Thermal Noise Effects of Optical Coatings

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Suspensions Working Group

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Syracuse Q Measurements 1

- Commercially polished slides,REO 3% transmittance, 14 layer SiO_2/Ta_2O_5 coating, 2.4 μm thick
  - × Slide 1: $Q_{uncoat} = 4.0\ 10^6$, $Q_{coated} = 1.1\ 10^5$
  - × Slide 2: $Q_{uncoat} = 4.9\ 10^6$, $Q_{coated} = 1.6\ 10^5$
- Superpolished disk, REO 1 ppm transmitance, 38 layer SiO_2/Ta_2O_5 coating, 24 μm thick
  - × $Q_{uncoated} = 3.48\ 10$, $Q_{coated} = 1.28\ 10^6$

Syracuse Q Measurements 2

$$\phi_{coat} = \frac{V}{S}\frac{1}{\mu \cdot d}\left(\frac{1}{Q_{coated}} - \frac{1}{Q_{uncoated}}\right)$$

- $\mu_{slide} = 3$, $\mu_{disk} = 1.2$
- Slide 1: $\phi_{coating} = 6.1\ 10^{-4}$
- Slide 2: $\phi_{coating} = 4.2\ 10^{-4}$
- Slide 3: $\phi_{coating} = 4.3\ 10^{-4}$
- Disk 1: $\phi_{coating} = 3.2\ 10^{-4}$

Thermal Noise Modeling

$$S_{th}(\omega) = \frac{2kT(1-\sigma^2)}{\omega Y_{sub} w\sqrt{\pi}} \phi_{readout}$$

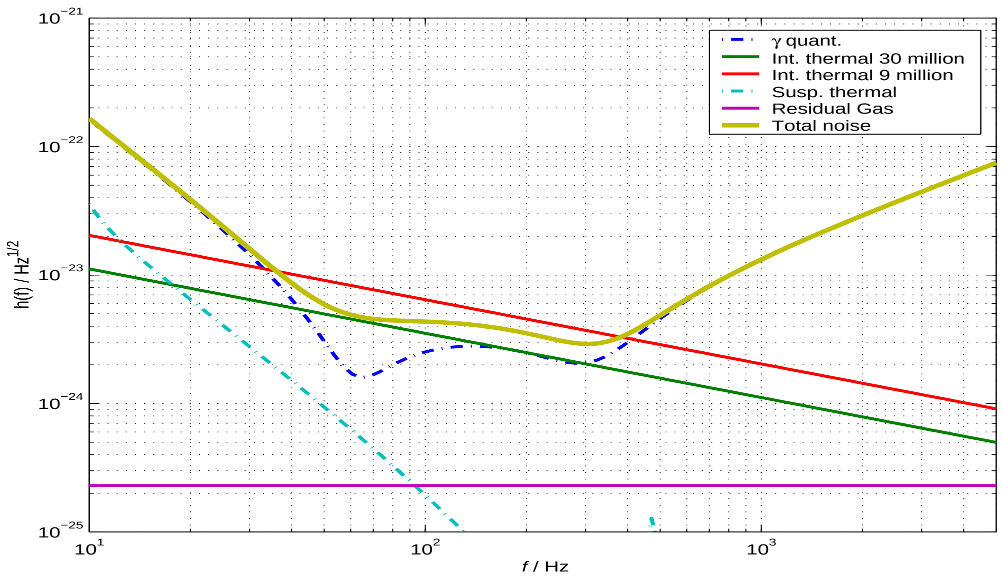
$$\phi_{readout} = \phi_{bulk} + \frac{1}{\sqrt{\pi}} \frac{(1-\sigma_{sub})}{(1-2\sigma_{sub})} \frac{d}{w} \left(\frac{Y_{coat}}{Y_{sub}} \cdot \phi_{coat||} + \frac{Y_{sub}}{Y_{coat}} \cdot \phi_{coat\perp} \right)$$

- w is 1/e width of beam, need to make large
- $\phi_{coat||}$ is being measured, 4 10^{-4}
- ϕ_{coat+} needs to be measured, can't be done with resonant Q, ellipsometry being explored at Syracuse

Effects on LIGO Thermal Noise 1

- Assumptions
  - × 6 cm beam radius
  - × Equal values for $\phi_{coat||}$ and ϕ_{coat+}
  - × 38 layer coating, 1 ppm transmittance
  - × Silica substrate with $Q_{bulk} = 30\ 10^6$
- Effective readout $Q = 9\ 10^6$

Effects on LIGO Thermal Noise 2



- BNS Inspiral Range from Bench
  - ×Q = 30 10^6 , range = 156 Mpc
  - ×Q = 9 10^6 , range = 104 Mpc

Questions and Experiments

- Is the loss from rubbing between coating and substrate?
  - × Coat with single layers and measure Q
- Is the loss from rubbing between coating layers?
  - × Coat with 14 and 38 layers, measure Q
- Is the loss from the intrinsic ϕ of the coating material?
  - × Coat with 14 and 38 layers for 0.5 μm, measure Q
  - × Coat with other materials, Hf/Al and/or Al_2O_3

Further Experiments

- Ellipsometry experiment to measure perpendicular component of coating loss
- Anneal samples at different temperature
- Measure Q's at different temperatures
- Change surface preparation of substrate
  - × Chemical treatments
  - × Ion polishing
  - × Heat polishing
- Compare Q's from coatings from different vendors

Further Modeling

- Include different Young’s moduli and Poisson ratios (preliminary version from N Nakagawa)
- Include finite size of mirrors
- Include effects from coatings on back of beamsplitters and input mirrors
- Optimize mirror size and/or shape to minimize thermal noise
- FEA modeling to include effects of silicate bonding