Frequency dependent loss in coated silica substrates

Peter Sneddon, David Crooks, Geppo Cagnoli, Jim Hough
University of Glasgow

Sheila Rowan, Marty Fejer, Roger Route
Stanford University

Gregg Harry
MIT

Steve Penn
Hobart and William Smith College

Norio Nakagawa
Iowa State University

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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

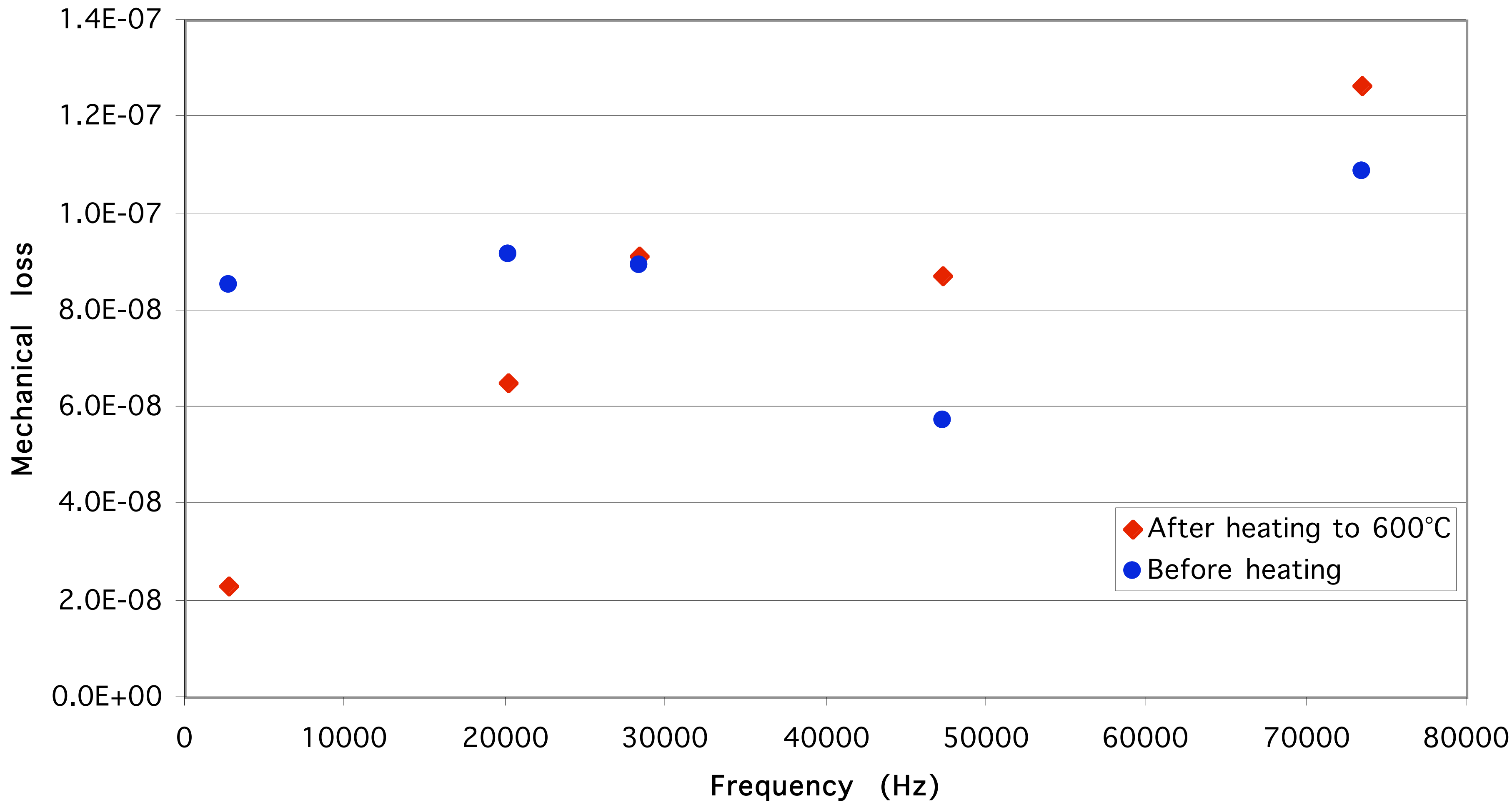
1. Substrate loss frequency dependence (Corning 7980 silica, grade 0A, sub-Angstrom polish; samples as in talk by P. Sneddon)

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

3. Frequency dependent loss of individual coating materials

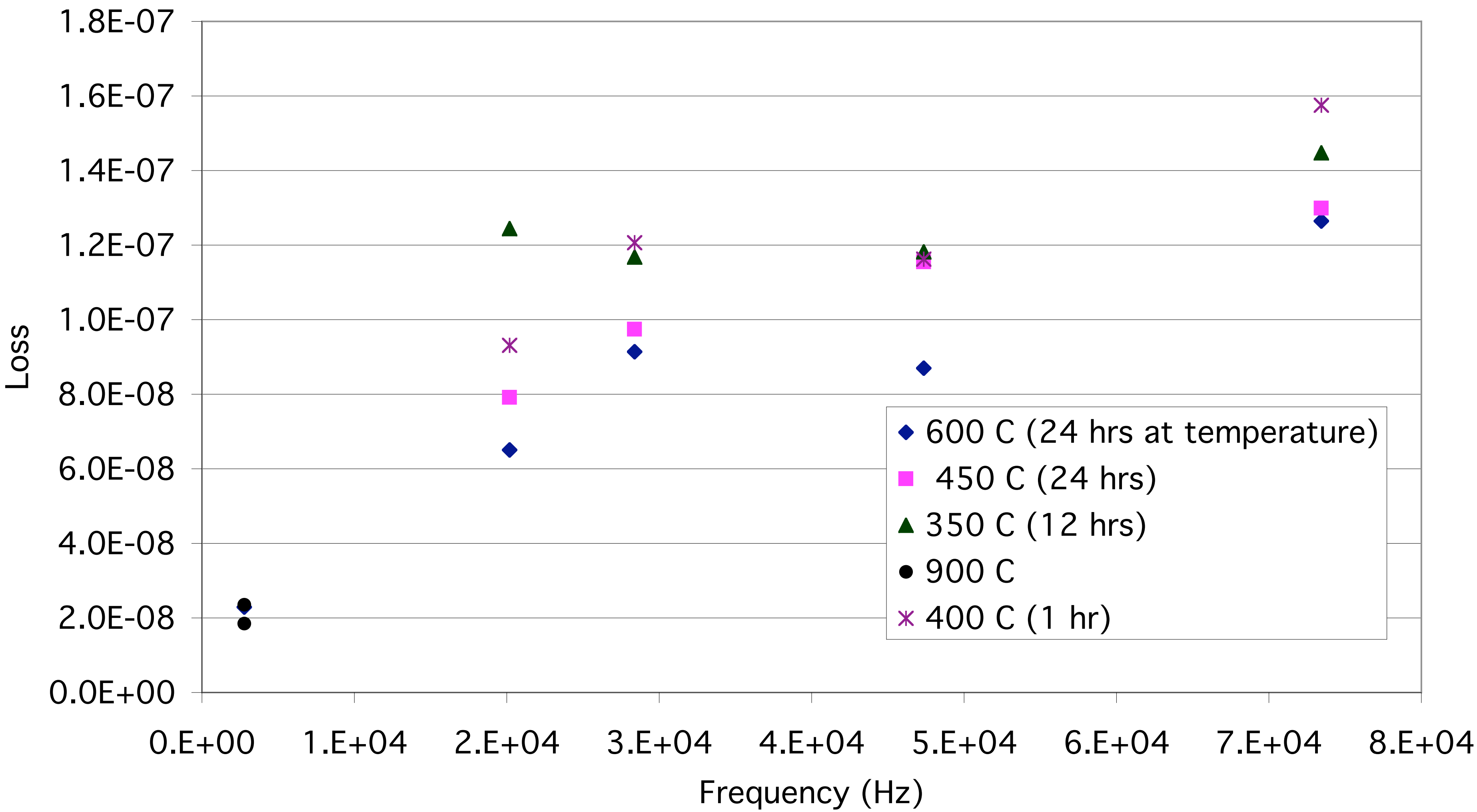
Frequency dependence of substrate loss on heating temperature

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

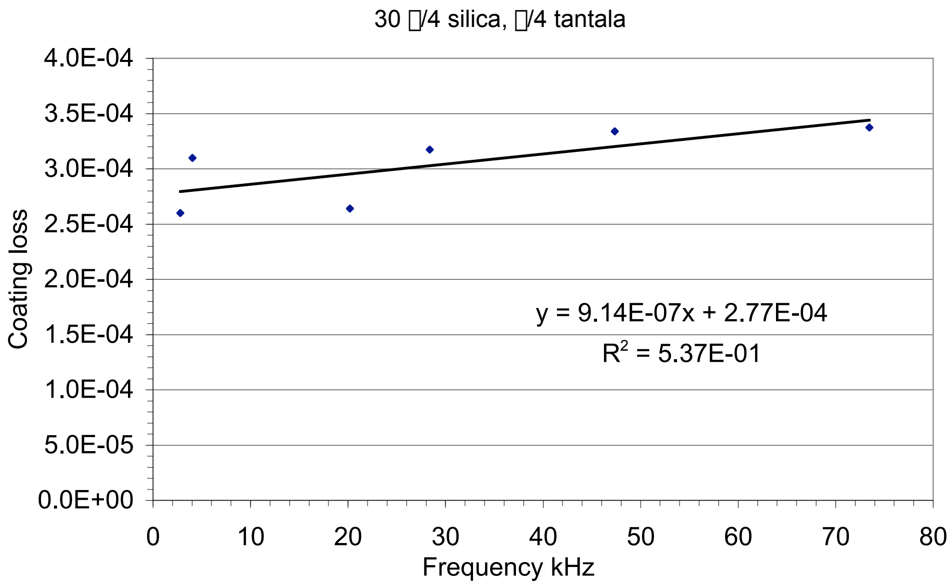
- Recall loss parameterisation(as in talk by P. Sneddon)

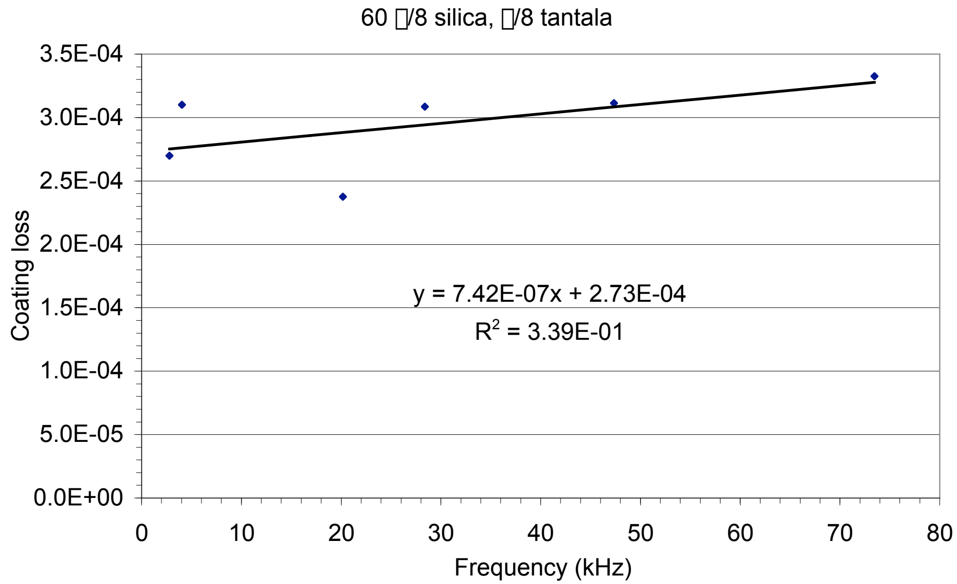
$$\phi_{coated}(\omega_0) = \phi_s(\omega_0) + \frac{E_{coating}}{E_{substrate}}\phi_c(\omega_0)$$

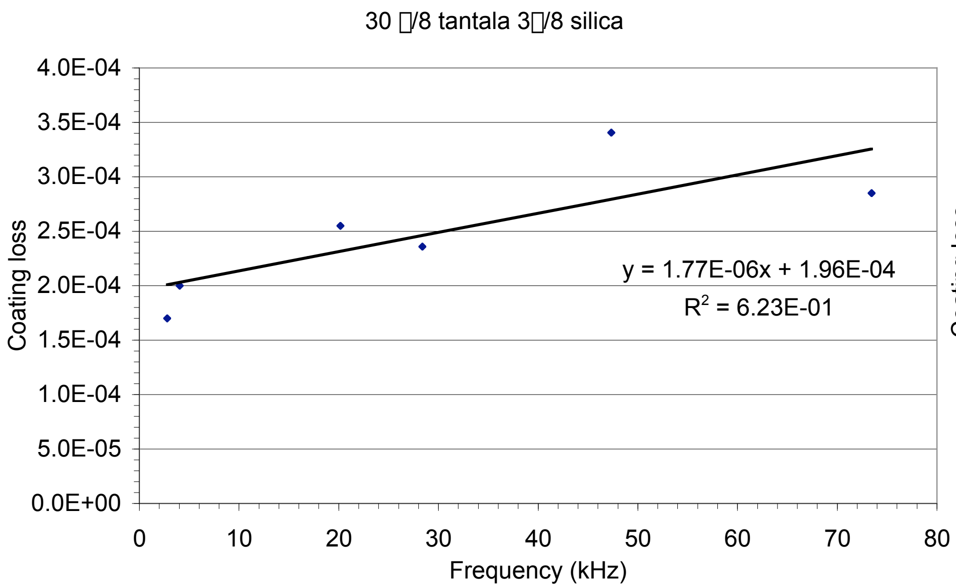
- Can use this to work out individual losses for each mode

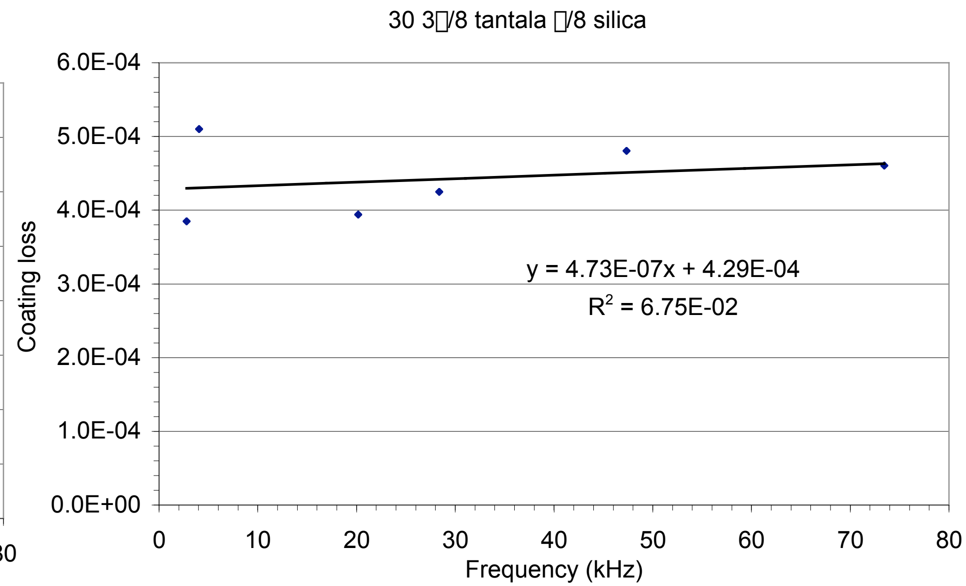
- Obtain different frequency dependences for each coating formulation

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:

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

then

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

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:
    - » $\phi_{Sc0} = (2.7 \pm 5.7) \times 10^{-5}$
    - » $\phi_{Tc0} = (4.9 \pm 0.4) \times 10^{-4}$
  - Frequency dependent loss
    - » $\phi_{Sc1} = (2.5 \pm 0.3) \times 10^{-9}$
    - » $\phi_{Tc1} = (-1.8 \pm 2.5) \times 10^{-10}$

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.)