Mechanical Loss Measurements of Tuned Mass Damper Epoxy and Aluminum-Gallium-Arsenide Single-Crystal Coatings

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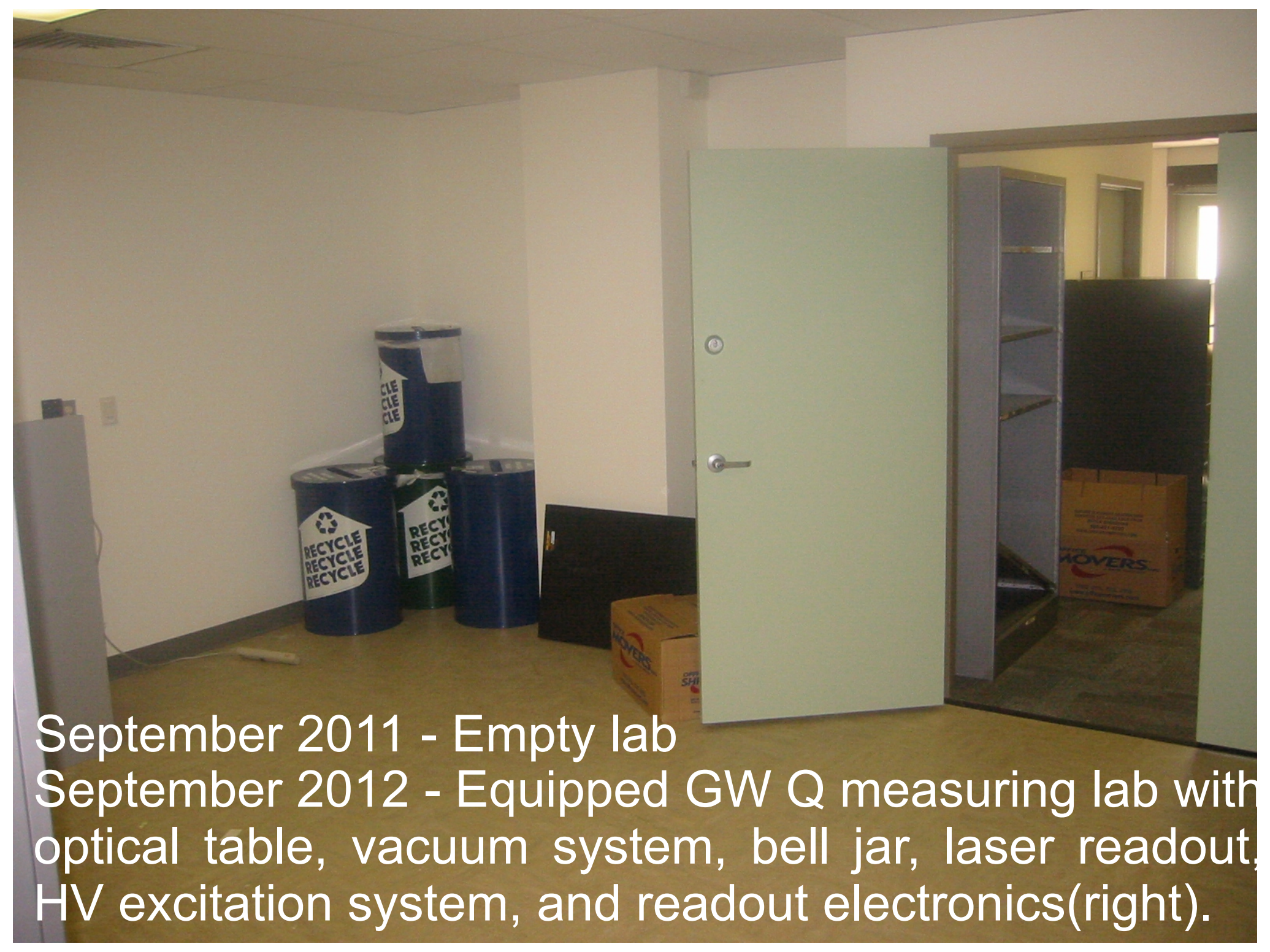
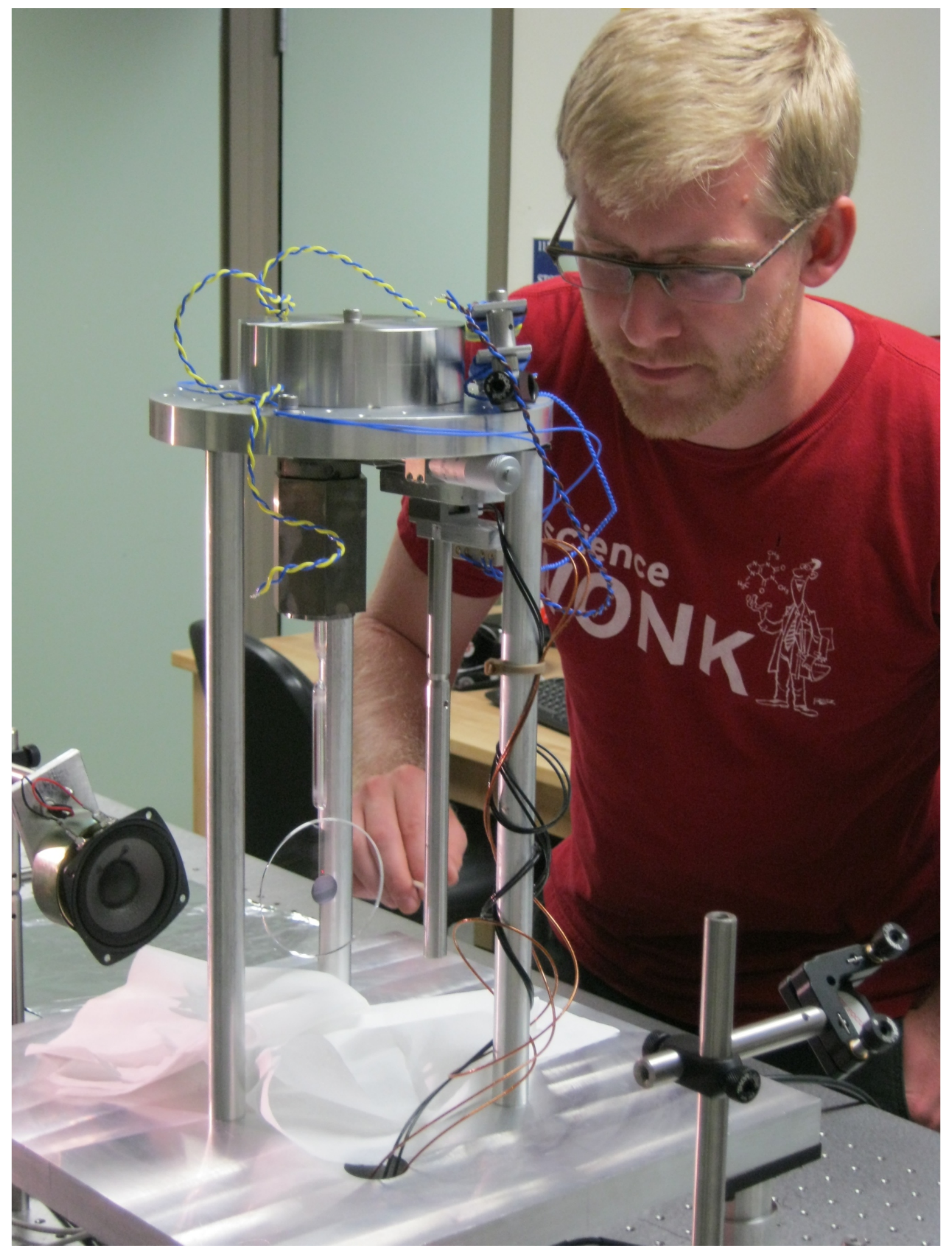
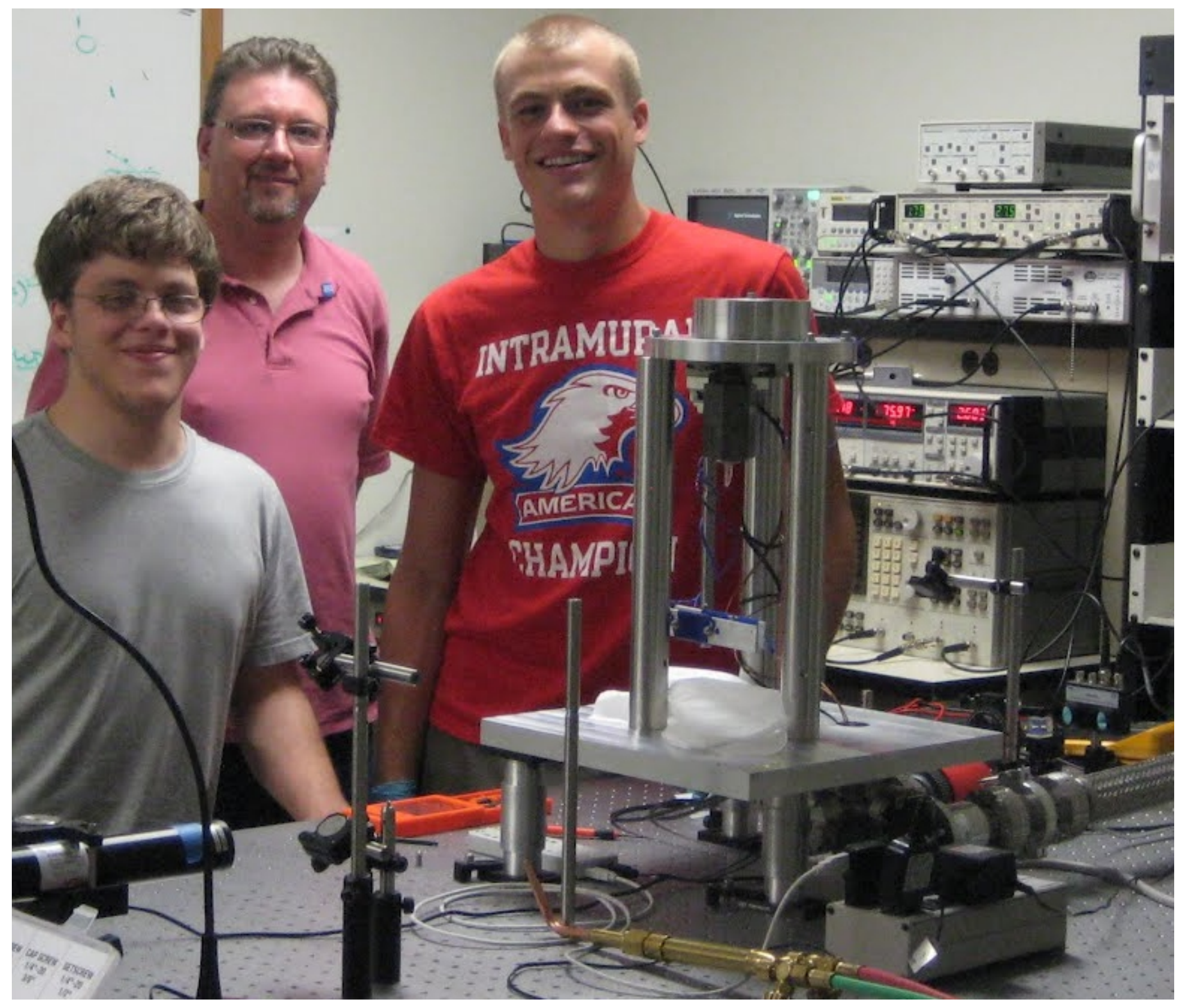
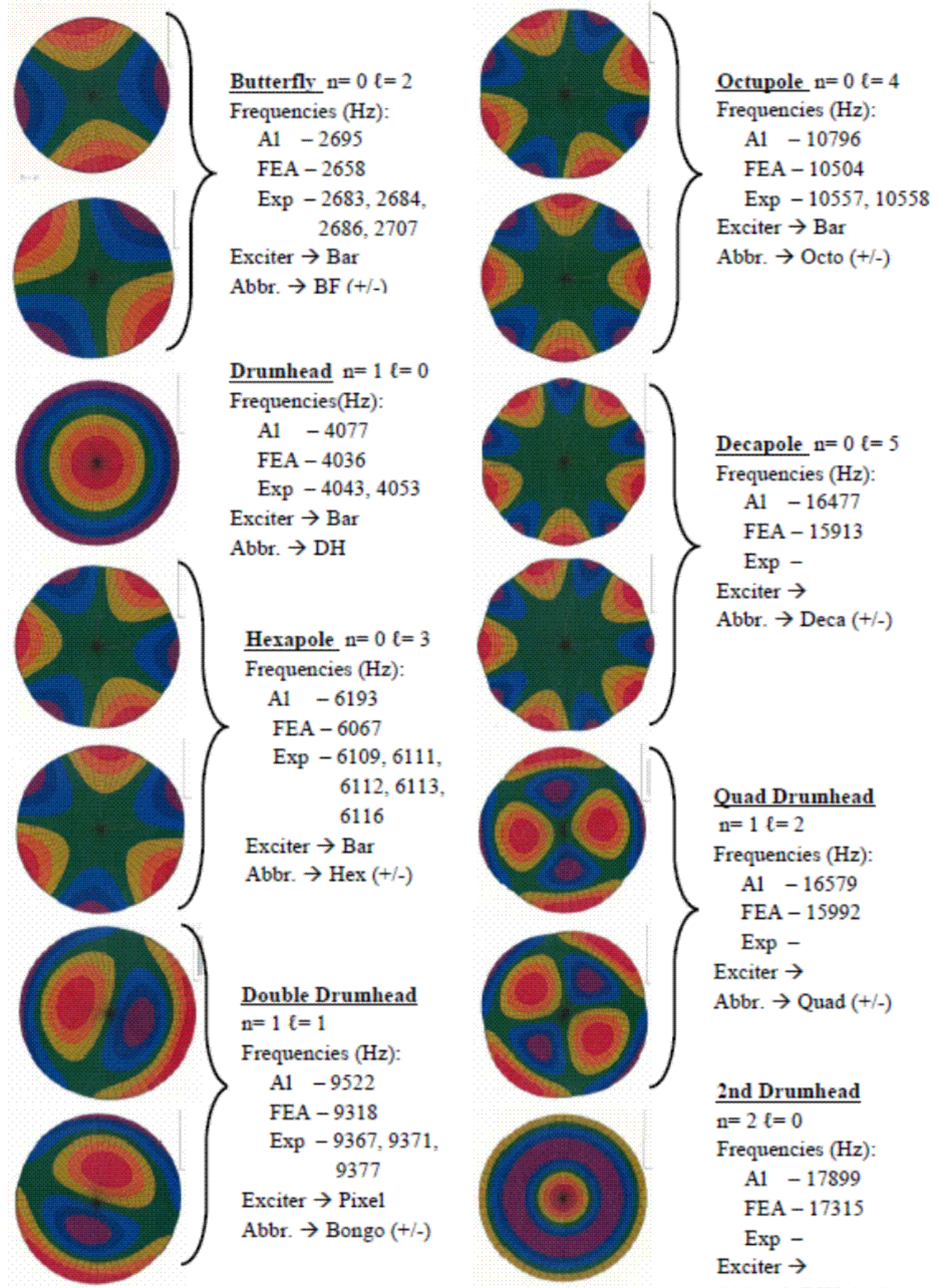
We studied the mechanical loss of Hysol EA 9313 epoxy and an AlGaAs crystal coating. The Hysol epoxy is of interest as a way of attaching tuned mass dampers to Advanced LIGO test masses to mitigate parametric instability. AlGaAs is a possible low thermal noise material for third generation test mass coatings.

Laboratory Setup and Equipment


September 2011 - Empty lab
September 2012 - Equipped GW Q measuring lab with optical table, vacuum system, bell jar, laser readout, HV excitation system, and readout electronics(right).

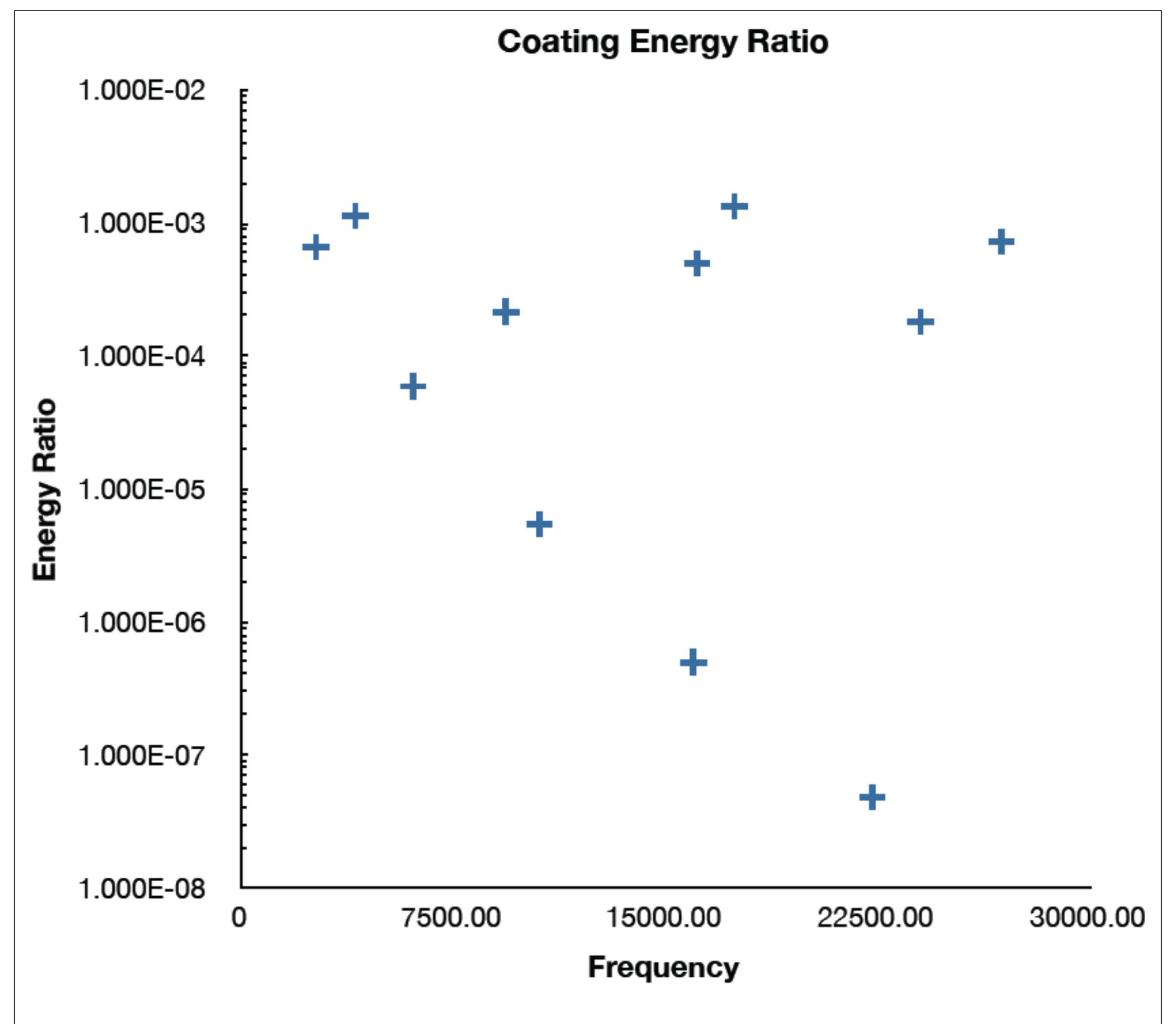



Newport (left) with AlGaAs sample and sample support and isolation system. Above, Belyea, Harry, and Robie with sample support, readout laser, vacuum hoses, and electronics.



Mode Energy Ratios

The graph to the right shows the ratio of elastic energy stored in the AlGaAs coating to the elastic energy in the substrate for each normal mode of the sample (shown above). One conclusion at this point is that a different geometry would allow for easier interpretation of results.



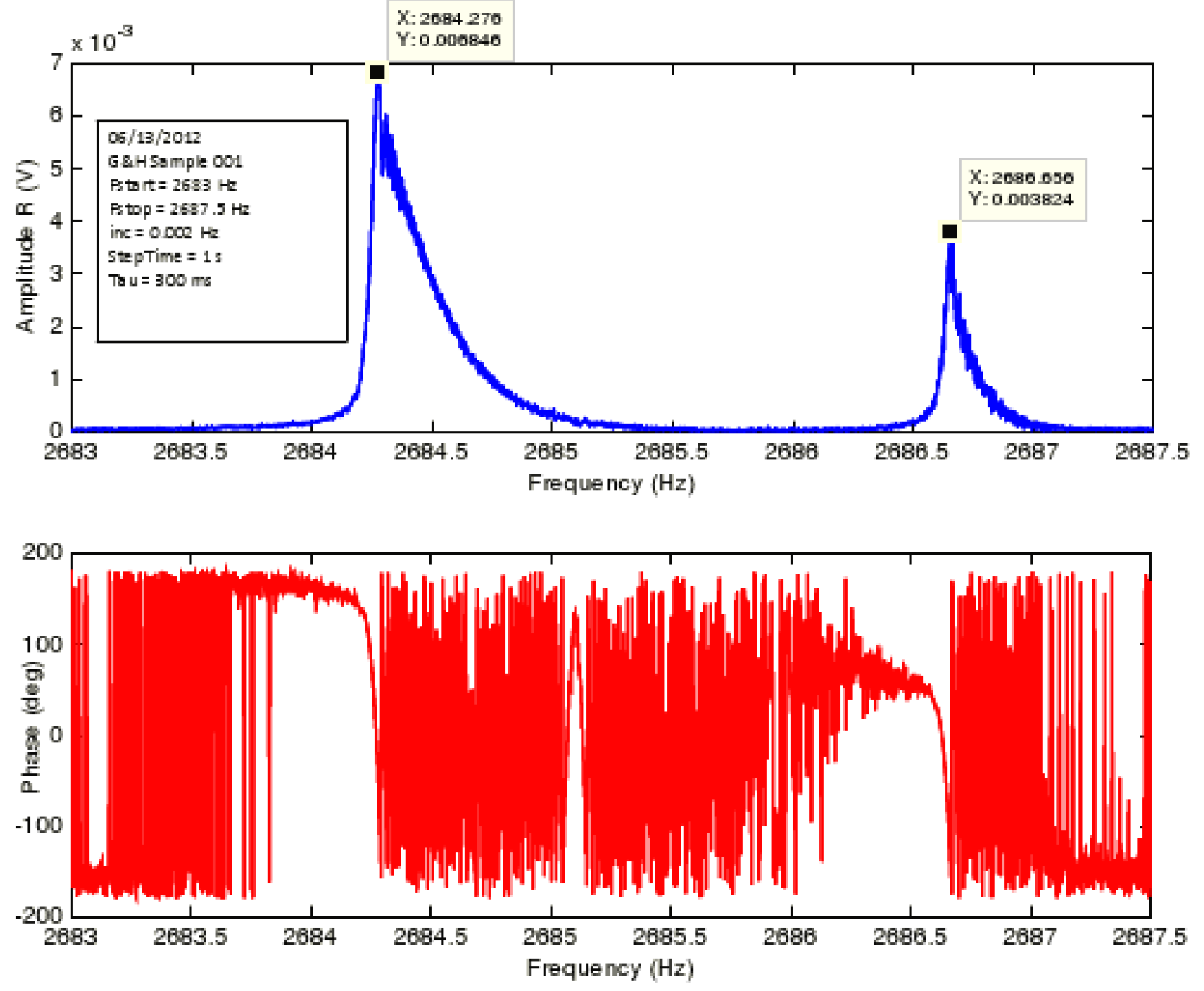
Preliminary Results

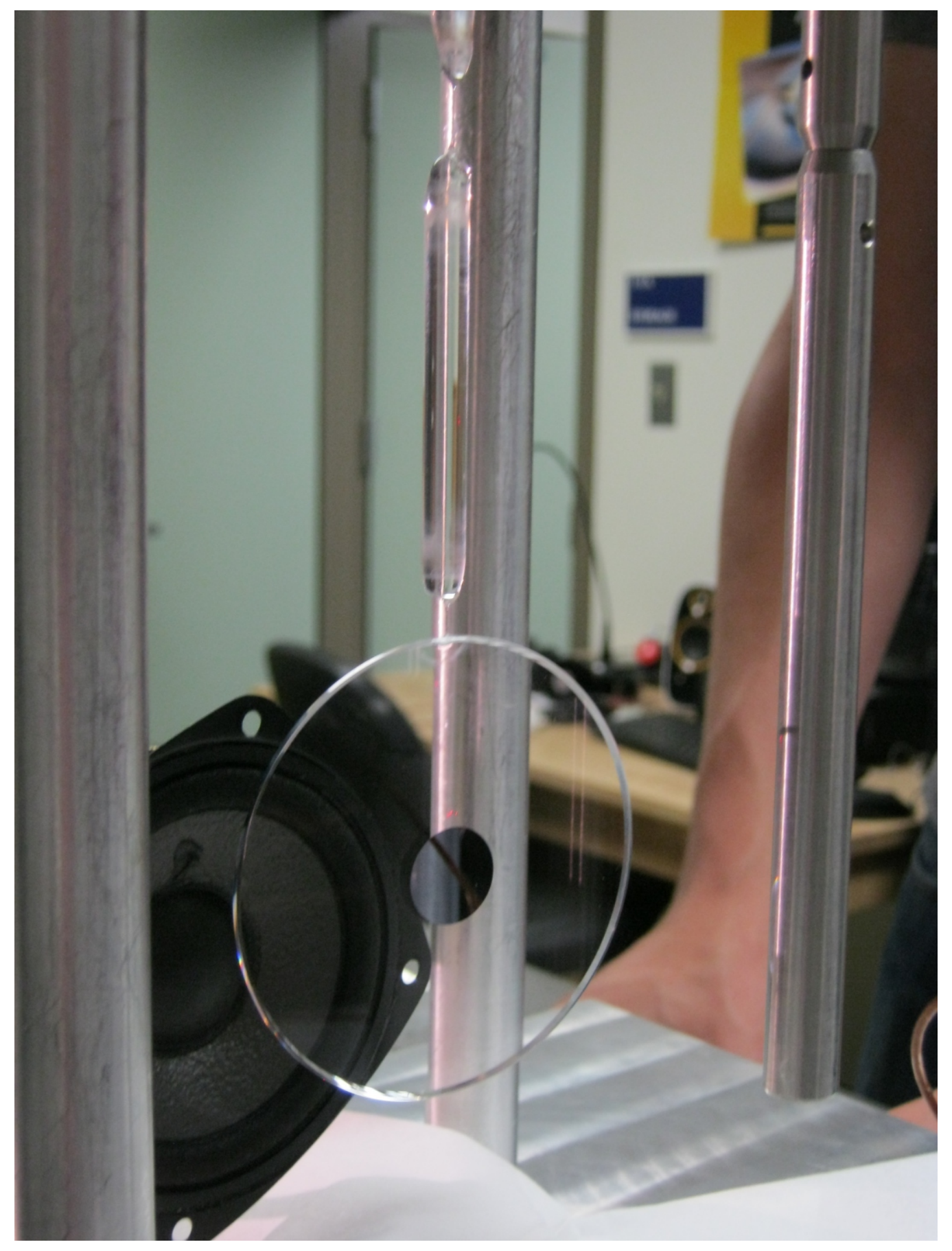
Free-standing GaAs/AlGaAs multilayers are a promising low-thermal noise alternative coating technology for third generation detectors. To be applied to a silica substrate, these films must be grown separately (on a lattice-matched GaAs wafer) and transferred on to it. It is unknown if this process introduces excess mechanical loss and is the primary question to be answered by this research.

AlGaAs Mechanical Loss

Mode	Frequency	Q
n=0, ℓ=1	2683.6 Hz	6.08 X 10^6
	2684.3 Hz	2.96 X 10^4
n=1, ℓ=0	4053.3 Hz	1.91 X 10^6
n=0, ℓ=3	6111.3 Hz	1.26 X 10^7
	6116.1 Hz	9.14 X 10^6
n=1, ℓ=1	9377.0 Hz	9.35 X 10^6
n=0, ℓ=4	10556 Hz	1.04 X 10^7
n=0, ℓ=5	15951 Hz	1.15 X 10^7
	15953 Hz	1.18 X 10^7
n=1, ℓ=2	16137 Hz	1.27 X 10^7
	16142 Hz	1.33 X 10^7
n=2, ℓ=0	17455 Hz	2.80 X 10^6

Techniques for Mode Finding and Q Measuring



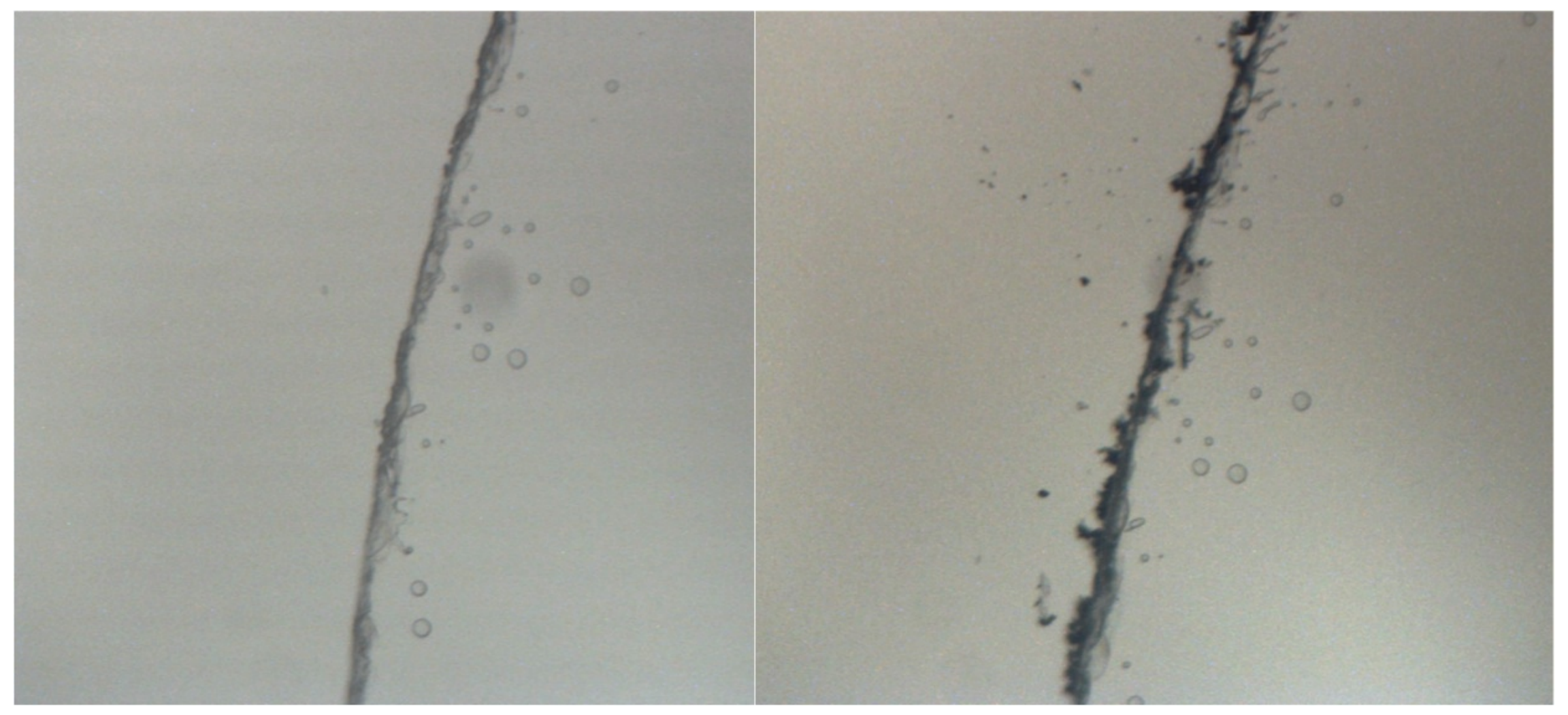


High Q modes are often difficult to find because their FWHM is very narrow and take a significant time to ring-up. Commercially available network analyzers allow for swept sine measurements for mode-hunting but are limited in step size, filter configuration and duration. We used a Matlab script controlling a function generator and a dual-channel lock-In amplifier to find resonant modes. The lock-in has excellent dynamic range and user-configurable filtering. These properties are particularly useful for finding degenerate modes that can be washed out by their partners if displayed on a network analyzer. The user is able to control the frequency step size to 1 μHz, the "ring-up" time, the frequency span and the lock-in's time constant. The script can also be configured to search for multiple mode ranges over the course of several days. This enables us to install a new sample and find several modes over the course of a weekend. It is also possible to find the Q in frequency space. This is used for low Q samples where taking ringdown data is not practical.

Epoxy Mechanical Loss

Mode	Frequency	Q
n=0, ℓ=1	2692.1 Hz	5.32 X 10^5
	2692.3 Hz	3.75 X 10^5
n=0, ℓ=3	6113.9 Hz	1.25 X 10^6
	6115.0 Hz	1.13 X 10^6
n=1,ℓ=1	9370.3 Hz	1.25 X 10^6

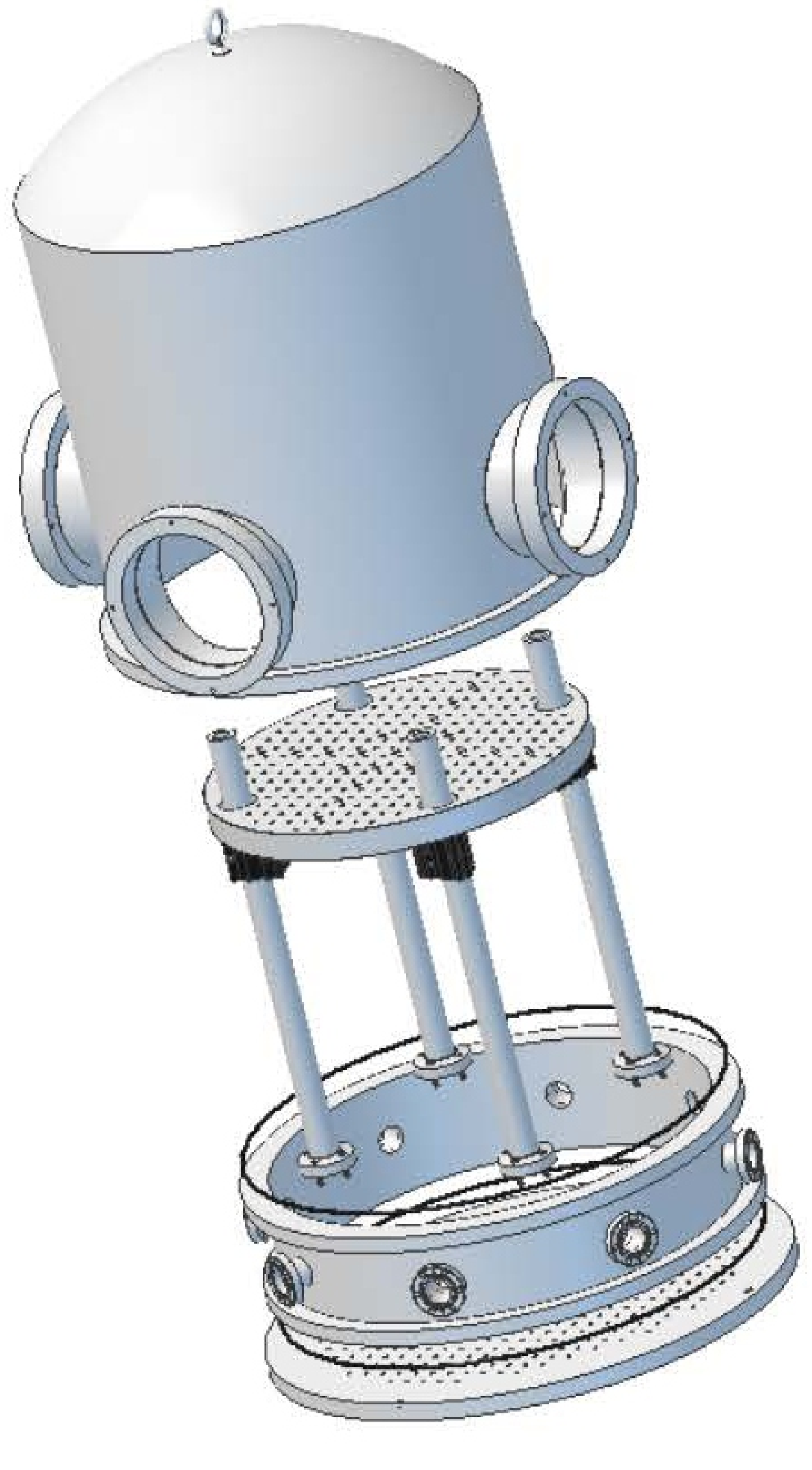
Epoxy was applied with a pipette and held down while curing with weights. Below shows improvement in cleanliness from ultrasonic cleaning, before (right), after (left).



All the Q's presented here had some repeatability problems. We attribute this to recoil damping effects in the small sample support and isolation system as well as external vibrations primarily from the vacuum pump reaching the sample. Some improvement was seen with the addition of thicker support legs and viton separators in the support system. We believe these problems are not fully solved but will be addressed with a larger bell jar and support system.

Future Plans

In the short term, we have designed and ordered a larger bell jar with a larger and stiffer sample support and isolation system. This is expected in late September 2012. this will allow immediate further Q measurements on both AlGaAs and epoxy samples that should give more repeatable results. In the middle term (a few months) we plan to investigate improved geometries to allow for more emphasis of the mechanical loss of the coating materials. This may include using cantilever samples in which we would modify the sample support system to take cantilevers with similar to geometry to those used in Glasgow, Taiwan, and other LSC institutions. New geometries will require additional finite element (FEA) modeling, which will be carried out using COMSOL. Longer term (six months and beyond) we plan to investigate the possibly different loss angles for shear and bulk moduli of substrate (silica, silicon), current coatings (tantala, silica, titania-tantala), and future coating (AlGaAs, AlGaP, zirconia, etc.) materials. This will require further FEA modeling.



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