R&D activity at LMA

M. Granata, L. Balzarini, G. Cagnoli, J. Degallaix, V. Dolique,
R. Flaminio, D. Forest, C. Michel, R. Pedurand, L. Pinard, J. Teillon

in collaboration with

E. Cesarini, M. Lorenzini
Università degli Studi di Roma Tor Vergata
INFN Tor Vergata
Gran Sasso Science Institute

D. Heinert, R. Nawrodt
Friedrich-Schiller-Universität Jena

F. martelli, F. Piergiovanni
Università degli Studi di Urbino Carlo Bo

L. Bellon, M. Geitner
Ecole Normale Supérieure de Lyon

E. Coillet, C. Martinet, V. Martinez, J. Margueritat, A. Mermet
Institut Lumière Matière

outline

substrates

- thermo-elastic damping of disks

amorphous coatings

- direct measurement of thermal noise
- structure and mechanical loss

for more details
Granata & al., GWADW14, Takayama

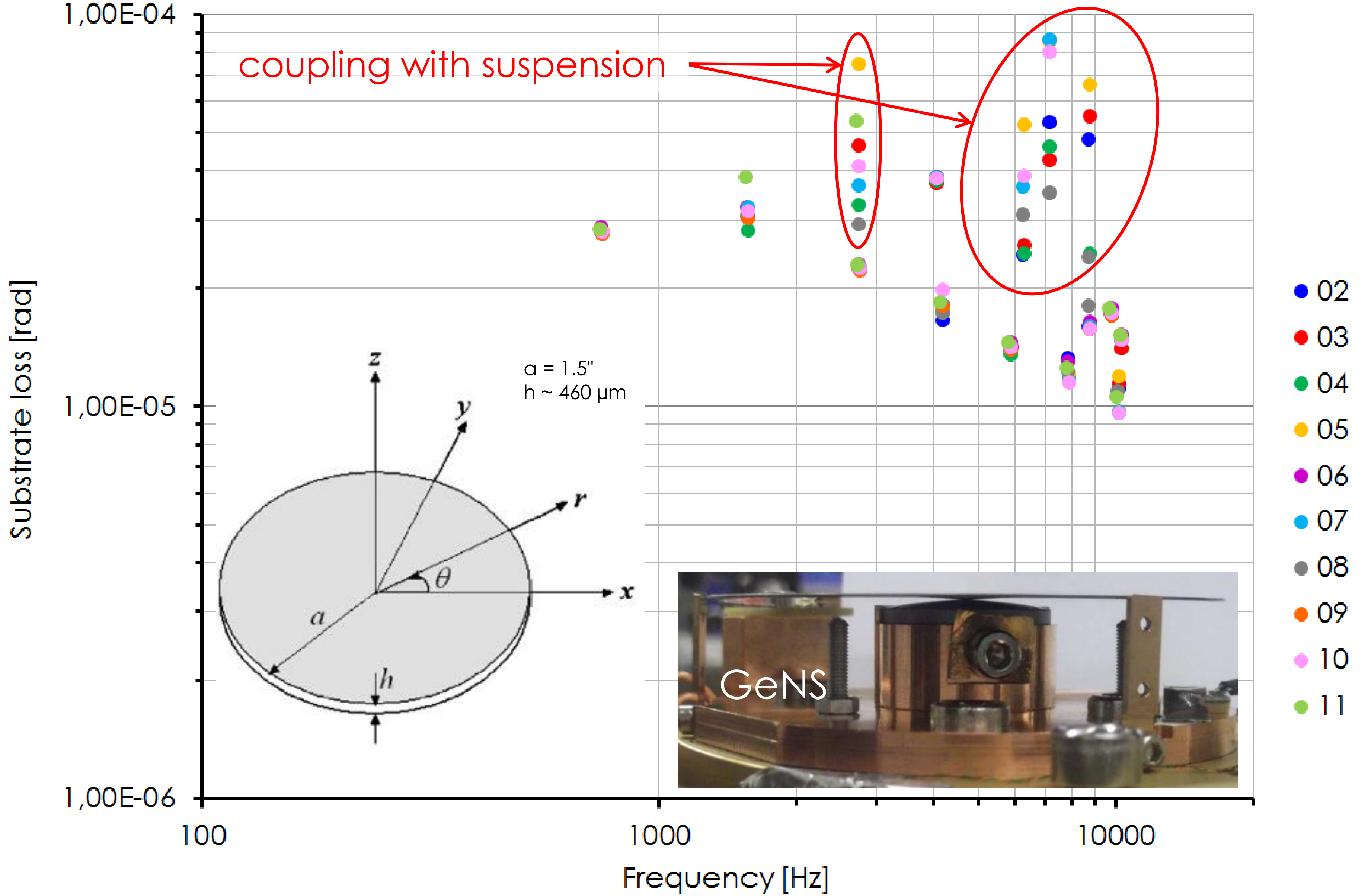
warning

coatings used in these studies
are not the same
as those of detector test masses

- different ion-beam-sputtering machines
- different deposition parameters

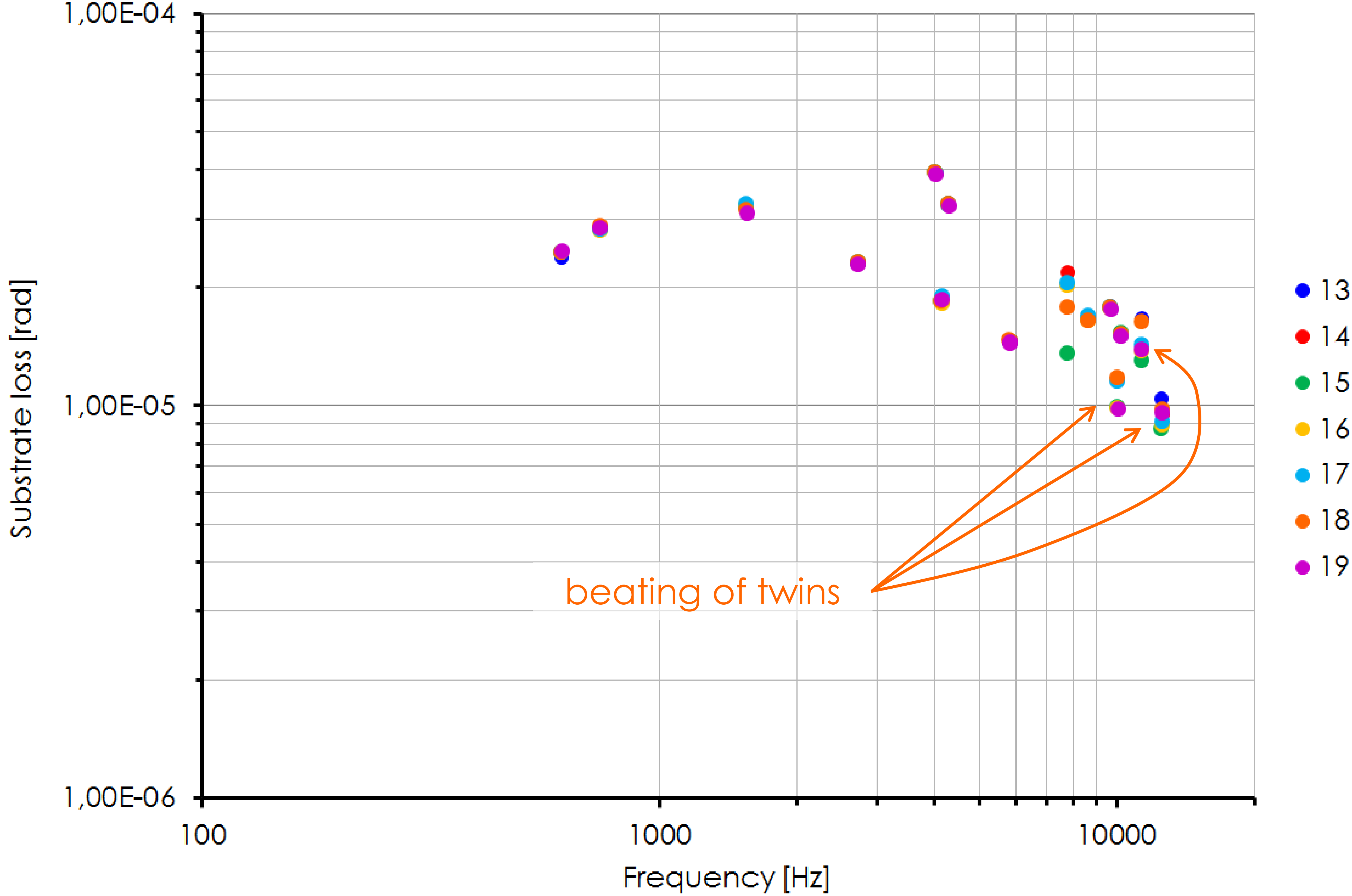
thermo-elastic damping of disks

patterns



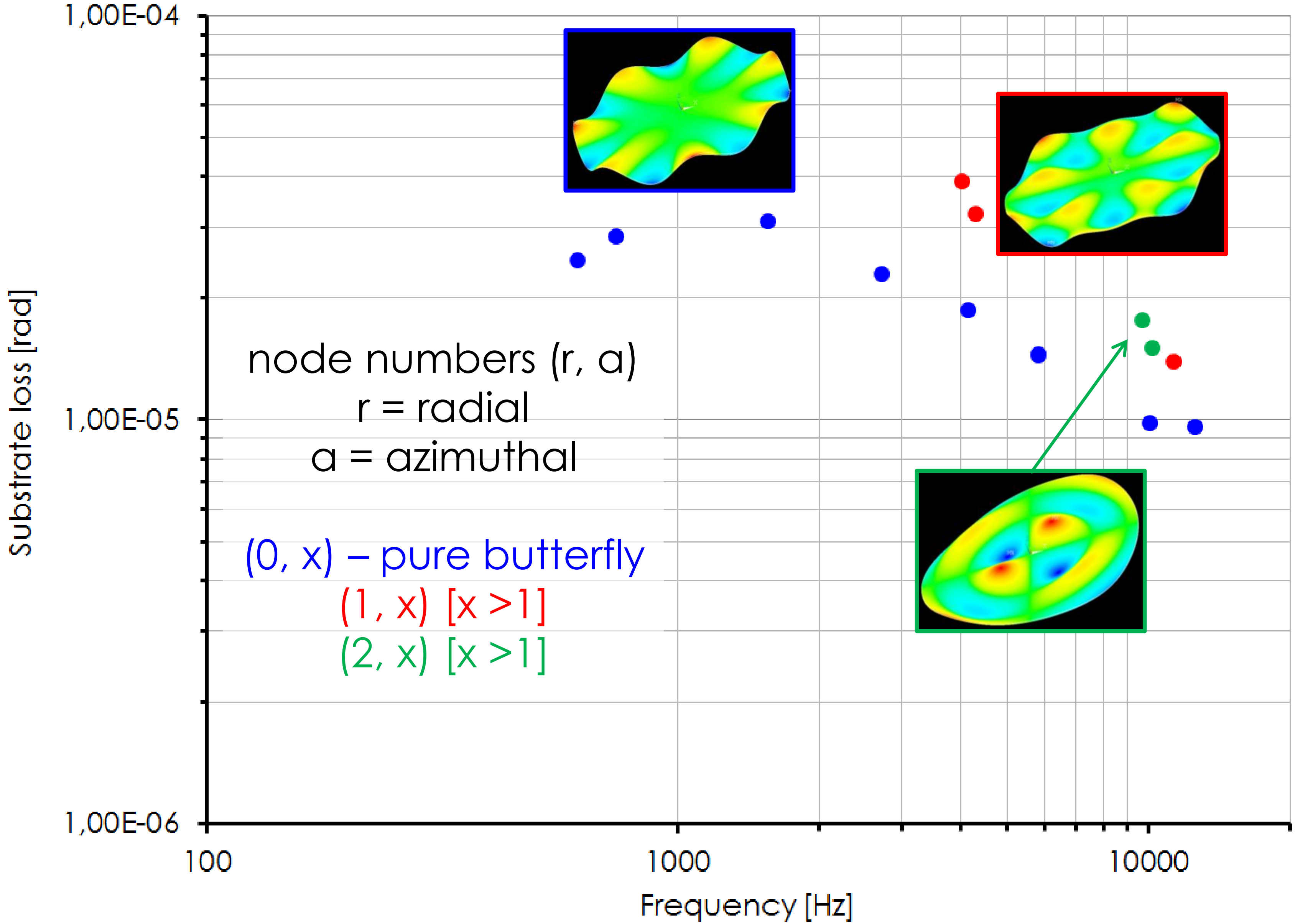
coupling with suspension
1,00E-04
1,00E-05
1,00E-06
Substrate loss [rad]
100
1000
10000
Frequency [Hz]
a = 1.5"
h ~ 460 µm
z
y
r
θ
x
a
h
GeNS
02
03
04
05
06
07
08
09
10
11

patterns

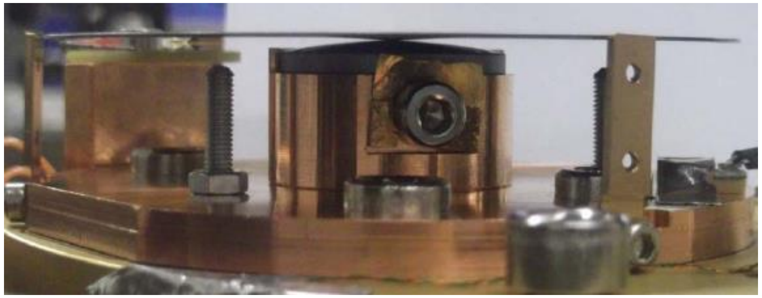


1,00E-04
1,00E-05
1,00E-06
Substrate loss [rad]
100
1000
10000
Frequency [Hz]
13
14
15
16
17
18
19
beating of twins

mode families



evidences



GeNS

- high repeatability

  $\Delta f/f \sim 10^{-4}$

  $\Delta Q/Q < 5\%$

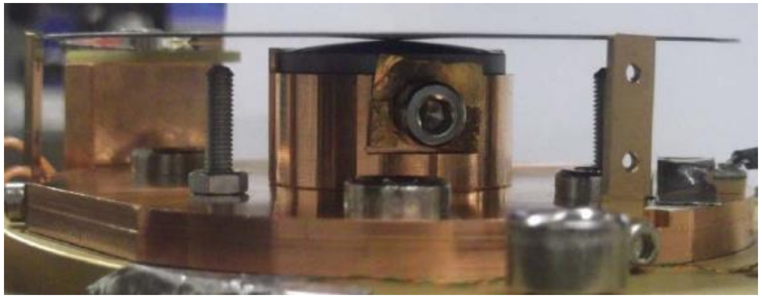
- very low excess loss ↔ at low temperature: $Q_{0,2} = 2.2 \times 10^{8}$

  $Q_{1,4} = 8.3 \times 10^{7}$

  $Q_{2,2} = 1.1 \times 10^{8}$

evidences

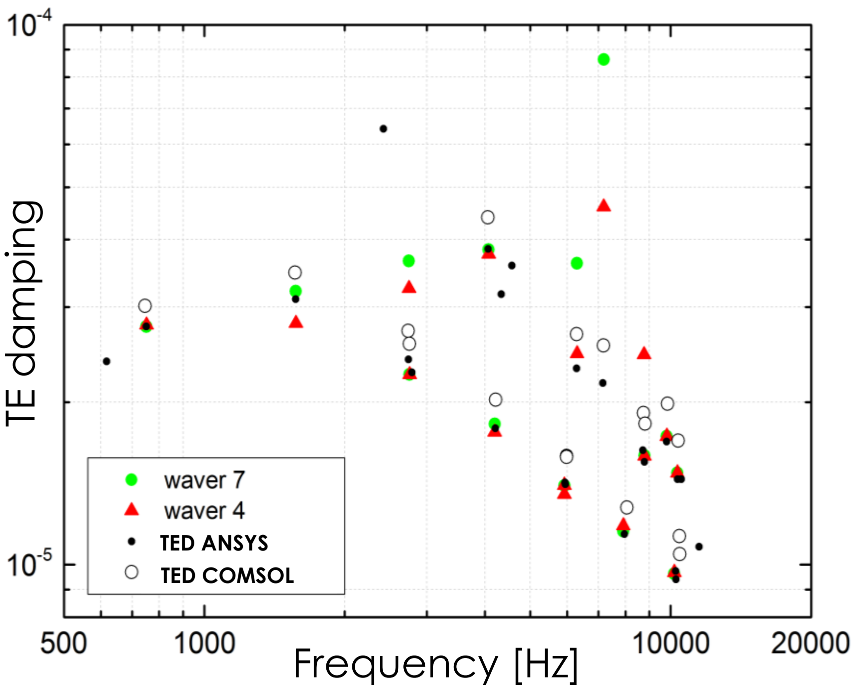
GeNS



- high repeatability
  - $\Delta f/f \sim 10^{-4}$
  - $\Delta Q/Q < 5\%$
- very low excess loss ↔ at low temperature: $Q_{0,2} = 2.2 \times 10^8$
  - $Q_{1,4} = 8.3 \times 10^7$
  - $Q_{2,2} = 1.1 \times 10^8$
- independent simulations
  - ANSYS + analytical
  - COMSOL

modes and loss confirmed

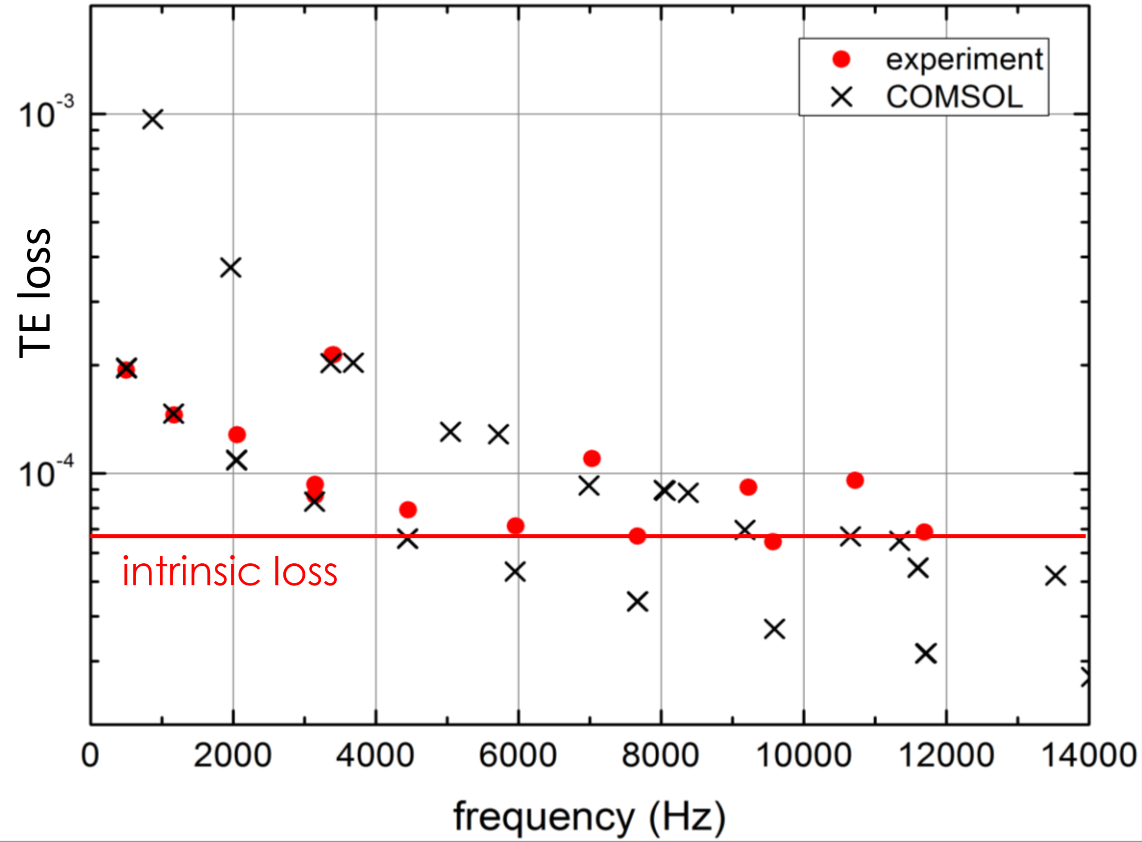
→ mode families are for real



isotropic sample

- d = 3", t = 0.8 mm, alpha-brass (Cu 64%, Zn 36%)
- simulations predict mode families
- preliminary measurements confirm expectations

→ all disks feature mode-dependent thermo-elastic damping



theory

correction of Zener's equation

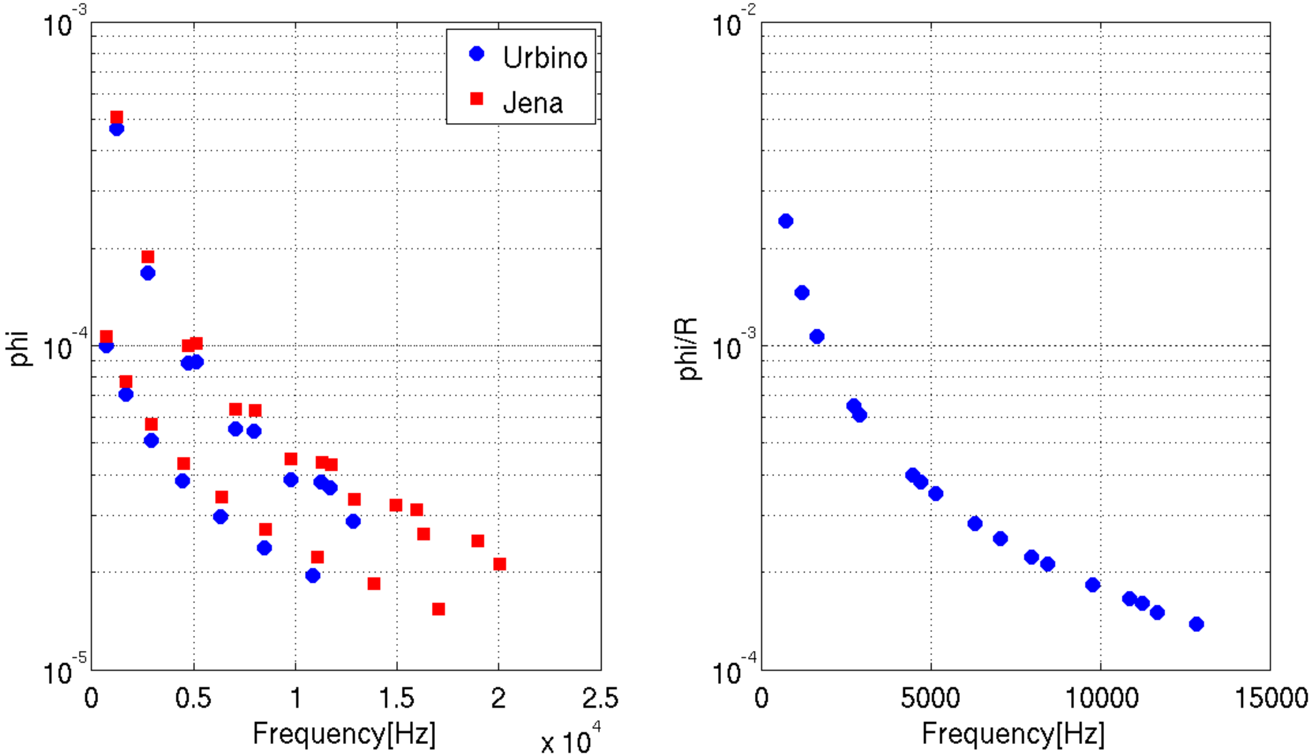
$$\phi_{TE}^{(Z)} = \frac{Y\alpha^2 T_0}{\rho C} \frac{\omega\tau}{1+(\omega\tau)^2}$$

- energy-based approach

→ introducing *R* = dilation energy/total energy

$$R = R_0\,(1+\sigma_{xx}\sigma_{yy})/Y$$

$R_0 = Y/9K$
same as for rods



paper in preparation

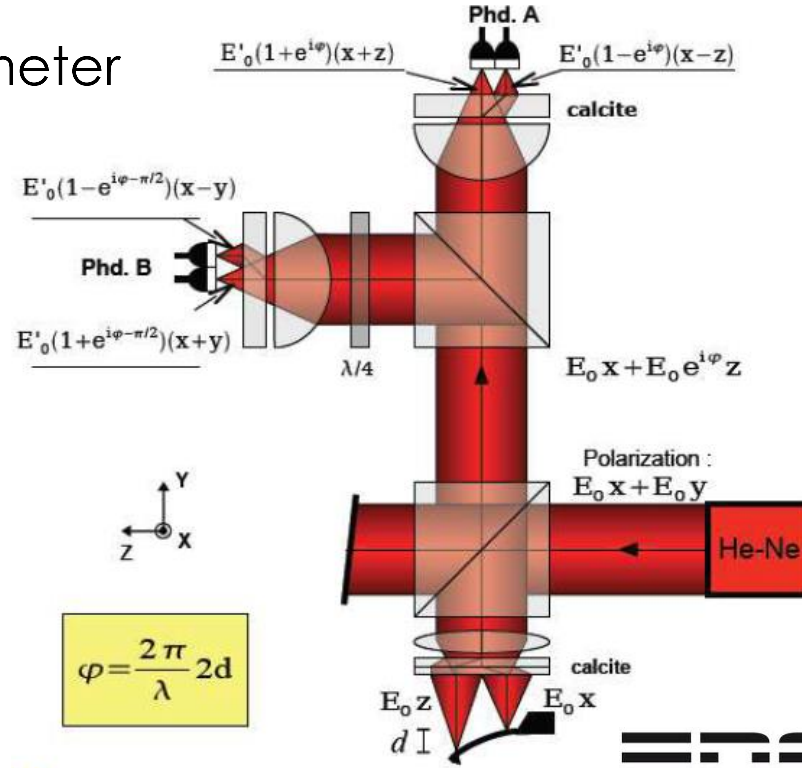
direct measurement of coating thermal noise

technique

quadrature-phase differential interferometer

Bellon et al., *Opt. Commun.* 207, 2002

Paolino et al., *Rev. Sci. Instrum.* 84, 2013



Bellon, Ciliberto et autres, Opt. Comm. (2002).

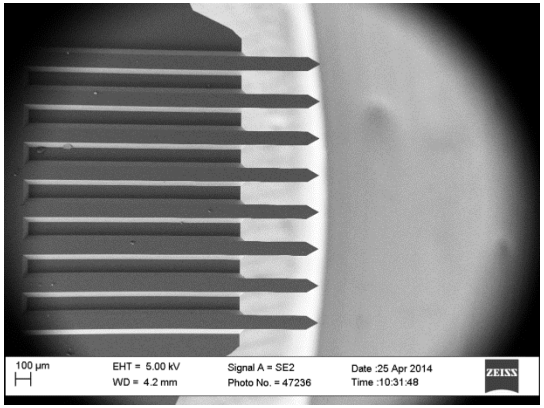
ENS DE LYON

• key points

AFM micro-cantilevers

linearly-polarized light

talk by L. Bellon in this session



nearly-common-path Michelson

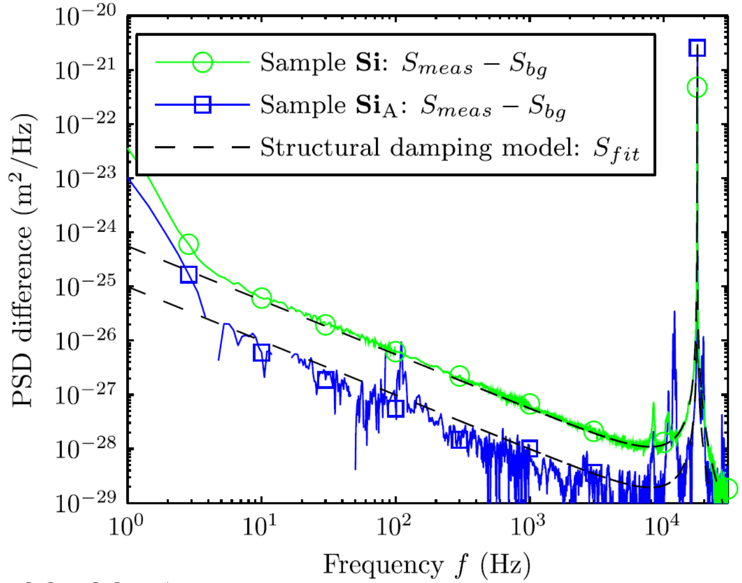
high noise rejection

very low drift

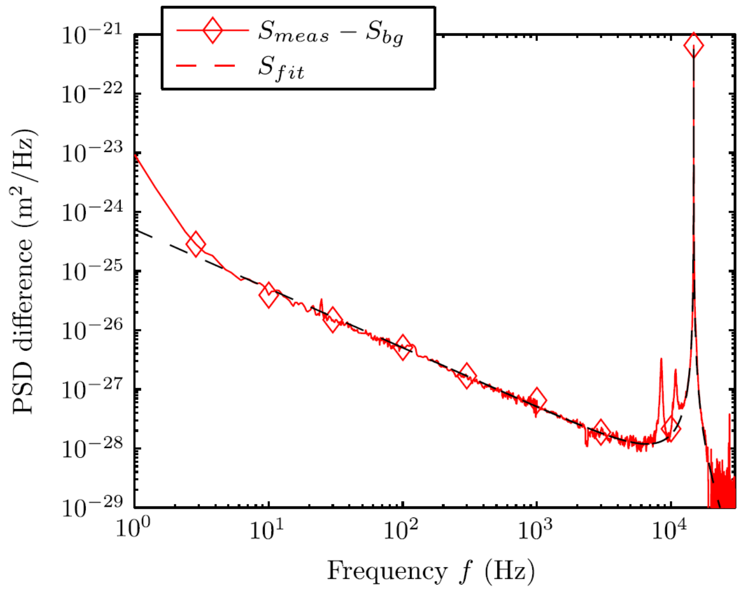
SiO2 and Ta2O5

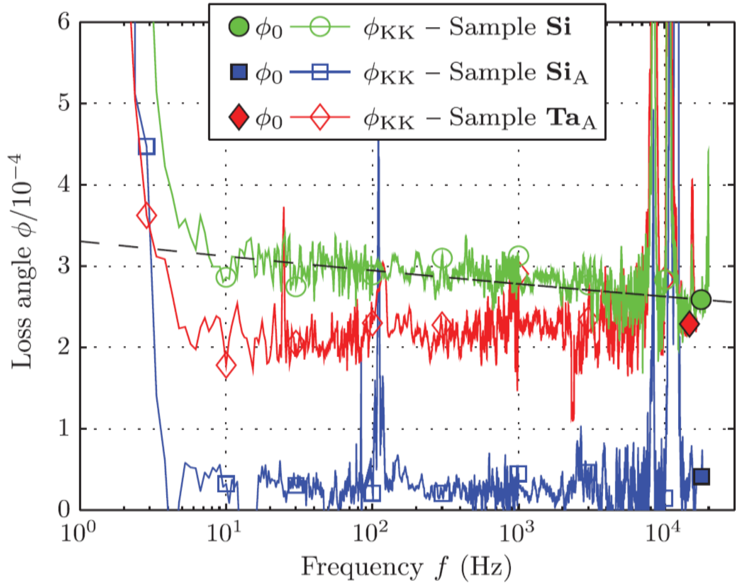
- 1/*f* noise – Saulson model confirmed
- *f*-independent loss after annealing

Coating	$\mathcal{D}$	$\phi_c \times 10^4$
SiO_2 as coated	0.40 ± 0.02	$6.0 \pm 0.3 (\pm 0.5)$
SiO_2 annealed	0.41 ± 0.02	$0.62 \pm 0.05 (\pm 0.43)$
Ta_2O_5 annealed	0.45 ± 0.02	$4.7 \pm 0.2 (\pm 0.4)$



Li et al., *Phys. Rev. D* 89, 2014





new mono-layer samples

better substrate measurements → improved coating loss estimations

measured dilution factor

$$D \approx 1 - (f_s/f_{cc})^2 \, \mu_s/(\mu_s+\mu_c)$$

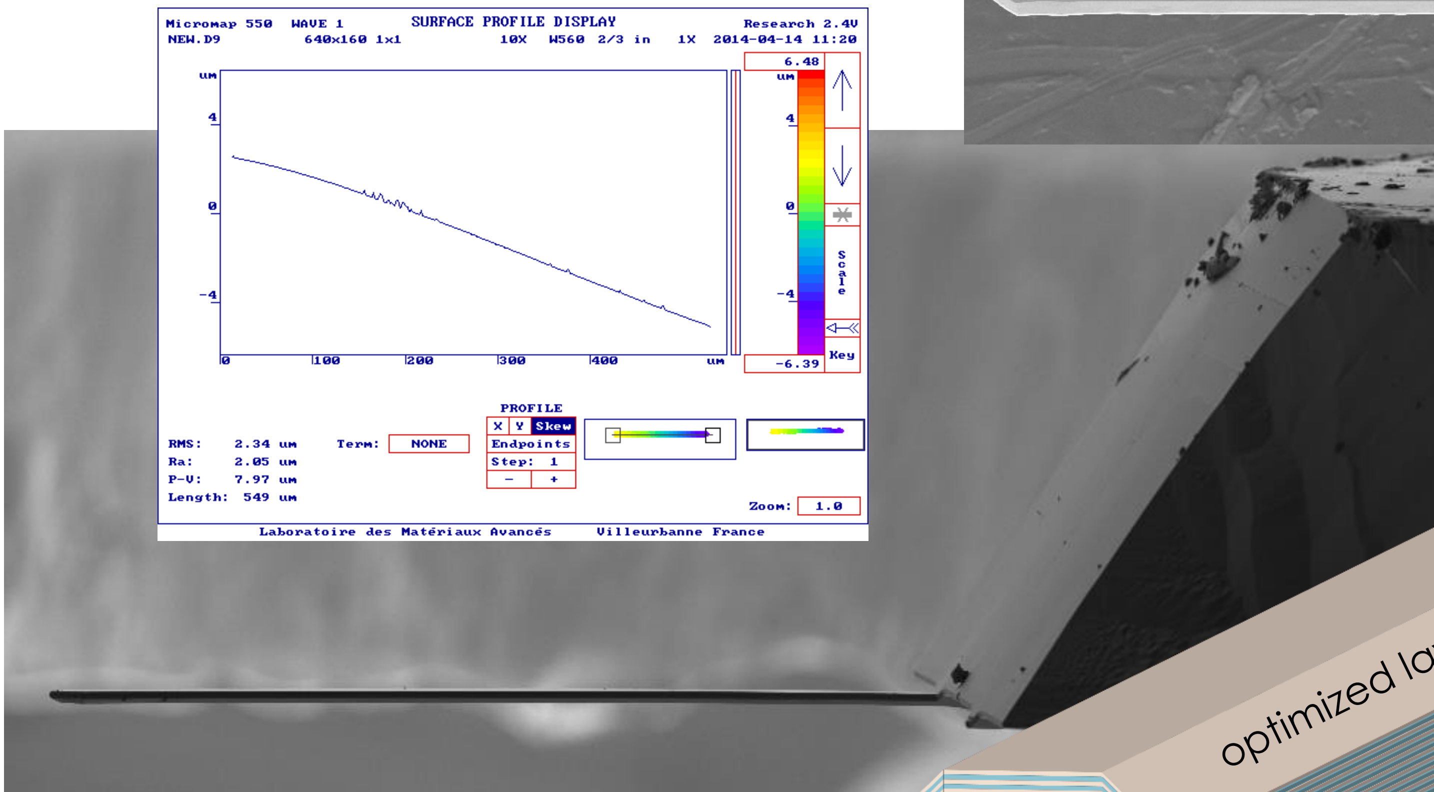
- SiO_2
  - as deposited: $\Phi_c = 6.0 \pm 0.8$ e-4 → $\Phi_c = 5.9 \pm 0.3$ e-4
  - annealed: $\Phi_c = 6.2 \pm 4.3$ e-5 → $\Phi_c = 3.1 \pm 0.8$ e-5
- Ta_2O_5
  - annealed: $\Phi_c = 4.7 \pm 0.6$ e-4 → … coming soon

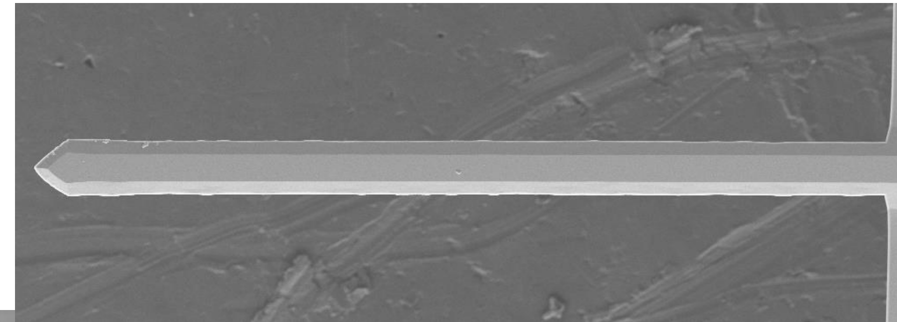
in agreement with GeNS measurements

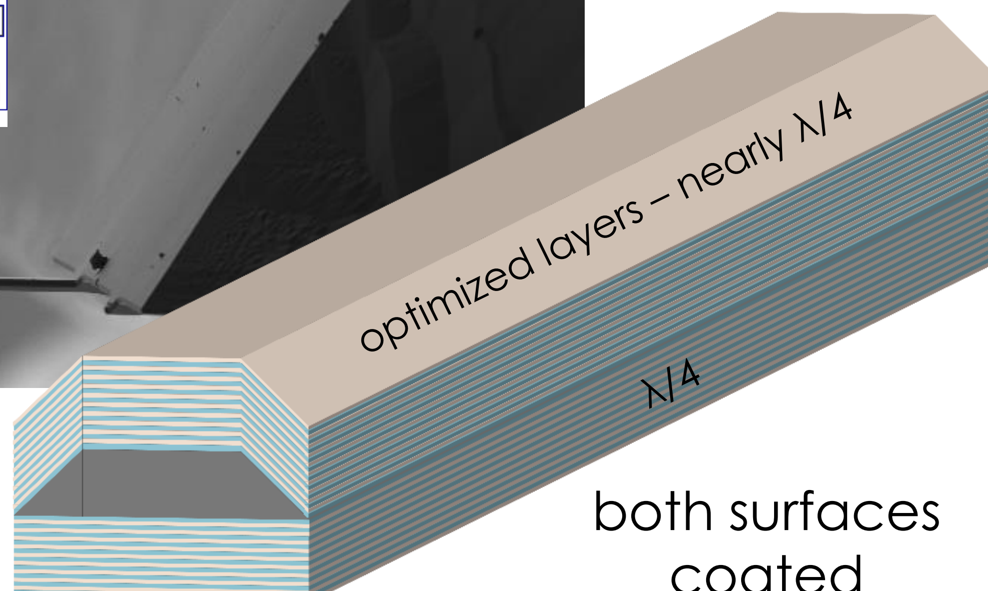
stacks

- quarter-wavelength coatings

  plain Ta_2O_5 and SiO_2 layers







– straight coated cantilevers –

technique developed at LMA

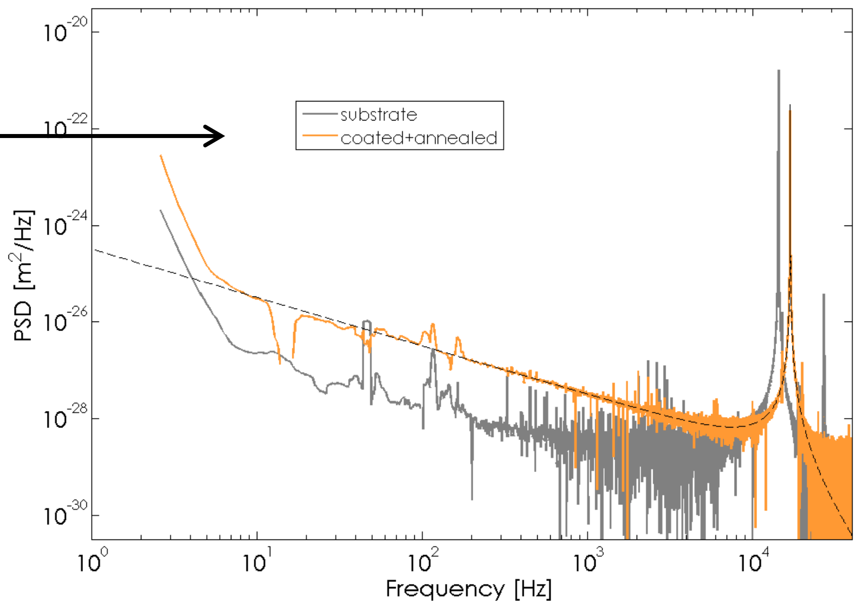
both surfaces coated

results

- $(LH)_5$

  measured: $\Phi c = 3.1 \pm 0.3$ e-4

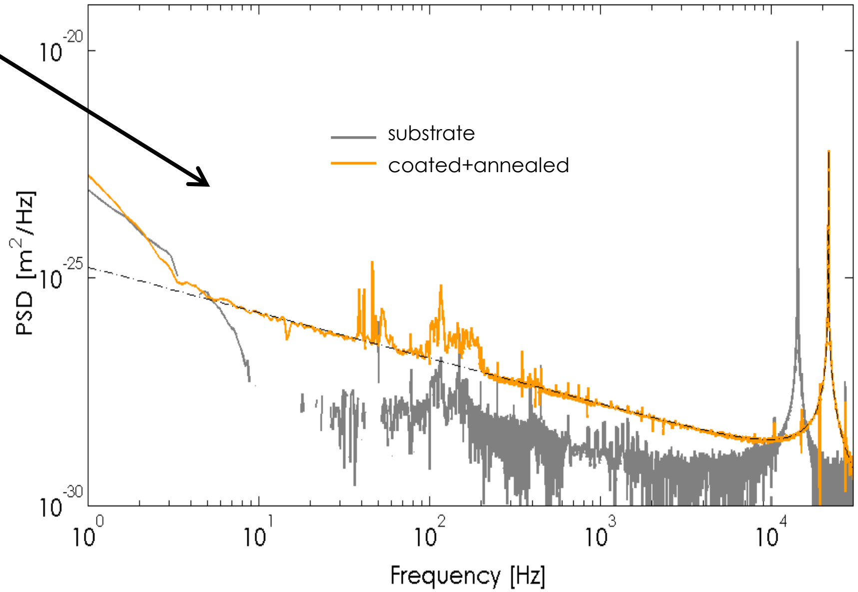
  expected: $\Phi c = 2.8 \pm 0.4$ e-4
  linear combination of mono-layer loss



- $(LH)_{10}$

  measured: $\Phi c = 3.9 \pm 0.2$ e-4

  expected: $\Phi c = 2.6 \pm 0.3$ e-4
  linear combination of mono-layer loss



same as with macro-cantilevers ?

M. Granata & al., *GWADW*, Waikoloa, 2012

coating structure and mechanical loss

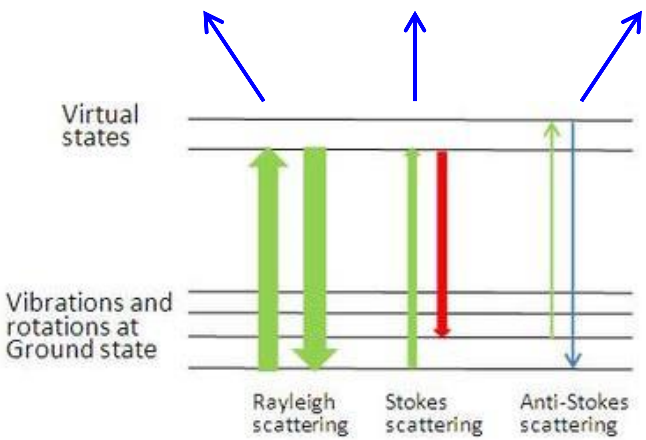
Raman in a nutshell

laser $\mathbf{E} = \mathbf{E}_0 \cos(2\pi f_0 t)$ → dipole $\mathbf{p} = \alpha \mathbf{E}$

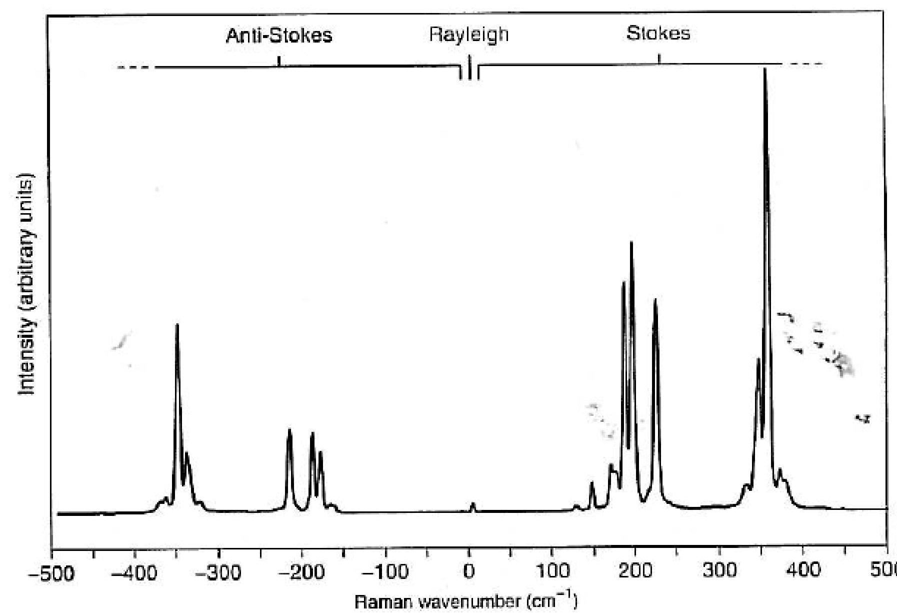
polarizability & normal coordinates $\alpha(Q_k) \sim \alpha_0 + Q_k \, \partial\alpha/\partial Q_k$

$Q_k = Q_{k0} \cos(2\pi f_k t)$

$\rightarrow \mathbf{p} = \mathbf{p}(f_0) + \mathbf{p}(f_0 - f_k) + \mathbf{p}(f_0 + f_k)$



→ spectrum of vibrational transitions

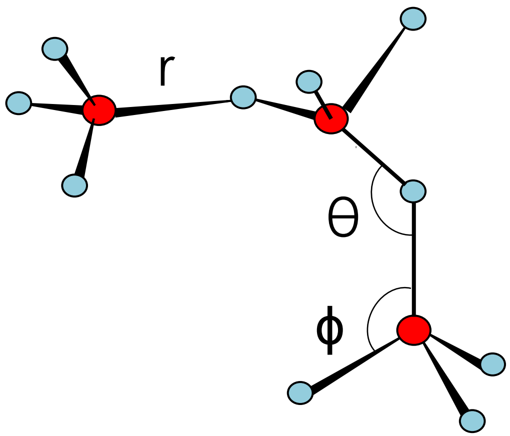


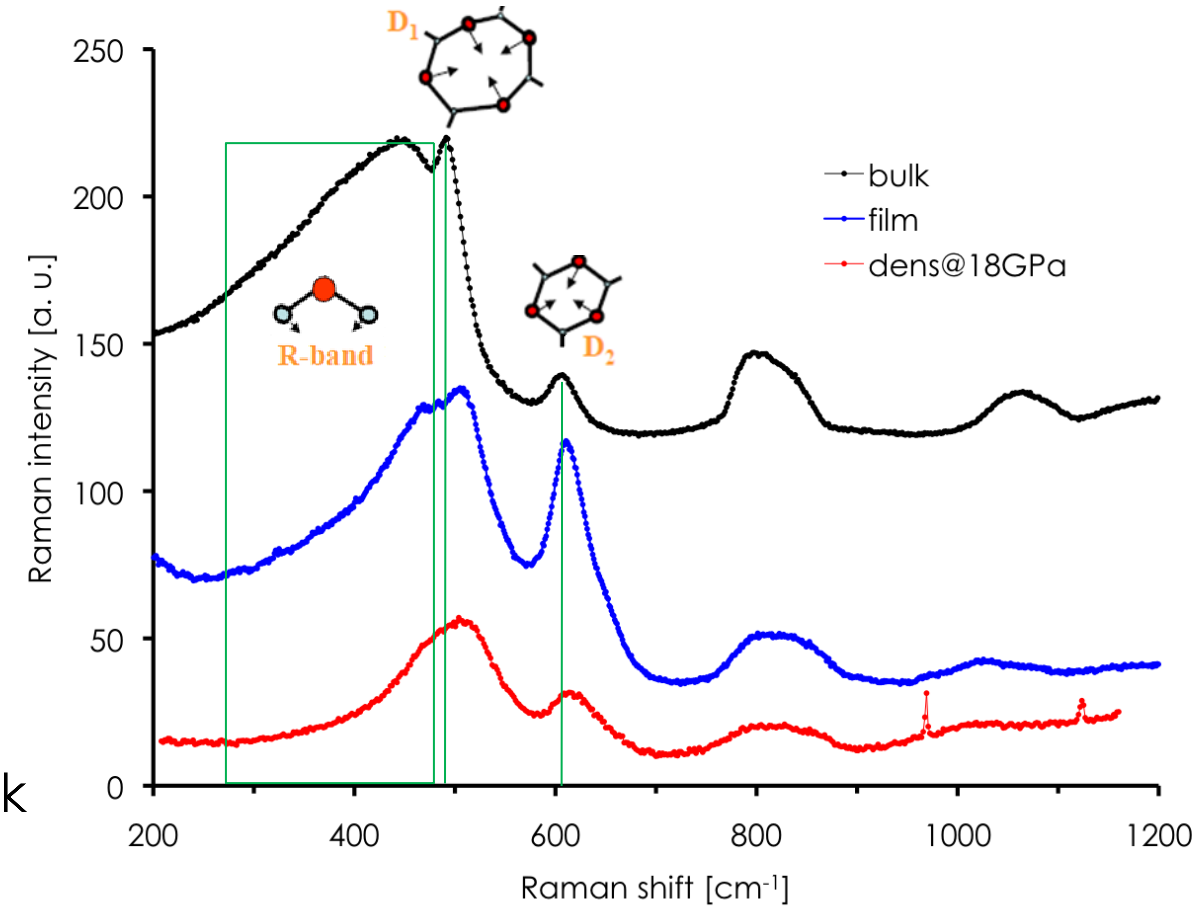
$\omega = (f0 - f)/c$

talk by V. Martinez in this session

P. Vandenabeele
Practical Raman Spectroscopy
Wiley, 2013

SiO2





- film
  - different R-band
  - shifted peaks
  - higher D2 intensity

→ similar to densified bulk

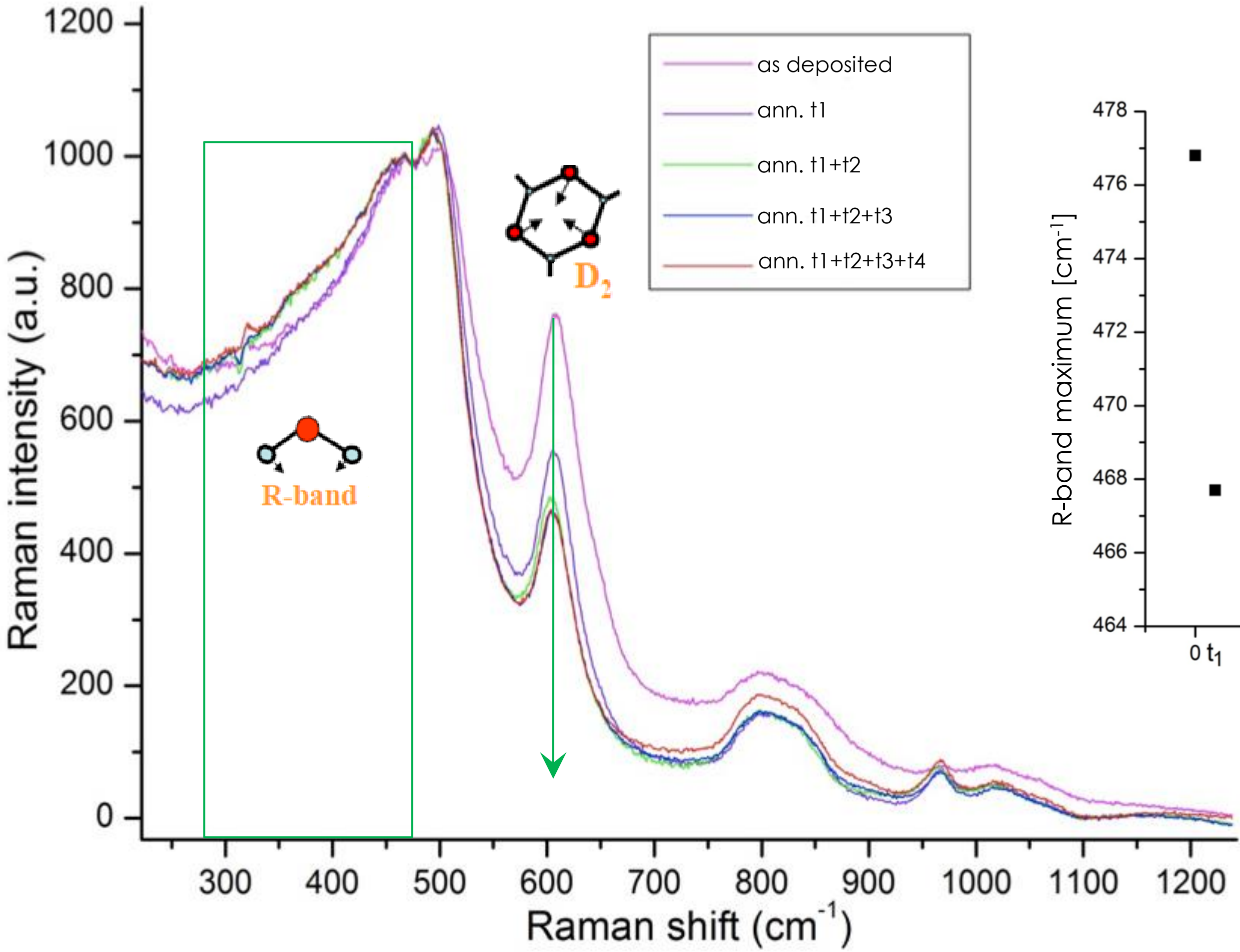
in agreement with density measurements:

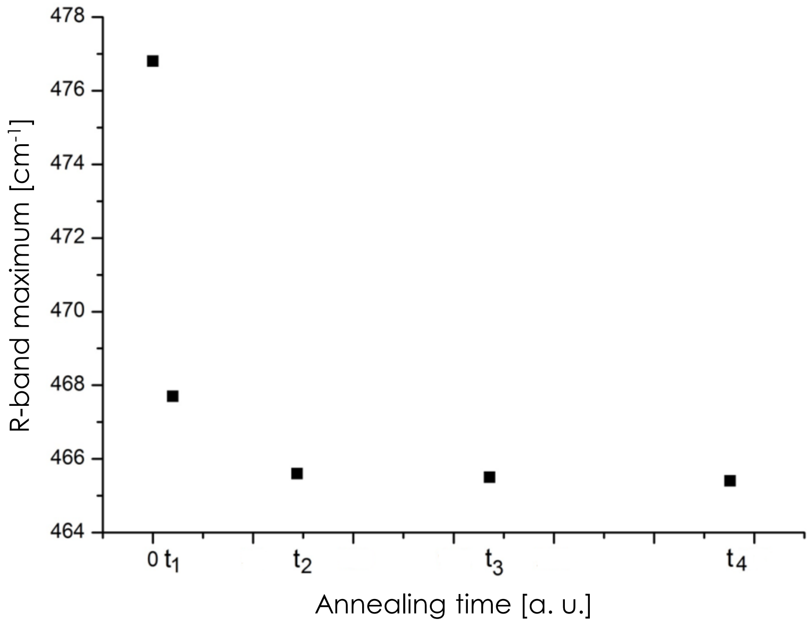
$\rho_{bulk} = 2.20\ g/cm^3$

$\rho_{film} = 2.47\ g/cm^3$

peak identification
Galeener, *J. Non-Cryst. Solids* 71, 1985

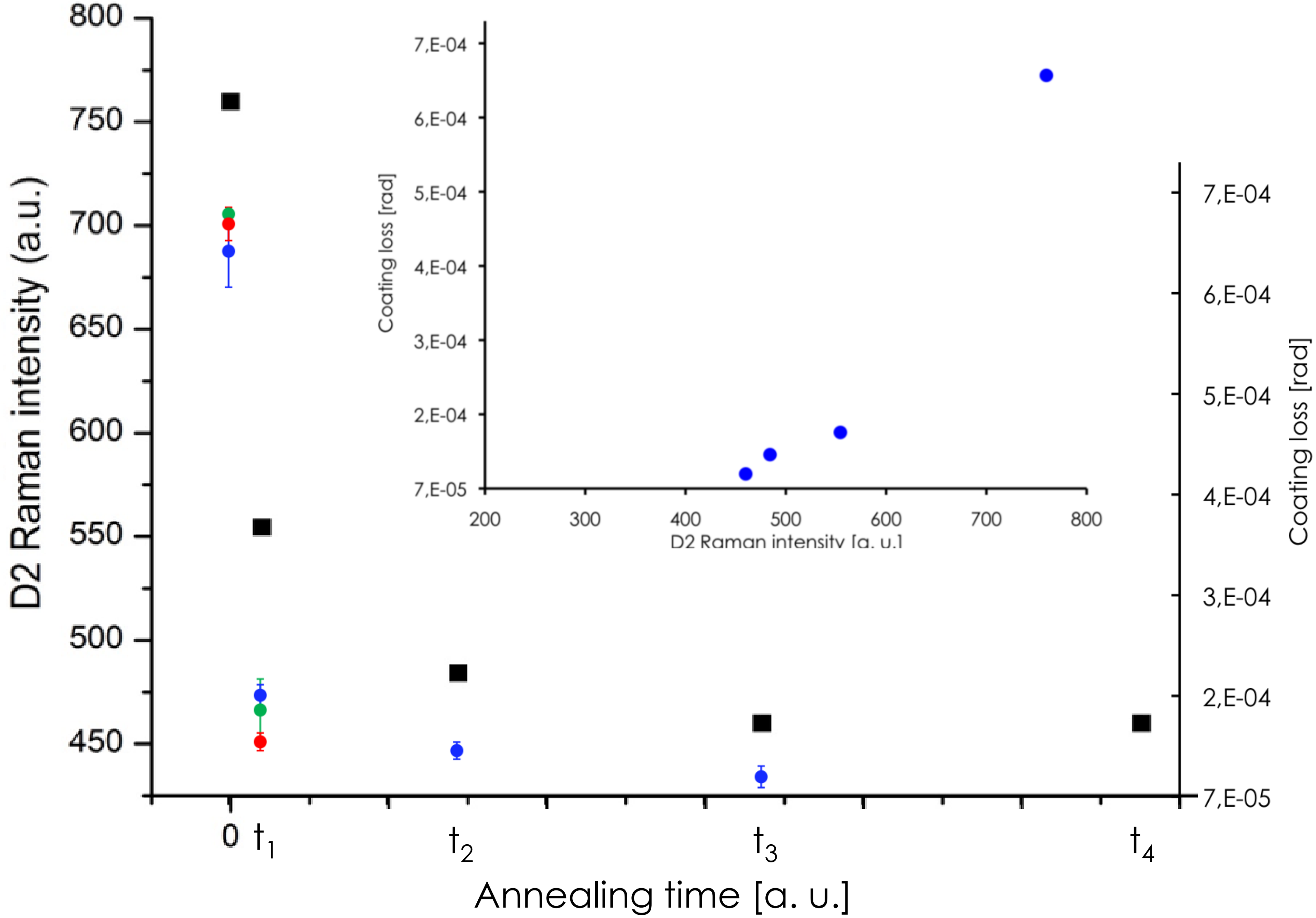
annealing





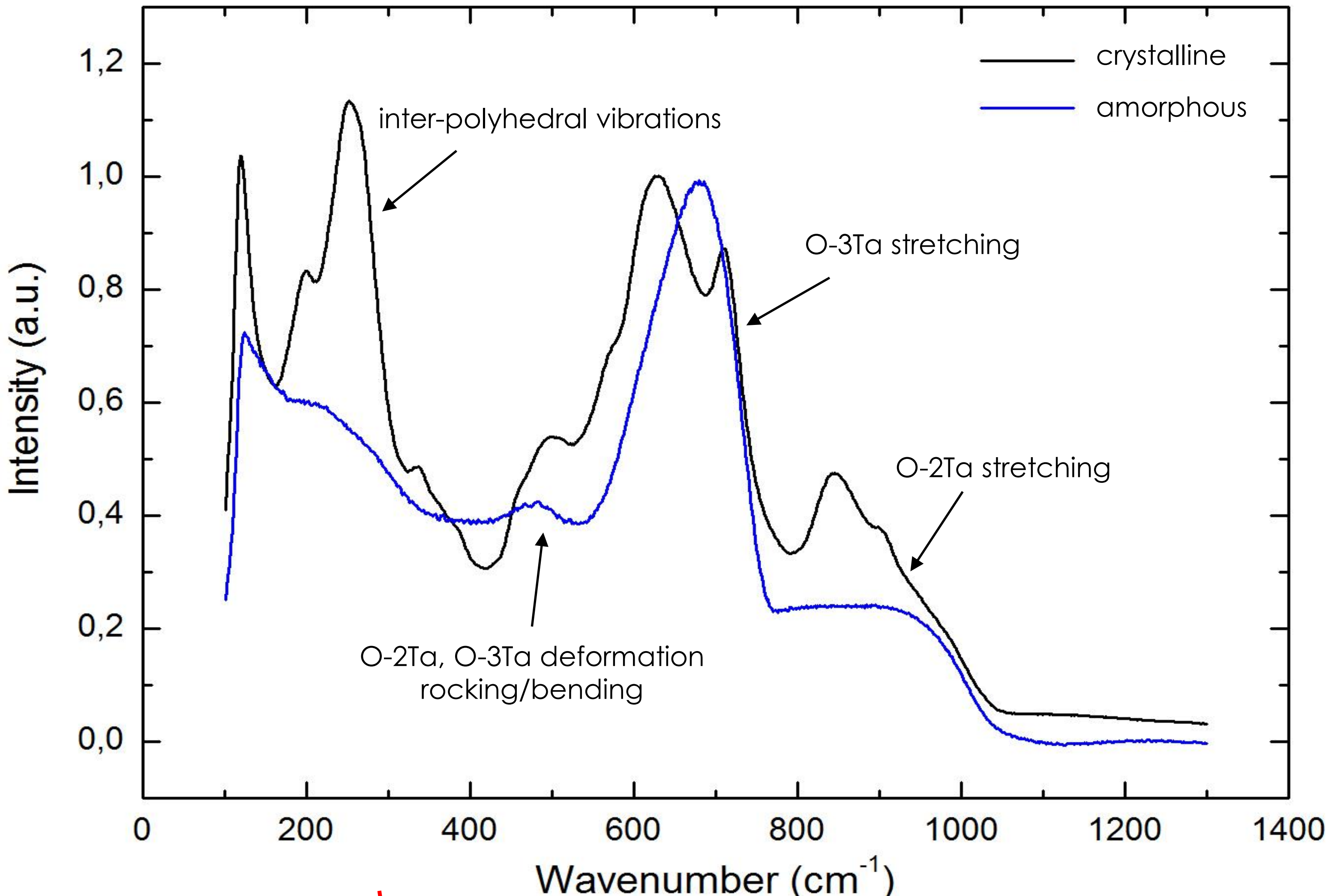
- remarkable evolution wrt annealing time
  - modification of the R-band → different θ distribution
  - reduction of D2 peak

SiO2 structure and loss



- loss measured on 3 SiO_2 cantilever blades
- close correlation between D2 spectral evolution and loss

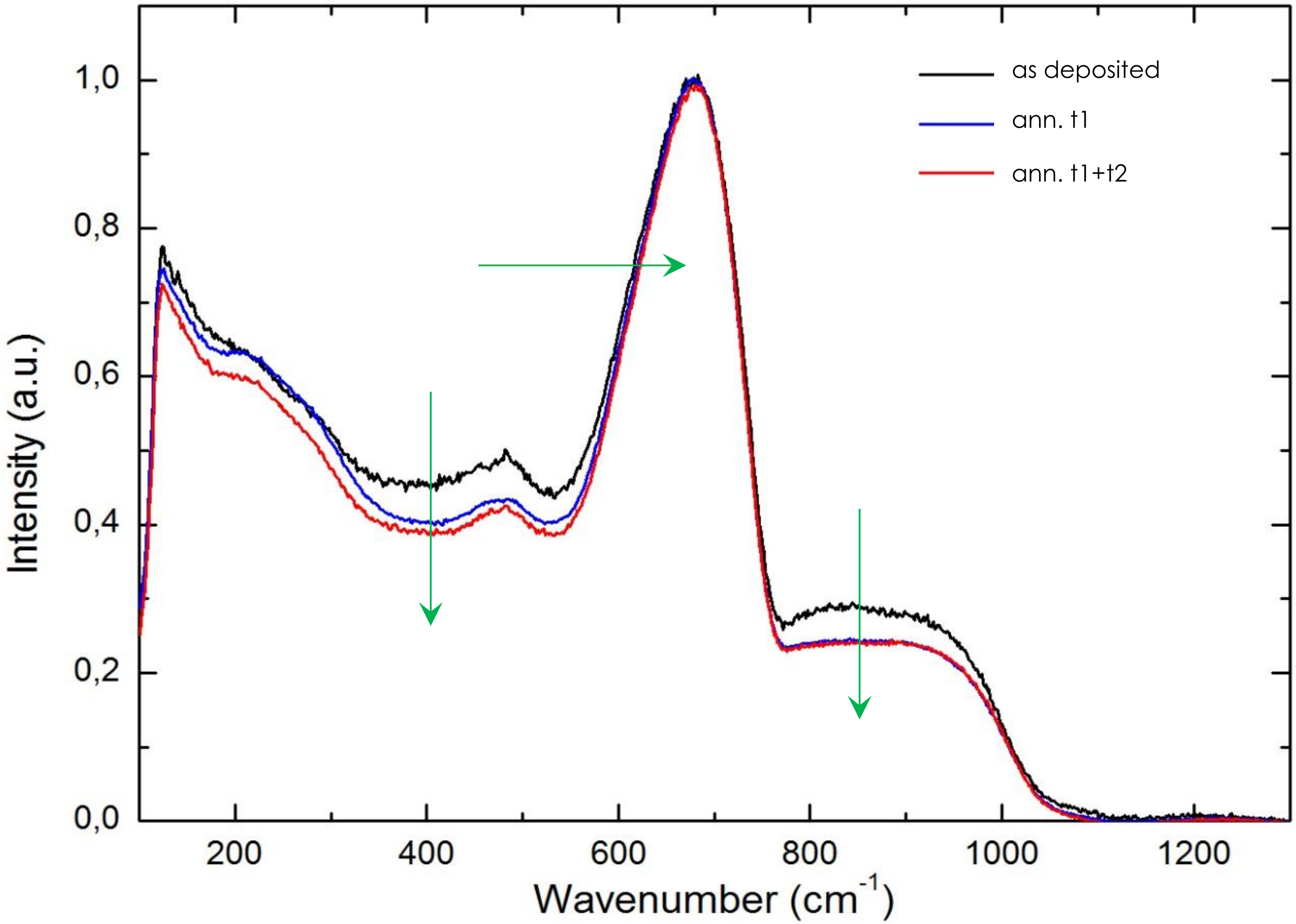
Ta2O5



poster by E. Coillet

peak identification
C. Joseph, *J. Raman Spectrosc.* 43, 2012

annealing

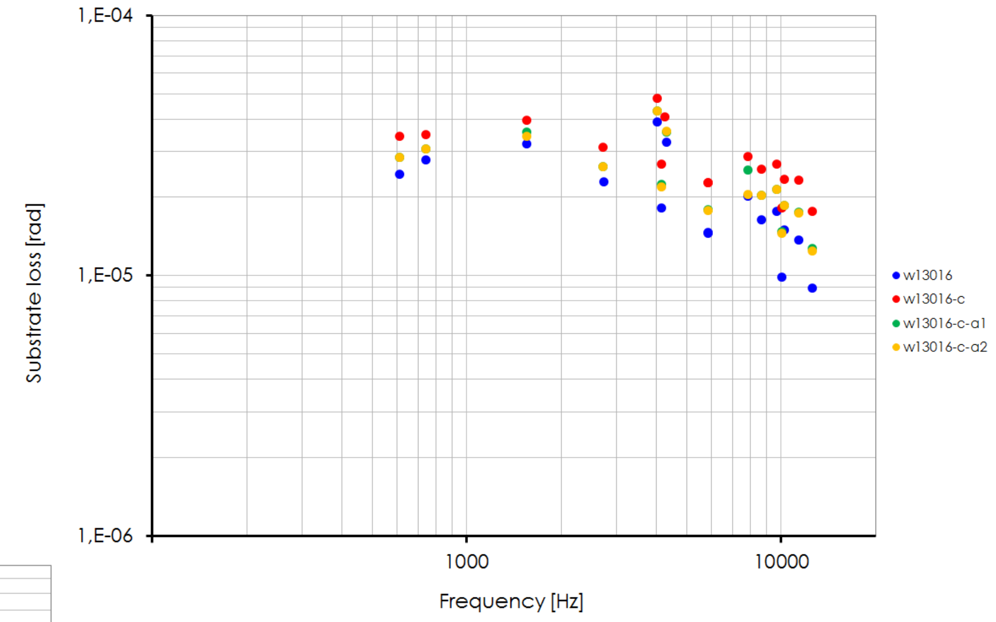


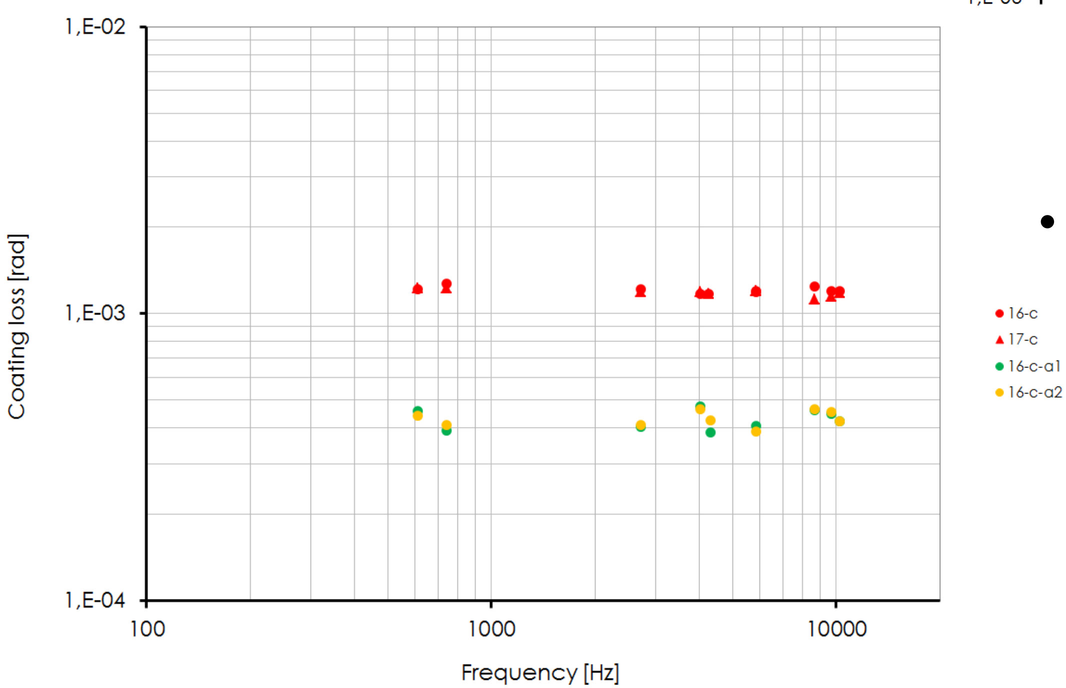
- evolution with1st annealing
- weaker changes with 2nd annealing

Ta2O5 structure and loss

- loss measured on Si disks
  as dep.: Φc = 1.2 ± 0.1 e-3
  ann. – t1: Φc = 4.3 ± 0.3 e-4
  ann. – t2: Φc = 4.3 ± 0.3 e-4

measured dilution factor
$D \approx 1 - (fs/fcd)^2\ \mu s/(\mu s+\mu c)$





- no evolution after 1st annealing

  work ongoing to correlate loss to Raman spectra

summary

summary

- mode-dependent thermoelastic damping confirmed
  → paper with model and measurements in preparation

- coating thermal noise measurements
  → improving mono-layer characterization
  → study ongoing on high-reflective stacks

- Raman spectroscopy to investigate coating structure
  → first observation of SiO2 structure/loss correlation
  → preliminary results on Ta2O5 – work ongoing

acknowledgements

Fédération de Physique André-Marie Ampère (FRAMA)