LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Real-Time Temperature Monitoring of Coated Silicon Samples at 123 K

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1 Introduction

First of its kind, the Laser Interferometer Gravitational-Wave Observatory (LIGO) is the manifestation of over a hundred years of brilliant thinking, creativity, and the desire to illuminate more of the Universe than ever before. The foundations for this joint Caltech and MIT project truly begins in 1915 with Albert Einstein's theory of general relativity, in which the proposed existence of gravitational waves is established. For many, being able to capture and analyze these gravitational ripples directly would mean bringing in some of the most exciting cosmic events, such as the collision of black holes, for a little bit of a closer "look". Following a spark of development in this goal during the 1970's, the world's first full-scale laser interferometer intended to detect gravitational waves is installed by the year 1999.

LIGO is currently composed of two detectors, the first is located in Washington state and the second in Louisiana. LIGO also collaborates with Virgo, its European counterpart located in Italy. The detectors are essentially gigantic Michelson interferometers, with each arm being about 4 km in length. In addition to being the largest, LIGO's detectors are also much more complex and detailed than any other Michelson interferometer. Observable gravitational waves typically result from energetic cosmic events occurring a billion light-years ago and the amplitude of these resulting waves are small, even more so by the time they reach Earth. LIGO is designed to be capable of detecting these signals. In fact, LIGO is currently sensitive enough to detect displacements below $10^{-23}\frac{1}{\sqrt{Hz}}$ between 70 and 1000 Hz. However, this means that LIGO is also very susceptible to local vibrations that contribute irrelevant data. LIGO tries to achieve this balance between being sensitive enough to detect gravitational waves and ruling out disruptive noise by introducing heavy modifications to the Michelson interferometer.

2 Objective

The Michelson interferometer, simply put, consists of passing a laser beam through a beam splitter that sends the two resulting beams down each arm of the interferometer. At the end of the arms, the laser beams are reflected off mirrors back to the beam splitter where they are to join into a single laser beam. The light waves from this interference are captured by a photodetector. LIGO's interferometers have incorporated, among other modifications, Fabry Perot cavities in each arm to increase sensitivity. Fabry Perot cavities use two test masses with which the laser beam is partially reflected continuously.

Despite such efforts, LIGO's current use of fused silica fixed by suspension still allows for a significant amount of noise production that needs to be accounted for. In hopes of reducing thermal noise in future versions of LIGO, notably LIGO Voyager, it is theorized that coated silicon test masses cooled to 123 K can be utilized in place of the current fused silica test masses. The cryogenic test masses are expected to reduce disruptive noise from thermal fluctuations. This project aims to contribute some more information on the feasibility of a Cryogenic LIGO, which if executed successfully will improve its accuracy by two-fold. It is necessary to rigorously test how the material properties of coated silicon, cooled down to such an extreme temperature, will be affected. Efficient experimentation and data collection must be performed to determine the most suitable coating material for the silicon test masses.

To achieve the best testing conditions, there are a few possible complications that must be reviewed. The complication that this project will focus on addressing is the method of temperature monitoring while the silicon sample is being tested within the cryostat. Currently, resistance temperature detectors (RTDs) are being used to monitor the temperature of the environment in which the silicon disk is resting. However, there is a delay in the control loop. A successful result for this project will be to implement a method to provide real-time temperature readings to the control loop without disturbing the silicon disk being tested.

3 Approach

The set-up of this project involves a cryostat that encloses the following environment: the sample, a silicon disk, will rest upon a lens to minimize any possible restrictions imposed on the frequency response; an electrostatic drive will excite the silicon disk; a laser beam is produced directly onto the silicon disk; and a photodiode is used to measure the excitations. Additionally, several RTD's rest in the environment and provide temperature readouts. This project begins with a preparation period in which the student is to familiarize themselves with the RTD readout circuitry, data acquisition process, and current control loop. In order to do so, the student will be expected to build their own RTD circuit and perform readout testing in an isolated cryostat with a sample silicon disk. Once the student has successfully built the RTD circuit, set up the cryostat for readout testing, and built a control loop comparable to the currently used one, they will move onto exciting the silicon disk in the main cryostat for data acquisition. After the necessary frequency shift measurements have been collected, the student will work on incorporating this into the current control loop. The anticipated result will be real-time temperature monitoring for the silicon sample.

4 Project Schedule

Program Duration: June 19^{th}, 2018 - August 24^{th}, 2018 (10 weeks)

Week	Description
1	Prep week; learn about RTDs; learn data acquisition process and temperature control loop
2	Build RTD readout circuitry
3	Set up in isolated cryostat for testing
4	Build control loop; verify control loop, compare to current control loop
5	Use main cryostat; excite silicon disk for testing; compare frequency at room temperature vs. at 123 K
6	Measure frequency shift
7	Calibrate RTD
8	Incorporate frequency shift in control loop
9	Incorporate frequency shift in control loop
10	Project conclusion, final draft of presentation finished

References

[1] https://www.ligo.caltech.edu/page/timeline

[2] https://www.ligo.caltech.edu/page/facts

[3] https://www.ligo.caltech.edu/page/gw-sources

[4] https://labcit.ligo.caltech.edu/~ajw/LIGO_SURF02_3.pdf

[5] https://www.ego-gw.it/public/about/whatIs.aspx

[6] https://www.osapublishing.org/DirectPDFAccess/FC76D588-9647-F85B-E626C7738B1BAA82_164903/oe-16-14-10018.pdf?da=1&id=164903&seq=0&mobile=no