LIGO-M070258-00

Attachment SUS to the Memorandum of Understanding LIGO-M050315-00 between the Hobart & William Smith Colleges LIGO Group (HWSLG) and the Laser Interferometer Gravitational Wave Observatory (LIGO)

For The Period

August 15, 2007 - August 14, 2008

This Attachment SUS to the Memorandum of Understanding LIGO-M050315-00 defines the role of the Hobart & William Smith Colleges LIGO Group (HWSLG) as a Member of the LIGO Scientific Collaboration (LSC), and a member of the Isolation/Suspension/Thermal Noise Development Group (ISTNDG). The period of performance for the activities in this Attachment is from August 15, 2007 - August 14, 2008.

1. Collaboration

The Isolation/Suspension/Thermal Noise Development Group (ISTNDG) is the scientific collaboration for defining and developing instruments in optics for use in advanced subsystems for the initial LIGO interferometers or in entirely new advanced interferometers. MOU Attachment SUS defines the roles and responsibilities of workgroups in this development group.

2. Participation

During the period August 15, 2007 - August 14, 2008, the members of HWSLG will participate in in ISTNDG in the following areas:

a. Coating Losses

The Coating Research Program is the one remaining technical research program for which new advances might lead to significant improvements in the Advanced LIGO sensitivity. Coating thermal noise is the limiting noise source in the most sensitive region of the Advanced LIGO's projected spectrum. Thus, even a modest improvement in the coating thermal noise could lead to substantial increase in the event rate, since the increase in the event rate goes as the cube of the sensitivity increase.

The HWS group is one of four groups performing resonant Q measurements on coating sample. Having two annealing ovens, our lab is also the primary facility for testing the effects of annealing on coating mechanical loss.

The initial goal of the Coating Program was to understand the source of the noise in the current LIGO coatings. We discovered that the loss was primarily in the high index, tantala layers rather than the low index, silica layers (see Penn, et al., Classical and Quantum Gravity 20 (2003) 2917-2928). While the proportion of loss ascribed to those two materials has changed slightly due to the direct measurement of the Young's modulus by Sheila Rowan, the essential conclusion stands. Thus our research has focused primarily on finding a high index coating material with low mechanical loss. We have explored doping the tantala layer and using other high index dielectrics instead of tantala. At present the best high index material is titanium-doped tantala (see Harry, et al., Class. Quantum Grav. 24 No 2 (21 January 2007) 405-415). In addition, we have seen that the loss in low index coating materials is much higher than what is measured in the corresponding bulk materials. Since we have a good understanding of the loss in these low index materials (silica and alumina) there is interest in understanding the source of the excess loss that results from the process of forming coating layers (see Crooks, et al., Class. Quantum Grav. 23 No 15 (7 August 2006) 4953-4965).

During the past year, our group has examined the dependence of annealing on low index coating materials, including silica/alumina coatings and silica coatings. The loss in the silica/alumina coatings is much higher than the loss of the corresponding bulk material. Is this higher loss due to residual stress in the coating, voids in the materials, both or something else? We tested the contribution of loss due to stress by measuring the loss as a function of peak annealing temperature. Annealing the sample to 600°C significantly reduced the loss, but annealing to 800°C and above caused the coating to breakdown. It became frosty and appeared to loose adhesion between the layers. As would be expected, the loss in the damaged coating was significantly worse. Thus there was some loss associated with residual stress that could be reduced through annealing, but the overall loss in the coating was still too high to be useful for Advanced LIGO.

Silica will be the low index coating material used for Advanced LIGO because of its low mechanical loss and good optical properties, and because it matches the substrate material, thus minimizing any losses at the interface. However, the loss in a silica coating layer is much higher than the loss in a bulk fused silica sample of similar dimensions. To better understand this excess loss, the Coating Group decided to study the loss in coatings consisting only of silica. Two silica coating samples were produced by CSIRO and were send to our lab where we measured of the loss as a function of peak annealing temperature. At present, half of the data has been collected. We expect this experiment to be completed sometime this fall, at which point we plan to write a paper on the combined silica and silica/alumina results.

Currently the Coating Group is formulating a new research plan in order to accelerate the rate at which we measure samples and thus learn about the coating loss. The proposed plan would focus our research into three areas: doped tantala/silica coatings, silica coatings, and other high-index coatings.

The current best coating, slated for Advanced LIGO, is a titania-doped tantala/silica coating. In the past year, LMA has demonstrated that undisclosed variations in the coating process can produce meaningful reductions in the loss. In addition CSIRO has shown that doping with silica causes a reduction in the loss, although no reduction in the thermal noise since the Young's modulus is also reduced. Thus the first thrust of the new coating research plan is continued research with doping methods and materials.

The second focus is understanding the loss of silica coatings and why it is higher than the loss in bulk fused silica.

Finally, there are other high index coating materials whose mechanical loss has not been measured. We may get lucky and find that the loss is much lower than titania-doped tantala. The best candidate appears to be hafnia, which is used in the National Ignition Facility because it is an extremely durable, low absorption, low scatter coating. Hopefully it also has low mechanical loss.

For the next year our group plans to complete the annealing study on the single-layer silica coatings, to write up these results, and to make a similar set of measurements on hafnia/silica coatings.

b. Suspension Design for Advanced LIGO

Not Applicable

c. Other Contributions

The performance of Initial LIGO is something about which our collaboration should be both delight and a little amazed. Given some of the assumptions that went into the SRD, it is amazing how well the current sensitivity curve matches the prediction. In the frequency band of 40–100 Hz there are several contributing noise sources and the sensitivity in this region can fluctuate with conditions in the interferometer. Yet at its minimum the noise in this band appears to have a lower bound that has an $f^{-2.5}$ dependence, which is the frequency dependence of suspension thermal noise. Moreover, the suspension thermal noise included in the Initial LIGO noise budget is calculated from measurements of the wire loss and not from a complete optic suspension. Thus sources of excess loss may have been overlooked.

Enhanced LIGO is a plan to upgrade certain systems in Initial LIGO over an 18 month period with the goal of increasing the sensitivity by about a factor 2. Then Enhanced LIGO would be able to collect data for about 20 months before the shutdown for the Advanced LIGO installation. However the Enhanced LIGO noise estimate assumes that the suspension thermal noise is at or near the level predicted for Initial LIGO. Since the suspension thermal noise is most prominent in the central region of the sensitivity curve, small variation in the suspension thermal noise could greatly impact the estimated event rate for Enhanced LIGO. Therefore in the Fall of 2005, after earnest motivation by Rai Weiss, Gregg Harry and I began a program to measure the suspension thermal noise in Initial LIGO, to locate sources of excess loss, and to design an improved suspension for Enhanced LIGO.

At HWS we have an experimental set-up to measure the Young's modulus and the mechanical loss for a free or tensioned wire or ribbon. At MIT, we have used an Initial LIGO pathfinder optic and a spare large optics cage to constructed a large optic suspension that is identical to the set-up used at the sites. These measurements allow us to separate out each contributing source of loss in the suspensions. We can also compare our results measured using the Pathfinder optic with comparable measurements made at the observatory.

Our results are as follows. In a free LIGO suspension wire, the mechanical loss is about $\phi = 1\times10^{-4}$. When the wire is tensioned to the same stress as is used in Initial LIGO, the loss increases to $\phi = 3\times10^{-4}+1.7\times10^{-7}f$, where f is in Hz. Given that this loss is dependent on the method of wire clamping, it is believed that this excess loss is largely due to the clamp. The lowest loss in a tensioned wire used a clamp from the Virgo suspension. Finally, when the wire is allowed to pass over a standoff, the loss increases to $\phi = 2.4\times10^{-3}+1.3\times10^{-6}f$. Thus the largest source of excess loss appears to be rubbing friction of the wire on the standoff. This hypothesis is in line with measurements of violin mode Q's measured at the sites. Gregg Harry made resonant Q measurements by driving the optic using the OSEMs and recording the ringdown in the time series. David Malling measured the Q by fitting the line shape in the power spectrum of the thermally-excited violin modes. Both sets of measurements found that the Q varied from run-to-run and wire-to-wire. However the shape of the distributions was similar and the lower amplitude excitation produced lower loss.

To reduce the loss from the standoff we have replaced the cylindrical silica standoffs with prisms of various materials. Reducing the contact area between the wire and the standoff reduces the loss. The best results were from a prism of BK7 in which the suspension wire was able to carve out a small groove. In that case the loss was $\phi = 3.7\times10^{-4}$.

Moving forward, we have designed a new set of prism standoffs made of fused silica and of sapphire with narrow grooves to capture and constrain the wire. We have also designed a new set of clamps that are based upon the Virgo clamps except that the bearing surfaces are sapphire and the clamp does not plastically deform the wire.

Finally we have been exploring the use of ribbons to suspend the optics. Ribbons have two major benefits over wires: the thermoelastic loss peak is shifted to high (4–5 kHz) frequencies away from the region of high sensitivity, and the dissipation dilution factor is increased thereby reducing the suspension thermal noise. If the standoff and clamp losses were minimized, the use of ribbons could significantly reduce the suspension thermal noise in Enhanced LIGO.

(See http://www.ligo.caltech.edu/docs/G/G070553-00, submitted to LSC meeting wiki though not uploaded to DCC as of 7 August 2007).

3. Resource Sharing

The LIGO Laboratory will contribute resources including allocation of appropriate scientific and engineering personnel, research facilities, and funding in support of the effort in Item No. 2, as indicated below.

a. Research accommodations for HWSLG group members while on LIGO research assignment at any LIGO Laboratory site.

   Not Applicable

b. Access to LIGO data through established LSC channels in support of this work.

   Not Applicable

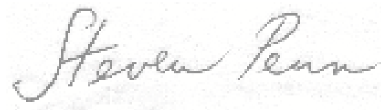
4. Coordination and Reporting

HWSLG will perform research within the structures established by the LIGO Laboratory and the LSC where appropriate. n particular, activities described in Item 2 will be carried out within the Isolation/Suspension/Thermal Noise Development Group of the LSC.
This includes keeping the Group leaders informed of activities and plans, reporting to the group at meetings and telecons, and through technical documents submitted to the LIGO Document Control Center.
In addition, an annual report will be submitted with the update to this Attachment, giving a summary status on research by topic as indicated in Item No. 2, including progress against the milestones if any, significant accomplishments such as new insights/discoveries or publications, issues of concern if any, and an indication of invested time.
This Attachment will be updated at least annually with a plan of activities for the succeeding one-year period. These documents will be due one month before the close of the period of performance under this Attachment.

5. Computer Code

All computer code delivered to the LSC under this Attachment must be developed in consultation with the LSC Data Analysis Software Working Group (DASWG) and archived, documented and reviewed as determined by that group.

Jay Marx
LIGO Laboratory Director



Steven Penn
Principal Investigator(s)
HWSLG

David Reitze
LSC Spokesperson