Exploring Coating Thermal Noise via Loss in Fused Silica Coatings

Steven Penn, for the LSC Coating Collaboration

Hobart & William Smith: Steve Penn, Jacob Podkaminer, Christine Luongo *Caltech:* H. Armandula, E. Black, E. Gustafson *Embry-Riddle:* A. Gretarsson *Glasgow:* E. Chalkley, R. Bassiri, J. Hough, I. MacLaren, I. Martin, R. Nawrodt, S. Reid, S. Rowan, A. L. Woodcraft
MIT: G. Harry *Stanford:* M. M. Fejer, R. Route, A. Markosyan

(This Document can be accessed through DCC # LIGO-G0900600.)

Abstract

Thermal noise in the test mass mirror coatings is a leading noise source for advanced interferometer gravity wave detectors. Reducing this noise to a point at or below the quantum limit should result in a significant gain in the detector's sensitivity and its estimated count rate. The coating thermal noise arises from the mechanical loss (dissipation) in the coating materials, predominantly the high-index material.

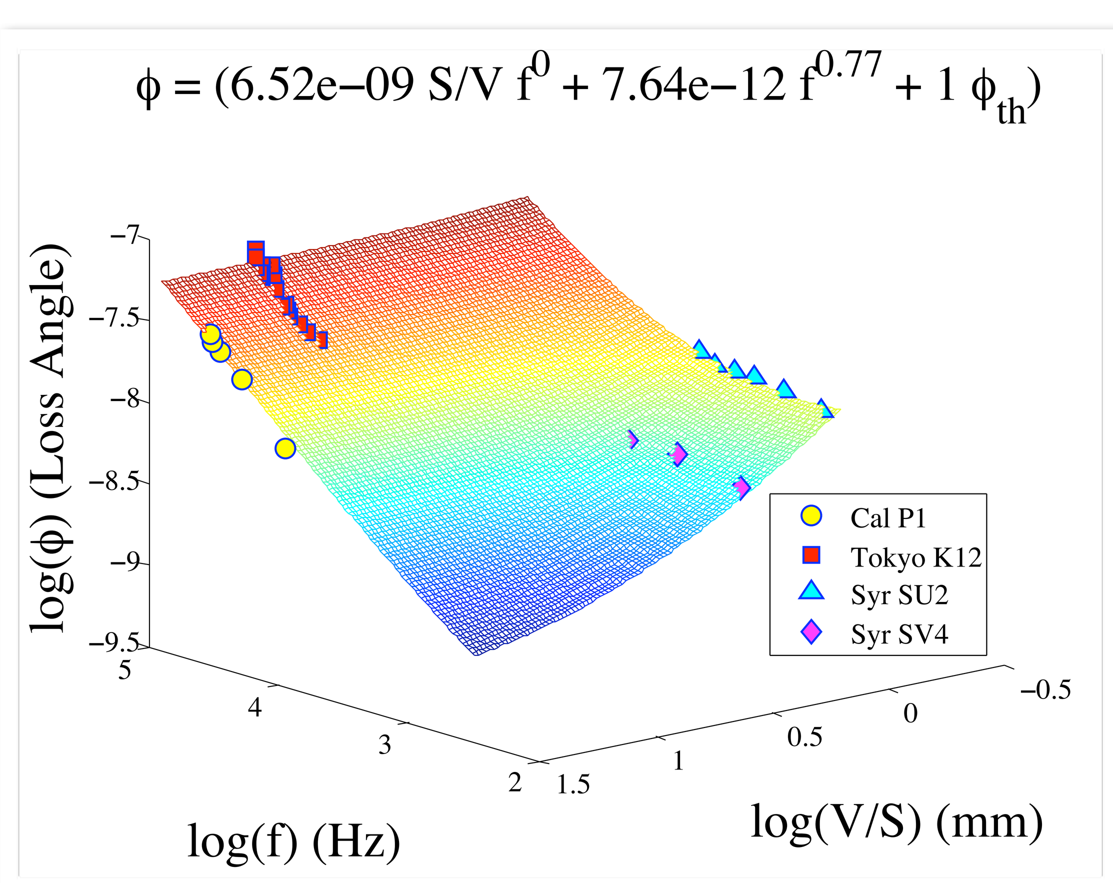
The mirror coating currently planned for Advanced LIGO is a multilayer dielectric consisting of silica (low-index) and titania-doped tantala (high index). Initial LIGO's high index coating is pure tantala. Many variations in doping and preparation were explored in an attempt to lower the mechanical loss in this material. Titania doping was found to reduce the loss by about 30%, a factor only marginally acceptable for Advanced LIGO.

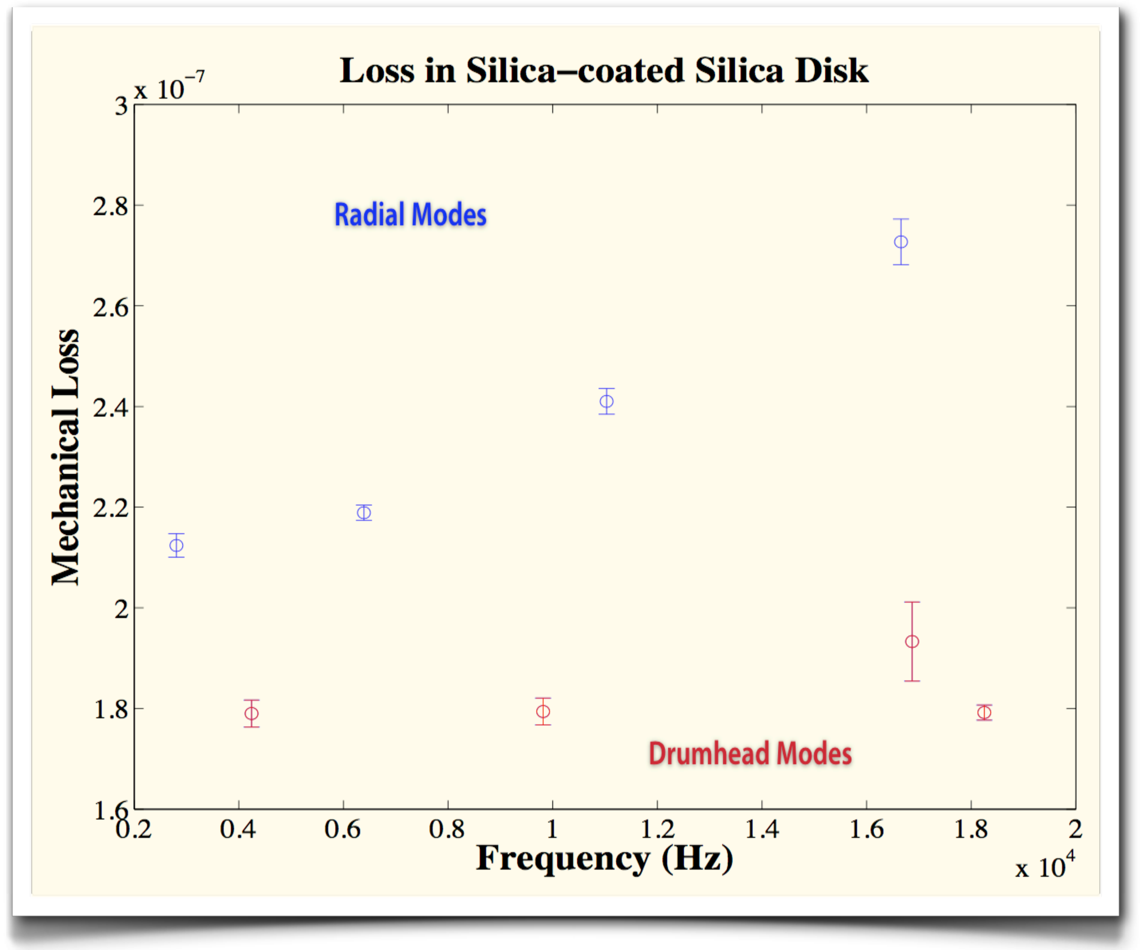
While the noise contribution from the silica coating layer is much less than from the high-index layer, its loss is higher than in the bulk material. The thermal noise research performed for the Advanced LIGO test mass substrate selection has given us a detailed understanding of this material. However we did not understand why the fused silica coatings had a higher loss than bulk fused silica. We believed that by exploring the source for this excess loss we may gain insight into the excess loss in the high index material.

Experiment

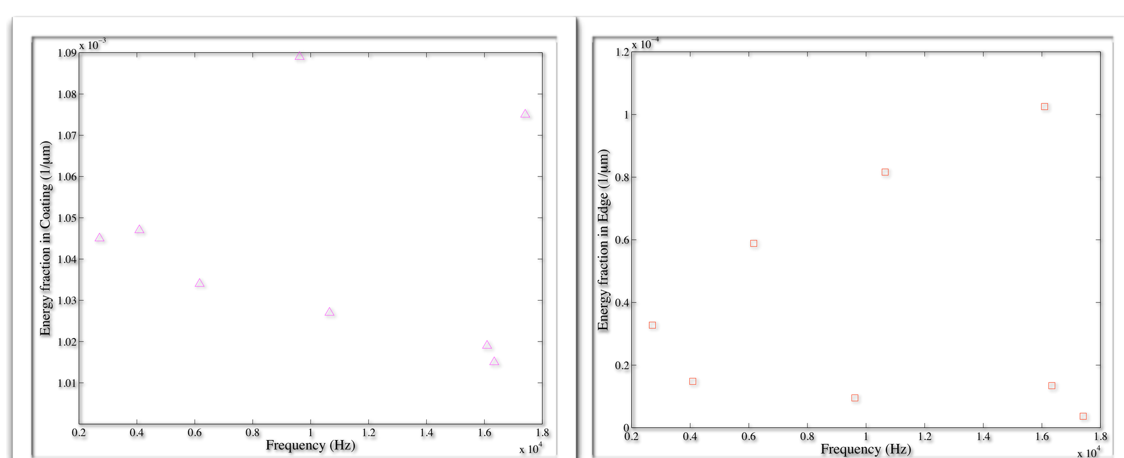
Fused silica has three main sources of mechanical loss: loss in the bulk material, loss in the surface, and thermoelastic loss, which is negligible except for thin geometries. [Below is shown a plot of the measured minimum loss in fused silica and the model of the loss from these three sources. Note that the loss coefficients are highly dependent on the specific type of fused silica]. Our research has shown that to attain the minimum loss, fused silica must be annealed and allowed to cool slowly. This process allows the molecules to relax into their lowest energy state and minimizes the inherent stress in the material. Thus when the material undergoes deformation, there is less dissipation because a smaller percentage of the bonds break or transition to another state.

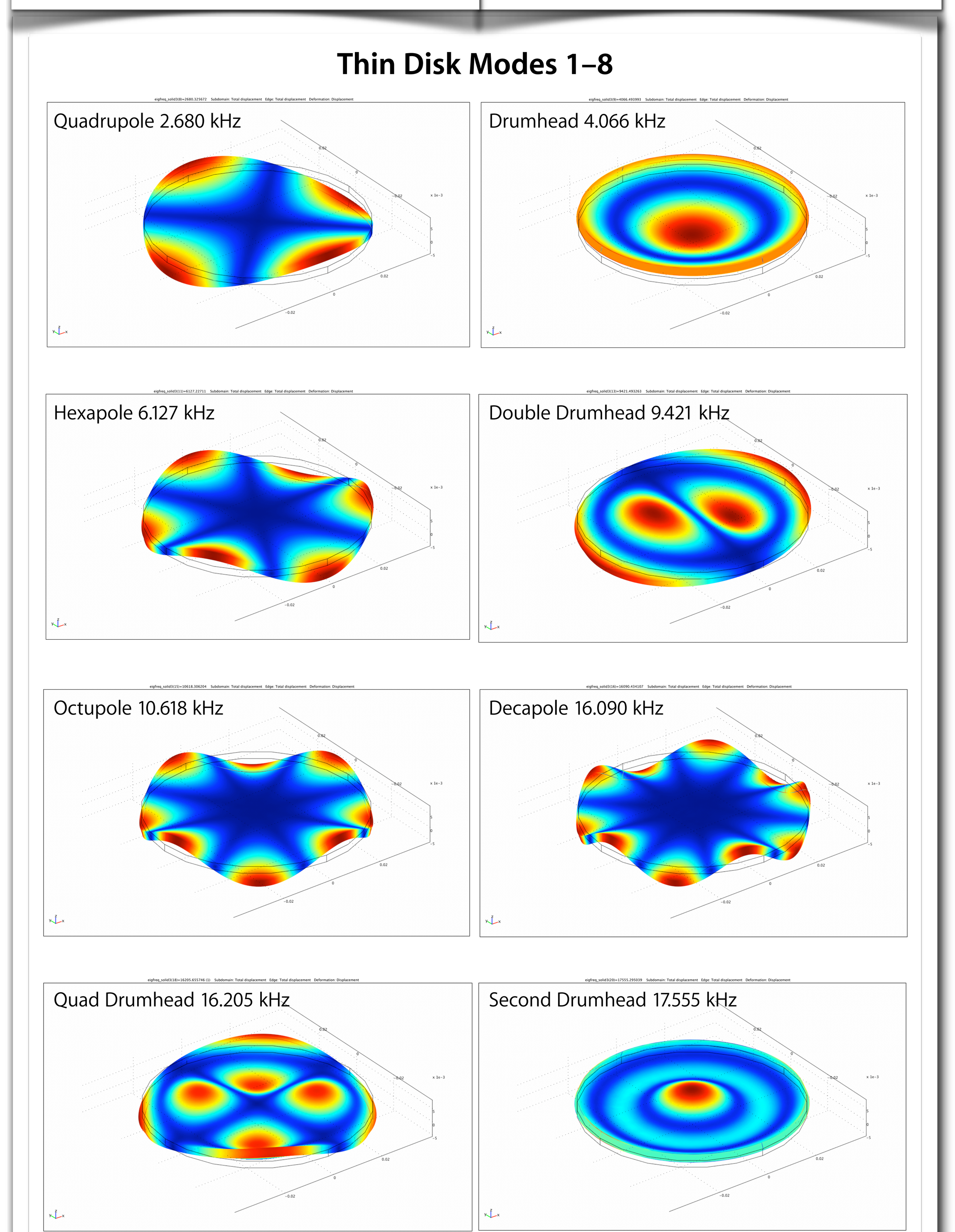
When an ion beam sputtered coating is deposited, the molecules are fired onto the surface, leaving the coating under considerable stress. We hypothesized that the excess loss observed in silica coatings resulted from the residual stress that remained after the coating undergoes a low temperature anneal (300–600 C). This experiment measured the loss in two fused silica coatings (0.5 and 2.0 microns) as the samples were annealed at successively higher temperatures, ranging from 600 C to 1100 C.

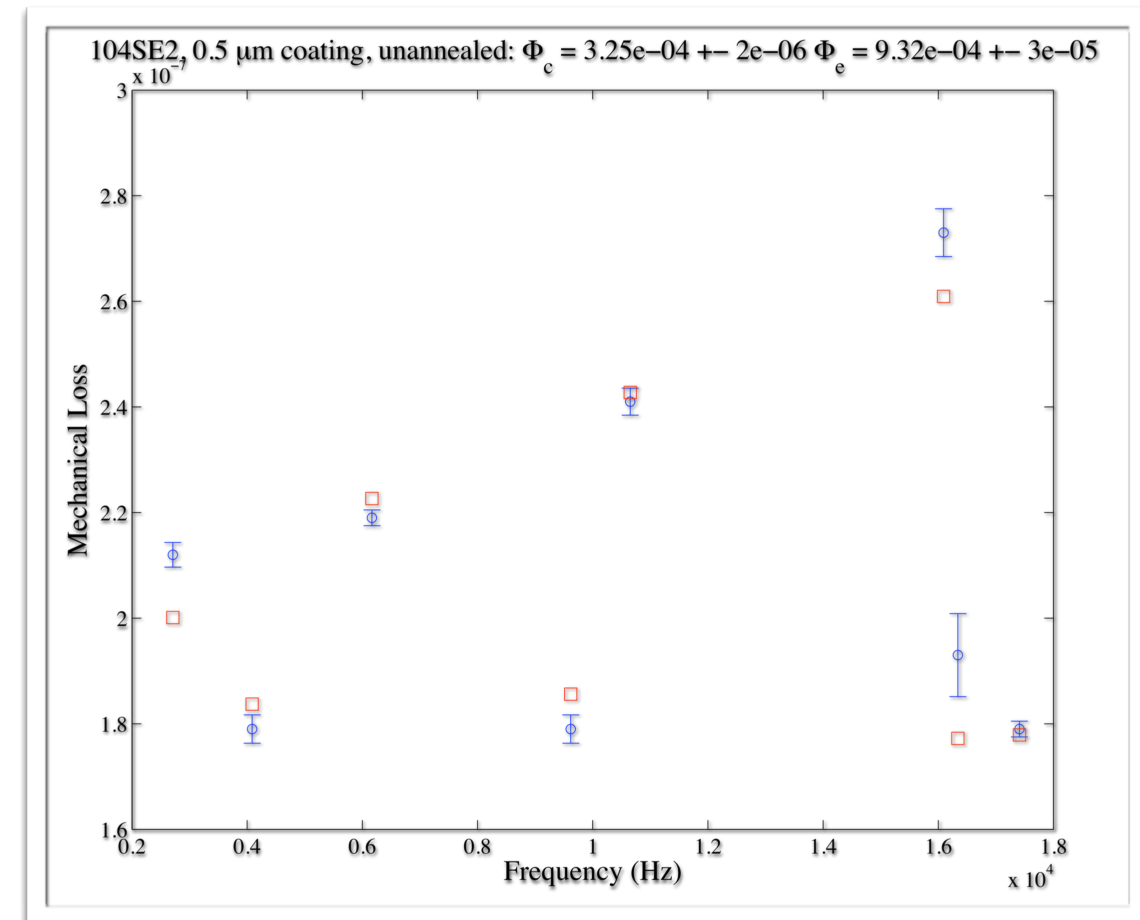




The substrates were fused silica disks (3 inch diamere x 0.1 inch thick). The initial measurements revealed a clear separation in the results between modes with radial nodal lines (#1,3,5,6) and modes with circular nodal lines (#2,4,7,8). As shown in the plot on the right below, the energy fraction stored in the edge (or barrel) of the optic, closely matches this pattern. The





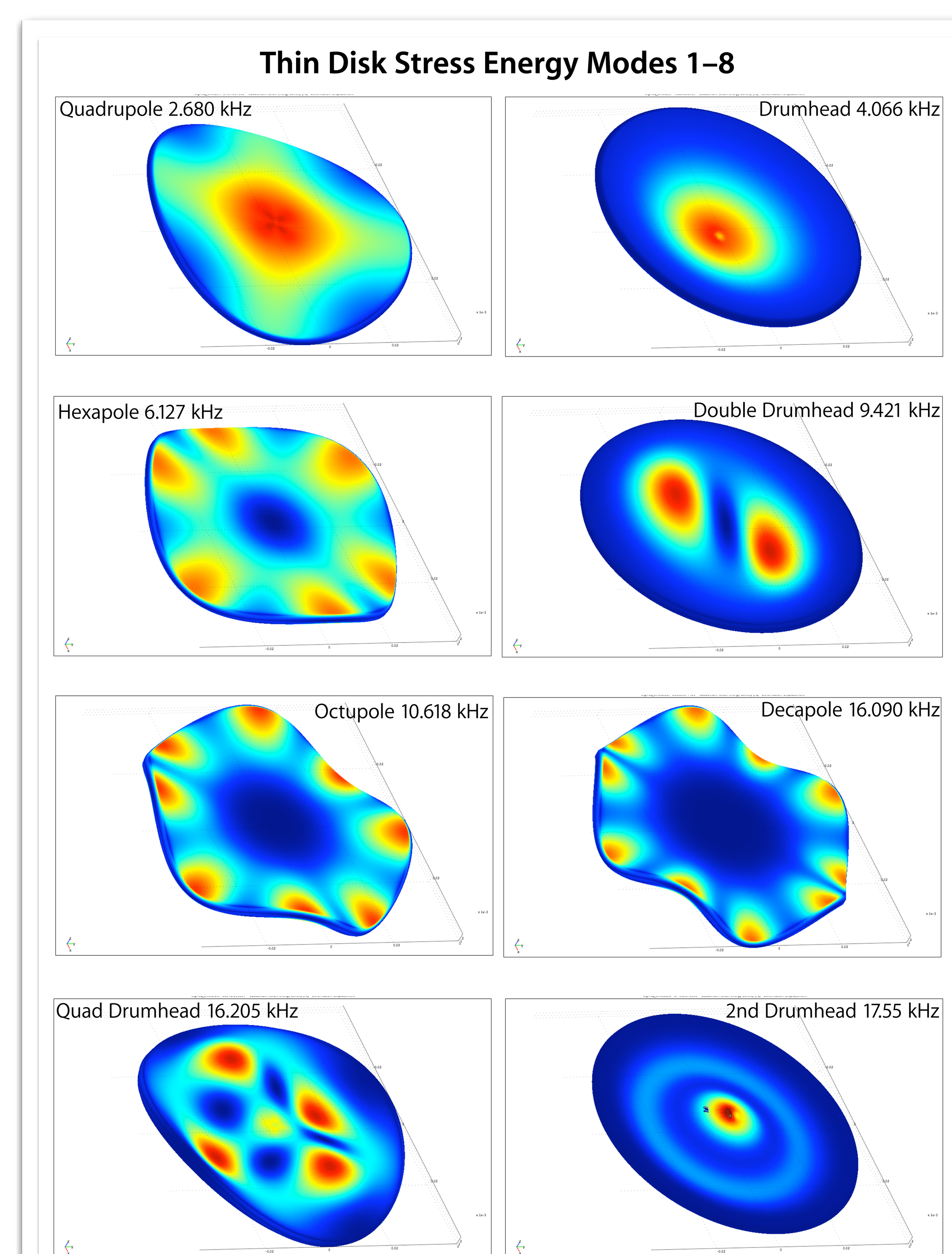


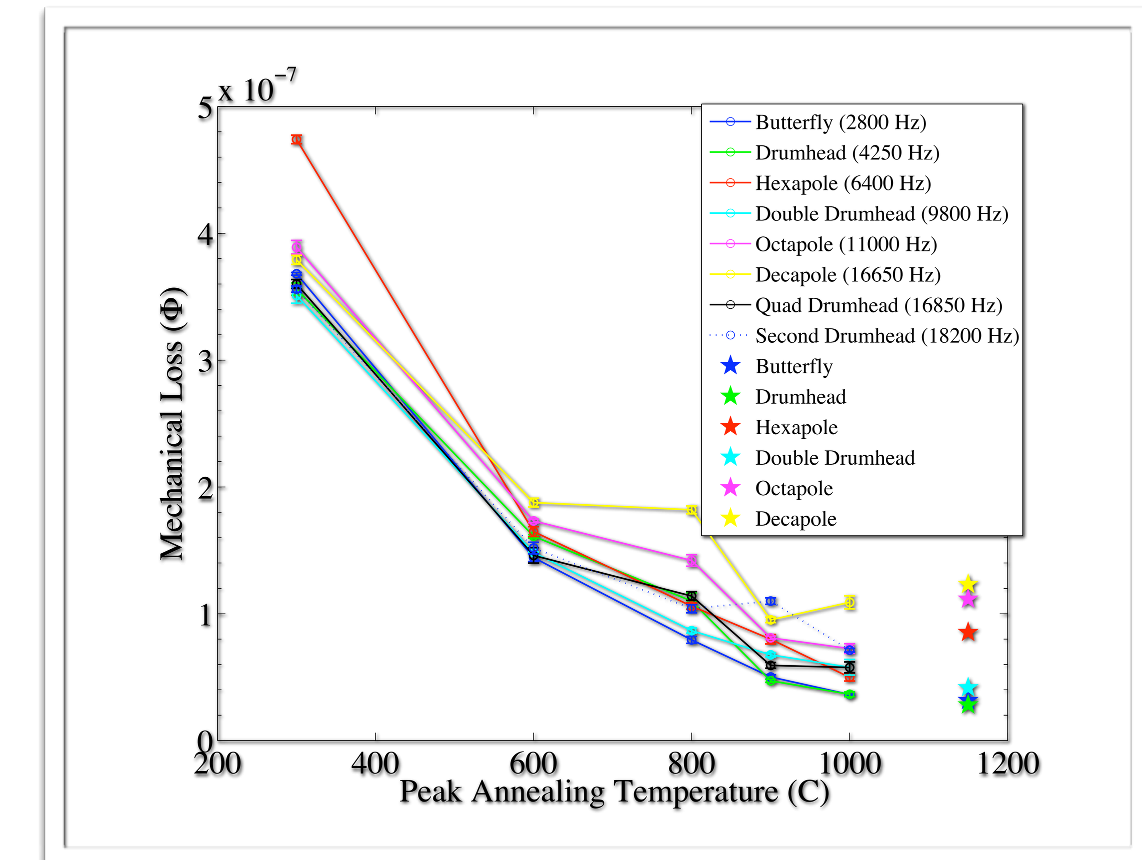
substrates have a higher-loss, commercial polish on the barrel and a super-polish on the face. This necessitated including the barrel loss in the fit to our data, as is shown in the loss function below:

$$\Phi_{\text{Total}} = \Phi_{\text{Bulk}}\, f^{0.77} + \frac{1}{E}\left(\frac{dE}{du}\right)_{\text{Edge}} u_{\text{Edge}}\Phi_{\text{Edge}} + \frac{1}{E}\left(\frac{dE}{du}\right)_{\text{Coating}} u_{\text{Coating}}\Phi_{\text{Coating}}$$

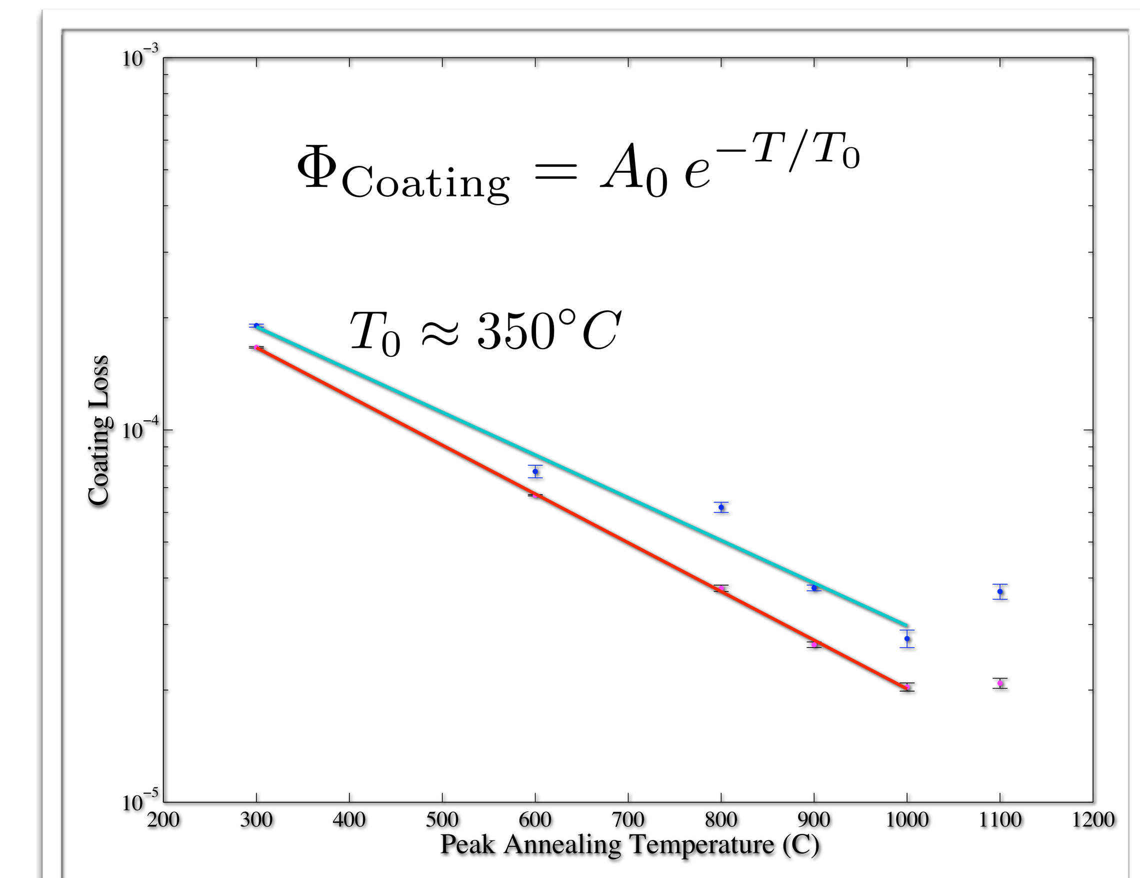
Above we show a samples set of data, in this case the 0.5 micron coating as annealed by the coater, and fit to a model including the coating and edge losses. The contribution from the bulk is negligible for these samples.

As we annealed the samples to higher temperatures, the loss progressively decreased. The plot in the upper right shows the general trend of the data, but it is clear that the loss distribution among the modes is changing from one annealing stage to the next. If for each stage one fits the contribution from the edge and coating losses, then we find that this variation re-

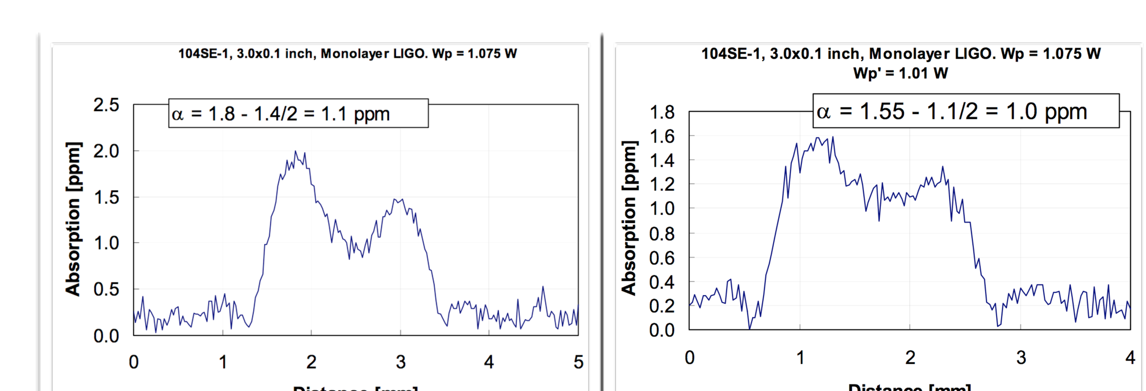




sults almost entirely from the edge losses. Below we plot the trend in the coating loss versus annealing temperature. The coating loss obeys a decaying exponential with a characteristic temperature $T_0 \approx 350$ C.



In addition, Ashot Markosyan has measure the absorption in these samples after successive annealing runs and has found the the absorption decreases until the coating is barely distinguishable from the substrate. We are currently having scattering measurements performed on these samples.



Conclusion

We have shown that annealing can successfully eliminate the excess loss observed in silica coatings. This result suggests that the same method could be used for a high index coating material, with a CTE similar to silica and that did not crystalize at low temperatures. Possible materials include diamond, with an index of 2, and zirconia, which must be doped to remain amorphous at high temperatures.

This work is in part supported by the National Science Foundation Grant PHY-0653590