LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Technical Note **LIGO-Tv-** **-** 2017/07/12

First Interim Report: In-Vacuum Heat Switch

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1 Project Motivation

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 [3], [2].

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 Progress

I will be studying 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, as shown in Figure 1. 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. I started with a sandpaper of grain of 280, then 400, 600, 1000, 1500, and finishing with 2000. I laid the sandpaper on a flat surface, wetted the aluminum piece and then moved it against the sandpaper in circular patterns of different diameter to ensure a flat and smooth surface at the end. The next step was to solder four leads to each of the temperature sensors to monitor voltage and current and

Figure 1: Cryostat with a work plate at the bottom that will be used to measure the heat flow across different sample interfaces.

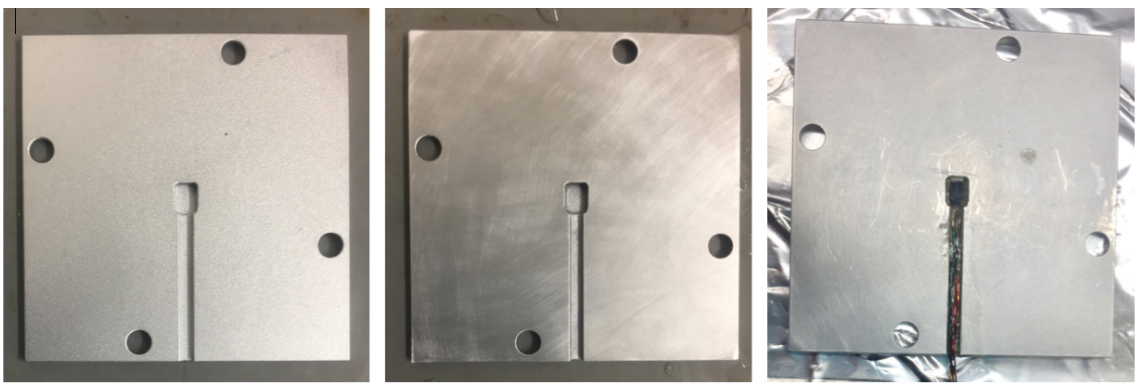

Figure 2: Left: temperature sensor plate before the sanding process. Middle: temperature sensor plate after sanding process. Right: temperature sensor glued into the plate with Lakeshore 7031 varnish.

then glue the RTDs into their aluminum plates. I used a Lakeshore 7031 varnish, which is thermally conductive and electrically insulating. See Figure 2. 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 3. 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, we 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 as shown in Graph 4. This is a fairly low resistance, and so for future experiments I will be switching to 500 Ω RTDs.

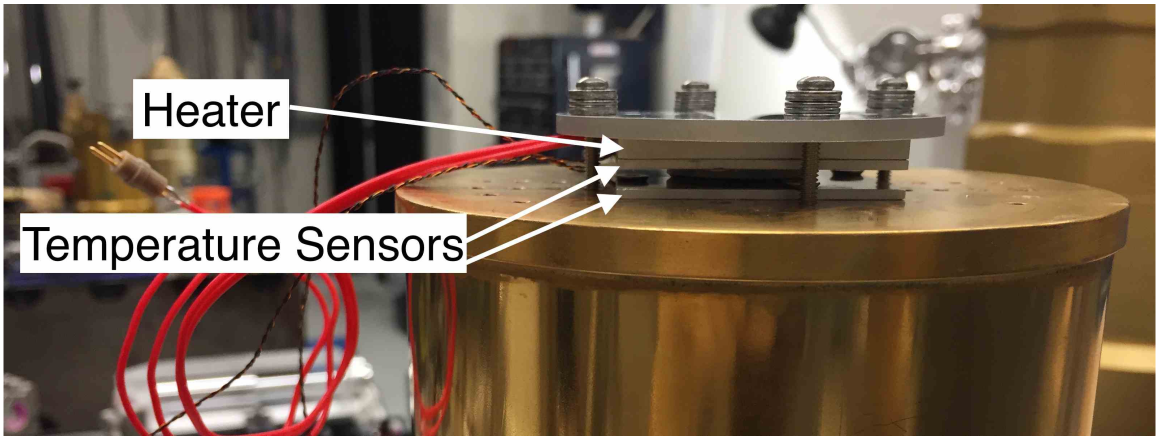

Figure 3: Assembly of the temperature sensors and heater on the workplate of the cryostat.

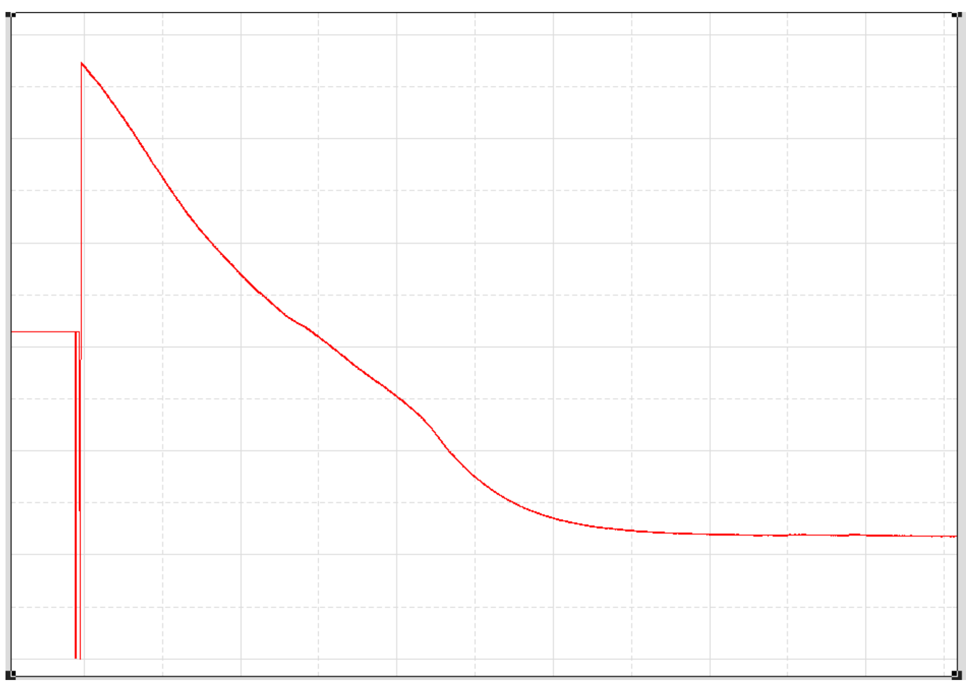

Figure 4: Time vs. voltage across the 100 Ω temperature sensor. Maximum and minimum voltages and resistances were 6V, 100 Ω and 1.2V, 24Ω respectively.

3 Future Work

Over the next four weeks I will be finalizing the set up of my experiment, including calibrating the 500 Ω RTDs and gluing them into the new aluminum plates. Once this set up is complete and the silicon samples have arrived, I will be able to perform different heat transfer measurements.

- **Optical Contacting:** I will create optically contacted silicon samples and vary the amount of time and pressure during the curing process. In the cryostat assembly, I can record the temperature gradient across each sample and understand how the efficiency of heat transfer varies with the different curing processes.
- **Clamping Force and Heat Transfer Relationship:** The amount of force that the clamping mechanism applies on the silicon samples could influence the efficiency of heat transfer. To understand this relationship, I will stack weights on top of a silicon sample and see how temperature gradient changes with increasing force.
- **Clamping Mechanism:** I am developing a clamping mechanism that can grab onto a silicon sample and then be disengaged after the sample is cooled.

References

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