Introduction

- Recent studies suggest loss of silica substrates improve at lower frequencies [Numata et al. LIGO Doc G010365-00.pdf, Penn et al. Rev Sci Inst 72(9) 3670]

- We have measurements of the losses of silica substrates and of dielectric coatings from ~2.8 kHz to ~73 kHz

- Have enough information to consider frequency dependence of coating losses

Overview

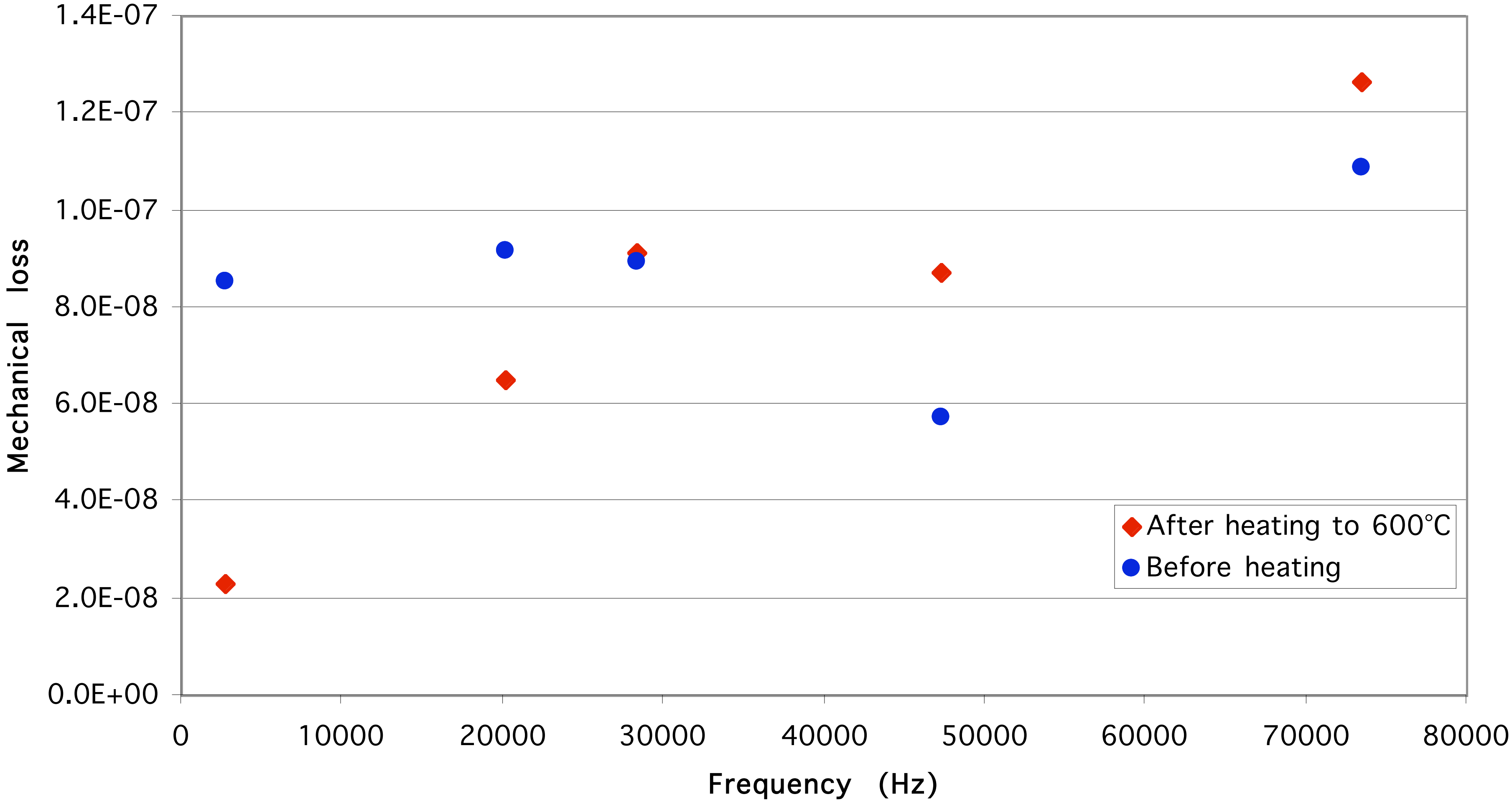
1. Substrate loss frequency dependence (Corning 7980 silica, grade 0A, sub-Angstrom polish; samples as in talk by P. Sneddon)

2. Frequency dependent mechanical loss of dielectric coatings (SiO_2:Ta_2O_5 coating)

3. Frequency dependent loss of individual coating materials

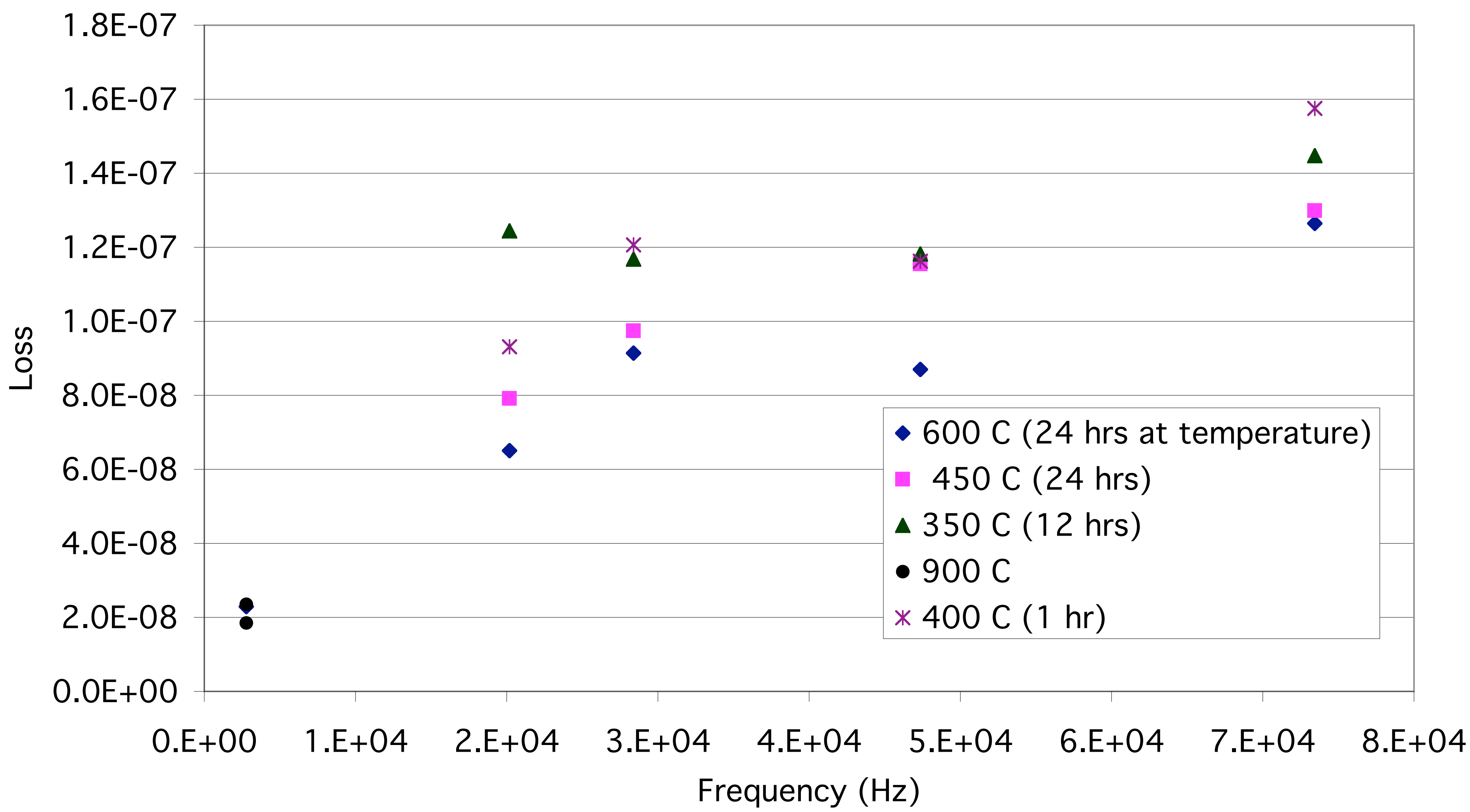
Frequency dependence of substrate loss on heating temperature

Measured loss as a function of frequency before and after heating



Frequency dependence at various temperatures

Measured loss as a function of frequency for annealed samples



Frequency dependence of coating losses

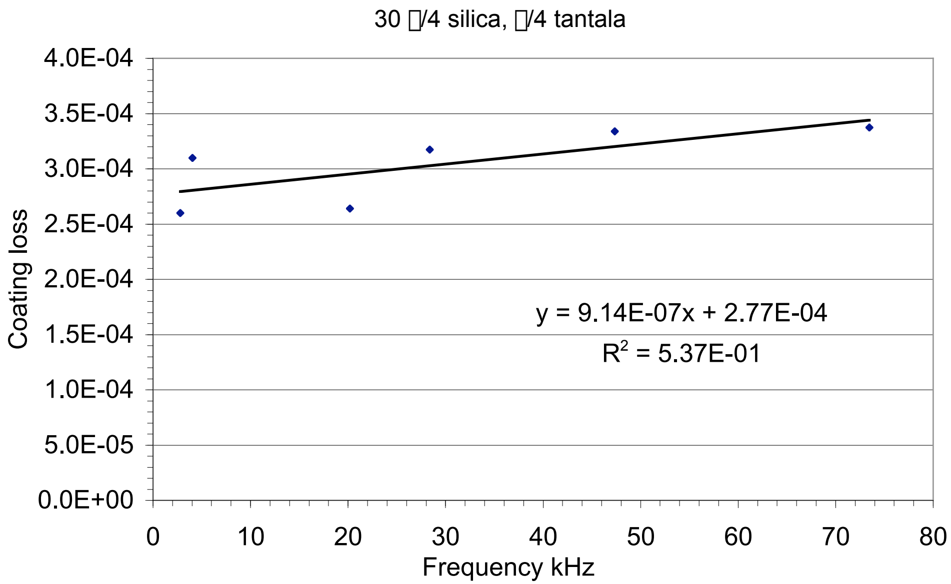
- Recall loss parameterisation(as in talk by P. Sneddon)

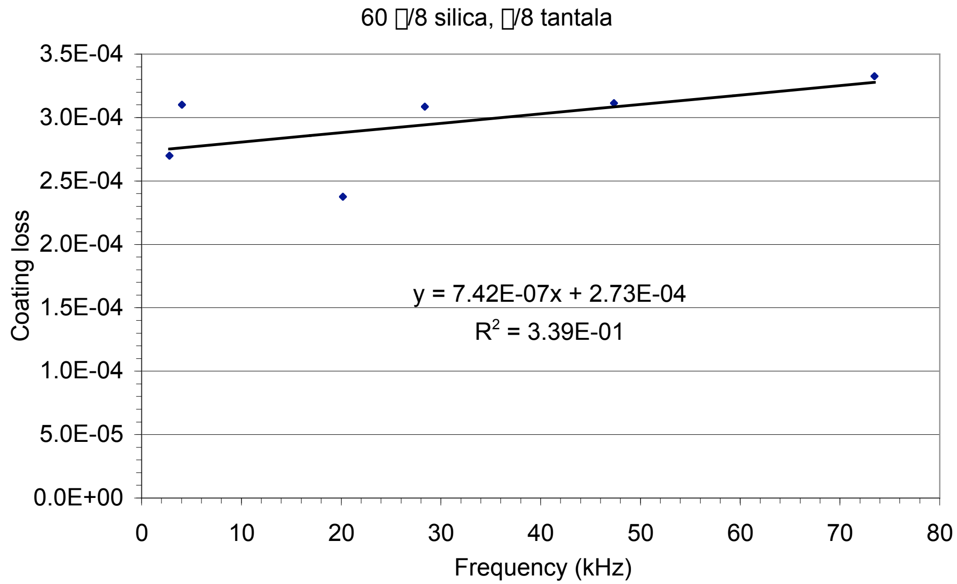
$$\phi_{coated}(\omega_0) = \phi_s(\omega_0) + \frac{E_{coating}}{E_{substrate}}\phi_c(\omega_0)$$

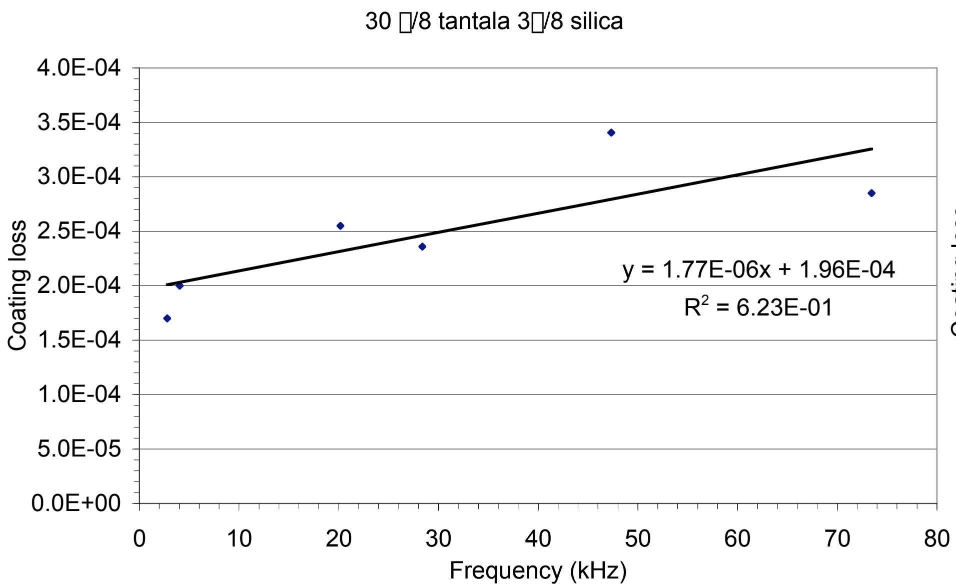
- Can use this to work out individual losses for each mode

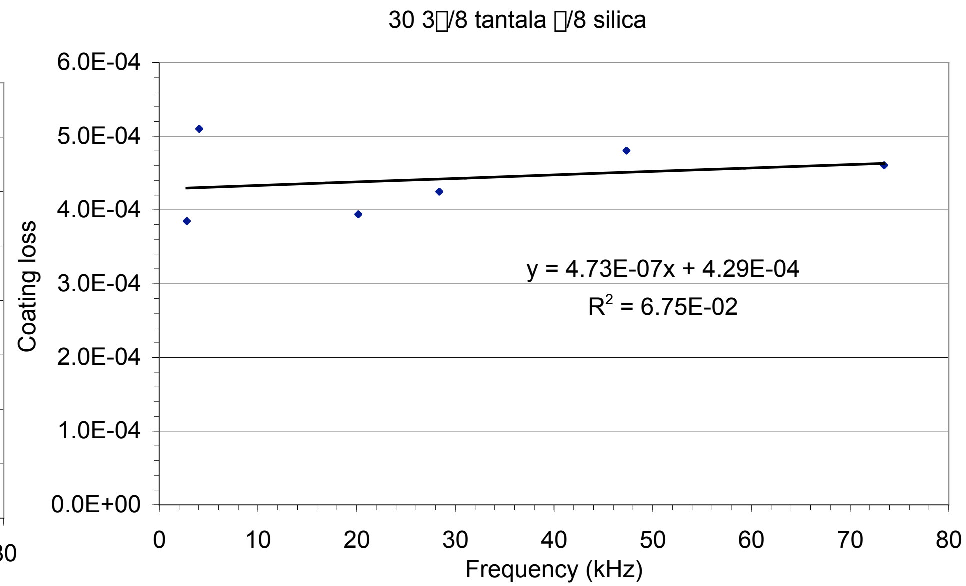
- Obtain different frequency dependences for each coating formulation

Frequency dependence of losses for different coating formulations









Coating split

- These graphs suggest the level of frequency dependence depends on the relative amounts of each coating material

- The contribution of the loss of each coating material to the total measured loss of a SiO_2:Ta_2O_5 coating is scaled by the energy stored therein. ϕ_{Sc} represents the loss of the SiO_2 component of the coating and ϕ_{Tc} represents the loss of the Ta_2O_5 component

$$\phi_c(\omega) = \phi_{Sc}(\omega)\left[\frac{Y_{Sc}t_{Sc}}{Y_{Sc}t_{Sc}+Y_{Tc}t_{Tc}}\right] + \phi_{Tc}(\omega)\left[\frac{Y_{Tc}t_{Tc}}{Y_{Sc}t_{Sc}+Y_{Tc}t_{Tc}}\right]$$

where Y is the Young's modulus and t the total thickness of each coating material

Note this neglects the effects of Poisson's ratio (expected to be small)

Coating split

- Model each material loss as having both a frequency linearly dependent and frequency independent term:

$$\phi_{Sc}(\omega) = \phi_{Sc_0} + \omega\phi_{Sc_1} \quad \phi_{Tc}(\omega) = \phi_{Tc_0} + \omega\phi_{Tc_1}$$

then

$$\phi_c(\omega) = (\phi_{Sc_0}A_i + \phi_{Tc_0}B_i) + \omega\,(\phi_{Sc_1}A_i + \phi_{Tc_1}B_i)$$

y = *c* + *m*x

where

$$A_i = \left[\frac{Y_{Sc}t_{Sc}}{Y_{Sc}t_{Sc}+Y_{Tc}t_{Tc}}\right] \quad B_i = \left[\frac{Y_{Tc}t_{Tc}}{Y_{Sc}t_{Sc}+Y_{Tc}t_{Tc}}\right]$$

- Use multiple regression to fit for *c,* the frequency independent loss and *m,* the frequency dependent loss.

Coating split continued

- Using this model observe a slight frequency dependence
- This gives:
  - Frequency independent loss:
    - » $\square_{Sc0} = (2.7\pm5.7)\text{x}10^{-5}$
    - » $\square_{Tc0} = (4.9\pm0.4)\text{x}10^{-4}$
  - Frequency dependent loss
    - » $\square_{Sc1} = (2.5\pm0.3)\text{x}10^{-9}$
    - » $\square_{Tc1} = (-1.8\pm2.5)\text{x}10^{-10}$

Conclusions

- There appears to be a frequency dependence not only in the annealed substrates but also in the coating itself
- Substrate loss frequency dependence appears to be associated with heating temperature
- Coating loss for each material appears to be divisible into frequency dependent and independent terms
  - Tantala frequency independent loss larger than that of silica
  - Silica frequency dependent loss larger than that of tantala

Conclusions 2

- Frequency dependence does not effect thermal noise level in sub kHz frequency band for silica tantala coatings

- Analysis of these results is preliminary and needs to be extended in light of new thermoelastic damping theory (Fejer et al.)