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- LIGO -
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INTERIM REPORT 1

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Quality Testing Optically Contacted Bonds

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Abstract

This project is aimed at determining the mechanical loss of optically contacted bonds in order to provide a quantitative measure of their quality. The eventual goal is to create an ideal optically contacted bond which minimizes damping and energy loss.

1 Background

Optical contacting uses intermolecular forces like the Van der Waals dispersion force to bond surfaces without glue. Optical contacting works by reducing the space between molecules of different surfaces. In order to reduce the space between molecules, the surfaces must be very flat and polished. Any diversity in the geometry of the plates would decrease the strength of the bond [3]. Once the surfaces are made flat and polished, they can be brought together, and the strength of the intermolecular forces will increase and essentially join the two surfaces into one. Though heat and pressure are known to increase the strength of the bond, little research has gone into characterizing optically contacted bonds [4]. This project will answer the question of what affects an optically contacted bond and how to make the most ideal bond.

2 Motivation

Optical contacting bonding has important implications for space equipment. Equipment in space relies on the presence of strong, light bonds. Adhesives may sometimes outgas and produce contaminants. Optical contacting bonds do not outgas and so could be one solution to the contaminant problem. Optical contacting bonds could also reduce the risk of failing that comes with having adhesives with different chemical and thermal properties. Optical contacting bonding is particularly useful in high sensitivity probes such as LISA and the LIGO Voyager when it is used to bond silicon, which has a small thermal expansion coefficient [3]. The ultimate goal is to use optical contacting in the LIGO Voyager to improve its sensitivity to gravitatonal waves.

3 Approach

This project focuses on testing the mechanical loss of an optically contacted bond within a silicon wafer. The silicon wafer will be given an initial impulse, and the ring-down will be measured. The quality factor (the inverse of the mechanical loss) can be obtained from a measure of how damped the response is.

The mechanical loss can be calculated using the following equation:

$\phi(\omega_0) = \frac{E_{dissipated}}{2\pi E_{stored}}$

where $\phi(\omega_0)$ is the mechanical loss at angular resonant frequency ω_0, $E_{dissipated}$ is the energy dissipated with each cycle, and E_{stored} is the total energy stored in the oscillating system [2].

The energies and resonant frequency can be found using finite element analysis [2].

In order to make the measurement of of the quality factor precise, the energy in the bond should be maximized while the energy in the rest of the system (the silicon and the clamp) should be minimized. An appropriate geometry should be selected for this purpose.

Gentle nodal suspension is an experimentally tested way of measuring the quality factor of a substrate [1]. In terms of beam stresses, gentle nodal suspension works by maximizing the bending and minimizing the shear stress. The sample is placed on top where the sheer stress is at its minimum, and the geometry used has a high normal stress compared to the shear stress. Since shear stress is generally much smaller than normal/bending stress in a cantilever, the highest contribution to the energy comes from the sample on top which experiences a high amount of bending stress. The issue with using this method for a bond is that the bond must be some distance from the top, so the highest contribution will come from whatever is above the bond. Additionally, gentle nodal suspension fails at cryogenic temperatures.

Three different cantilever geometries were analyzed in order to find a suitable energy ratio between the bond and the rest of the silicon wafer. The ratio between shear and bending energy was estimated for the geometries shown in figure 1 using the following equations where M is the moment, I is the moment of inertia, l is the length, E is young's modulus, K is a constant that depends on the geometry (1.11 for circular and 0.5 for rectangular sections), V is the traverse shear force, G is the modulus of rigidity, and A is the cross sectional area.

$constant\ bending\ energy = \frac{M^2 l}{2EI}$

$constant\ traverse\ shear\ energy = \frac{KV^2 l}{2GA}$

A tapered cantilever was selected to maximize shear stress and minimize bending. In a tapered cantilever, the bond in the middle will experience maximum shear stress, and the whole cantilever will have its bending stress minimized. However in general, the bending stress in a cantilever is greater than the shear stress. The actual ratio will be determined using finite element analysis.

4 Data Acquisition

In order to measure the oscillations of a cantilever, an optical lever was setup as in figure 2.

An initial test of the setup was conducted by gently knocking on the top of the vacuum chamber. The oscillation of the laser was measured on the oscilloscope (figure 3, figure 4), and the following analysis was performed to find the quality factor.

The signal was modeled in python using the scipy curve fit function and the following equa-

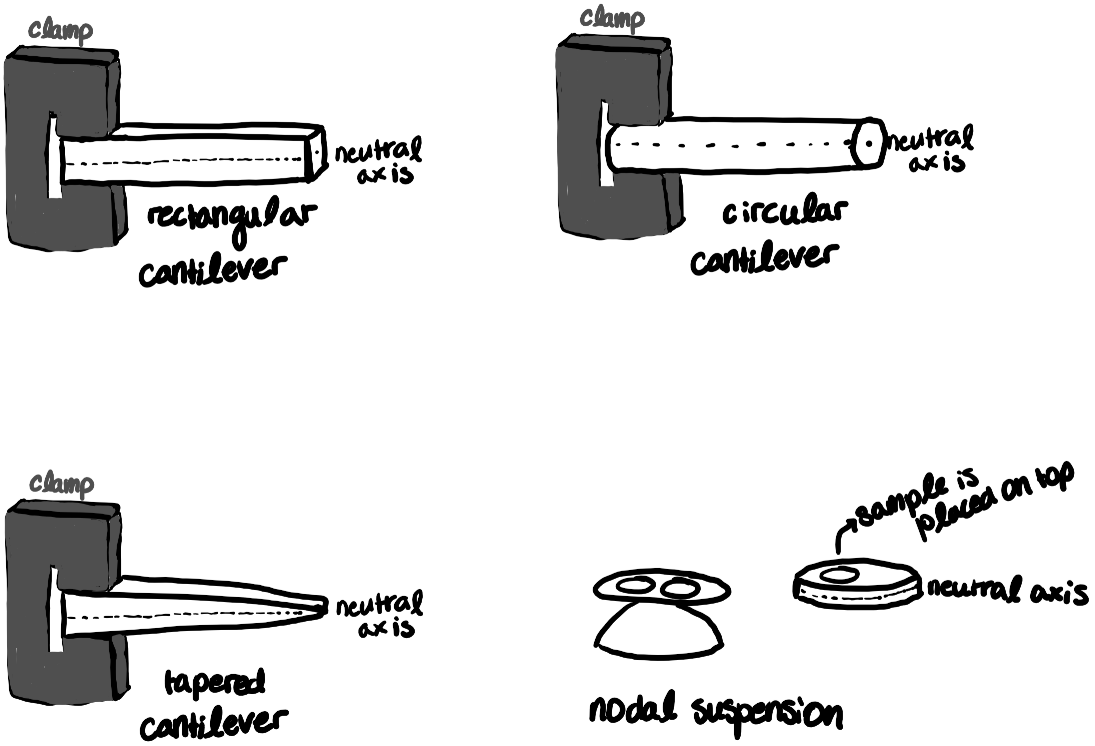


Figure 1: A diagram of three sample cantilever geometries and the setup for gentle nodal suspension.

tion where ω is the angular frequency, U_0 is the initial energy, ϕ is the phase shift, and Q is the quality factor.

$$U(t) = U_0 \exp -\frac{\omega}{2Q} t \cos \omega t \sqrt{1 - \frac{1}{4Q^2}} + \phi$$

As can be seen in figure 5 and figure 6, the frequency was not very well resolved, so the procedure was repeated with a signal amplifier in order to determine if the suggested value for the frequency was a good fit. From this signal (figure 7), a frequency was obtained which generally agreed with the frequency initially guessed by the fit (figure 8).

5 Conclusion

The experiment was setup, and a silicon Q measurement (table 1) was obtained. A special geometry was suggested for determining the Q of the bond. Obstacles were encountered when determining an optimal experimental setup and fitting the data for a test run of the setup and were overcome by diving deeper into the literature and refining the experimental setup respectively. The next steps are to model the energy of the suggested cantilever geometry, order the silicon wafers, and conduct the experiment with our samples.

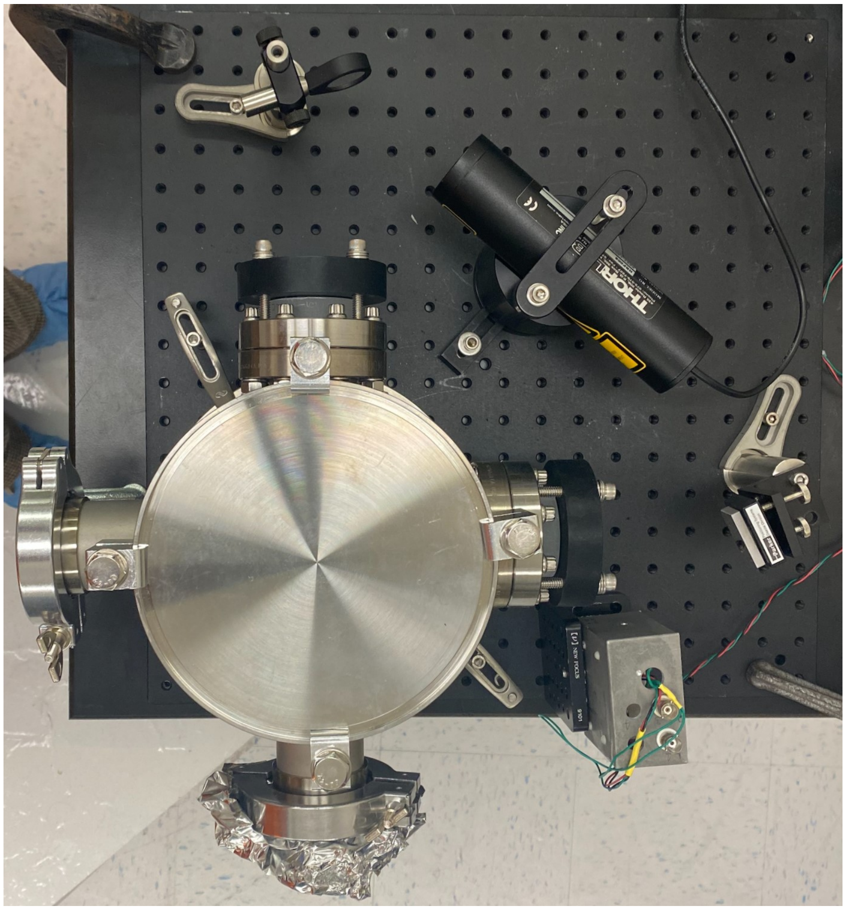
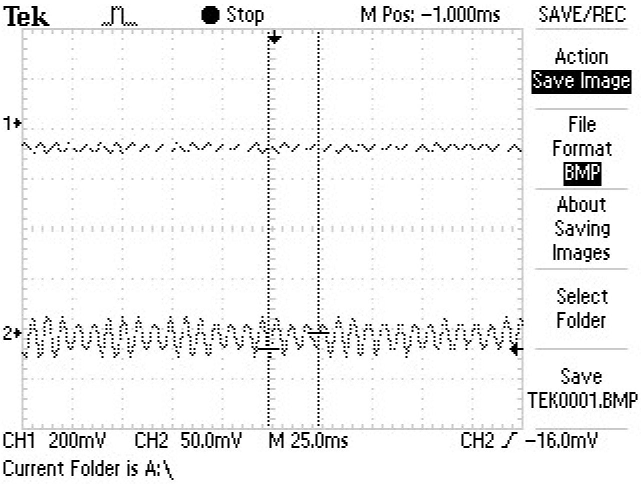


Figure 2: Experimental setup for measurement of ring-down. Notice the laser beam hits a mirror and is then directed into a vacuum chamber containing a silicon rectangular cantilever which is clamped. The beam then hits another mirror and is directed into a photo diode connected to a power supply and an oscilloscope.



M Pos: −1.000ms

CH1 200mV CH2 50.0mV M 25.0ms CH2 −16.0mV

Current Folder is A:\

Figure 3: Oscillation of the laser after knocking the cantilever.

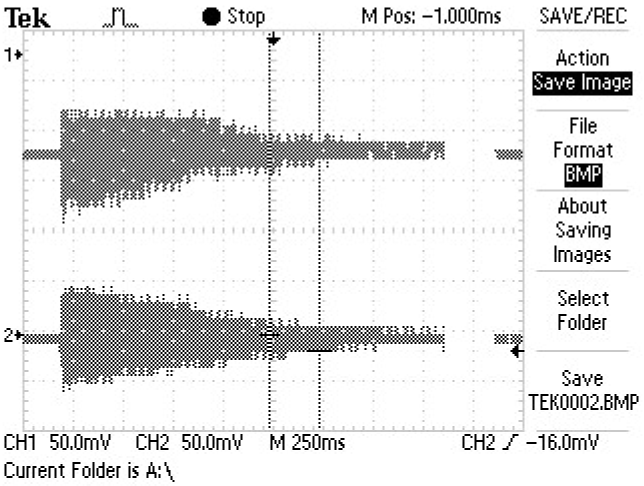


Figure 4: Oscillation of the laser zoomed out.

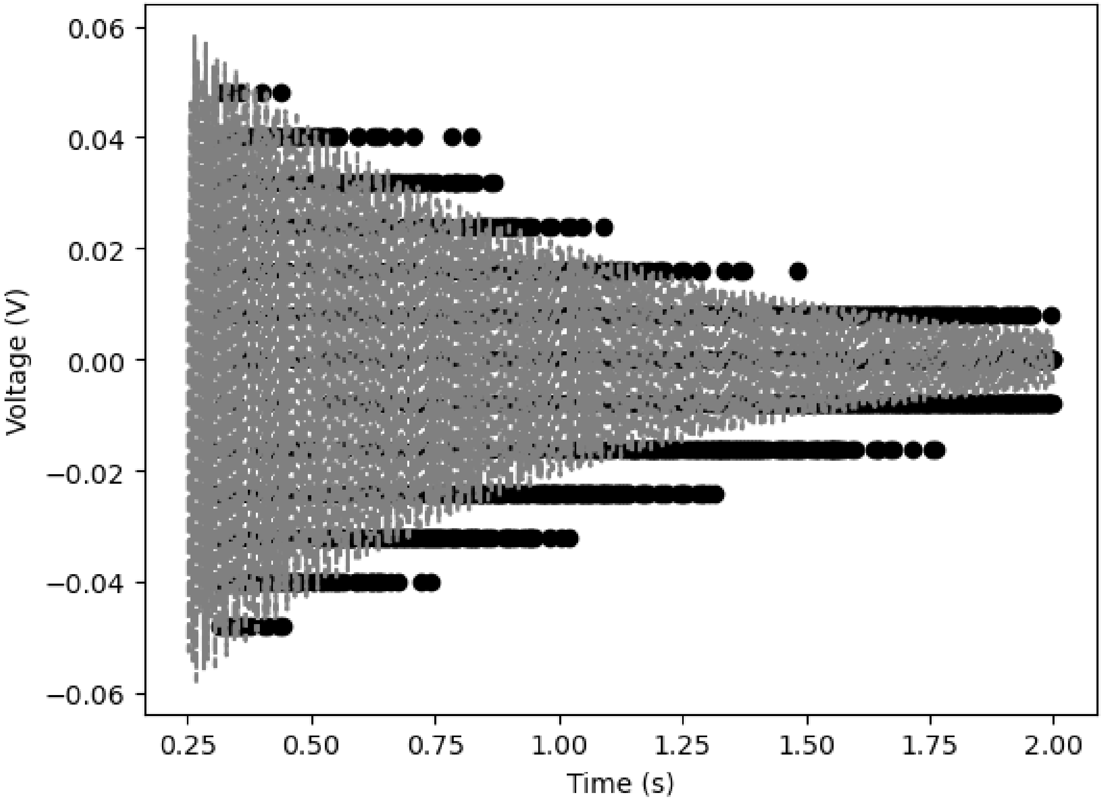


Figure 5: Graph of time (s) vs. voltage (V) with the fit. Notice that it is hard to decipher the individual peaks on the graph of the data. This is due to insufficient data points.

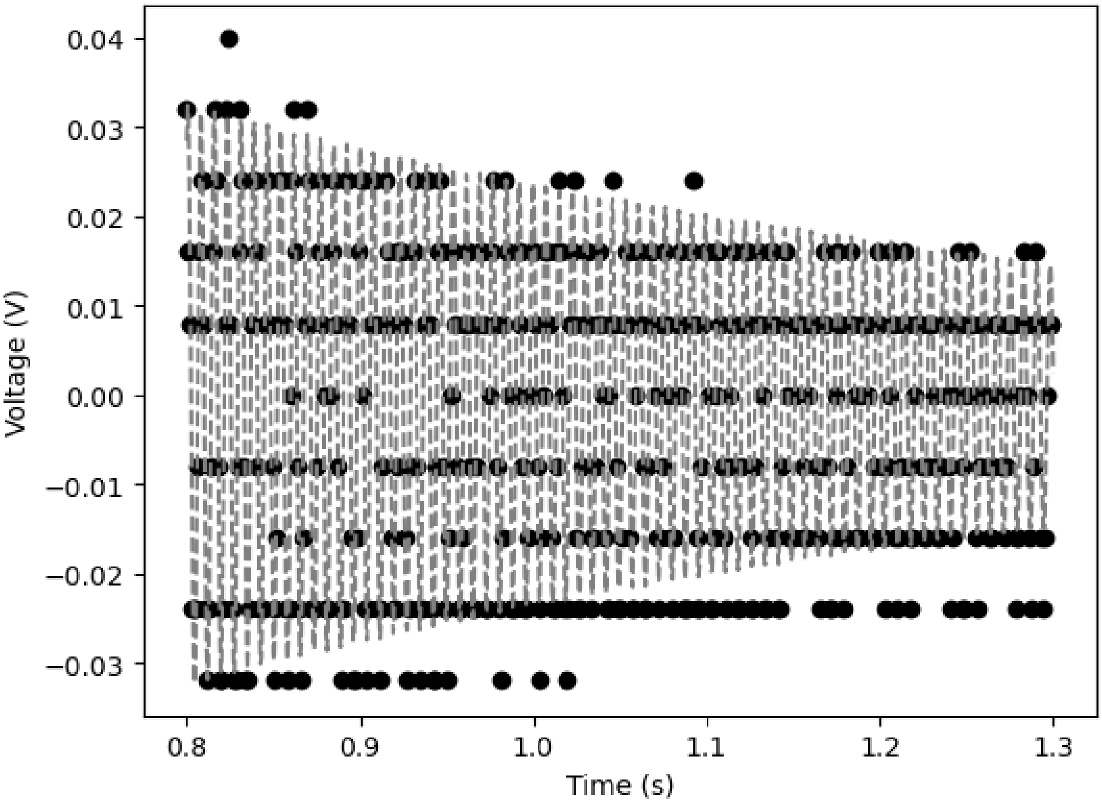


Figure 6: The same fit as in figure 5 but on a smaller section of data.

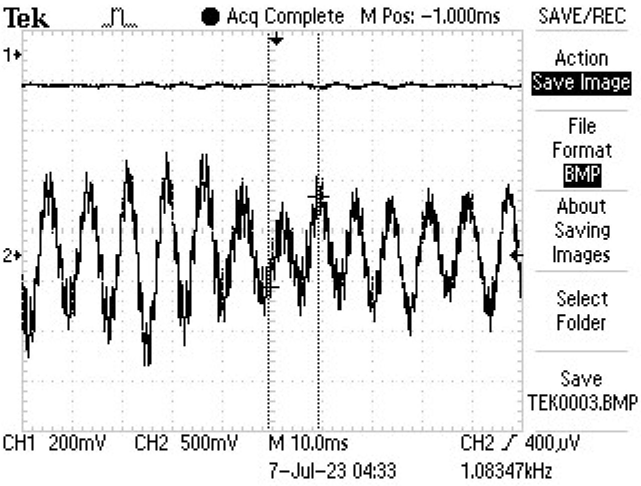


Figure 7: Oscilloscope signal of the laser oscillation after adding a signal amplifier.

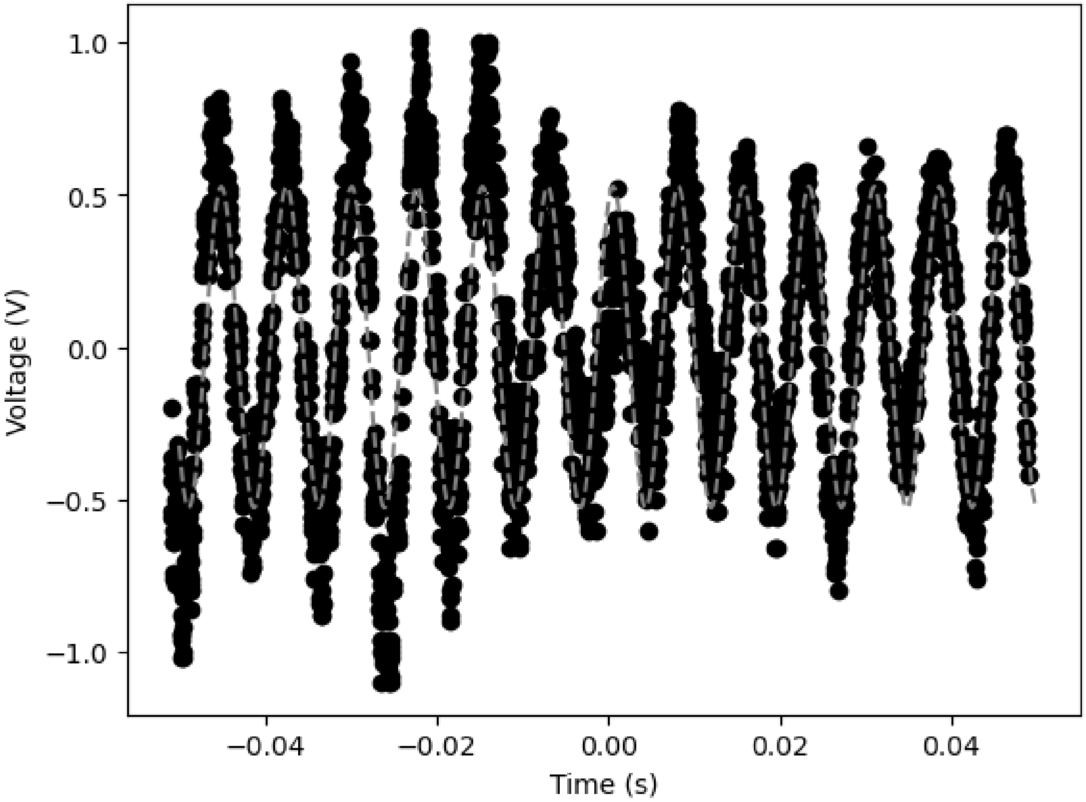


Figure 8: A fit of the laser oscillation after amplifying the signal. Notice the fit clearly lines up well with the frequency of the data points.

Table 1: Fit parameters obtained from measured laser signal.

Signal	U_0	ω	ϕ	Q
Initial	-8.487e-02	8.200e+02	4.115e-01	2.935e+02
Zoomed	-1.159e-01	8.206e+02	-4.198e-01	2.586e+02
Amplified	-8.487e-02	8.200e+02	4.115e-01	2.935e+02

References

[1] Cesarini, E., Lorenzini, M., Cagnoli, G., Piergiovanni, F. (2009). A gentle nodal suspension for measurements of the acoustic attenuation in materials. *2014 IEEE Metrology for Aerospace (MetroAeroSpace)*, 528-532.

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