The Mechanical Loss of Thin-Film Hafnia as a Function of Temperature

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Overview

- Introduction: Tantala and beyond
- Experimental setup
- Measurements of low temperature dissipation in hafnia
- Applications of hafnia as a high index coating
- Calculation of hafnia/silica multilayer coating loss

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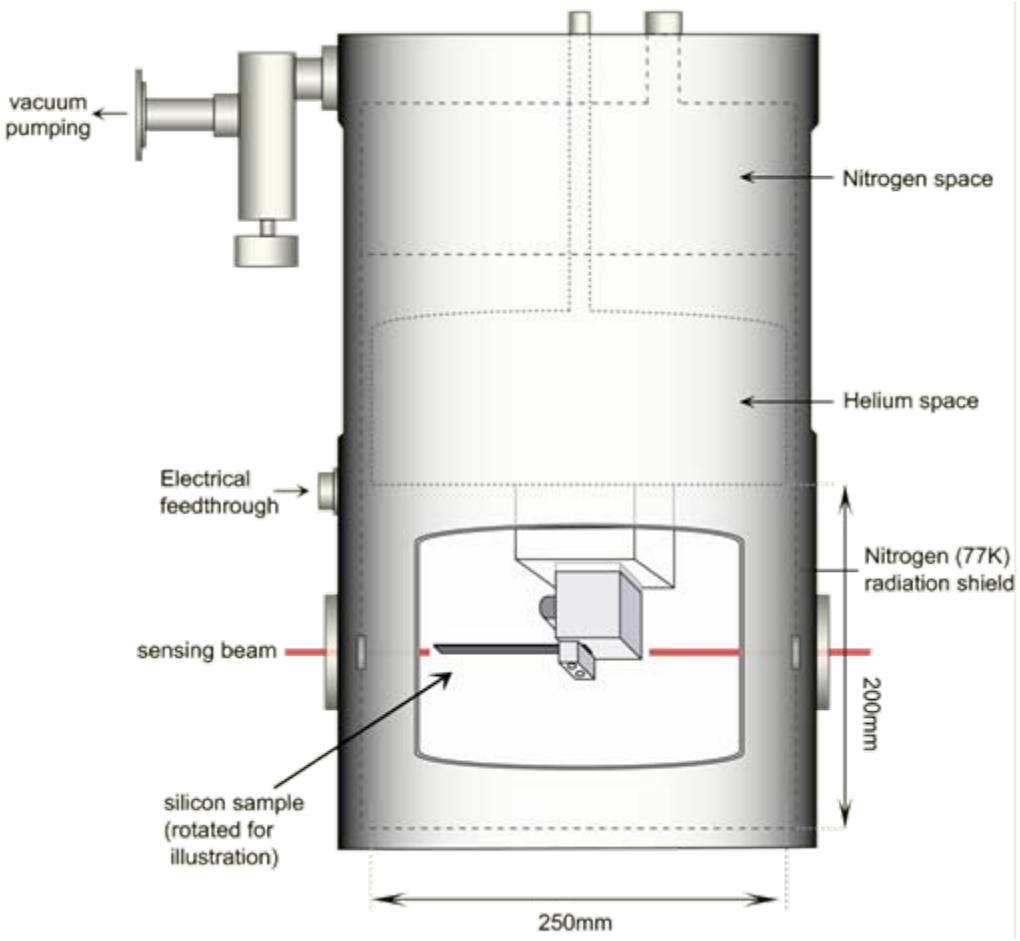
Beyond Tantala Coatings

- The high index coatings required in gravitational wave detector optics have been determined to contribute significantly to detector thermal noise.
- Ta_2O_5 is the dominant source of dissipation in current coatings – mechanism under investigation.
- Ta_2O_5 is known to grow with oxygen deficiencies. HfO_2 is known to have better stoichiometry – alternate high index material.

- Is the dissipation mechanism similar?

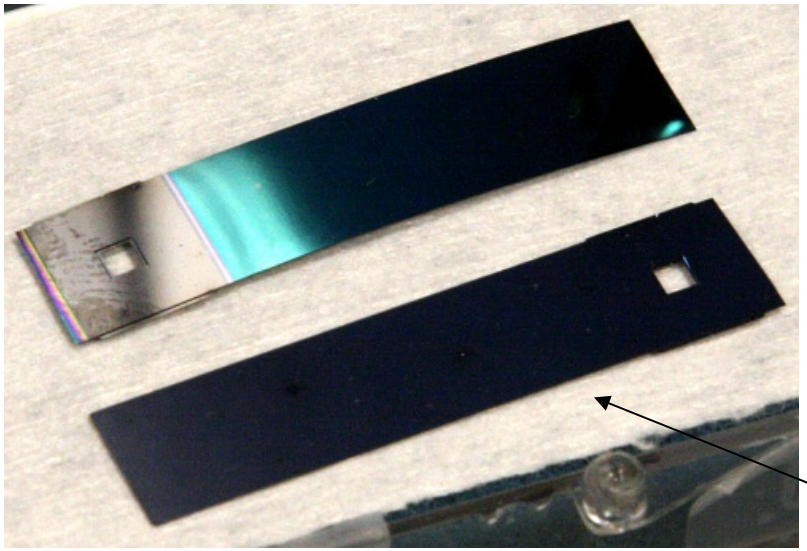
Cryogenic Mechanical Loss Measurement

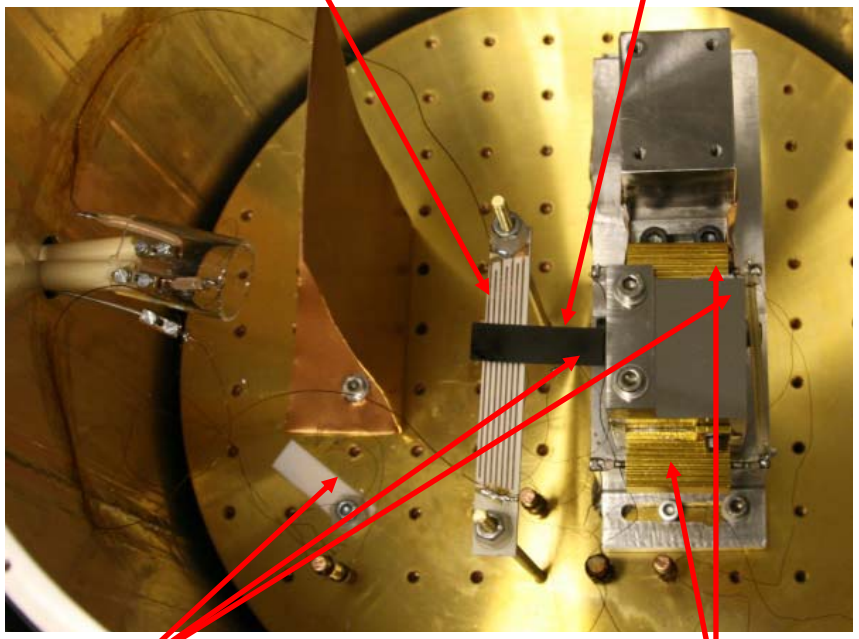
- Experimental method – see previous talk.
- Small, lightweight cryogenic system:
  - efficient cryogen use
  - fast cool down
  - good thermal control
- Motion sensed by cantilever shadow – very little variation of beam alignment with temperature.



Cryogenic Mechanical Loss Measurement

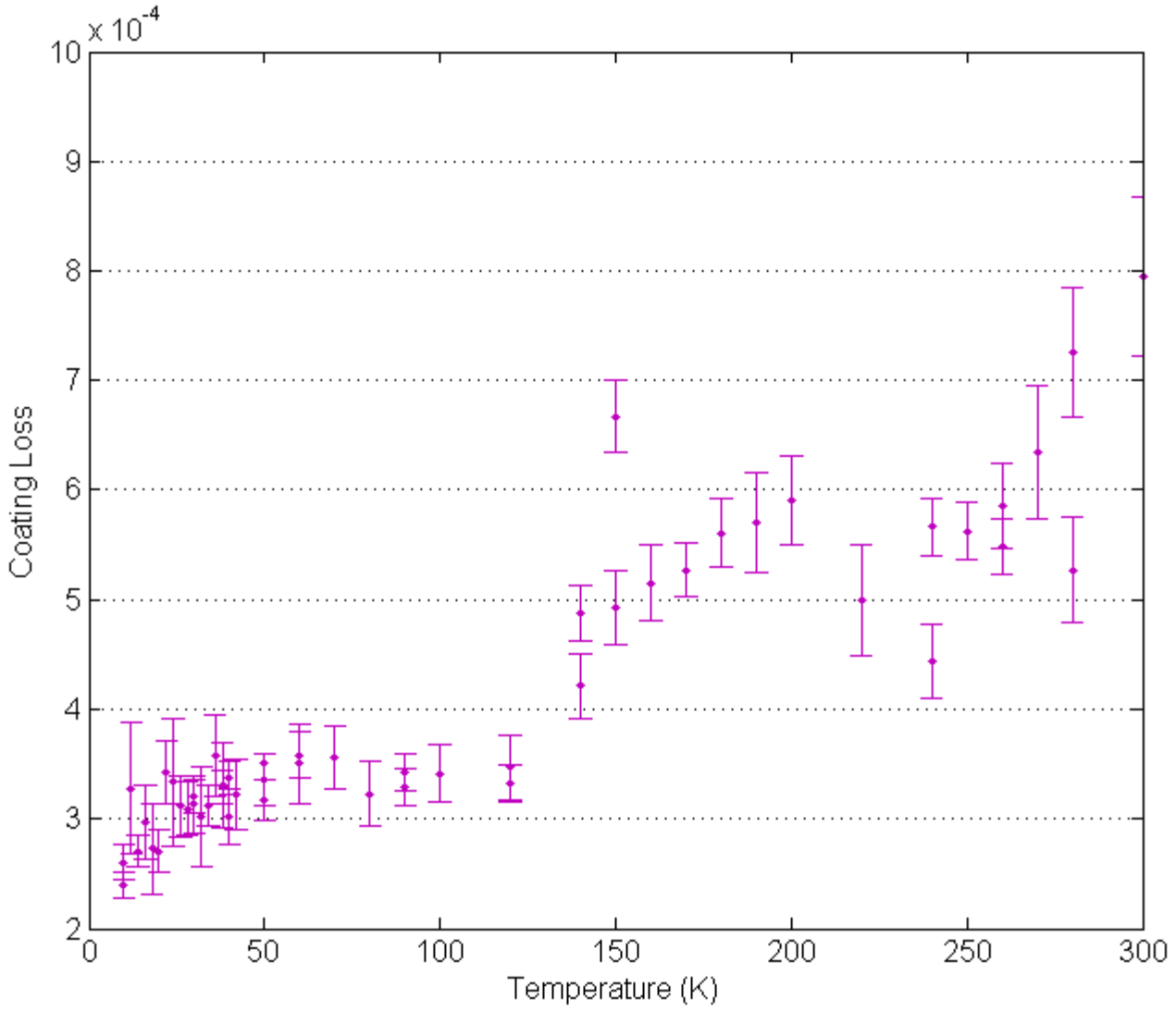
- Sample dimensions:
  - Length = 40mm
  - Width = 10mm
  - Substrate thickness = 59.2μm
  - Coating thickness = 500nm





Cantilever substrates fabricated at Stanford and coated by CSIRO

Temperature Dependence of Coating Loss for Mode at f = 56Hz



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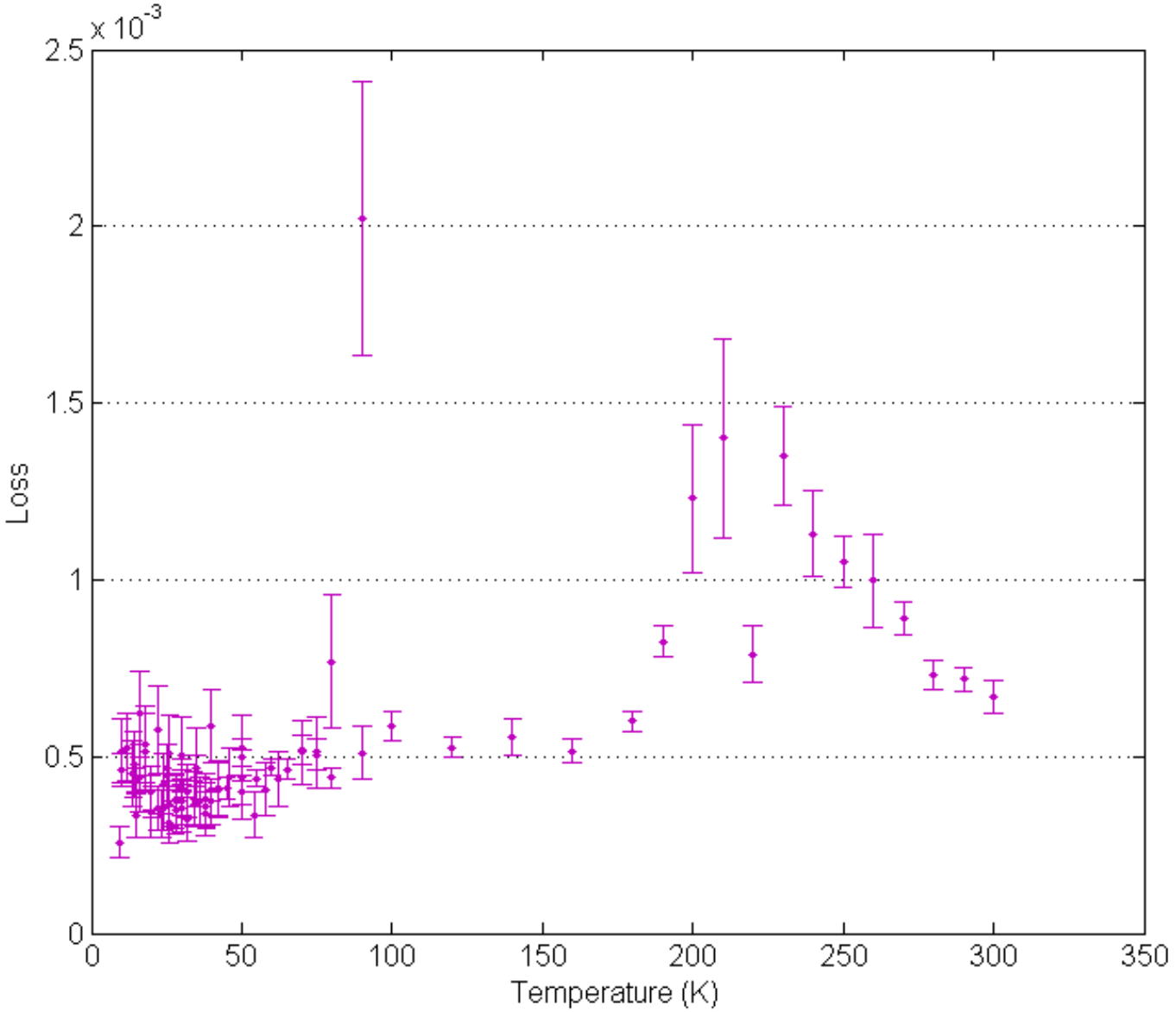
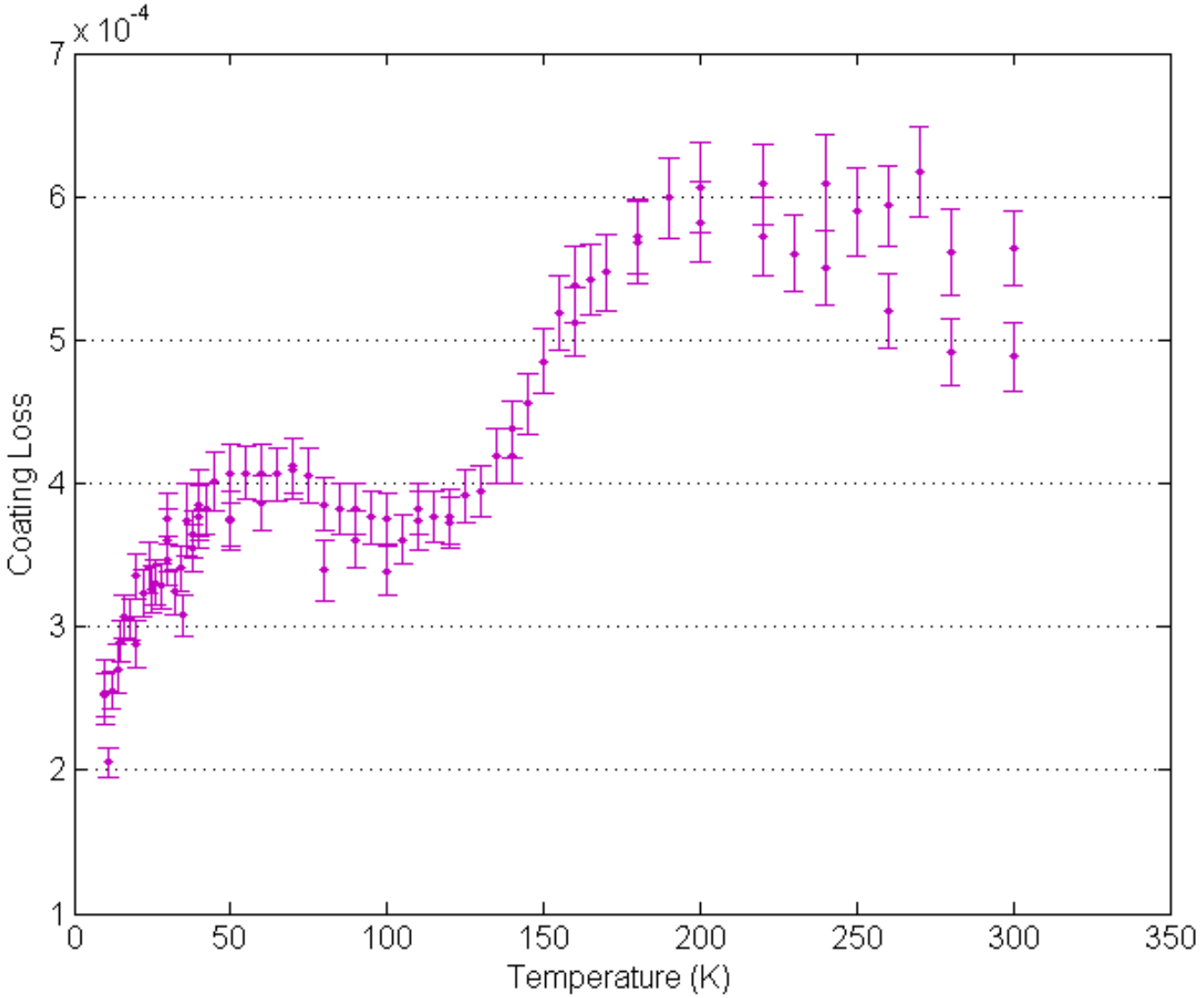
Mode at f = 330Hz



Mode at f = 950Hz



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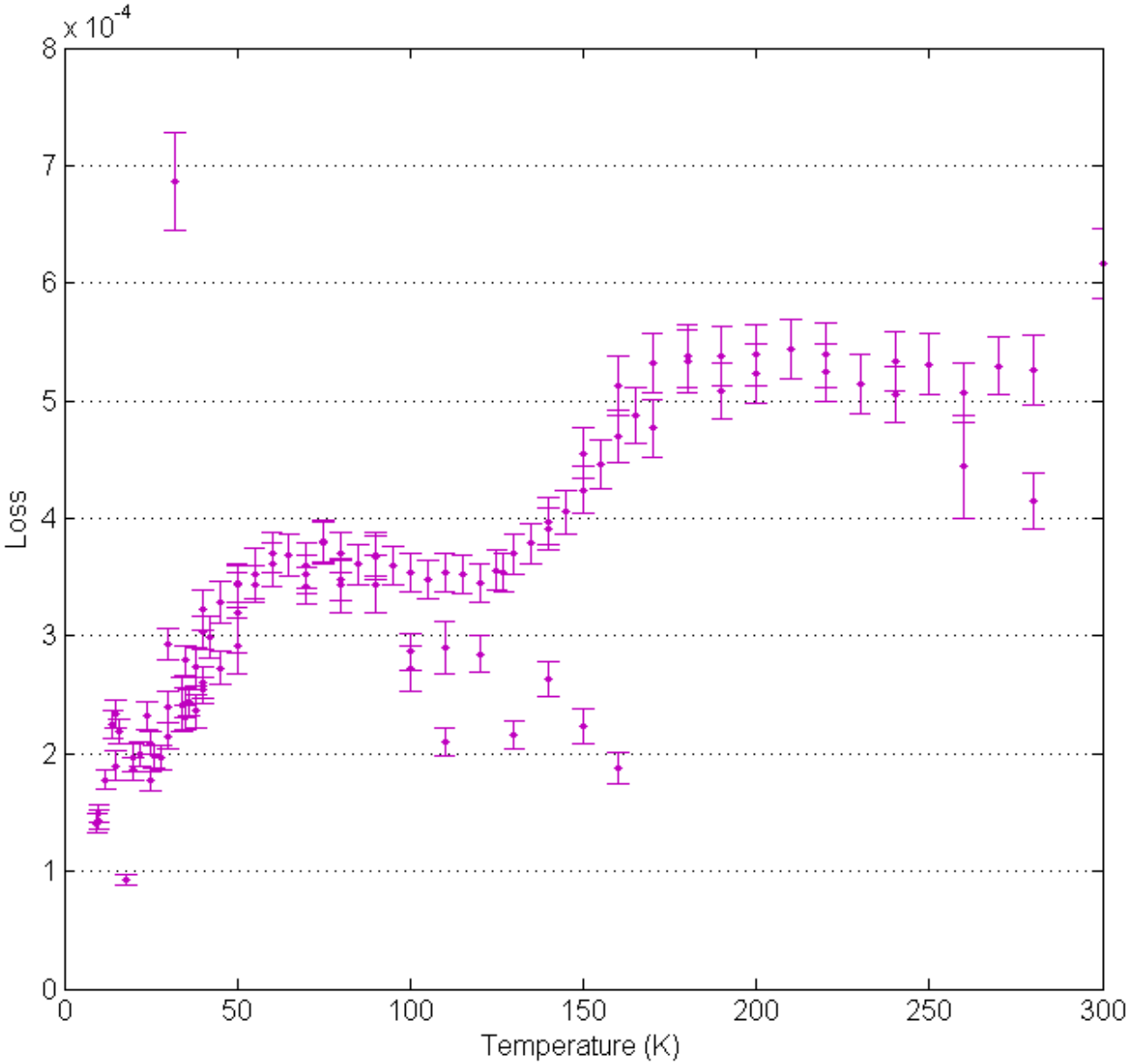
Mode at f = 1950Hz



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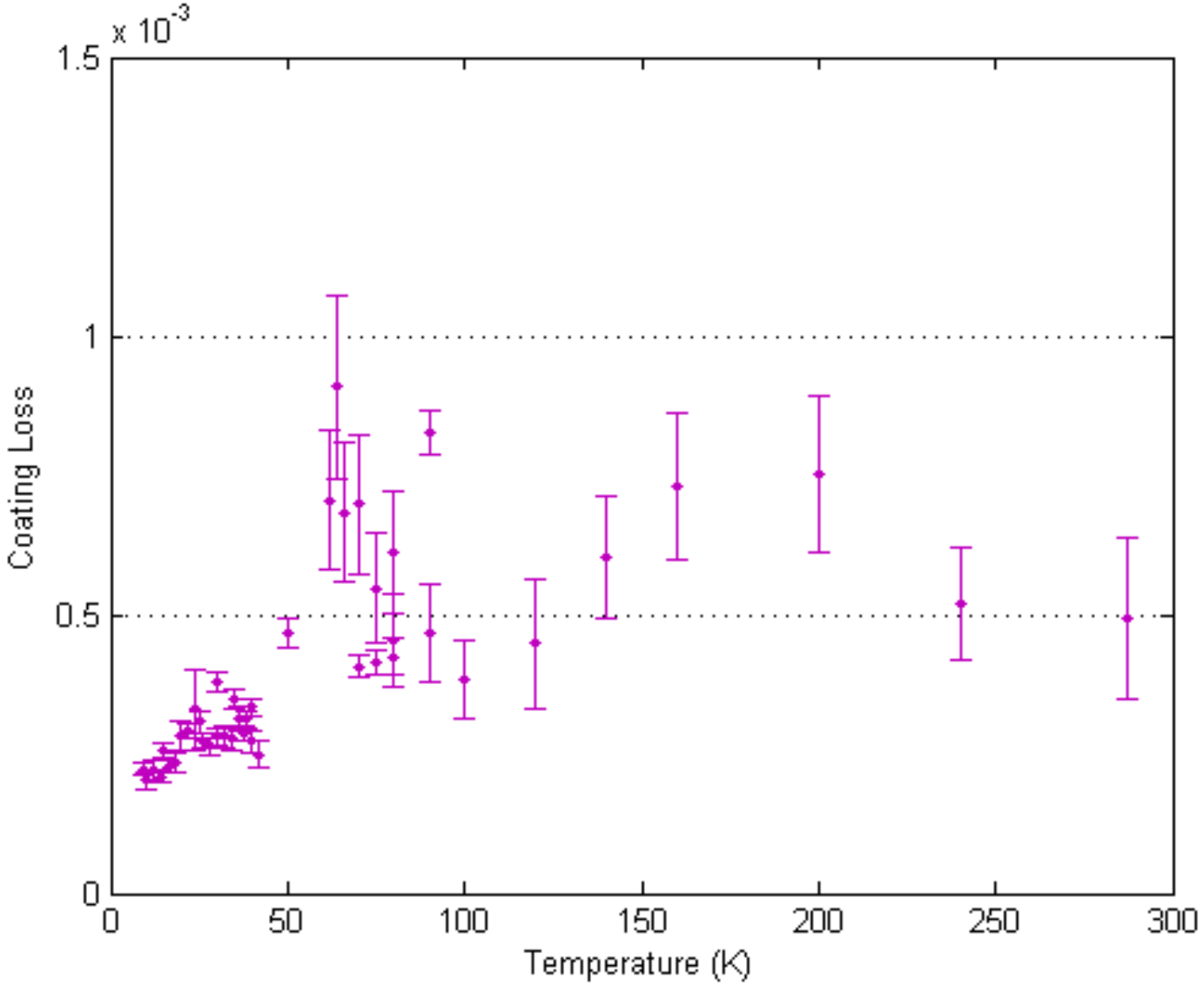
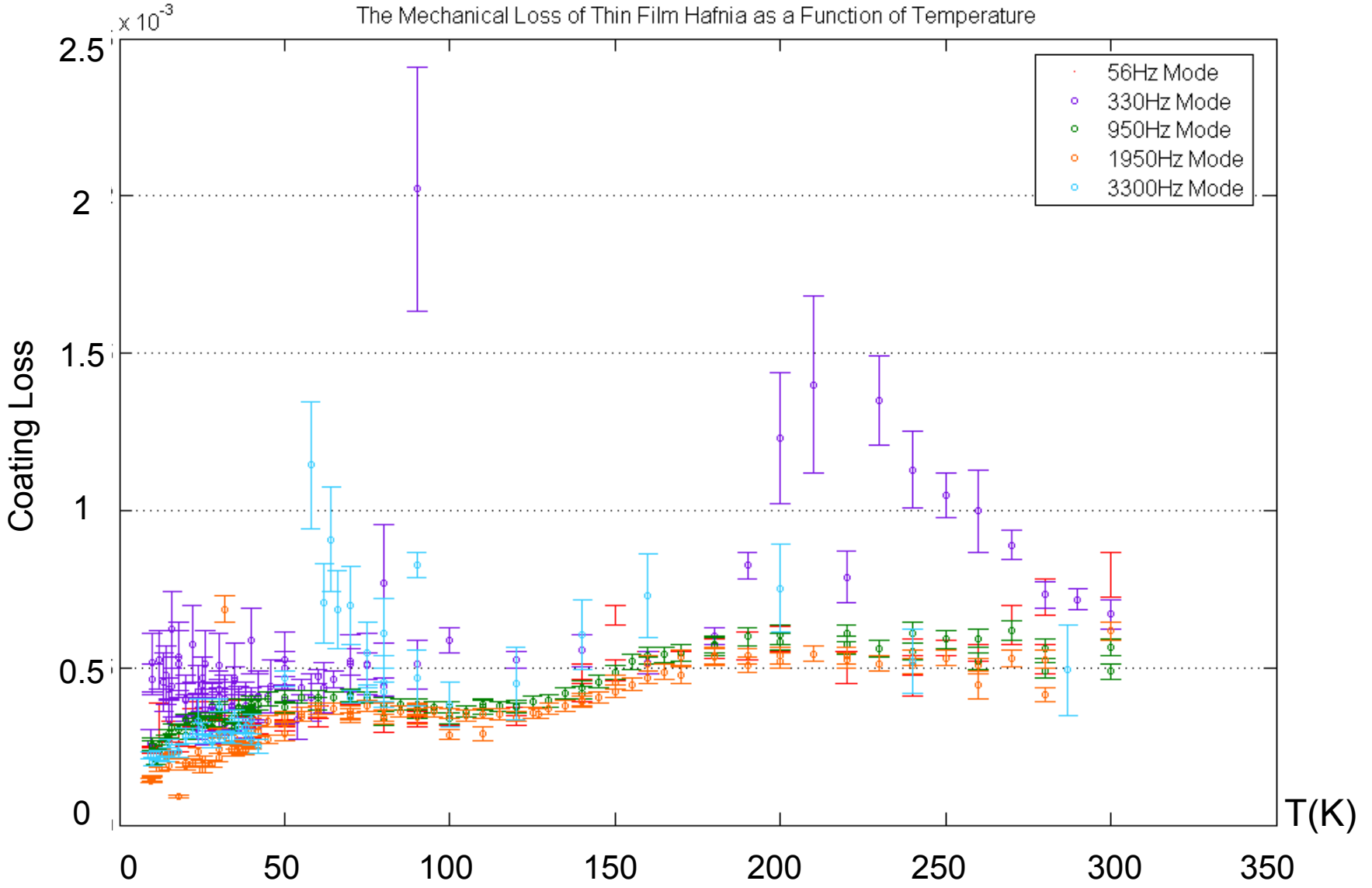
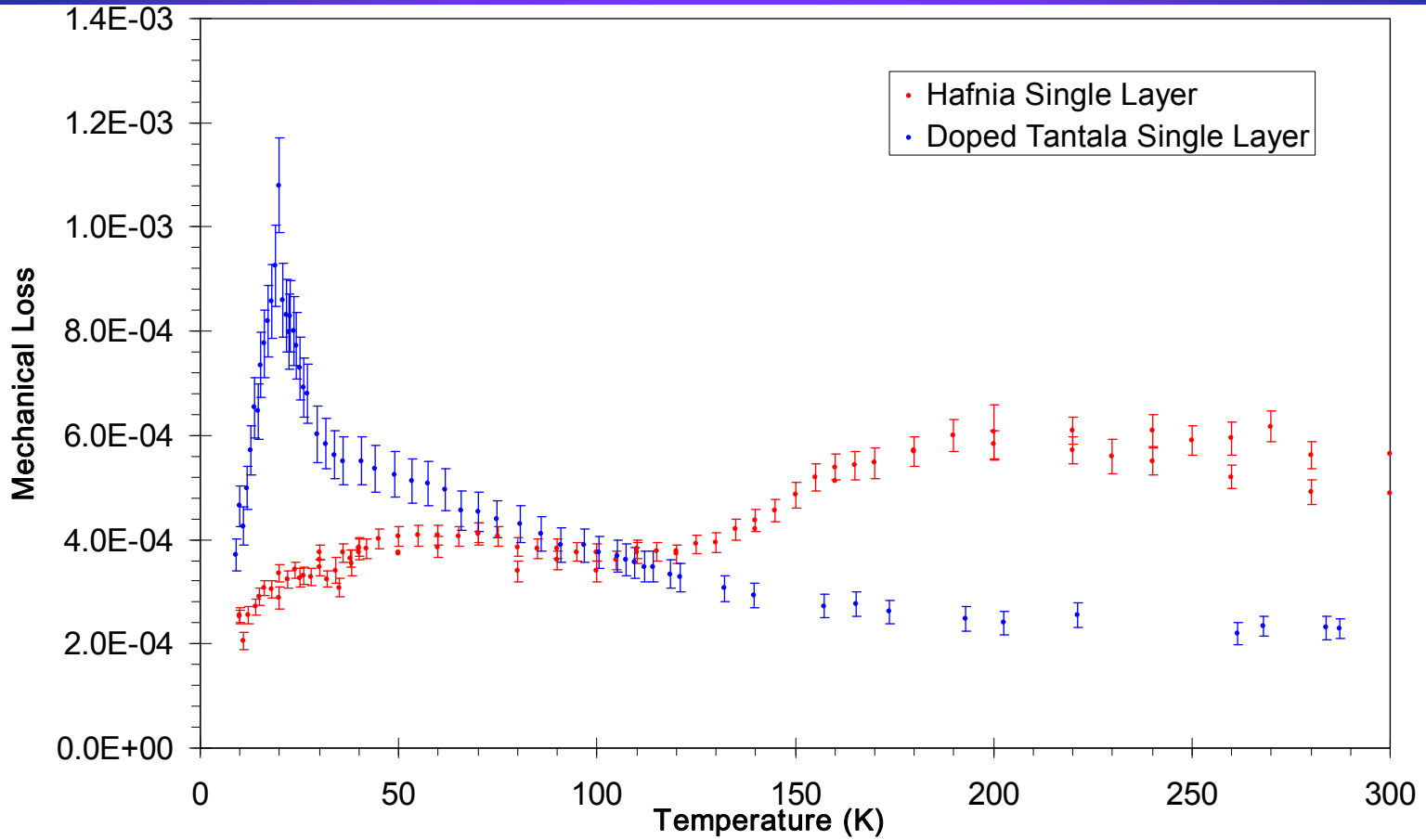
Mode at f = 3300Hz



Plot showing coating loss for all modes studied



Comparison with Tantala



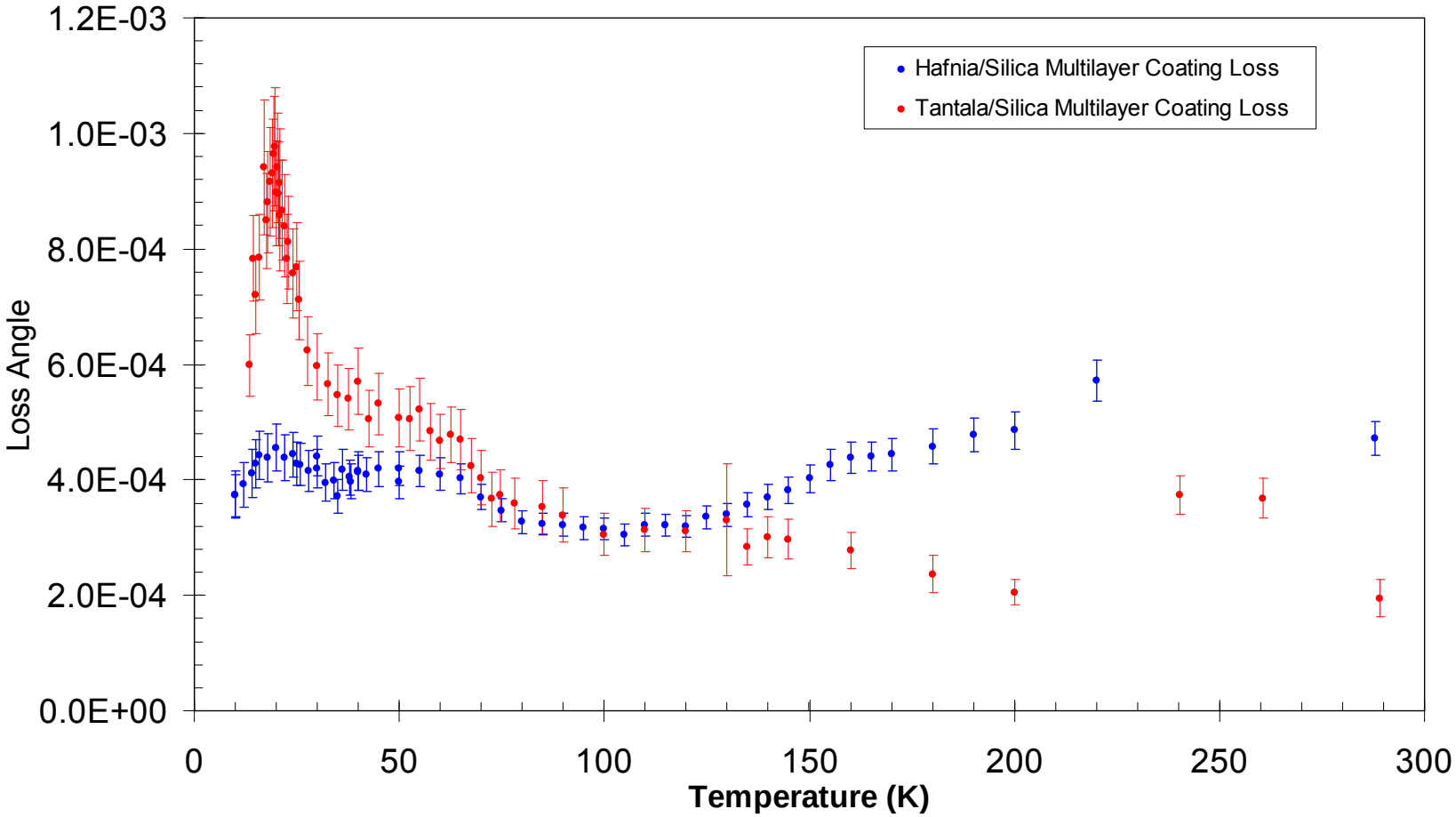
- At 100 K, the level of mechanical loss associated with both doped tantala and hafnia appears at a level $\phi(\omega)_{coating} \sim 4\times10^{-4}$
- HfO_2 shows no major low temperature dissipation peak, loss appears to decrease to below 3×10^{-4} at ~15 K.

HfO_2 as a Coating Component

- Initial results of the mechanical loss of HfO_2 do not show a large peak in dissipation at T ~ 20K in contrast to Ta_2O_5
- Broad peaks do appear to occur at ~50K and ~200K – could this indicate a different dissipation mechanism?

- Initial room temperature studies on a multi-layer silica-hafnia coating on a fused silica substrate were found to be $\phi_{hafnia}=(5.7\pm0.3)\times10^{-4}$

Calculated Loss of 31-layer Coatings



- above 130K, the silica/tantala coating has a factor of 2 lower loss
- below 70K, the silica/hafnia coating stabilizes at a loss of about 4e-4, with a very slight bump at around 20K, due to the dissipation peak in silica.

HfO_2 as a Coating Component

- However, thermo-mechanical material properties for ion-beam-sputtered thin-film HfO_2 are not terribly well studied – could change absolute values of the loss results presented here.

- The optical properties also require further investigation, where initial recent absorption studies of a multilayer silica-hafnia coating by Markosyan et al. (Stanford University) lie in the range 60-80ppm, which is considerably higher than required.