Mechanical loss studies at Maastricht University

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1. Motivation

For current gravitational wave interferometers, the limit in sensitivity at their most sensitive frequencies originates from the thermal noise, dominated by the loss angle of high refractive index material. As part of a new coating characterization laboratory at Maastricht University, a gentle nodal suspension system has been built. We will present initial studies of the mechanical loss of different compositions of TiO_2 doped with a few percent of GeO_2 as part of a comprehensive study of the effect of composition and heat treatment on loss and absorption of magnetron-sputtered germania-based coatings.

2. Gentle Nodal Suspension (GeNS) system

- GeNS system: the sample is suspended on the top of spherical surface, inside the vacuum tank [1].
- Only applied force is its weight, no external damping.
- A non-contacting electrostatic actuator can excite the characteristic mode vibrations of the sample.

2.1 the Samples

- 2x PIAD EBE (electron beam evaporation) coatings made by Helia Photonics:
  1. 85% TiO_2 and 15% GeO_2
  2. 95% TiO_2 and 5% GeO_2
- for reference: 3x uncoated SiO_2 substrates 50mm x 1mm, heat treated @ 900° for 4hrs.

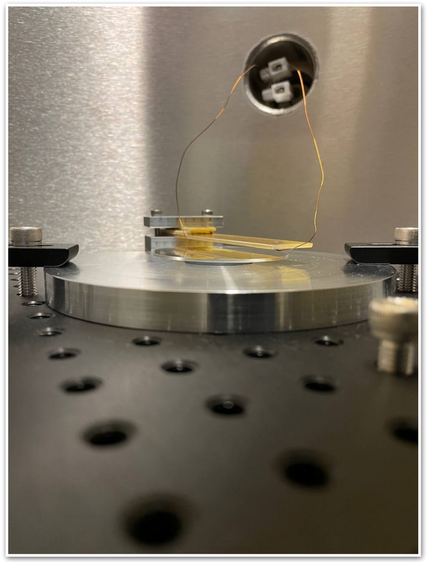


Fig. 1. Photo of out GeNS setup.

Fig. 2. Fused silica disk.

3. Uncoated Loss

- Test for the repeatability of GeNS.
- Characterization of SiO_2 substrates of same geometry of the coated germania samples.
- Visible trend of the loss angle as a function of the modes family for each disk.
- Mean value for the loss angle at $(2.2 \pm 1.0) \times 10^{-7}$.

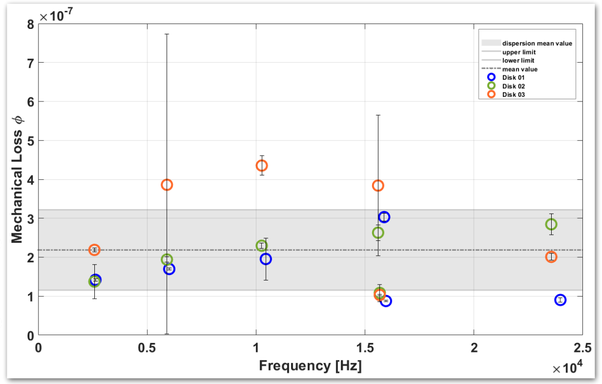


Fig. 3. Summary of all measurements on the uncoated SiO_2 samples.

5. Results

- Previous studies on ZrO_2:Ta_2O_5 and heat-treatment showed the mechanical loss correlated with fraction of corner sharing in the amorphous structure [2].
- Loss level of coated disks very consistent for all the modes.
- Lower loss of 15% Ge-doped Ti coating due to different layer thickness
  → cancel out after the analysis
- 5% Ge-doped Ti as-deposited give loss angle at $8.8 \times 10^{-4} \pm 2.0 \times 10^{-7}$.
- 15% Ge-doped Ti as-deposited give loss angle at $9.1 \times 10^{-4} \pm 3.1 \times 10^{-7}$.

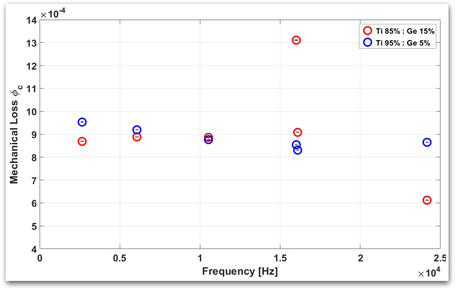
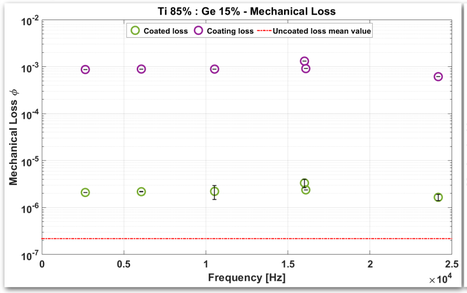
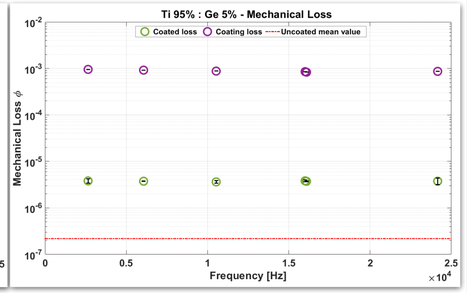


Fig. 6. (top) Coating loss angle of mixed GeO_2 samples. (bottom) Comparison between uncoated, coated and coating loss for 85% and 95% in TiO_2.





4. Energy Ratio

$$\phi_{\text{coating}} = \frac{E_s}{E_c}\left(\phi_{\text{coated}} - \phi_s\right)$$

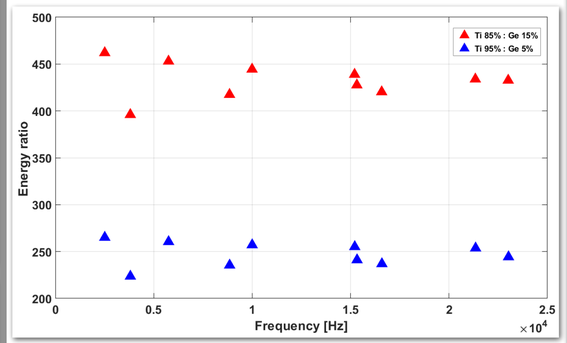


Fig. 4. Energy ratio as function of different frequency for the two different TiO_2:GeO_2 coated samples.

Coating sample	Thickness	Young modulus	Poisson ratio
85% TiO_2:GeO_2	395 [nm]	138.8 [GPa]	0.27
95% TiO_2:GeO_2	650 [nm]	149.4 [GPa]	0.28

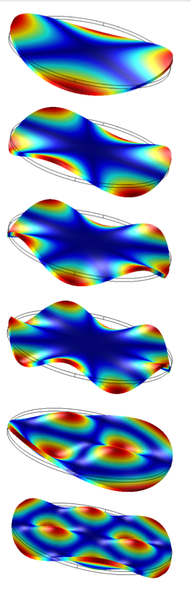


Fig.5. Simulated mode shapes measured in the measurement system.

6. Current status and next step

Done:

- Characterization of uncoated SiO_2 substrates.
- Mechanical loss measurement of 85% and 95% TiO_2:GeO_2 as-deposited.

To do:

- Explore the effect of heat treatment on the same doped samples.
- Further investigations on germania doped titania samples in different concentration and different geometry.

References:

[1] E.Cesarini *et al.*, *"A 'gentle' nodal suspension for measurements of the acoustic attenuation in materials"*, Rev. Sci. Instrum. **80**, 053904 (2009).
[2] K. Prasai *et al.*, *"High Precision Detection of Change in Intermediate Range Order of Amorphous Zirconia-Doped Tantala Thin Films Due to Annealing"*, Phys. Rev. Lett. **123**, 045501, (2019).