Mechanical Loss Measurements of TRA-DUCT 2902 Epoxy and Shear and Bulk Mechanical Loss of Silica

Jonathan Newport[1], Danika Balas[1], David Belyea[1], Alexandra France[1], Steve Penn[2], Raymond Robie[1], Gregory Harry[1]

[1]American University, [2]Hobart and William Smith Colleges

We measured the mechanical loss of TRA-DUCT 2902 conductive epoxy and bare silica disks. Both were analyzed to determine separately the shear and bulk components of mechanical loss. The epoxy is of interest as a way of attaching tuned mass dampers to Advanced LIGO test masses to help mitigate parametric instability. Measuring the shear and bulk components of silica mechanical loss are a first step towards designing coatings with partial cancellation of shear and bulk thermal noise. *LIGO-G1300163*

Shear and Bulk Mechanical Loss in Silica

Theory: We modeled the mechanical loss in silica starting with the technique of Penn *et al*, Physics Letters A **352,** (2006) 3, but expanded to allow for a loss angle associated with the shear modulus, ϕ_{shear}, and bulk modulus, ϕ_{bulk}.

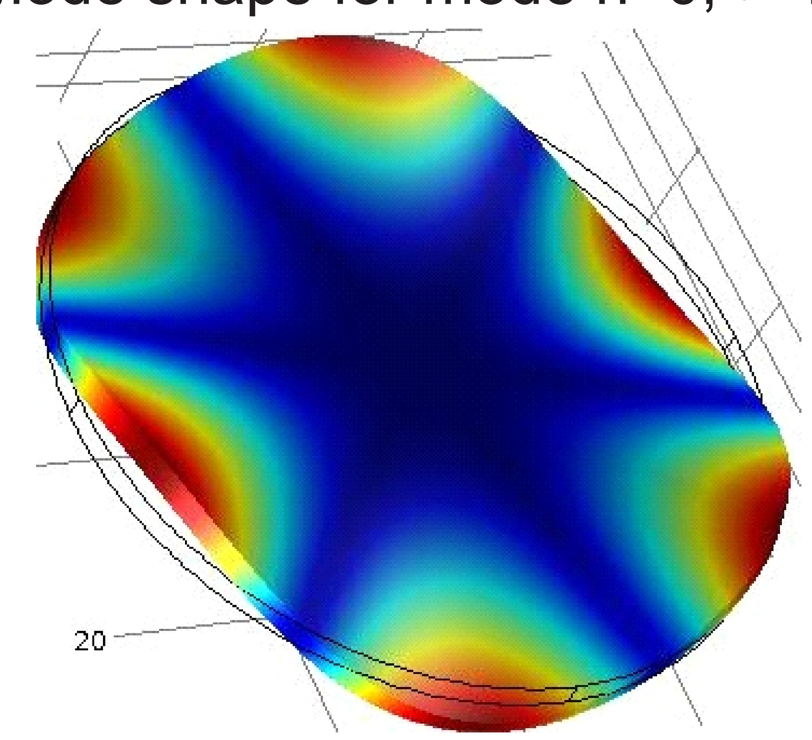
$$\phi_{substrate}(f_n) = a_n\, \phi_{shear}\, f_n^{0.77} + (1-a_n)\, \phi_{bulk}\, f_n^{0.77}$$

where $\phi_{substrate}$ is the mechanical loss of the silica substrate (excluding surface effects), n is normal mode number, f_n is the normal mode frequency, a_n is the fraction of elastic energy of the normal mode in shear deformation, and ϕ_{shear} and ϕ_{bulk} are loss angle coefficients to be determined from experimental data.

Measured Q Values

Mode	Frequency	Q	a_n
n=0, ℓ=1	2699.3 Hz	2.17×10^7	0.935
n=0, ℓ=3	6148.5 Hz	1.90×10^7	0.898
n=1, ℓ=1	9438.3 Hz	1.32×10^7	0.656
n=0, ℓ=4	10612 Hz	0.92×10^7	0.876

Mode shape for mode n=0, ℓ=4



Silica Results

The two modes n=1, ℓ=4 and n=0, ℓ=4 have the widest spread in their shear and bulk energy ratios. Using these two modes, we find

$\phi_{shear} = 9.8 \times 10^{-11}$

$\phi_{bulk} = 4.5 \times 10^{-12}$

Predicted and Measured Q's

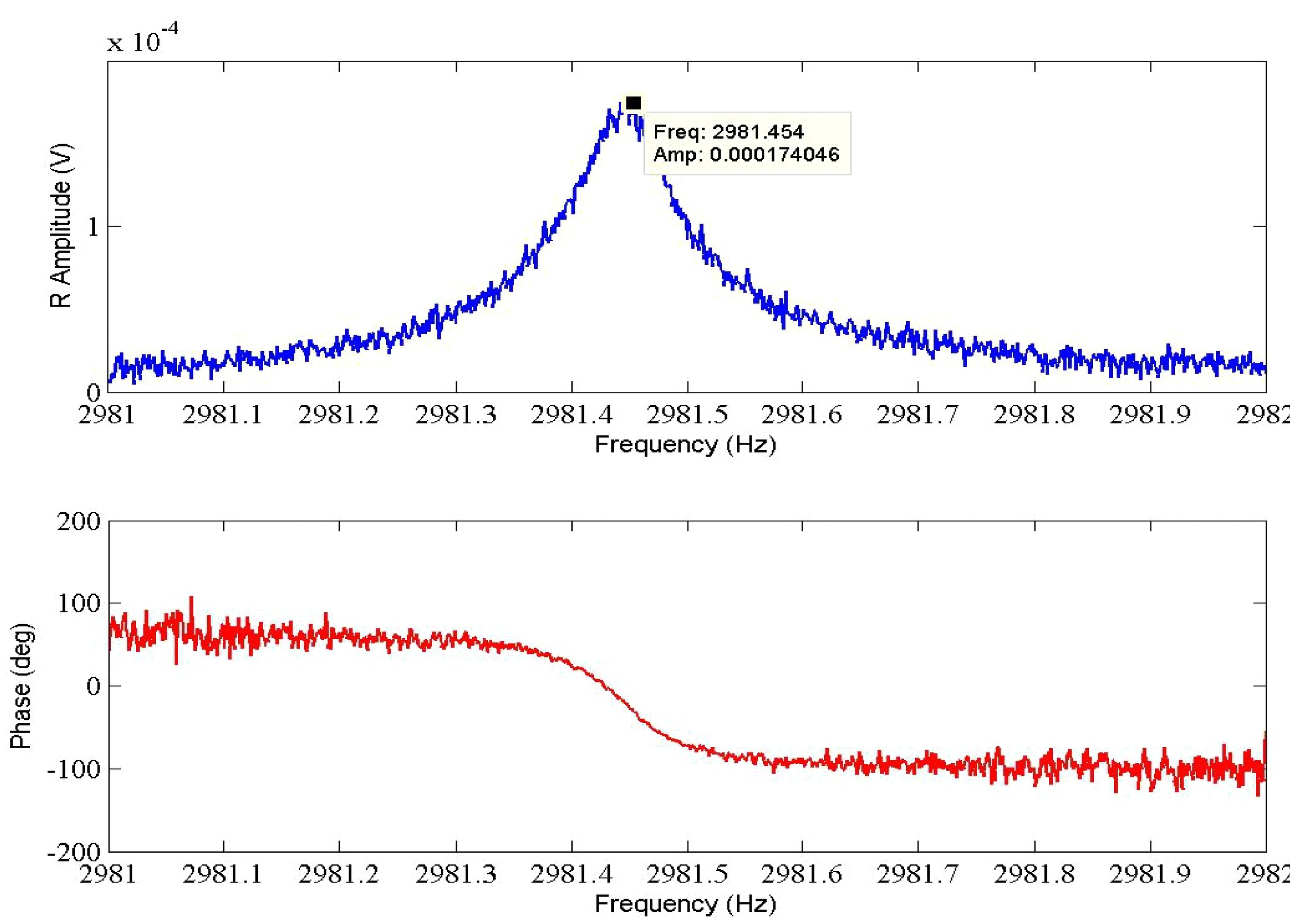
Using the values found to the left for ϕ_{shear} and ϕ_{bulk} we predict the Q's for the n=0, ℓ=1 and n=0, ℓ=3 modes and compare with measured values.

	$Q_{predicted}$	$Q_{measured}$
n=0, ℓ=1	2.47×10^7	1.93×10^7
n=0, ℓ=3	1.36×10^7	1.90×10^7

Mechanical Loss of TRA-DUCT 2902 Epoxy

Theory: Exchange of energy between optical and acoustical modes, parametric instability, is a potential problem in high power operation of Advanced LIGO. Tuned mass dampers, designed to reduce the modal Q's of test masses have been proposed to solve this problem. These dampers could be held to the test masses with epoxy. Excess thermal noise from the epoxy is a concern. To predict the level of thermal noise, mechanical loss of epoxy must be measured. TRA-DUCT 2902 conductive epoxy has been proposed, and we have measured its mechanical loss.

Sample showing epoxy (silver), suspension bob and exciter (blue).



Amplitude and phase shift of n=0, ℓ=1 mode.

Measured Q Values

Mode	Frequency (Hz)	Q	Energy % in Epoxy
n=0, ℓ=1	2707.5	1.76×10^4	0.11
	2981.5	2.07×10^4	0.09
n=1, ℓ=0	4137.5	1.63×10^4	0.11
n=0, ℓ=3	6157.6	4.11×10^4	0.09
	6312.8	5.49×10^4	0.08
n=1, ℓ=1	9457.8	2.15×10^4	0.07
Shear	37071.2	9.51×10^4	0.04
	37155.1	8.64×10^4	0.04

Epoxy Results

$\phi_{shear,epoxy} = 4 \pm 1 \times 10^{-2}$

This mechanical loss is about a factor of 2 better than was used in the model in G1001023. However, it may still be too high to avoid excess thermal noise in Advanced LIGO.

Future Plans: On the shear and bulk loss project, expand the model to include surface loss, measure additional modes including higher bulk energy, and anneal substrates. Once silica is understood, coatings like titania-tantala, AlGaAs, and Si_3N_4 will be measured.

On the epoxy project, measure additional epoxies including MasterBond EP30-2, Hysol TRA-BOND, EPOTEK 353ND and natural resin from Australia. Also measure higher frequencies to determine any frequency dependence of the epoxy loss.