a 3D print of it. A Solidworks model of the design is shown in Figure 7. Small adaptations will be made and more prototypes will printed before the design is sent to be fabricated by a machine shop.

3 Future Work

- **Optical Contacting:** Over the next few weeks I will create more bonded samples and vary the amount of time, pressure, and heat the samples are subjected to during the curing process. Then, in the cryostat, I will measure the efficiency of heat transfer for each sample as a way of characterizing its bond strength and determine how the curing process impacts this bond strength.
- **Clamping Force and Heat Transfer Relationship:** It is important to understand how much force will need to be applied in the clamping mechanism to reach maximum

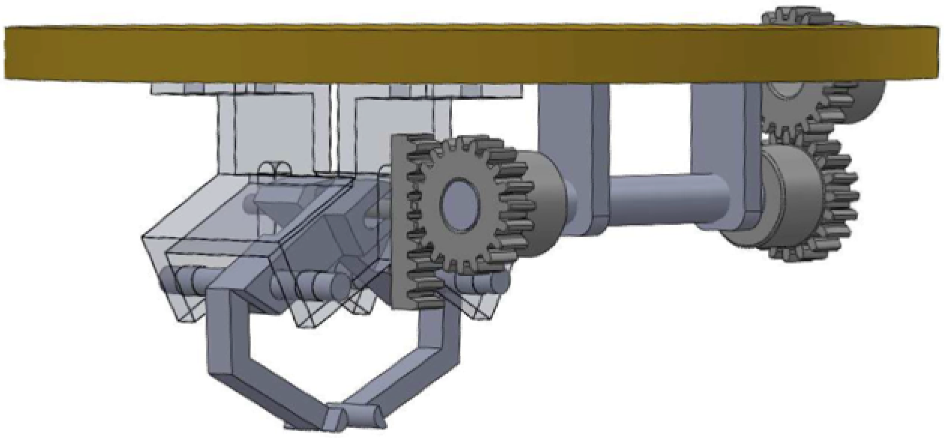

Figure 7: First prototype of a clamping mechanism that will attach onto the cold plate. Rotary feedthrough and silicon sample are not pictured.

efficieny of heat transfer. To understand the relationship between force and efficiency of heat transfer, I will stack weights on top of a silicon and copper interface and see how temperature gradient changes with increasing force.

- **Clamping Mechanism:** I will finalize my clamping mechanism design and send it off to be fabricated. Then, I will assemble the mechanism in the cryostat and verify that it can be accurately controlled by an external rotary feedthrough.

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