Virgo Coating R&D

Geppo Cagnoli - LMA
for the VCR&D

The 2 fundamental axes of coating research

- **Materials**

Pragmatic

Selection and Optimization

♦ Advanced detectors upgrade
♦ 3^{rd} generation

Fundamental Physics

♦ Origin of losses and relaxations in amorphous materials

Collaborations

♦ ViSIONs: origin of relaxations
♦ **Virgo Coating R&D** +Jena U.+PTB
♦ GAST: FR, D, UK, IT, crystalline coatings on sapphire

- **Coaters and metrology**

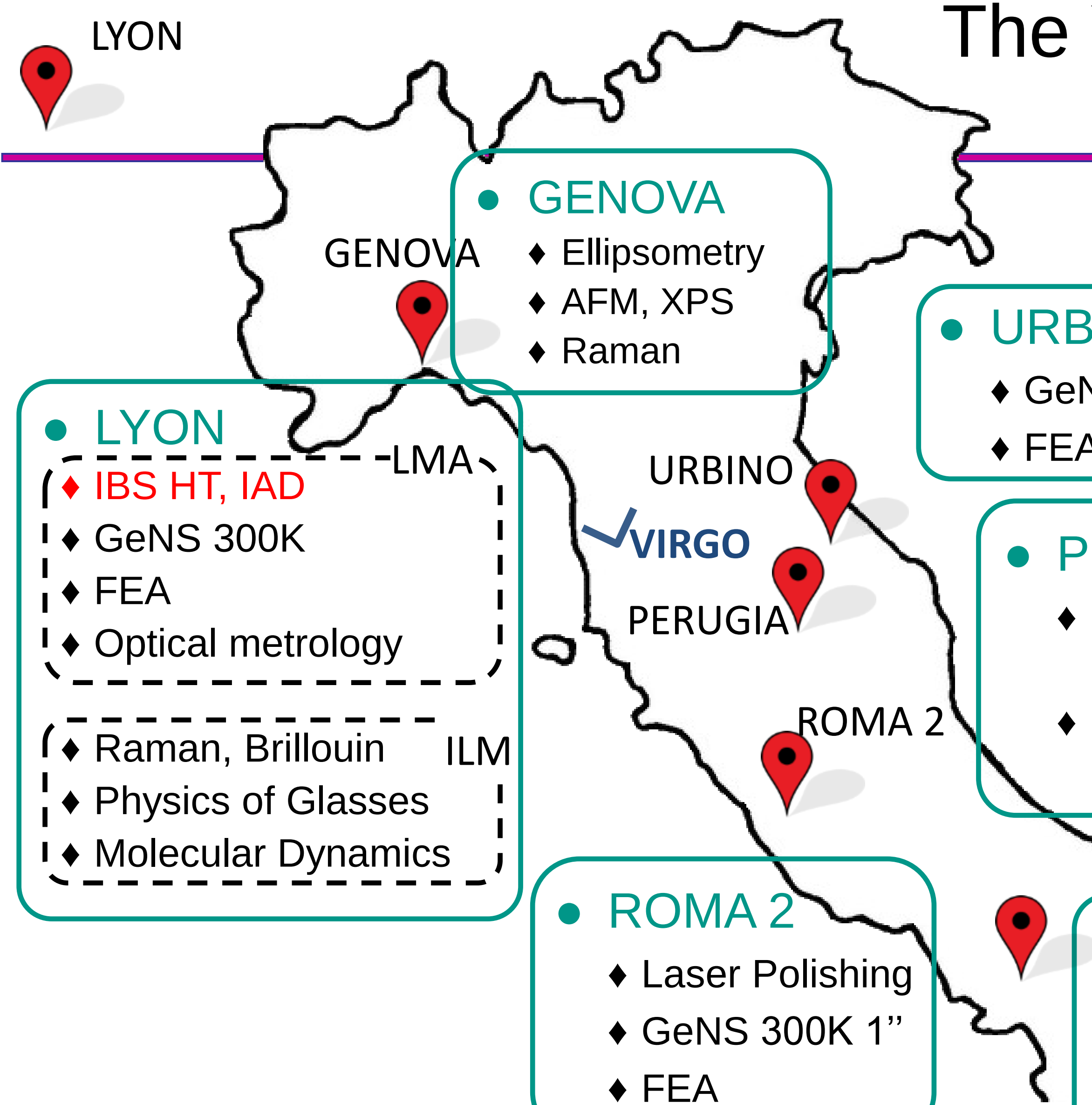
Ongoing

♦ Uniformity
♦ In-situ optical metrology for real time thickness control
♦ Spectrophotometric bench for large optics

Planned

♦ High T deposition
♦ Point like defects
♦ Post deposition coating correction

The Virgo Coatings R&D Collaboration



- GENOVA
  - ♦ Ellipsometry
  - ♦ AFM, XPS
  - ♦ Raman

- URBINO
  - ♦ GeNS Cryo
  - ♦ FEA

- LYON
  - LMA
    - ♦ IBS HT, IAD
    - ♦ GeNS 300K
    - ♦ FEA
    - ♦ Optical metrology
  - ILM
    - ♦ Raman, Brillouin
    - ♦ Physics of Glasses
    - ♦ Molecular Dynamics

- PERUGIA
  - ♦ Cantilevers & GeNS Cryo
  - ♦ Physics of Glasses

- ROMA 2
  - ♦ Laser Polishing
  - ♦ GeNS 300K 1’’
  - ♦ FEA

The University of Sannio is defining its role inside this collaboration

- ♦ nanolayered composites and Mie-metamaterials
- ♦ IAD

VCR&D active research lines

IMPLEMENTATION

2022 2023 >2023

- Metology
  - GeNS vs cantilevers
  - Mode families on discs
  - Thermoelasticity in crystalline materials
- New Materials
  - New optimization of TiO_2/Ta_2O_5
  - Study of TiO_2/Nb_2O_5
  - Optimization of SiO_2
  - Si_3N_4
  - ZnS, ZnSe
  - MgF_2, CaF_2
  - Crystalline coatings
- Deposition parameters
  - Exploring the ion gun parameters
  - Investigation on the deposition rate
  - High Temperature deposition

Loss measurements on the materials and HR coatings used in the Advanced detectors

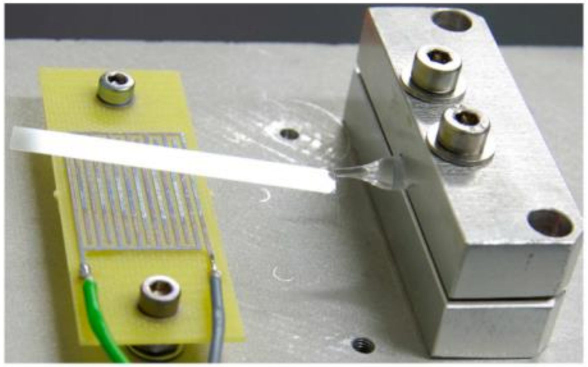
- The article of Flaminio et al. (2010) has been updated by the Granata et al. (2016)

PHYSICAL REVIEW D **93,** 012007 (2016)

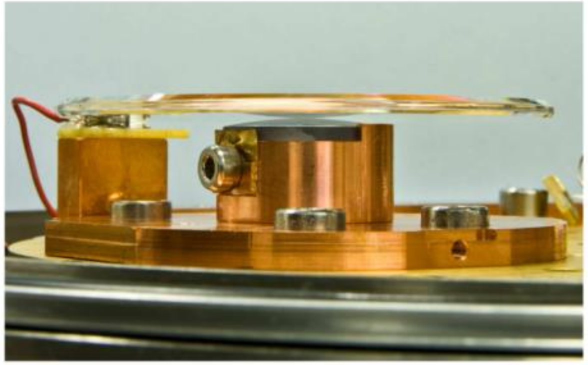
Mechanical loss in state-of-the-art amorphous optical coatings

Massimo Granata,[1,*] Emeline Saracco,[1,†] Nazario Morgado,[1,‡] Alix Cajgfinger,[1] Gianpietro Cagnoli,[1,2]
Jérôme Degallaix,[1] Vincent Dolique,[1] Danièle Forest,[1] Janyce Franc,[1,§] Christophe Michel,[1]
Laurent Pinard,[1] and Raffaele Flaminio[1,3]

MASSIMO GRANATA *et al.*



PHYSICAL REVIEW D **93,** 012007 (2016)



From Granata et al. (2016)
Metrology problems

- Single vs double sided deposition

sample[a]	coating	N	r	k	ϕ_k^{cs}	D	ϕ_e	$\langle\phi_m\rangle$	R [m]
H-5	HR	18	0.35	0	0.186	12.2	1.3 ± 0.2	2.2 ± 0.1	
				1	0.190				
H-5	$2 \times$ HR[b]	18/18	0.34	0	0.281	6.3	1.2 ± 0.2	1.7 ± 0.1	∞
				1	0.288				
				4	0.291				
HTM-A108	HR	38	0.56	0	0.443	6.5	1.5 ± 0.2	2.7 ± 0.1	-0.21 ± 0.01
				1	0.449				
				2	0.435				
HTM-A108	$2 \times$ HR[b]	38/38	0.56	0	0.726	3.2	1.5 ± 0.2	2.3 ± 0.1	-0.30 ± 0.01
				1	0.745				
				2	0.756				
				3	0.754				
				4	0.778				

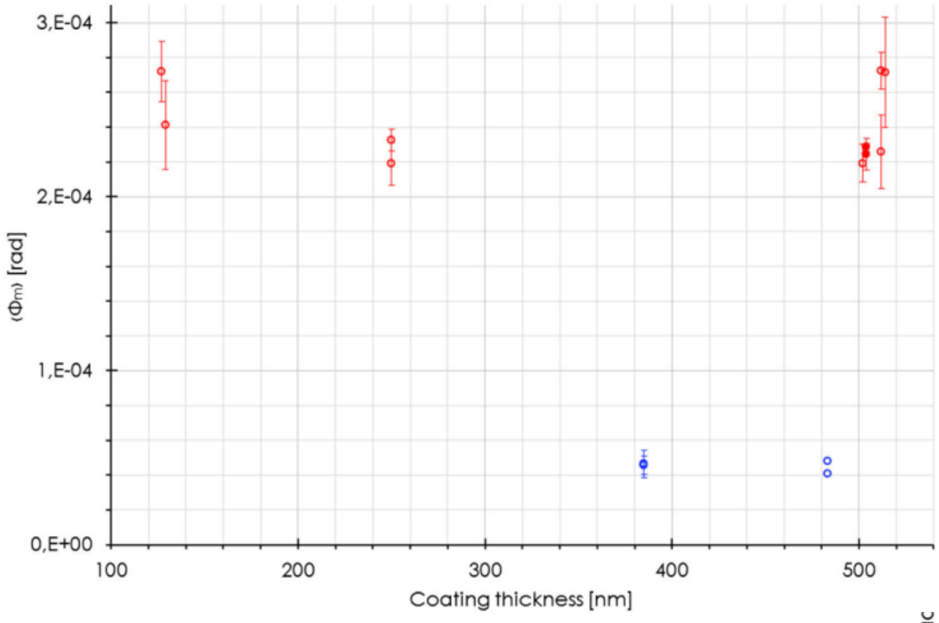
- GeNS vs Cantilevers

TABLE VI. Specifications and results of fused-silica disks coated with stacks: sample, coating design, number of coating layers N, thickness ratio r, mode order[a] $(r, a)_k$, simulated dilution factor D_k, expected coating loss ϕ_e, and measured coating loss $\langle\phi_m\rangle$. Loss angles are given in units of 10^{-4} rad.

Sample	Coating	N	r	$(r,a)_k$	D_k	ϕ_e	$\langle\phi_m\rangle$
39	HR	18	0.32	$(0,2)_1$	237.1	1.2 ± 0.2	1.5 ± 0.1
				$(0,3)_4$	237.6		
				$(0,5)_{10}$	240.3		
				$(1,2)_{12}$	236.0		
				$(0,6)_{15}$	242.2		
38	HR	38	0.56	$(0,2)_1$	112.5	1.5 ± 0.2	2.1 ± 0.1
				$(0,3)_4$	112.6		
				$(0,5)_{10}$	113.7		
				$(1,2)_{12}$	111.1		
				$(0,6)_{15}$	114.6		

From Granata et al. (2016)
Interfaces or metrology problems?

FIG. 8. Mechanical loss of monolayers of silica (blue) and titania-doped tantala (red) as a function of the layer thickness, as measured on fused-silica cantilever blades coated on one (open circles) or on both surfaces (dots).



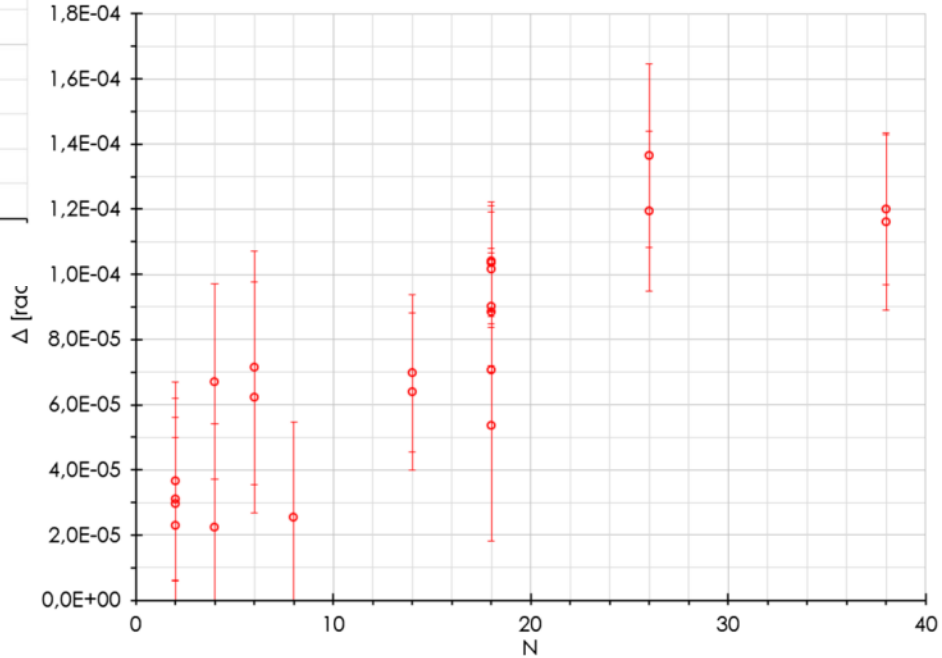
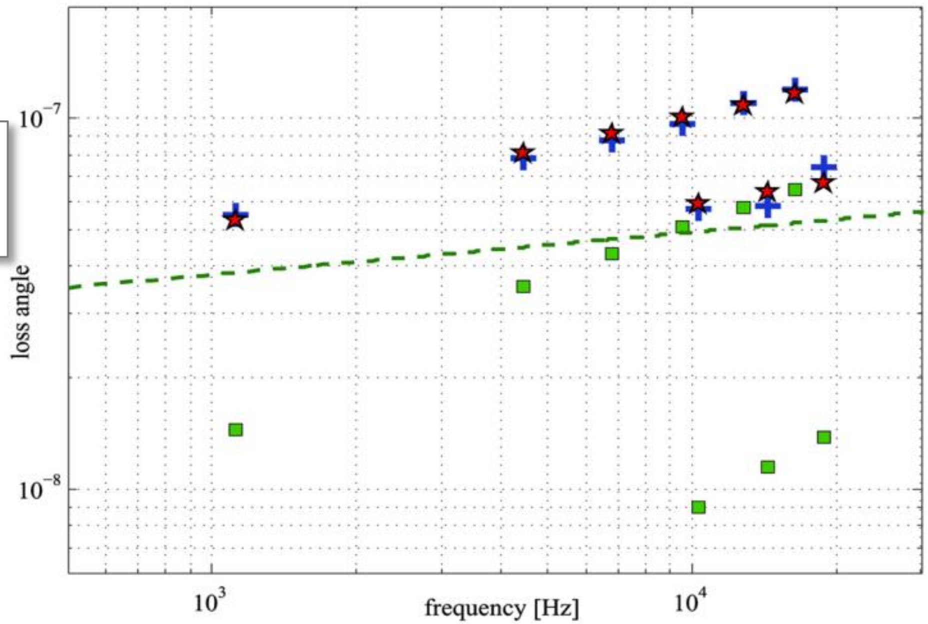


FIG. 9. Excess loss Δ of coating stacks deposited on cantilever blades, as a function of the number N of layers in the stack. Excess loss is observed, in violation of Eq. (3).

Metrology again

- Mode families in GeNS substrates due to edge excess losses

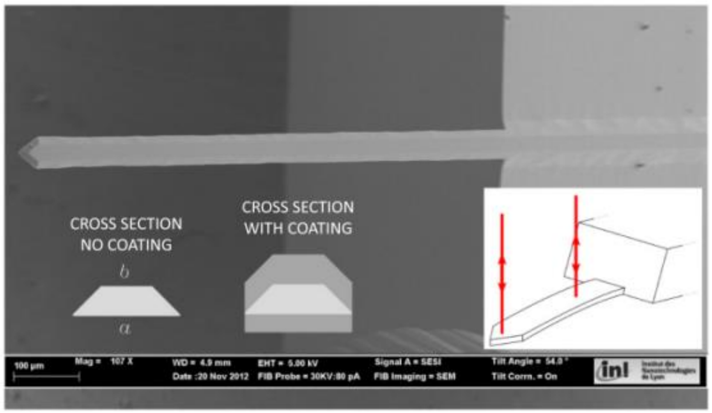
G. Cagnoli et al. Mode-dependent mechanical losses in disc resonators, Phys. Lett. A (2017) https://doi.org/10.1016/j.physleta.2017.05.065



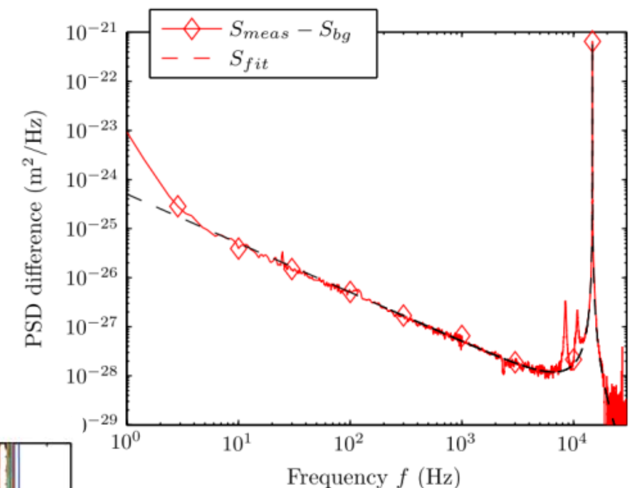
- Edge losses are observed in coatings too
  - ♦ Effects on:
    - − Frequency dependent loss
    - − Dilatation and shear loss angles

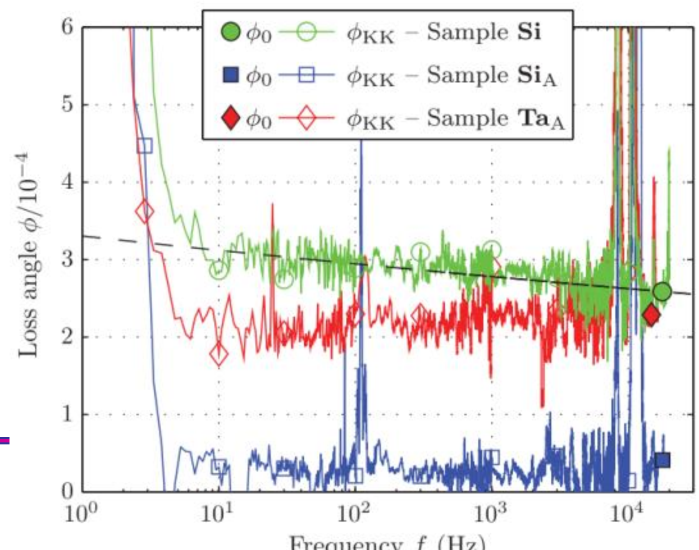
Direct measurements of thermal noise

- Quadrature Phase Interferometer
  (developed by L. Bellon of LPENS-Lyon)



TIANJUN LI *et al.* PHYSICAL REVIEW D **89**, 092004 (2014)



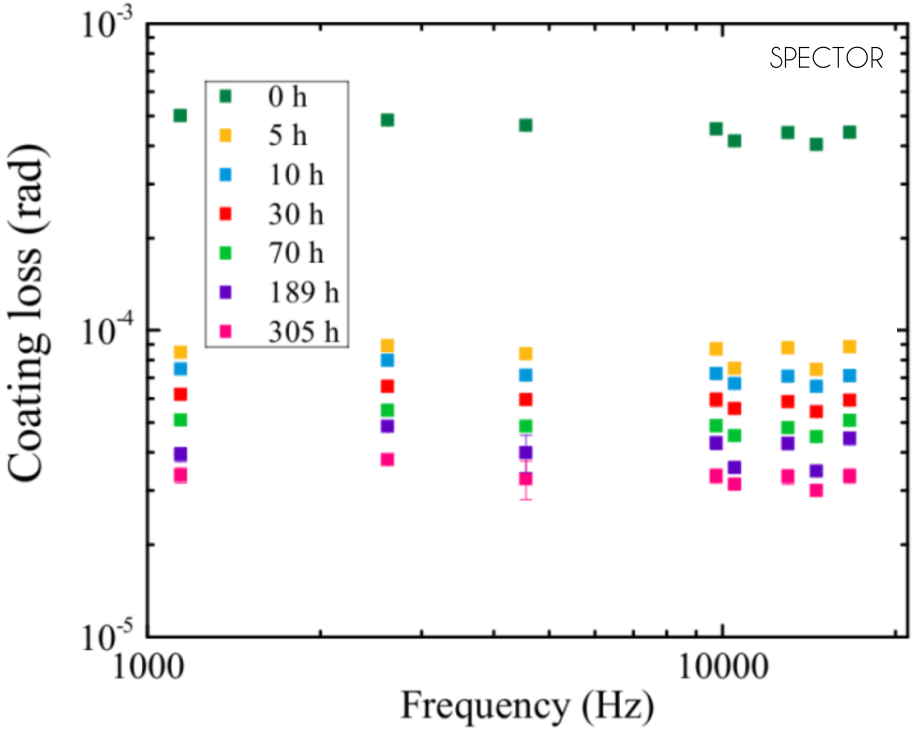


Open questions and results

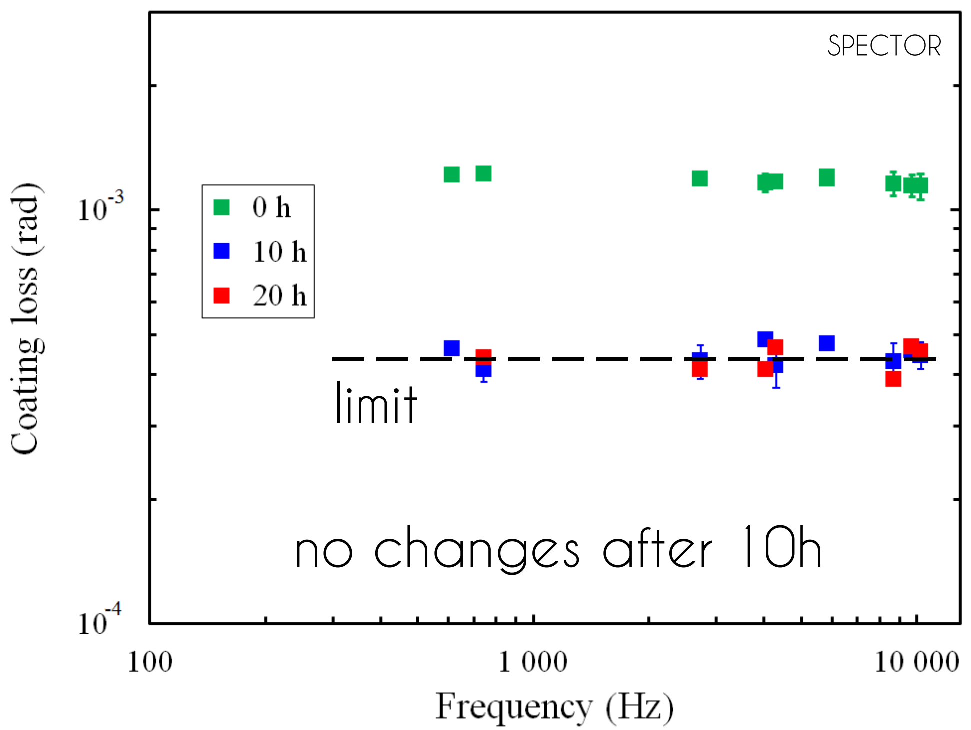
(details can be found here: LIGO-G1701598-v1
https://dcc.ligo.org/DocDB/0144/G1701598/001/LVC1708_Granata_LMAcoatings.pdf)

Silica vs Tantala: annealing duration

SiO2



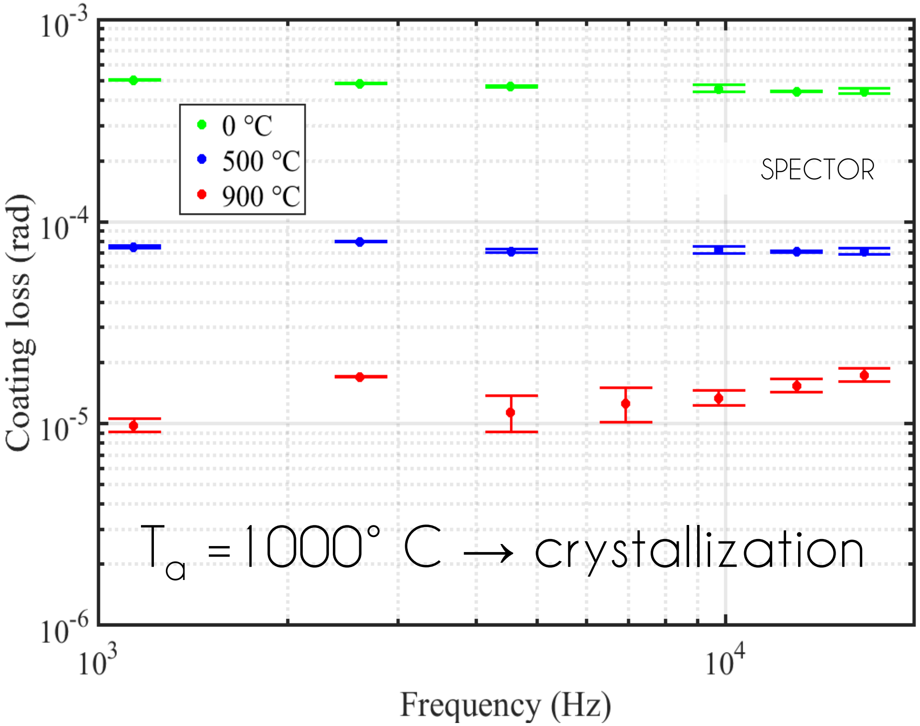
Ta2O5



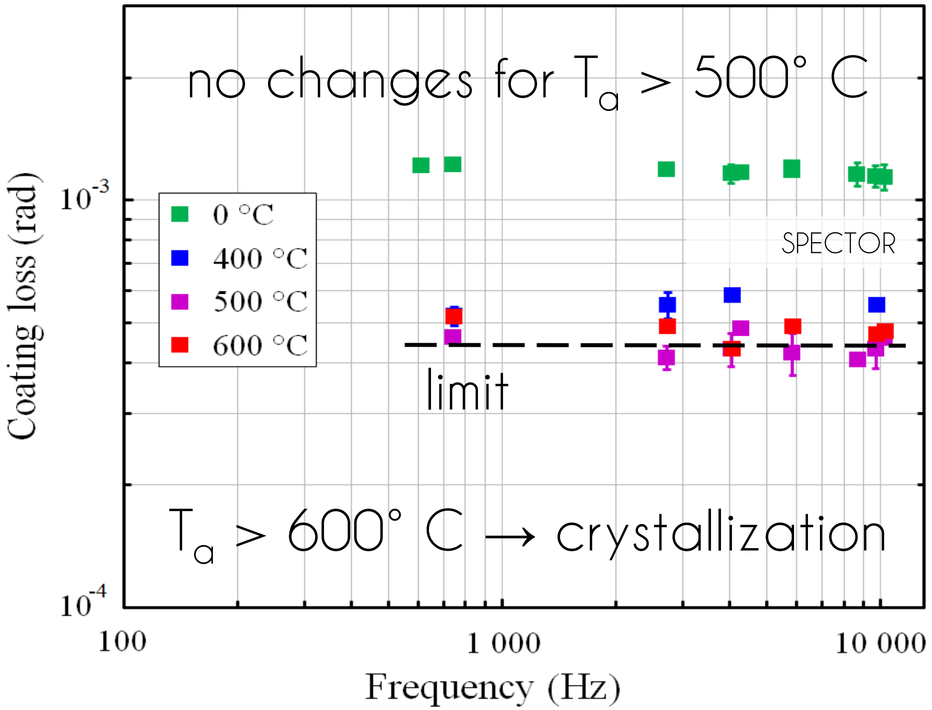
T_a = 500° C

Silica vs Tantala: annealing temperature

SiO2

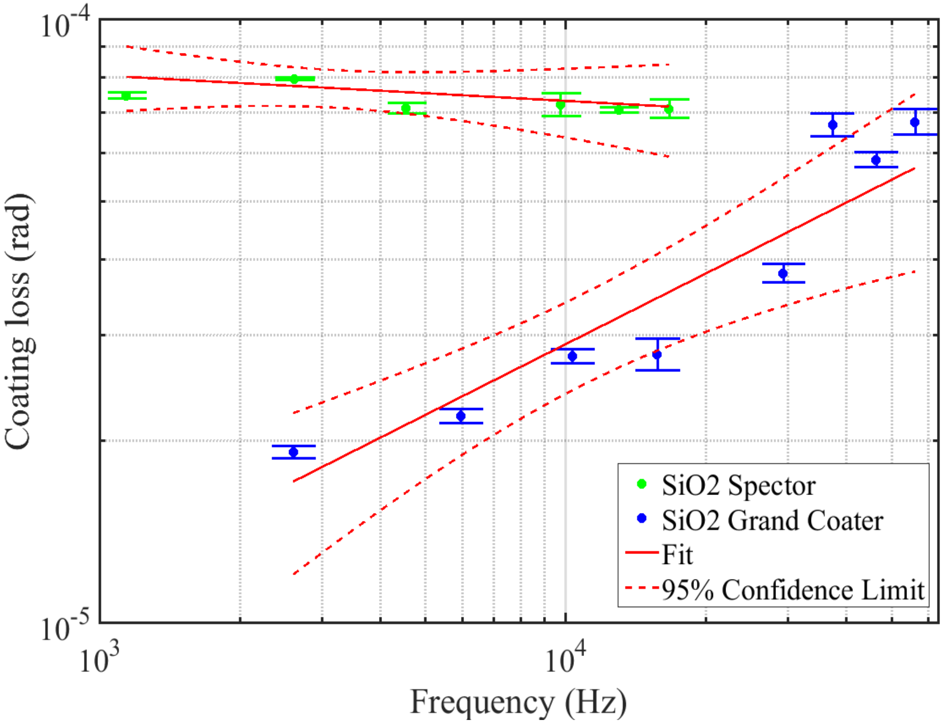


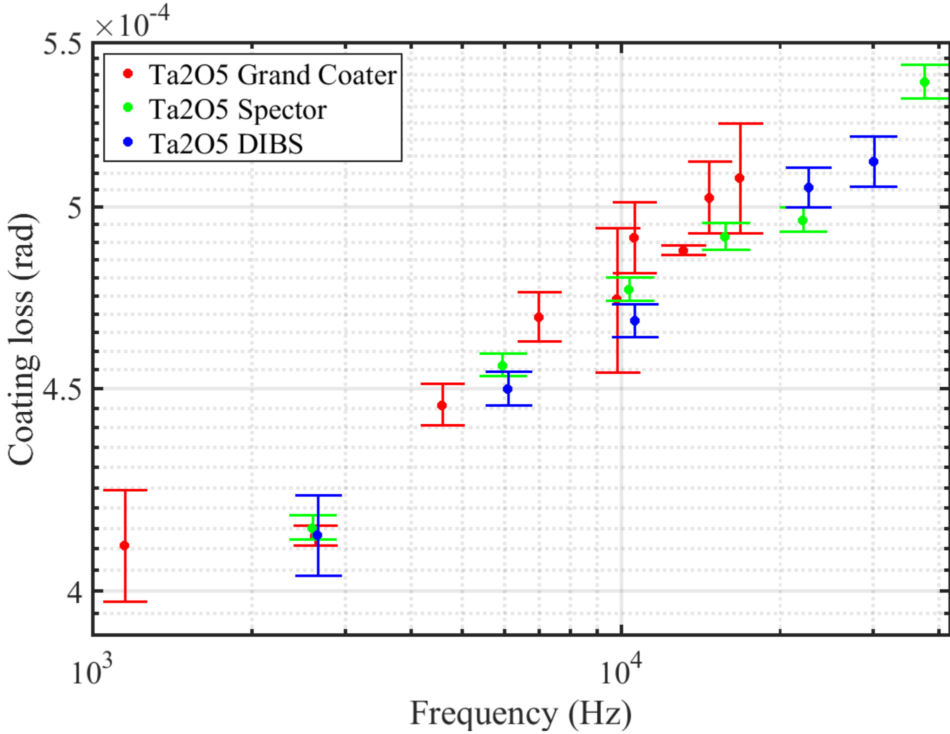
Ta2O5



Δt = 10 h

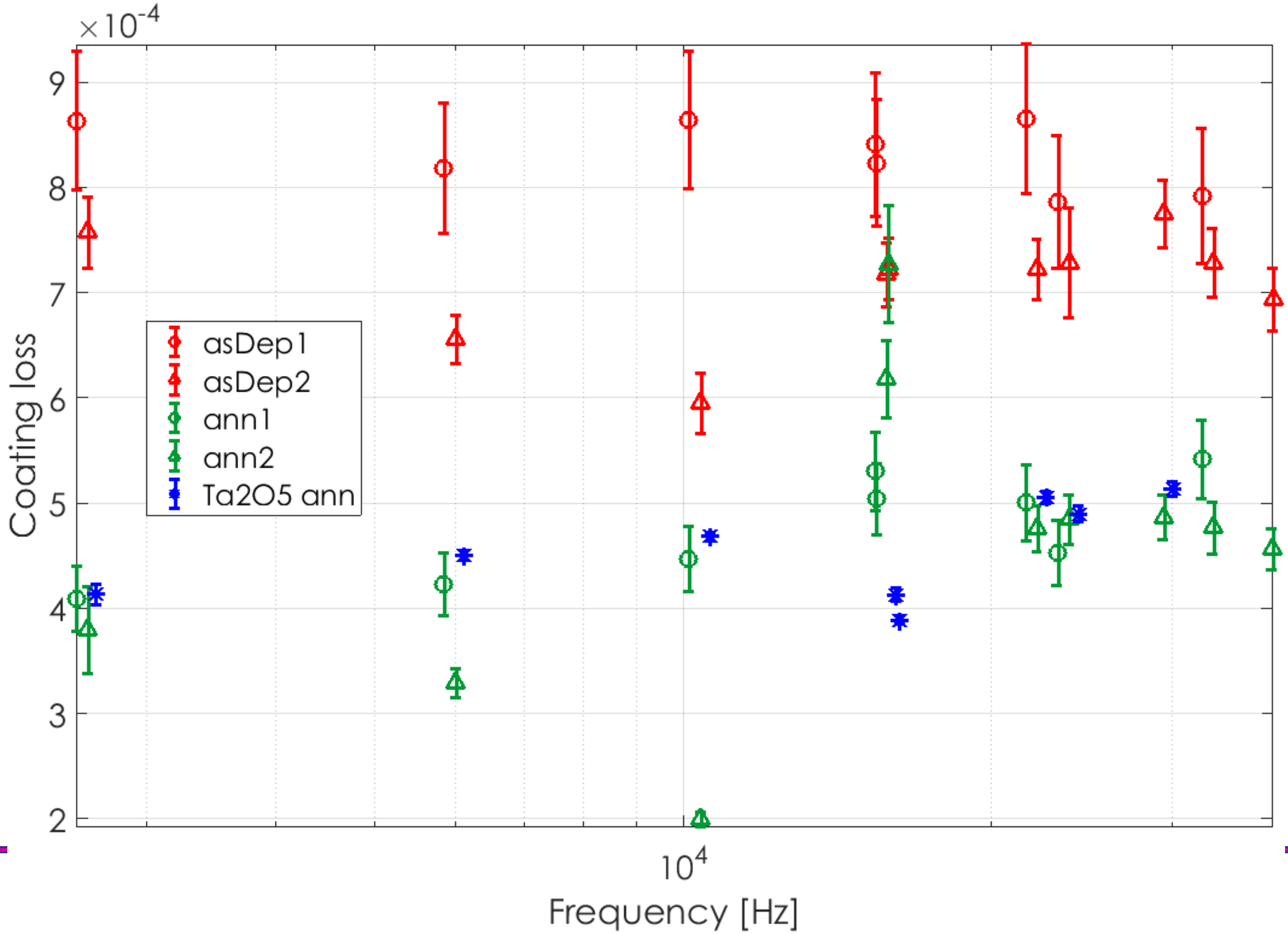
Silica vs Tantala: deposition parameters





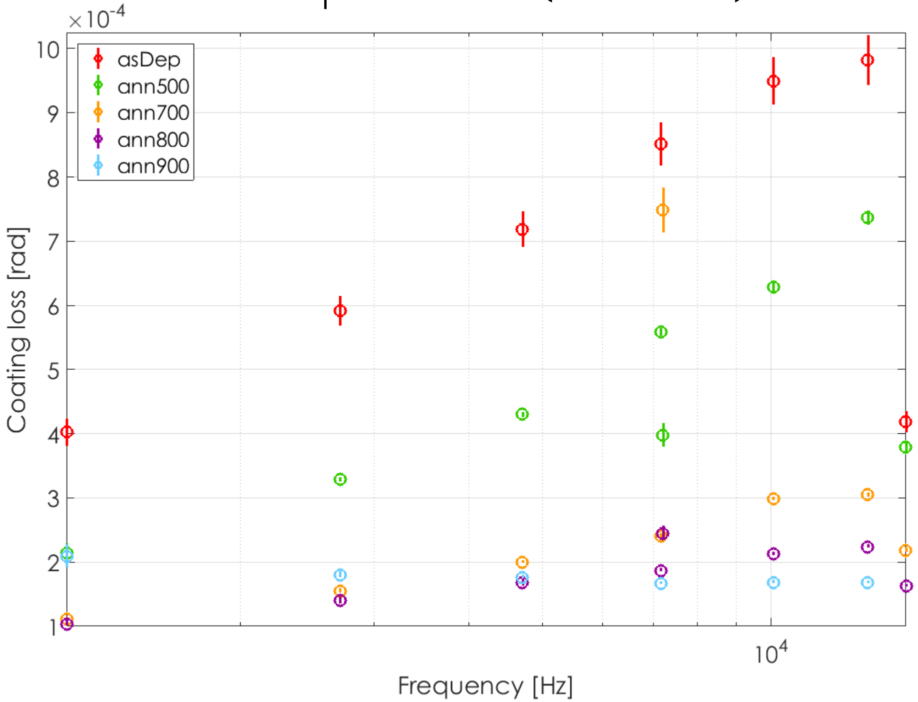
New materials: Nb2O5

- n_{Nb2O5} = 2.18 > n_{Ta2O5} = 2.01 @ 1064 nm [DIBS]
- directly scalable to the Grand Coater (large mirrors)

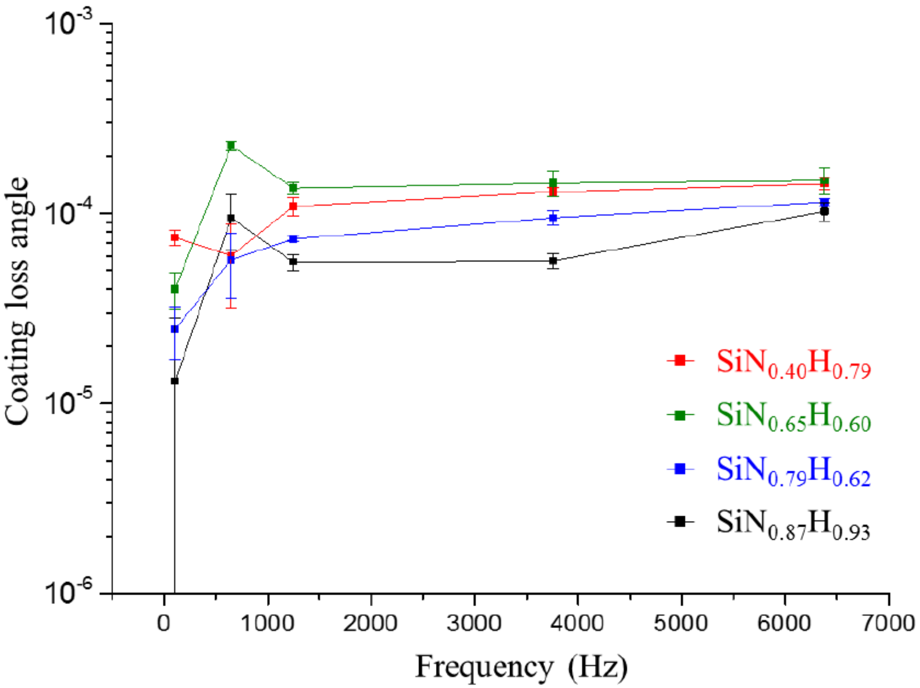


New materials: Si3N4 (by CVD)

low-pressure (LP-CVD)



plasma-enhanced (PE-CVD)

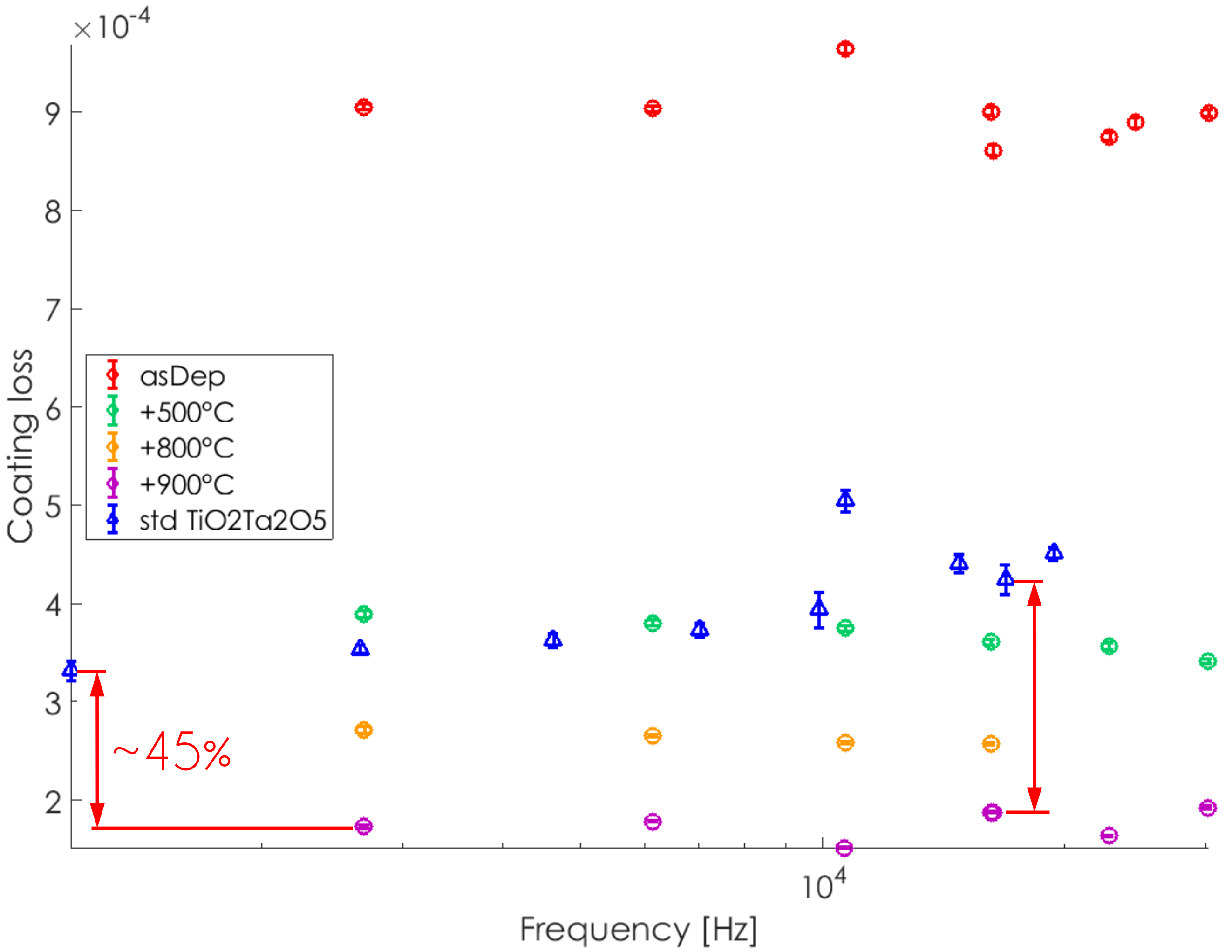


- 800° C deposition
- SiO2 disk resonators [GeNS]

- 300° C deposition
- Si cantilever resonators

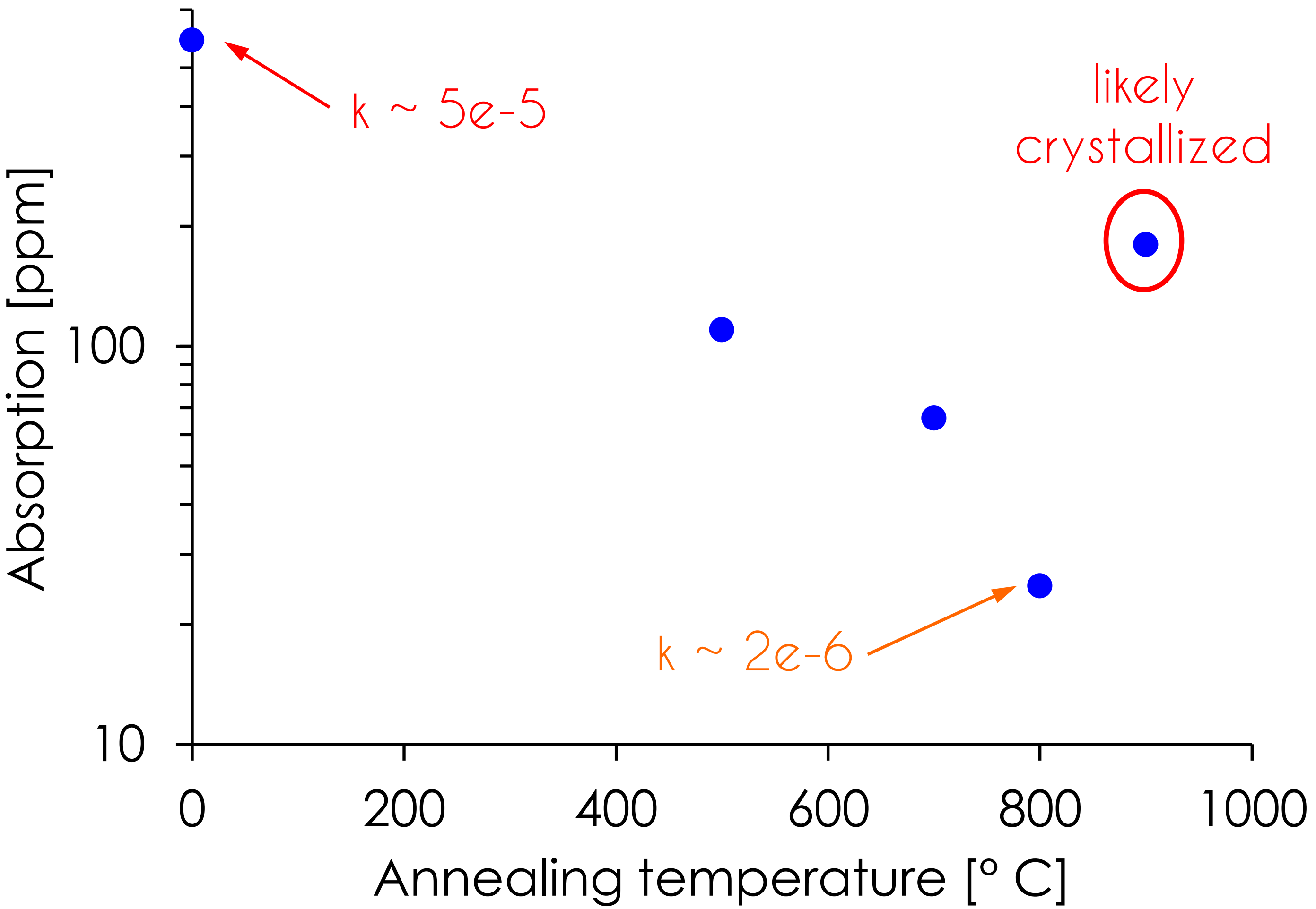
optical absorption k ≥ 1e-5

New materials: Si3N4 (by IBS)



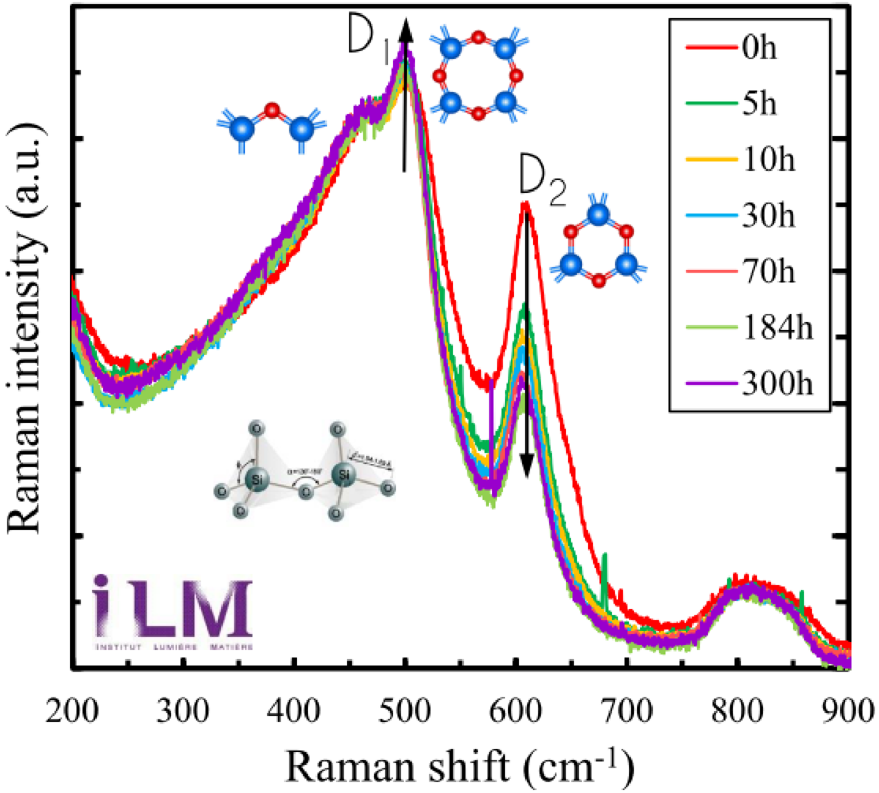
New materials: Si_3N_4 (by IBS)

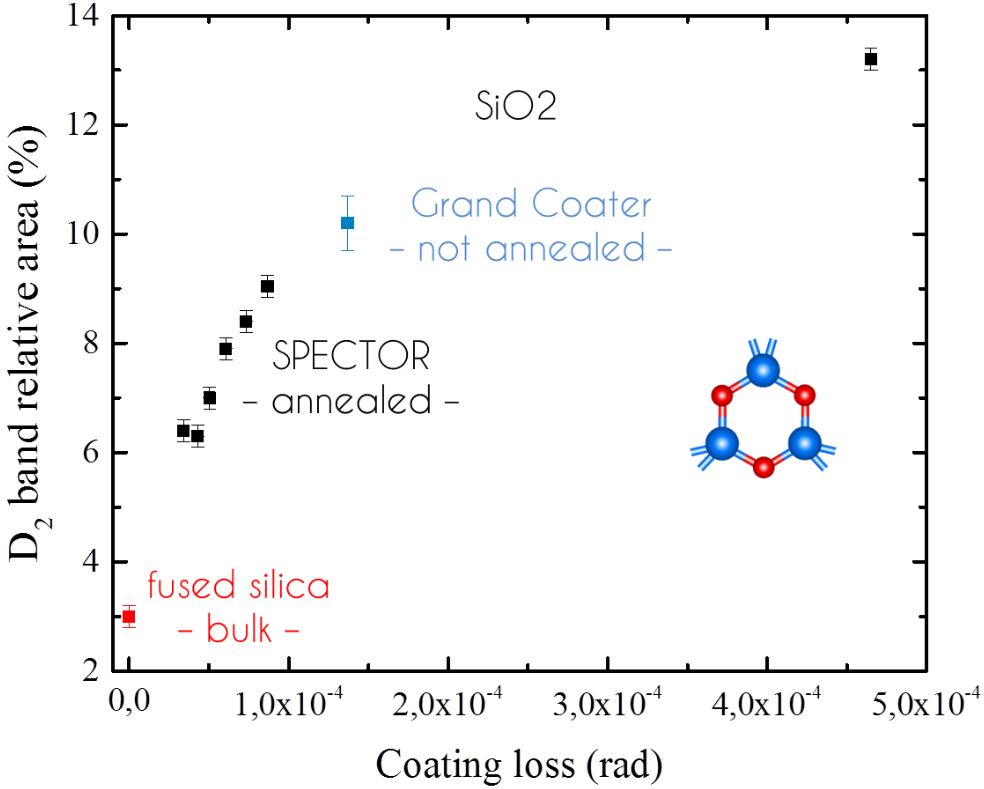
- potentially low optical loss
- scalable to the Grand Coater (large mirrors)



Structure loss correlation

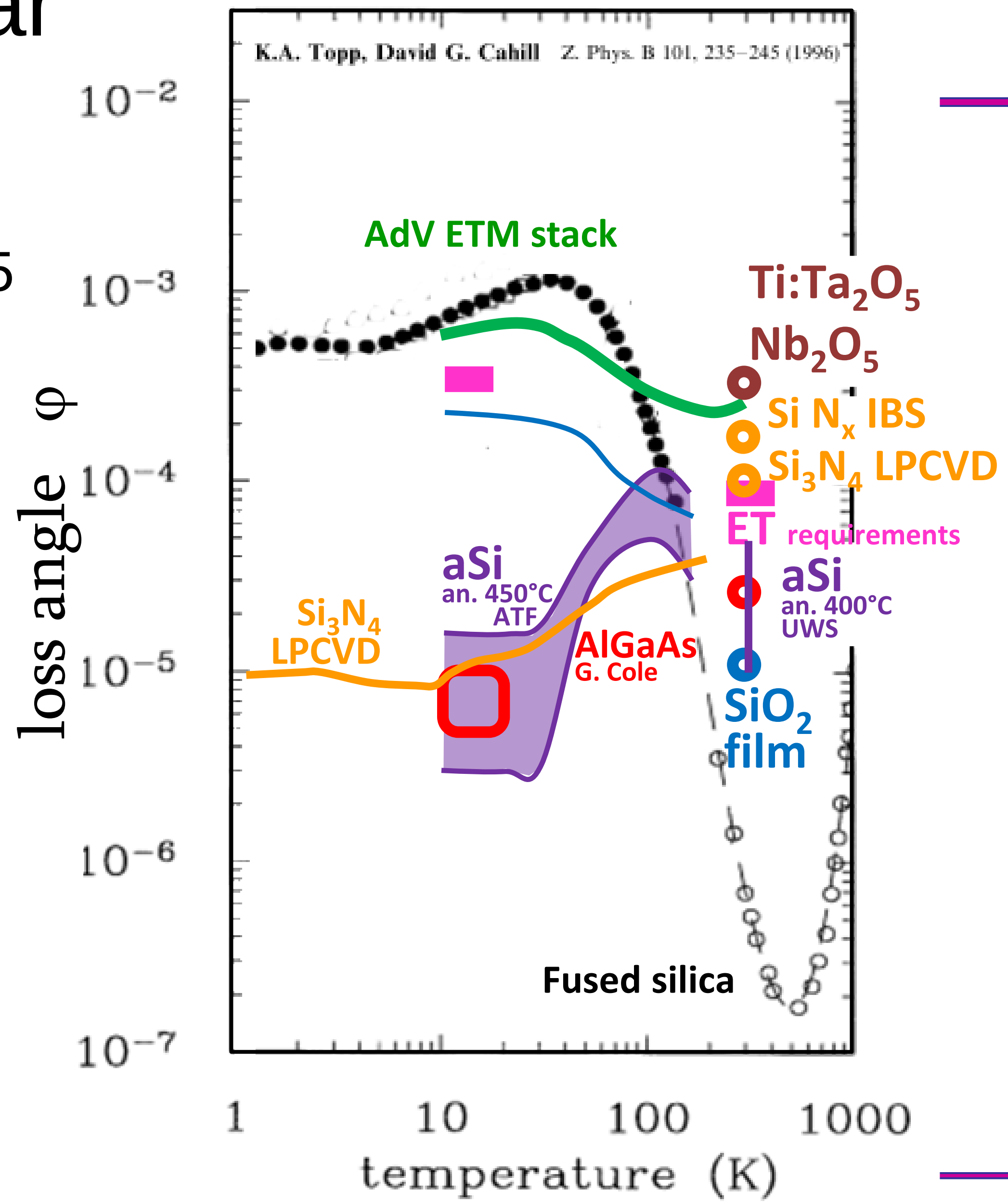
Granata & al., arXiv:1706.02928





The materials so far

- Nb2O5
  - ♦ Same losses of Ta2O5 but higher n
- Si3N4
  - ♦ Loss is 3 times less than Ti:Ta2O5
- SiO2
  - ♦ φ = 10^{-5} annealed at 900°C
- Some amorphous materials are not far from crystalline ones



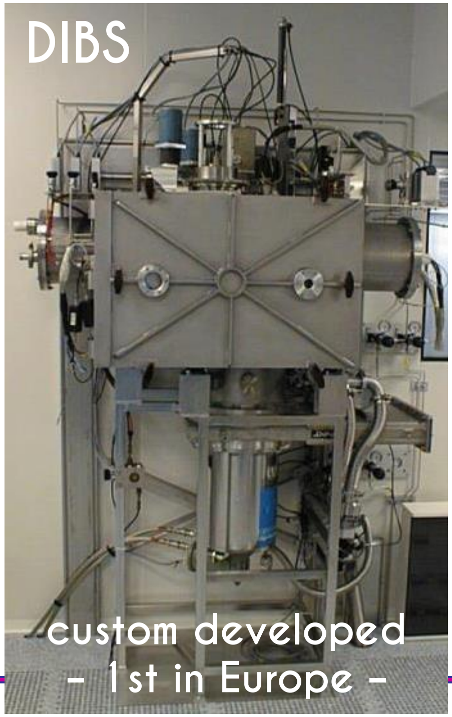
Final comments

- Time to the next mirror upgrade is short
  - We should not duplicate the efforts
  - The CCR and VCR&D paths should not diverge

- Collaboration examples
  - GeNS from LMA to Caltech
  - Direct measurements of thermal noise at MIT

Coaters and Metrology at LMA

Ion-beam sputtering (IBS)



photos: C. Fresillon – photothèque CNRS / E. Le Roux / LMA

Metrology – optics

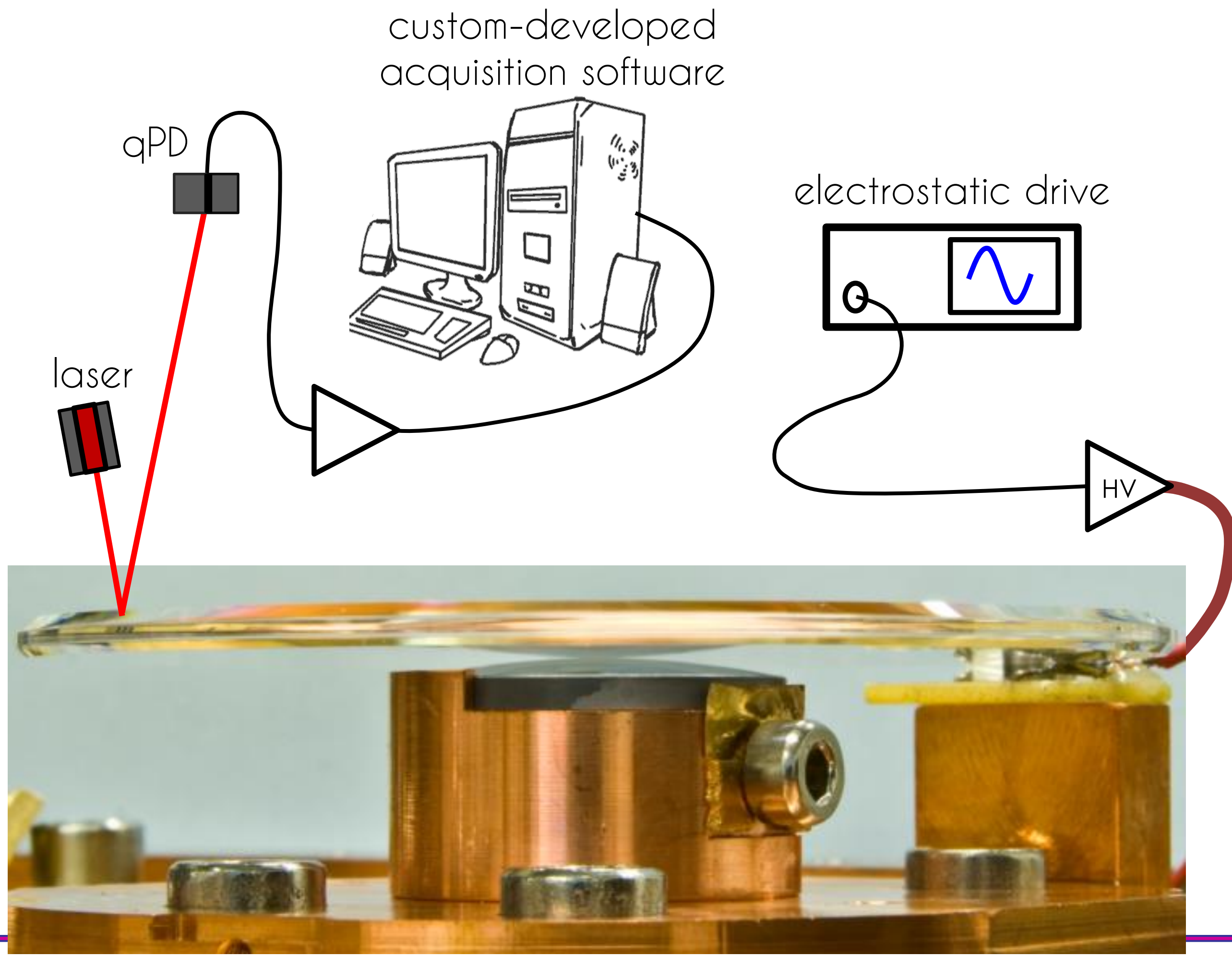
- scattering
- surface defects
- wavefront
- absorption [ambient/cryogenic]
- refractive index
  spectrophotometry
  spectr. ellipsometry [@ Genova]

photos: C. Fresillon – photothèque CNRS

Metrology – mechanics

Gentle Nodal Suspension (GeNS)

- clamp-free
- high repeatability
- measure of
    - dilution factor
    - mechanical loss
    - elastic constants



Cesarini & al, Rev. Sci. Instrum. 80 (2009)
Cesarini & al, Class. Quantum Grav. 27 (2010)
Granata & al, Arch. Metall. Mat. 60 (2015)
Granata & al, Phys. Rev. D 93 (2016)