Optical performances and thermal noise measurements of crystalline coatings

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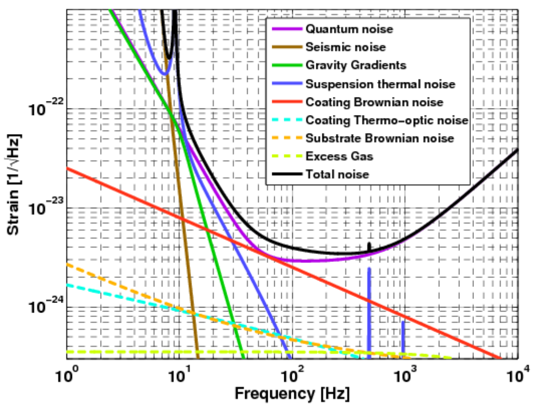
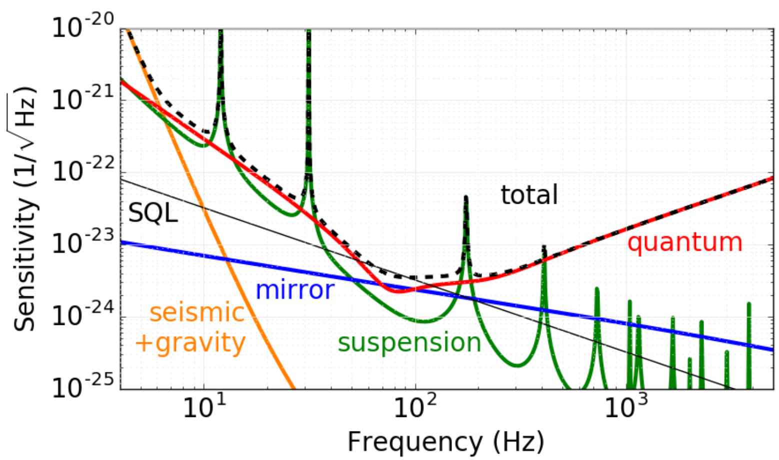
東京大学 THE UNIVERSITY OF TOKYO · KAGRA · LMA LABORATOIRE MATÉRIAUX AVANCÉS · NAOJ · CMS · MIT

Motivation

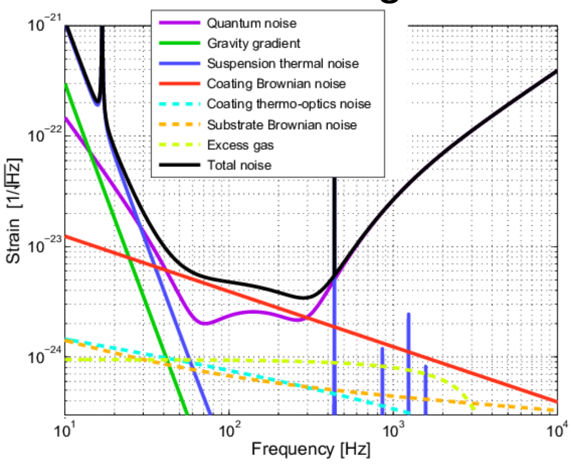
aLIGO



KAGRA

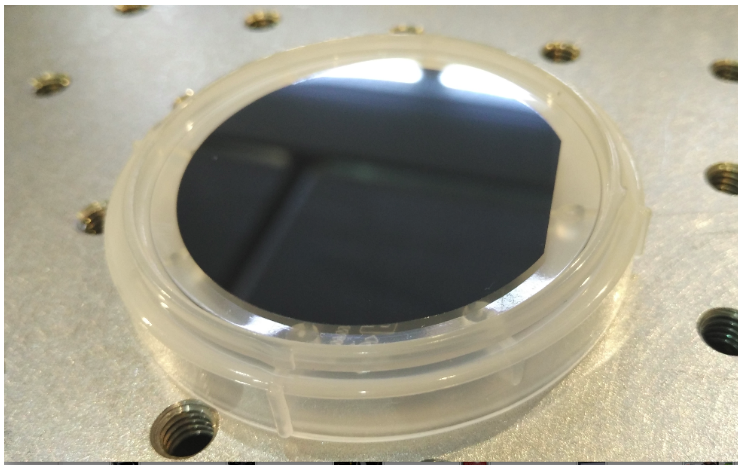


AdVirgo

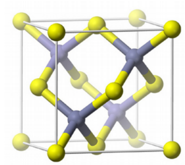


- The limiting noises at mid frequencies are **mirror thermal** noise and **quantum noise**.
- To reduce thermal noise KAGRA cools down the test masses.
- New crystalline coatings are proposed as upgrade.
- CMS is able to fabricate large area crystalline coatings.
- Optical characterization is needed.

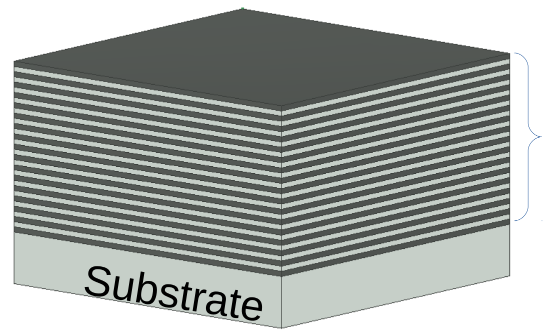
Crystalline AlGaAs samples



2 inches diameter



zinc blende structure



35.5 doublets of GaAs / $Al_{0.92}Ga_{0.08}As$

- Grown with Molecular Beam Epitaxy (MBE) on a **GaAs** substrate
- Then transferred onto the final substrate
- Two samples, **SILICA** and **SAPPHIRE** substrates. 2 inches x 0.5mm

Optical characterization

- Defects
- Transmission
- Scattering
- Roughness
- Absorption
- Thermal noise @ MIT

Check for updates

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Optical performance of large-area crystalline coatings

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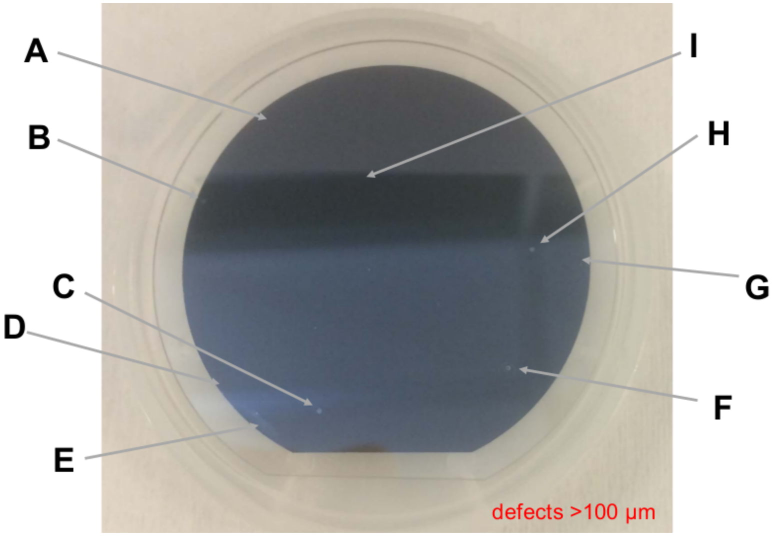
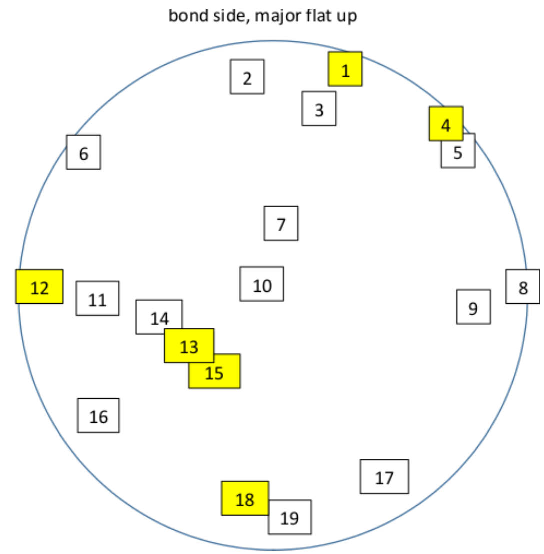
Defects

On sapphire substrate

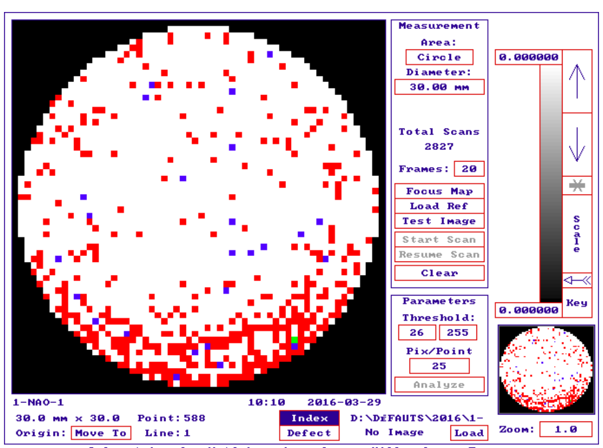


Defect	Size (µm)
A	216
B	690
C	1304
D	957
E	1462
F	941
G	171
H	875
I	250

On fused silica substrate



Defect #	Size (µm)	Defect #	Size (µm)
1	200	10	63
2	85	11	55
3	62	12	121
4	186	13	185
5	65	14	98
6	60	15	117
7	75	16	76 &68
8	75	17	52
9	52	18	271
		19	51

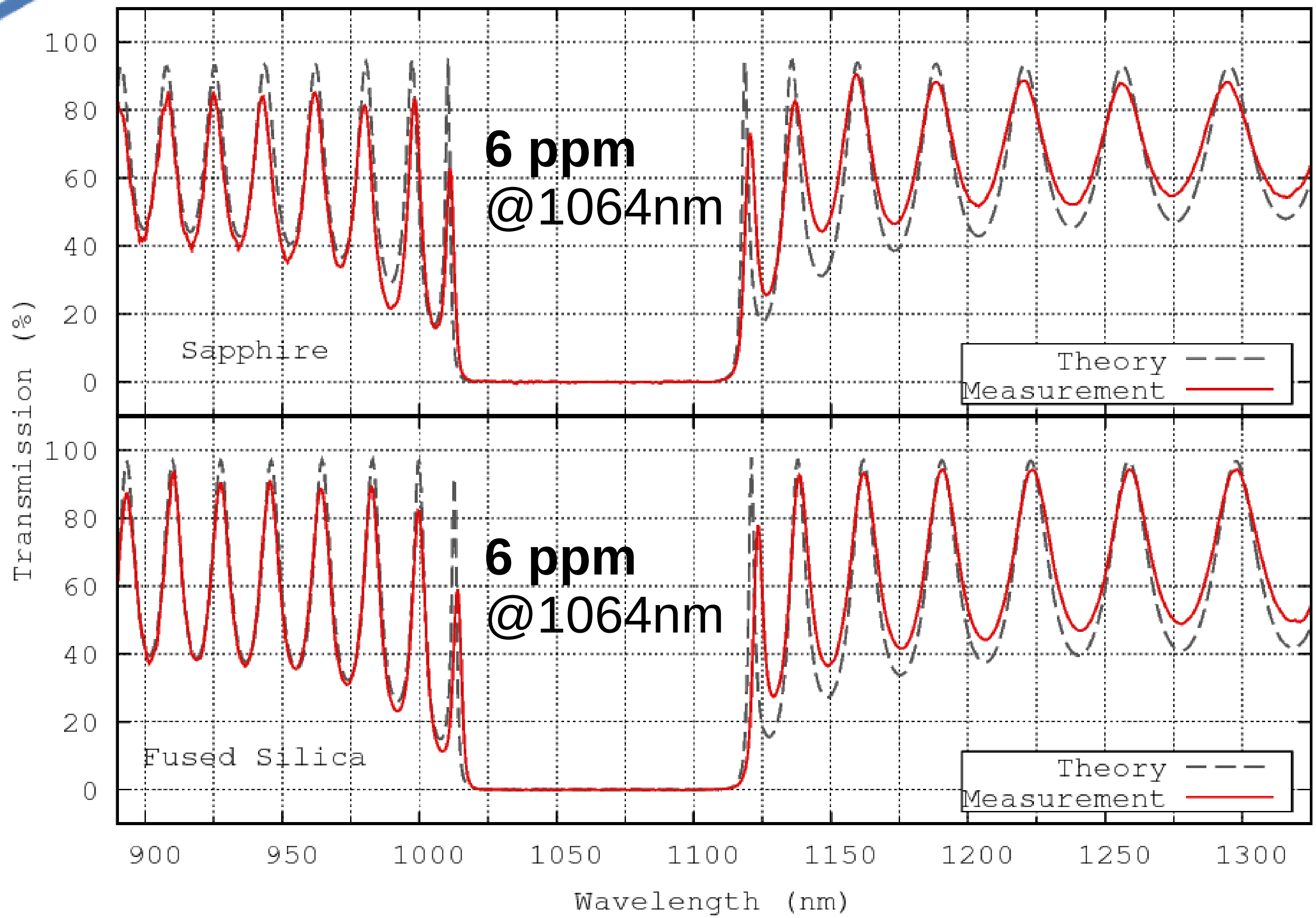


Small defects < 5 um. Micromap

Defects rate: 0.85/mm²

(LIGO/Virgo: 0.7/mm²)

Transmission



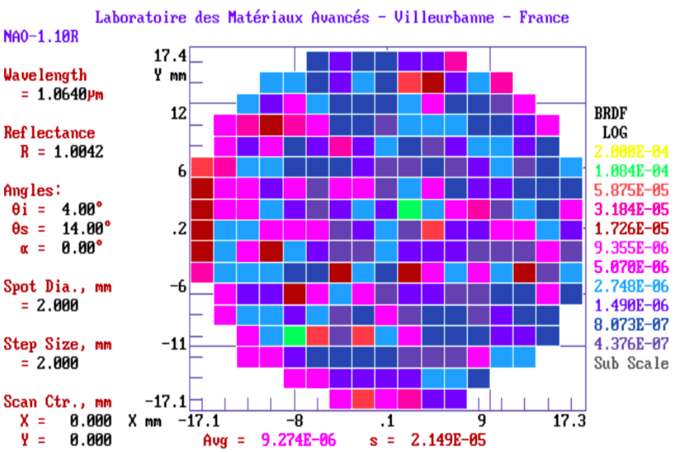
- Spectrophotometer measurement
- Fit with model
- Transmission measurement @1064

Measurement consistent with the design and the fit

Scattering

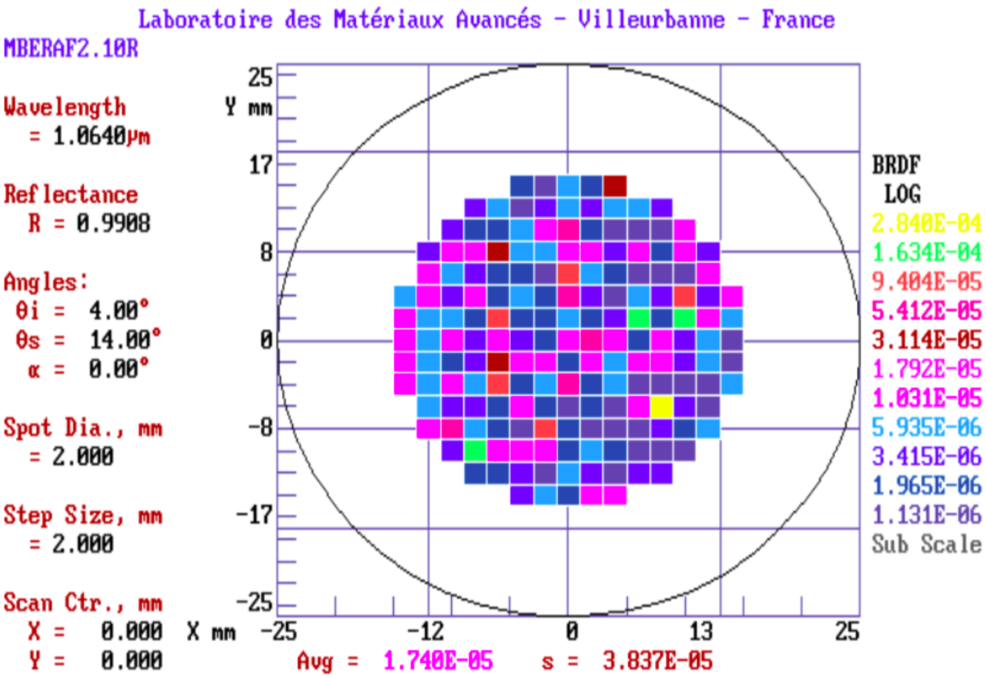
- Map of BRDF at fixed angles ([0°,4°],[0°,14°])
- Then converted to **T**otal **I**ntegrated **S**cattering

On sapphire substrate



TIS = 6 ppm

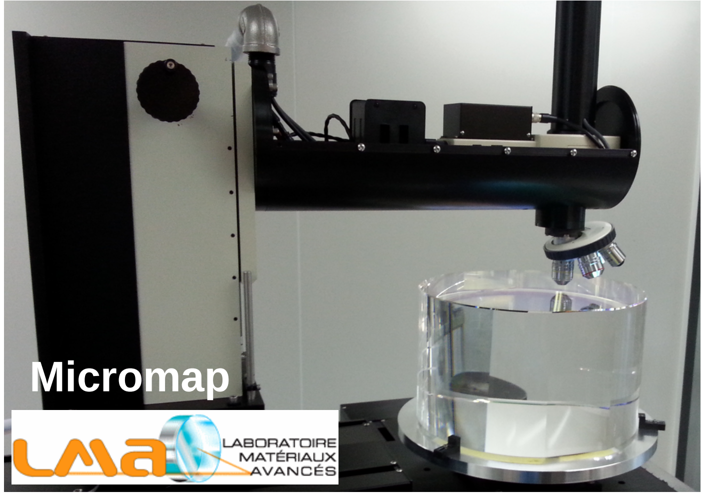
On fused silica substrate

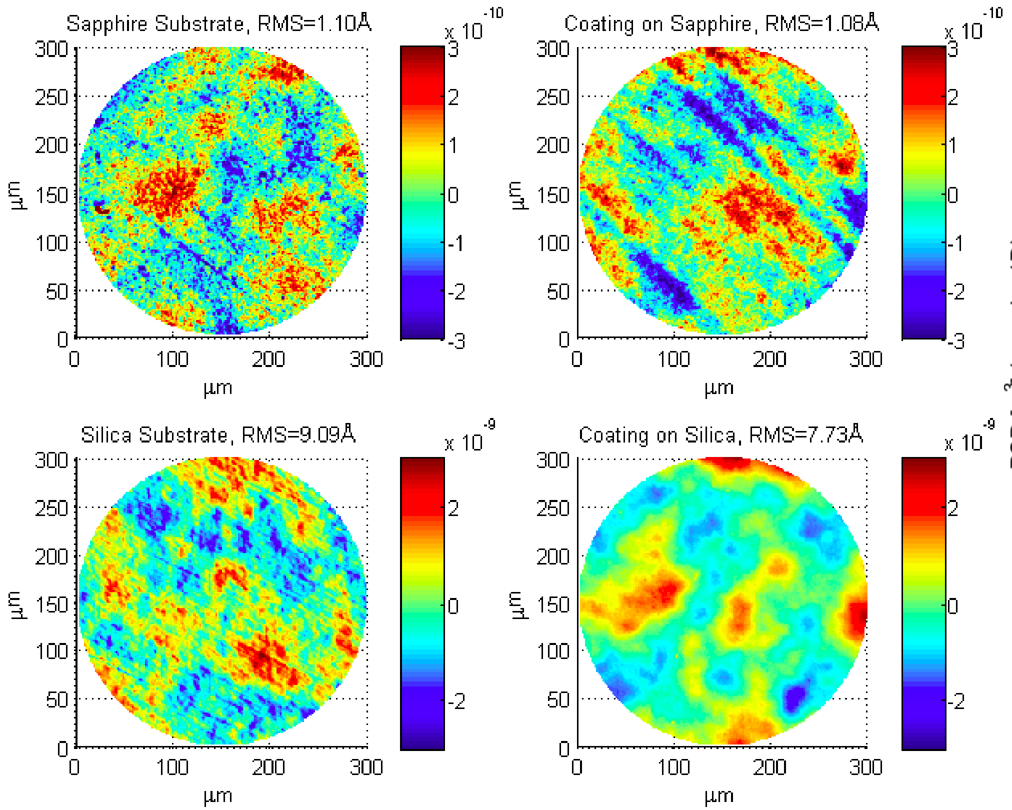


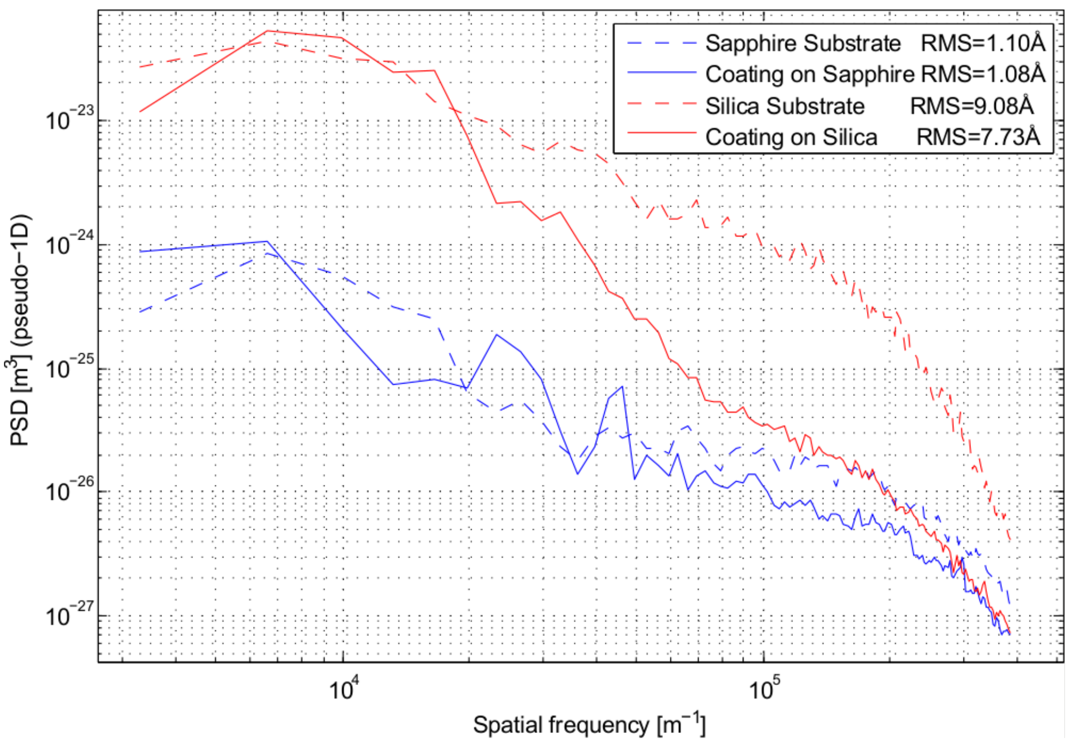
TIS = 9.5 ppm

Roughness

- Micromap (Fizeau interferometer)
- Subtract tilt, defocus and astigmatism
- Plot the PSD

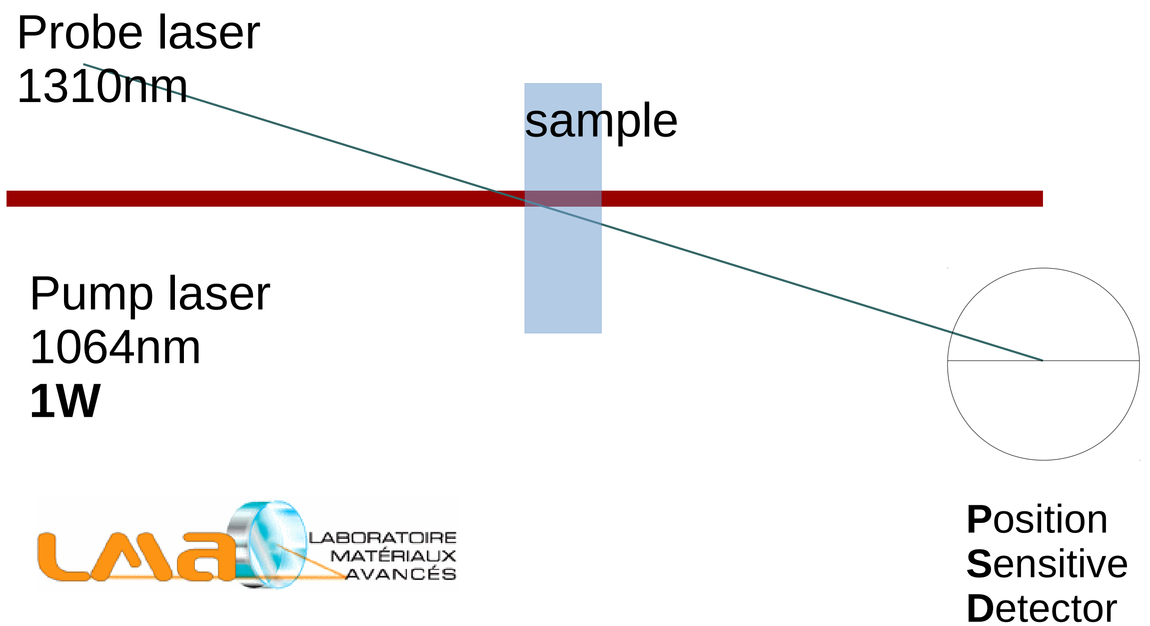






- Coating roughness is limited by the substrate roughness
- Coating doesn’t follow silica substrate’s roughness at high frequencies

Absorption



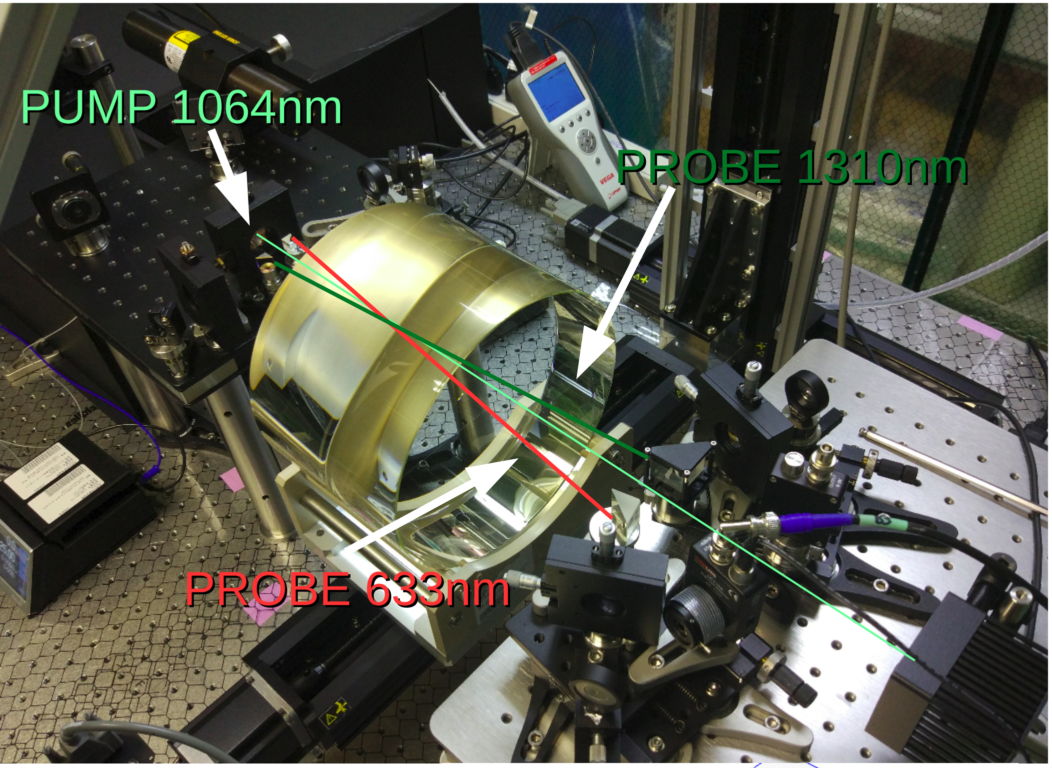
PHOTOTHERMAL DEFLECTION

- Single point measurement
- GaAs / $Al_{0.92}Ga_{0.08}As$ transferred on **silica** substrate: **< 0.8 ppm**
- **Sapphire** has higher thermal diffusivity, so the signal is too small (below the noise level)
- Low SNR → need more pump power.

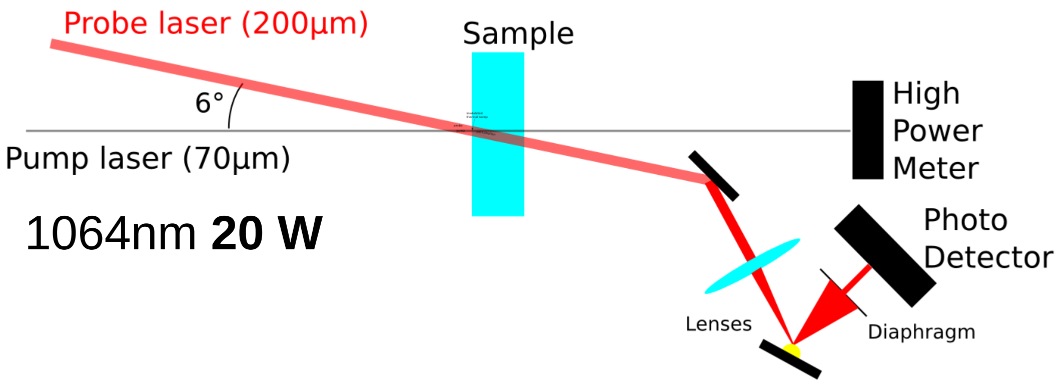
Summary of published results

Measurement	Coating on silica substrate	Coating on sapphire substrate
Transmission @1064 nm	6 ppm	6 ppm
Absorption @1064 nm	$\leq$ 0.8 ppm	below the noise floor
Scattering @1064 nm	9.5 ppm	6 ppm
Coating Roughness	7.7 Å RMS	1.1 Å RMS
Substrate Roughness	9.1 Å RMS	1.1 Å RMS

Absorption map
planned @NAOJ

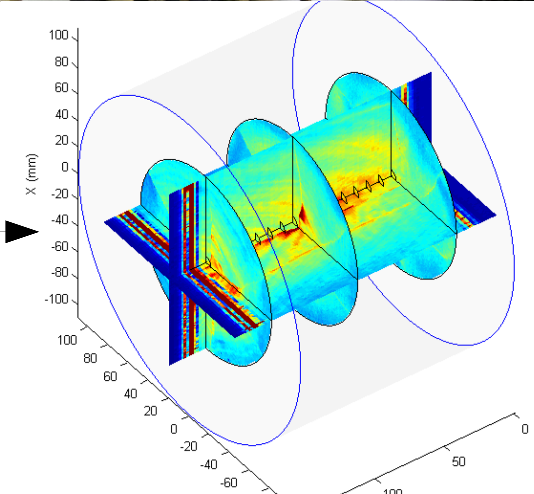


PHOTOTHERMAL COMMONPATH INTERFEROMETER



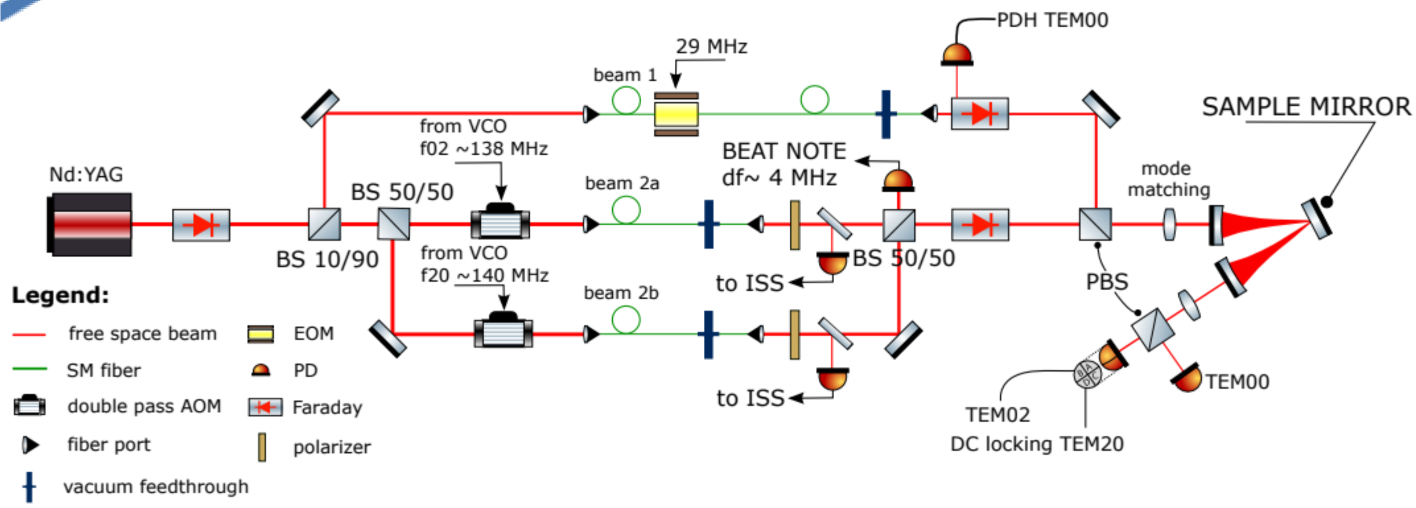
1064nm **20 W**

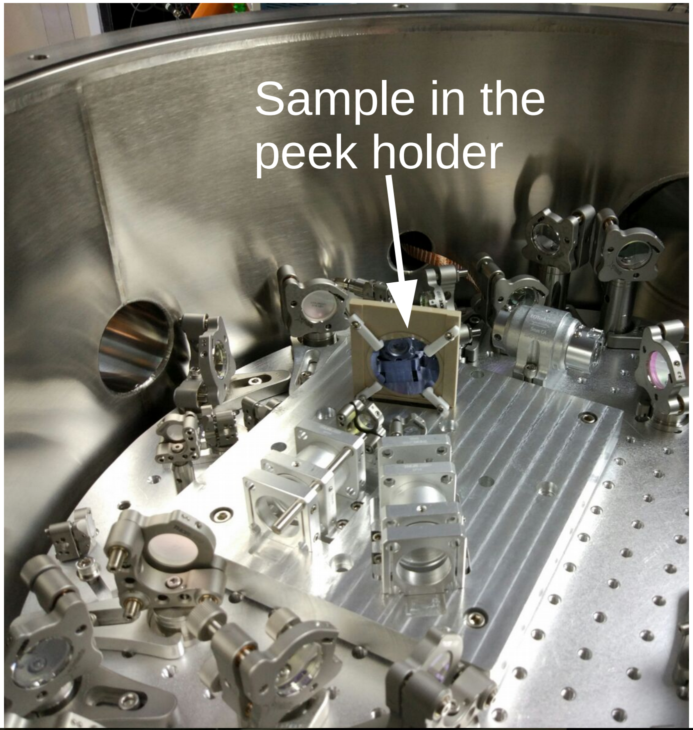
KAGRA substrate absorption maps



- Measure crystalline coatings soon…
- Expected sensitivity better that 0.1ppm

Thermal noise @MIT





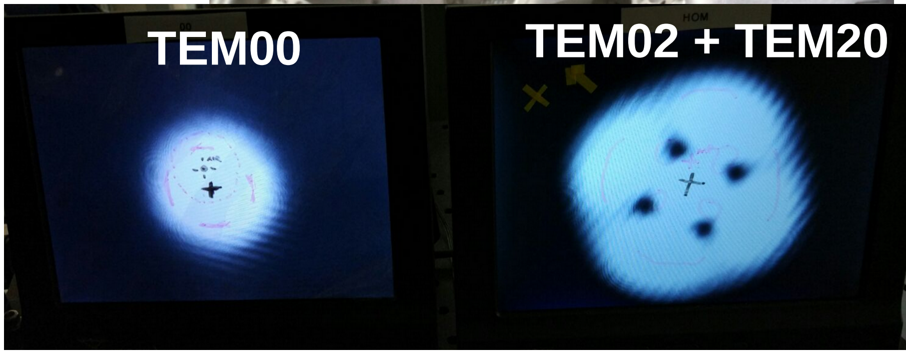
- TEM00 + TEM20 + TEM02 coresonate in the folded cavity

- TEM00 is used to lock the cavity and suppress common noises.

- TEM02/20 are spatially separated, so they sense uncorrelated noise.

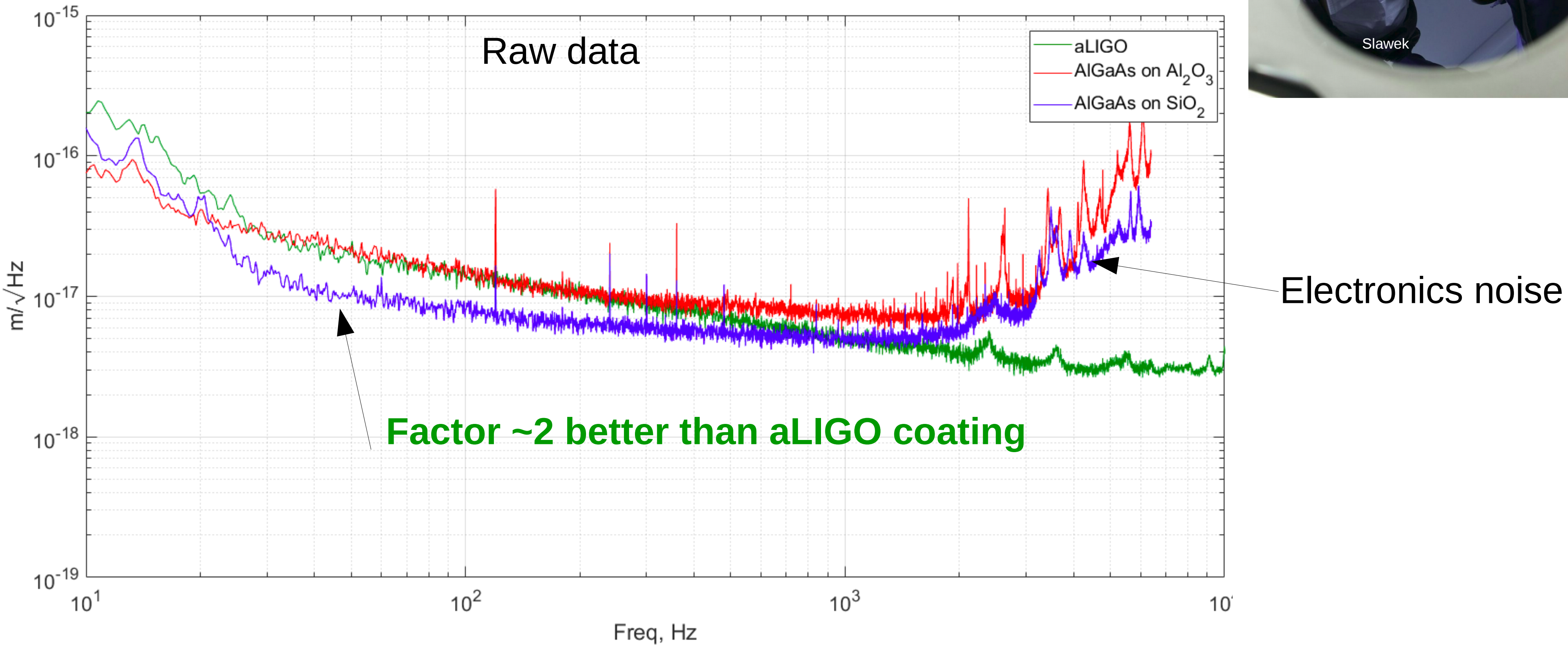
- TEM02/20 have different resonance frequency.

- The **beatnote** between TEM02 and TEM20 contains the thermal noise information.



Audio-band coating thermal noise measurement for Advanced LIGO with a multimode optical resonator
S. Gras, H. Yu, W. Yam, D. Martynov, and M. Evans. Phys. Rev. D 95, 022001 – Published 10 January 2017

Thermal noise @MIT



- Sapphire and silica samples give different noise.

- Sapphire has higher Young modulus (Thermo-Elastic noise), but is designed for cryogenic operation.

- Data analysis is ongoing to estimate Thermo-Refractive and Thermo-Elastic noise contributions and fit the measurement.