Status of R&D activity on IBS TiO2:GeO2 coatings

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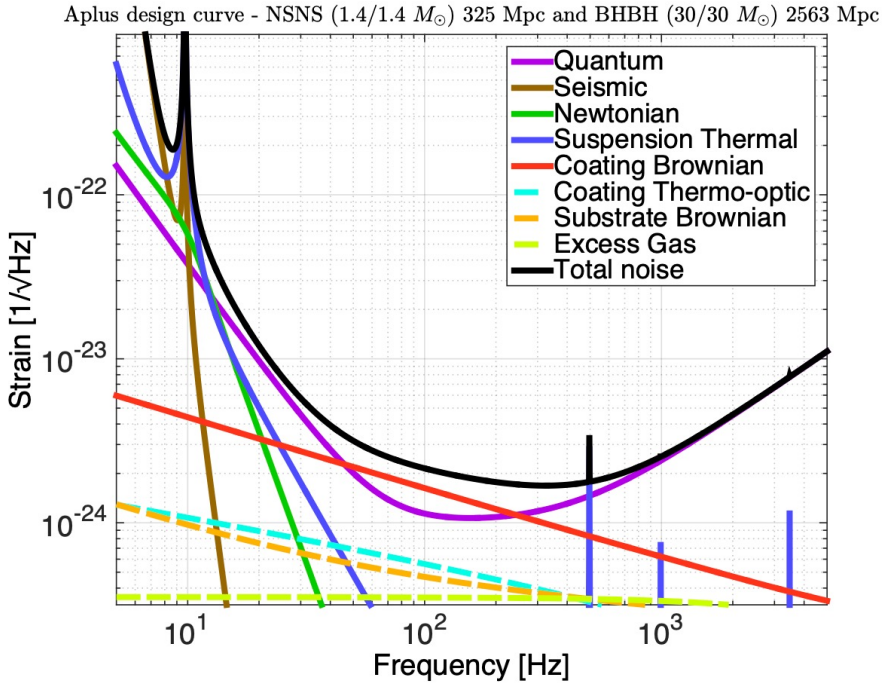
Brownian noise in A+



From IS white paper T2000407-v3

$$S_{A+}^{1/2}(100\,\mathrm{Hz}) = 0.65 \times 10^{-20}\mathrm{mHz}^{-1/2}$$

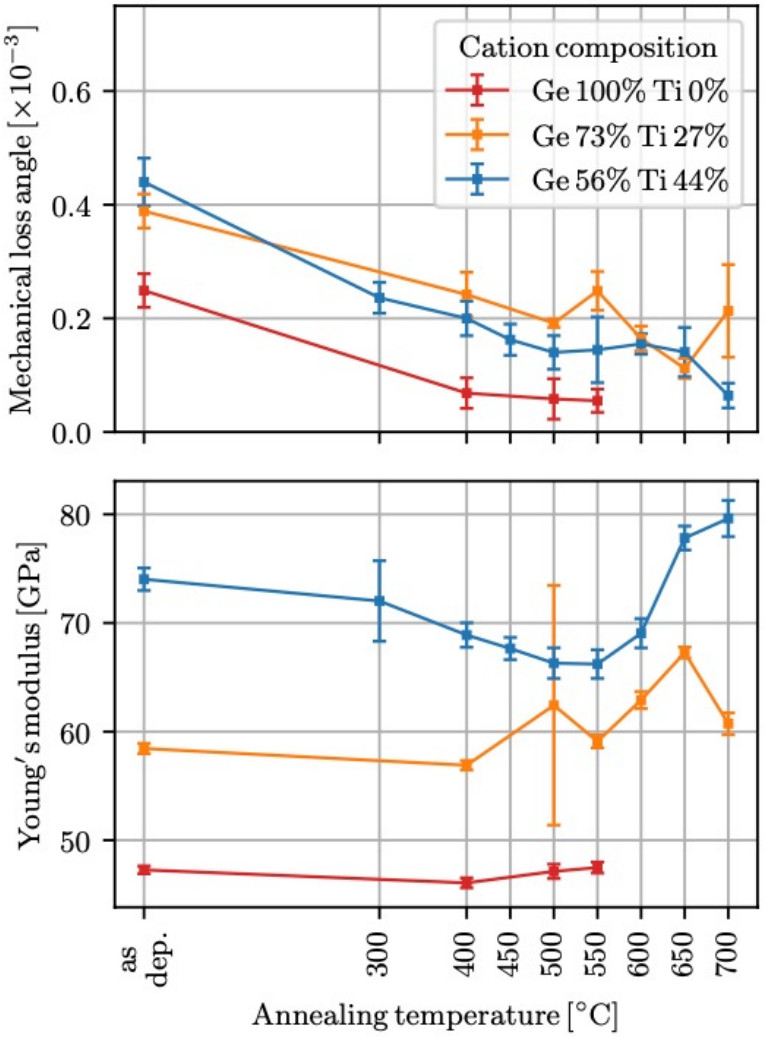
- Improve coating Brownian noise by about a factor 2
- By a combination of loss angle(s), Young's modulus and refractive index

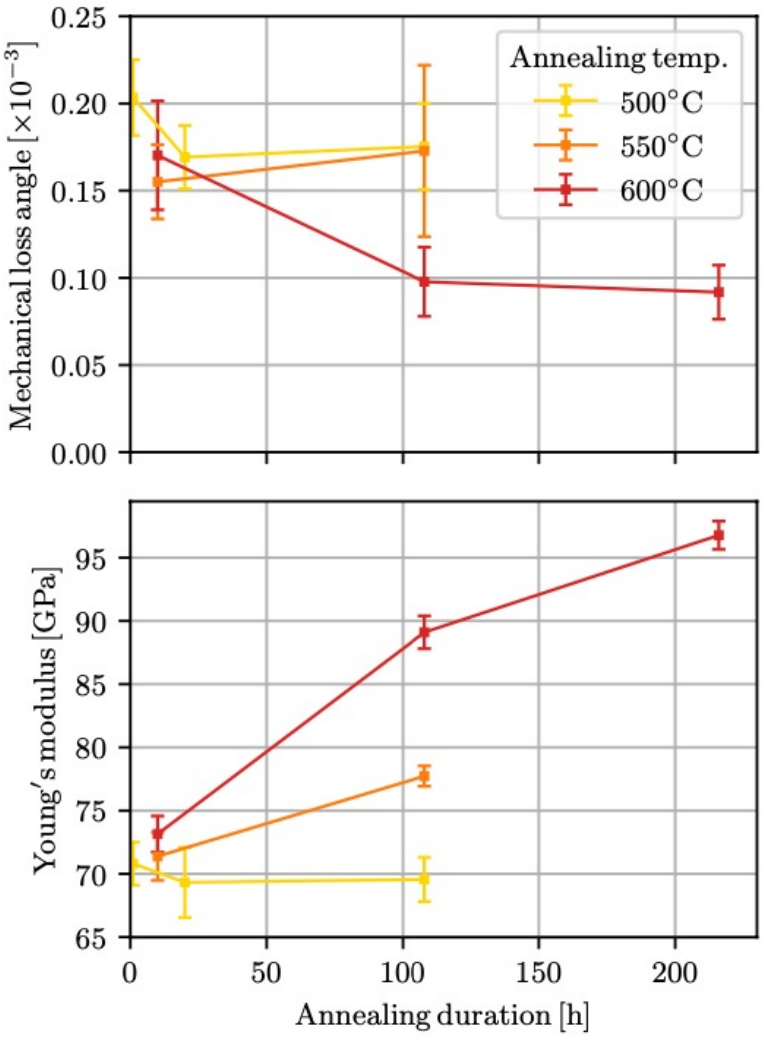
$$S_x(f) = \frac{2k_BT}{\pi^2 f}\frac{d}{w^2}\left\{\left[\frac{1}{3}\left\langle\frac{(1-2\sigma)}{(1-\sigma)^2}Y\phi_K\right\rangle + \frac{2}{3}\left\langle\frac{1-\sigma+\sigma^2}{(1-\sigma)(1-\sigma^2)}Y\phi_\mu\right\rangle\right]\frac{(1+\sigma_s)^2(1-2\sigma_s)^2}{Y_s^2}\right.$$
$$+\frac{2}{3}\left\langle\frac{(1-2\sigma)(1+\sigma)}{(1-\sigma)^2}\left(\phi_K-\phi_\mu\right)\right\rangle\frac{(1+\sigma_s)(1-2\sigma_s)}{Y_s} \qquad (3.1.7)$$
$$\left.+\left[\frac{1}{3}\left\langle\frac{(1+\sigma)^2(1-2\sigma)}{(1-\sigma)^2}\frac{1}{Y}\phi_K\right\rangle + \frac{2}{3}\left\langle\frac{(1+\sigma)(1-2\sigma)^2}{(1-\sigma)^2}\frac{1}{Y}\phi_\mu\right\rangle\right]\right\}$$

M. M. Fejer, Effective Medium Description of Multilayer Coatings, https://dcc.ligo.org/LIGO-T2100186/public

Titania-doped Germania films

First set of deposition (with the LANS system) described in **P2100075**

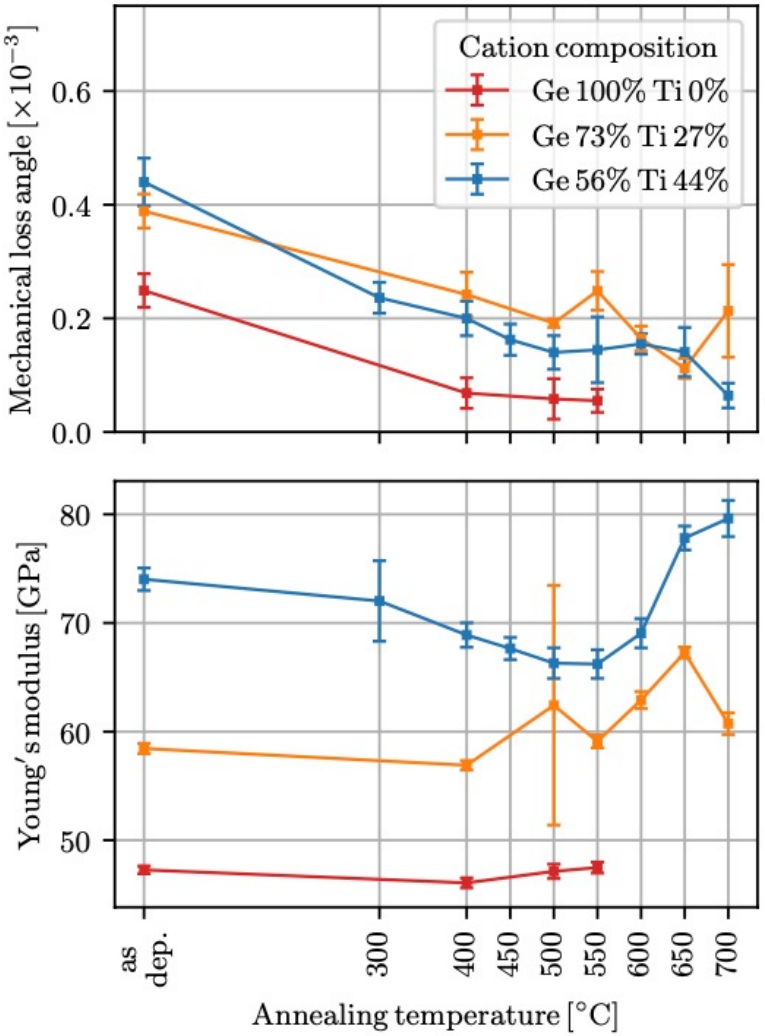


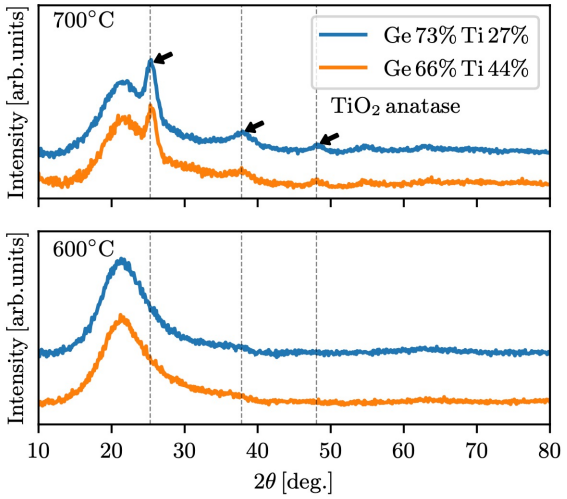


Titania-doped Germania films

First set of deposition (with the LANS system) described in **P2100075**

Crystallized after annealing at 700°C / 10 hours, but still amorphous after 600 °C / 108 hours





Parameter	Value
Cation concentration, Ti/(Ti+Ge)	44%
Refractive index at 1064 nm	1.88
Density	3700 kg/m^3
Young's modulus	90.3 ± 1.3 GPa
Poisson ratio	0.24 ± 0.05
Loss angle	(0.96 ± 0.18) ×10^{-4}
Optical absorption for a QWL	2.3 ± 0.1 ppm

TABLE I. Measured parameters for the best TiO_2:GeO_2 mixture, after annealing at 600°C for 108 hours.

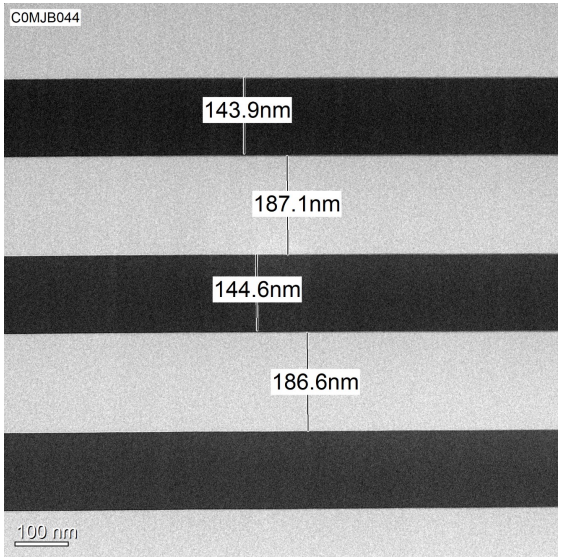
Film deposited with Spector

- Silica and Titania-Germania single layers (deposition details in T2100183)
- Multi-layer stacks of 10 and 40 layers total
- It is not straightforward to compare Young's modulus and loss angle of single layers and stacks
- In a (very) simple approximation

$$Y_c = \frac{\sum_i d_i Y_i}{\sum_i d_i} \quad \phi_c = \frac{\sum_i \phi_i d_i Y_i}{\sum_i Y_i d_i}$$

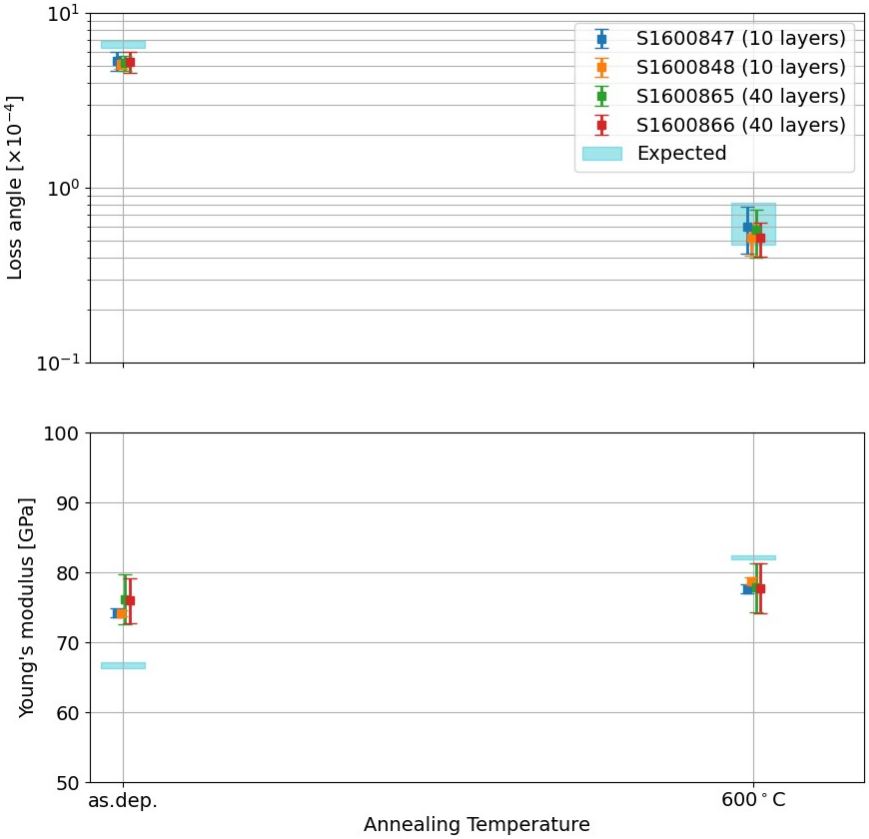
- No evidence of excess loss in the stack

TEM image ofSiO_2 / Ti:GeO_2 stack



40 LAYERS Absorption loss @ 1 μm

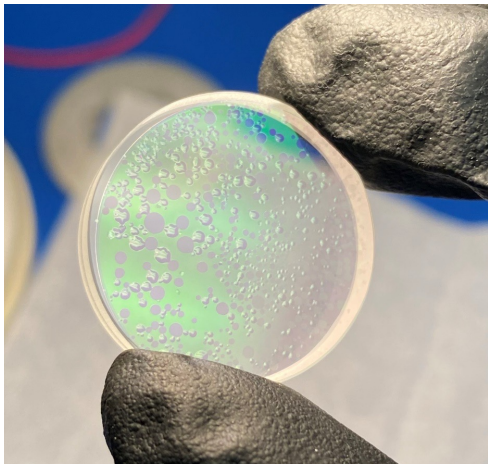
Coating	Abs. (ppm) @ 1 μm
As dep	46.4
600°C for 10 h	3.4



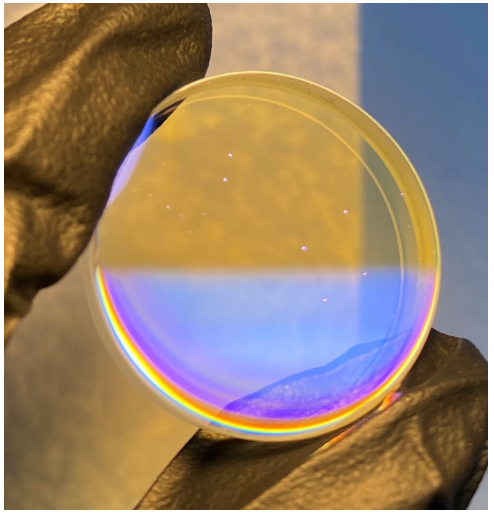
Delamination issues

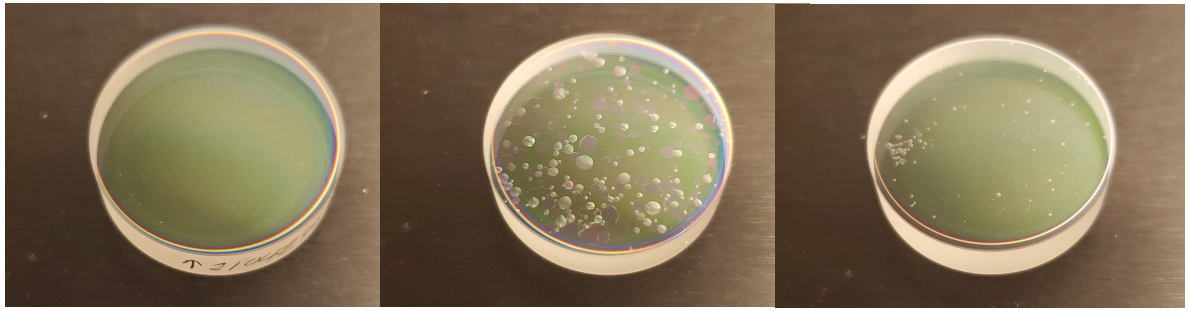
- Annealing the multilayers creates bubbles / delamination
- Highly dependent on the stress in the deposited film
- High stress tracked down to the silica layers
  - Bubbles form also in tantala / silica stacks
  - Bubbles reduced with deposition of lower stress silica
- Two step annealing (300°C then 600°C) reduces bubbles in 40 layers
- Some bubbles still present on 52 layers after 300°C then 500°C annealing (No bubbles after 300°C)
- Work in progress

Normal stress SiO2 layers



Low-stress SiO2 layers





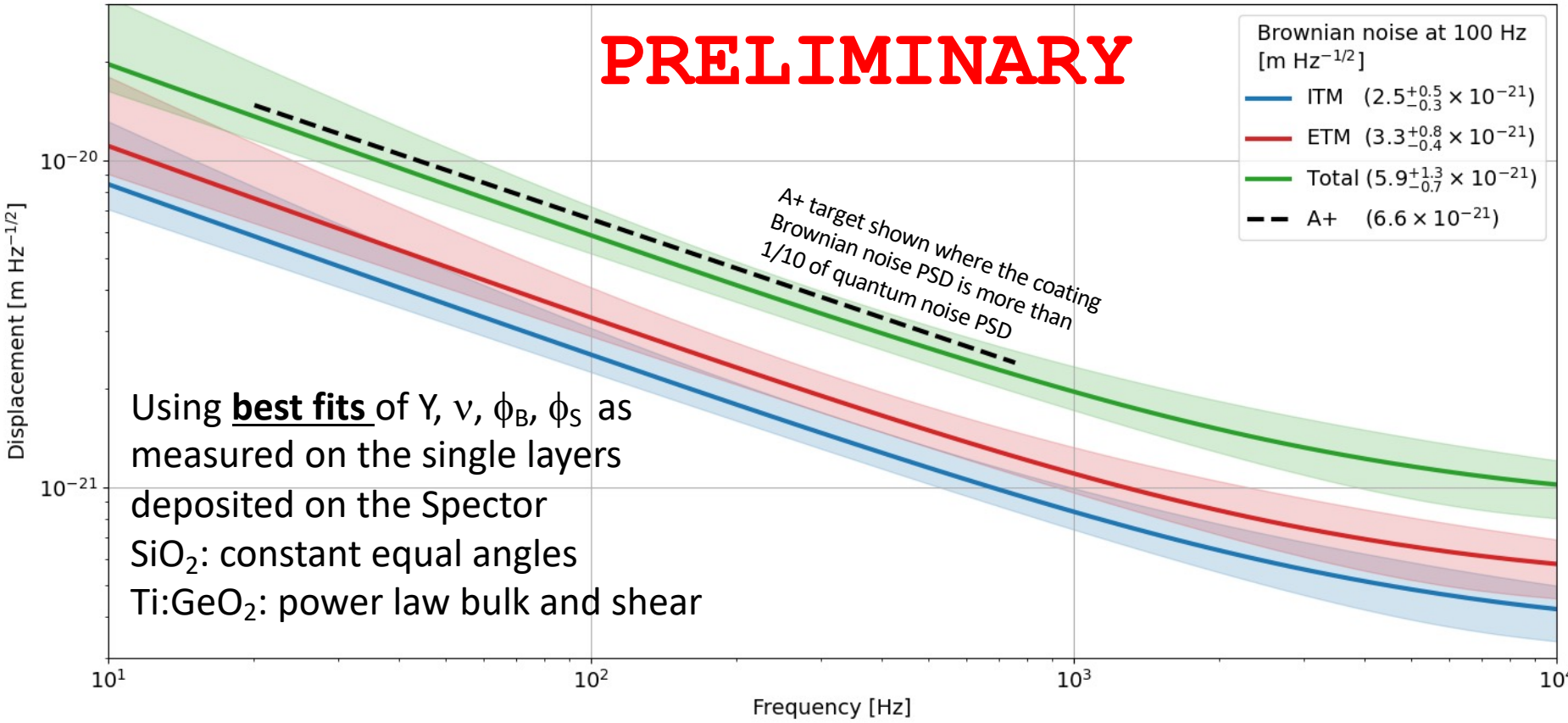
As deposited

300 C straight to 600 C anneal

Separate 300 C and 500 C anneal

Brownian noise prediction for A+

- Mirror design (physical thickness in nm)
  - ITM = [SiO2 367, TiGeO2 106] [SiO2 228, TiGeO2 106]*10: T = 1.4%
  - ETM = [SiO2 367, TiGeO2 123] [SiO2 208, TiGeO2 123]*25: T = 5 ppm
- Measured bulk and shear loss angles (preliminary) for silica and 44%-titania-germania



Summary

- **Titania-Germania** films are a very promising candidate for A+ coatings
- Annealing at 600°C for 100+ hours gives the best loss angle without crystallization
- Issues with delamination when annealing at 500°C and above, related to high stress in silica. Work in progress
- Optical absorption of a 40 layer stack 3.4 ppm, still room for improvements

- Exploration of different titania concentration on-going with film deposited at Cutting Edge Coatings, with University of Strathclyde and University of Montreal. Annealing and analysis in progress