Development and test of an absorption bench to characterize the KAGRA mirrors

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MOTIVATION:

- The gravitational wave detector KAGRA will operate at cryogenic temperature (20K) to reduce thermal noise.
- Sapphire mirrors will be used for its good thermal properties.
- Need to minimize mirror **optical absorption** to make cryogenic operation as easy as possible.

OBJECTIVES:

- Measure optical absorption of KAGRA substrates and coatings
- Investigate new mirror materials for future upgrades – crystalline coatings.

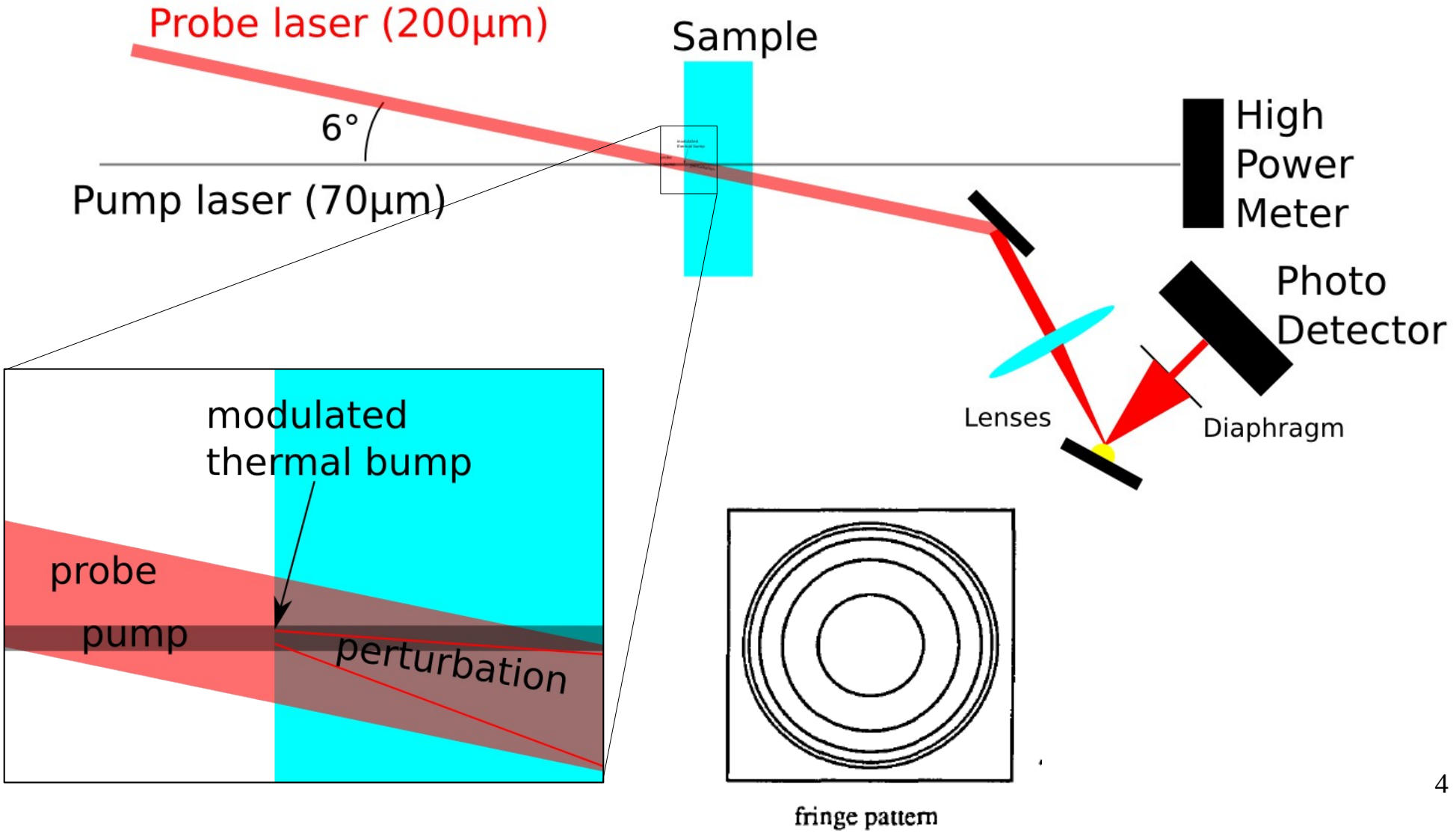
STEPS

- Setup absorption experiment
- Validate calibrations
- Simulations
- Absorption measurements

How it works

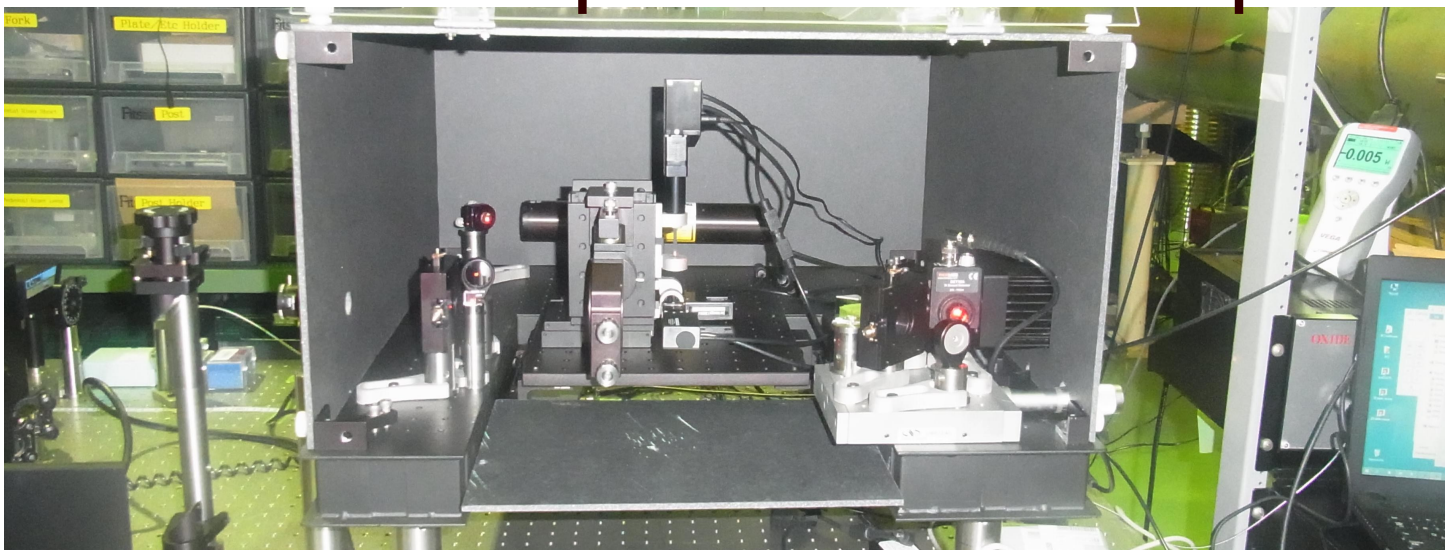
Photo-thermal
Common-path
Interferometer

$$e^{ikz}e^{\Delta\phi(t)} \simeq e^{ikz} + i\Delta\phi(t)e^{ikz}$$



Absorption measurement system

Experimental setup features:



- Scan along the sample depth
- 2D maps of the surface and inside the substrate
- Pump power up to 10W
- Best sensitivity:
  - 1 ppm/cm for bulk absorption
  - 0.1 ppm for surface absorption

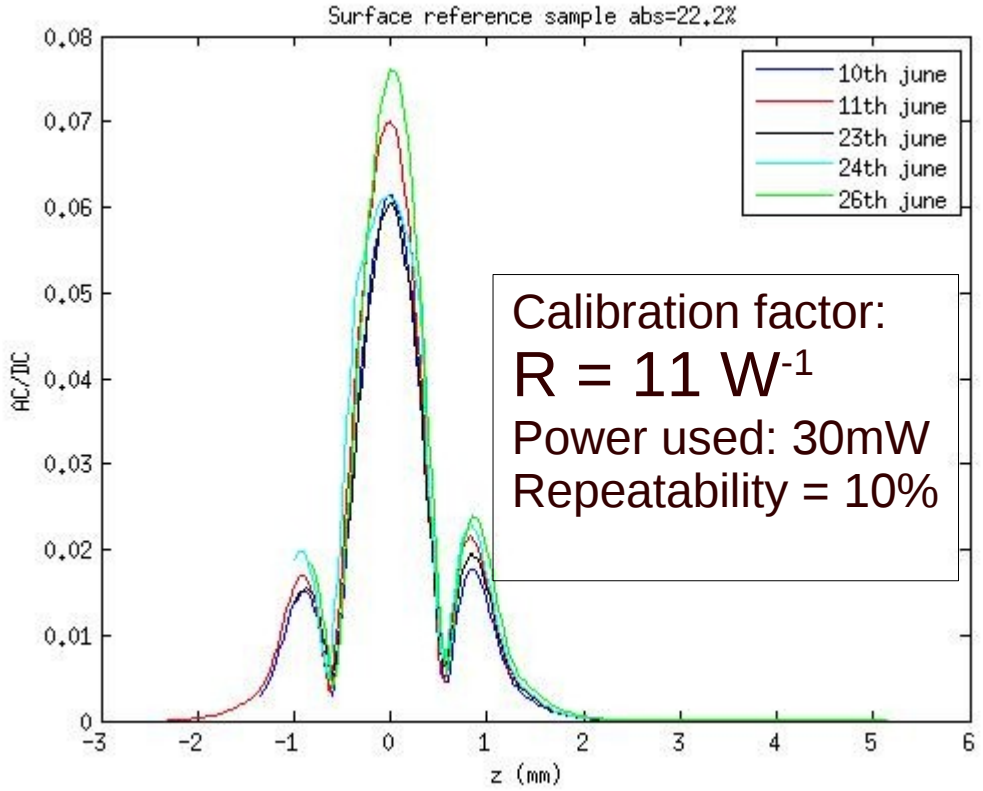
Scans of known absorption samples give the calibration

SURFACE Reference sample:

Newport FRQ-ND02

Inconel coating on silica substrate

Known absorption: **22.2%** at 1064 nm

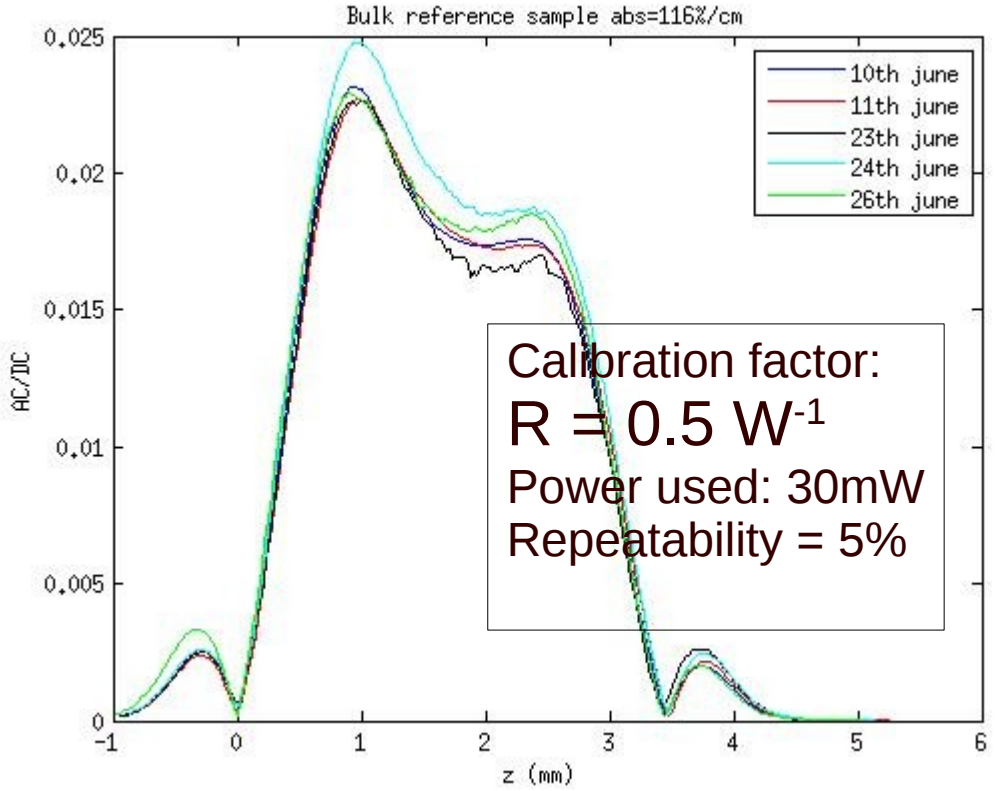


BULK Reference sample:

Schott glass NG-12

Silica substrate

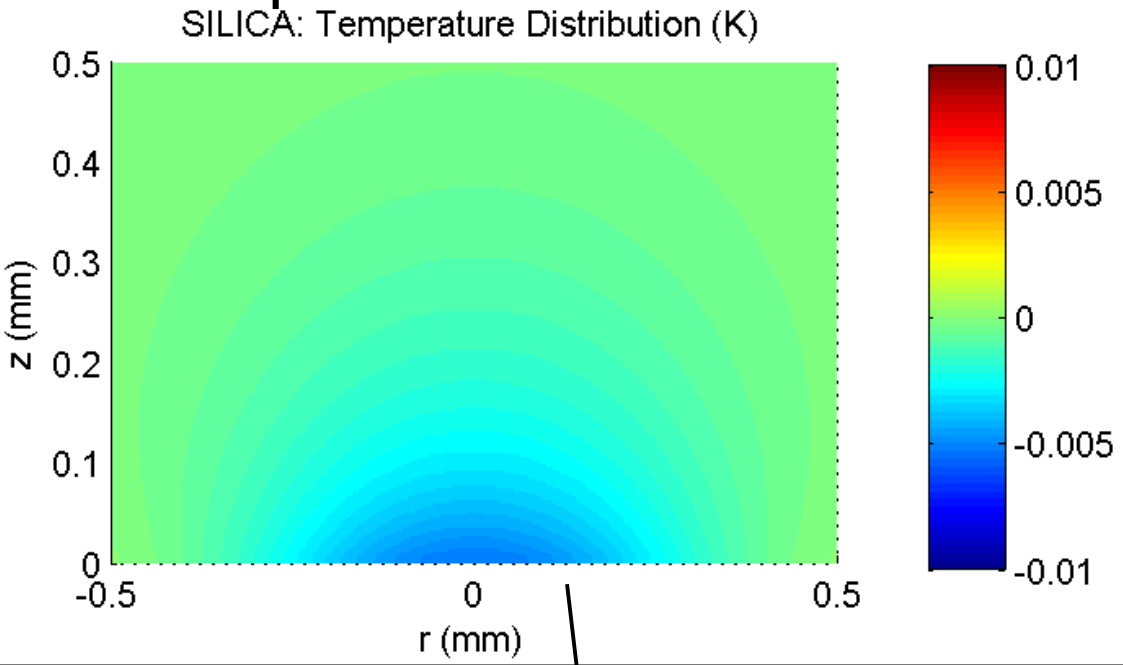
Known absorption: **116%/cm** at 1064 nm



- Calibration factors change for different materials because of different thermal diffusivity
- Lack of some reference samples for other materials
- SIMULATIONS ARE NEEDED TO CALCULATE THE CORRECTION FACTOR

Simulations:

1. Heat equation solution inside the sample

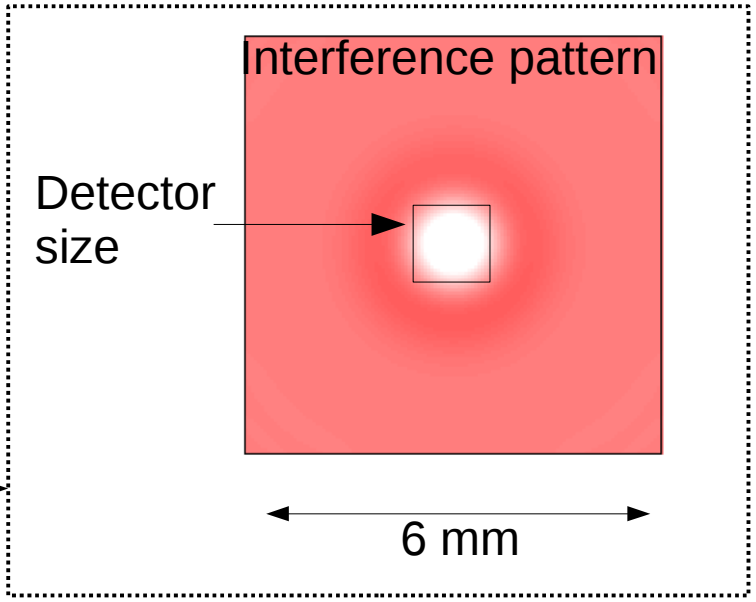


Parameters:
Heat source power = 1W
Sine wave freq = 1Hz
Absorption: 12 ppm in 10 μm

2. Probe beam propagation through the sample and then to the detector

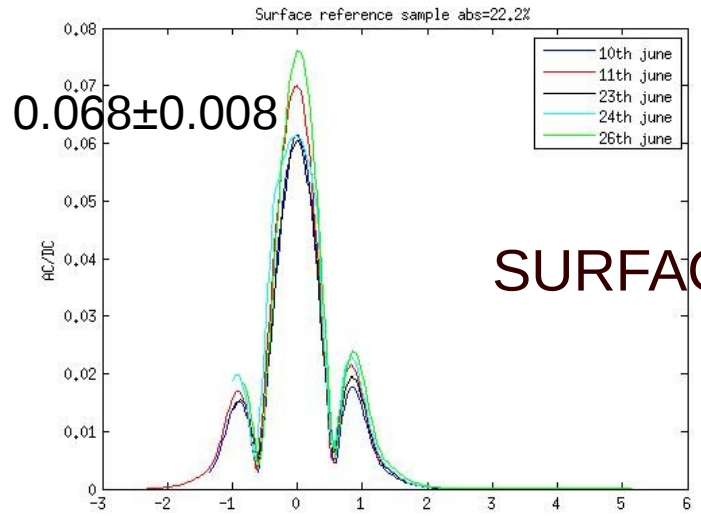
$$E(x,y) = E_0(x,y)e^{ik\mathrm{OPL}(x,y)}$$

FFT code:
Propagation up to detector distance



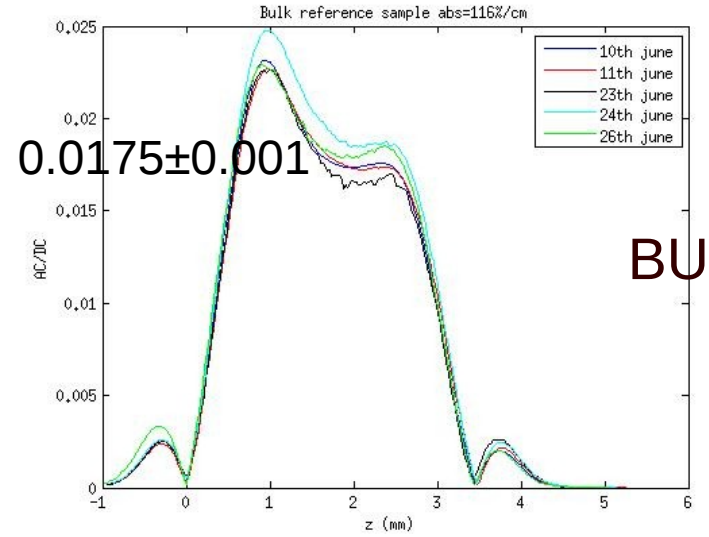
Reference samples simulation and measurements

MEASUREMENTS



0.068±0.008

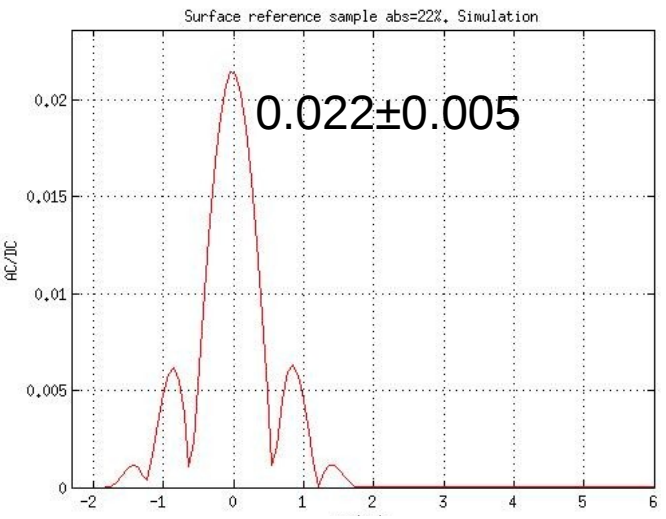
SURFACE



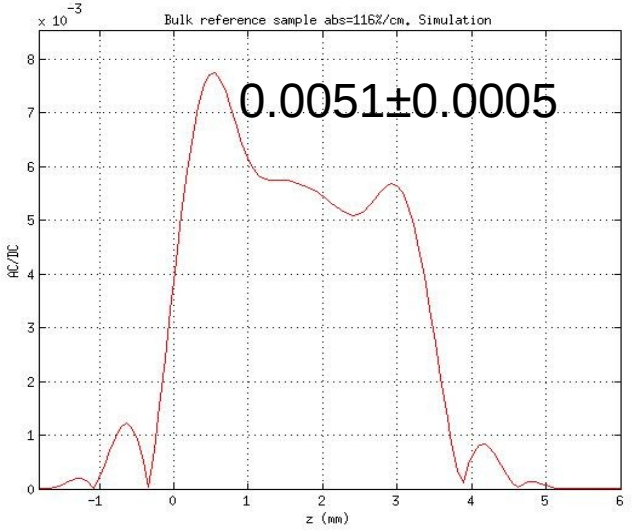
0.0175±0.001

BULK

SIMULATIONS



0.022±0.005



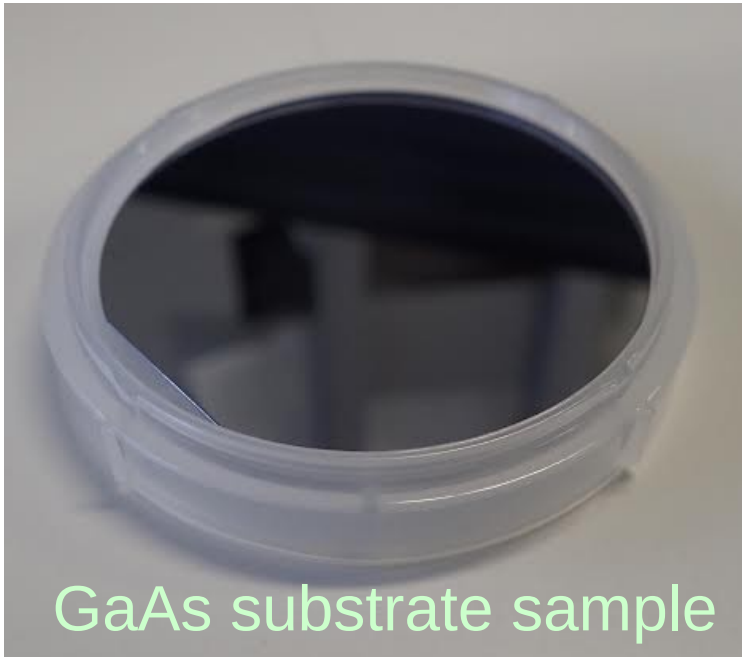
0.0051±0.0005

- Good match between measurements and simulations.
- There is a different scale factor which depends on signal amplification and demodulation in the Lock-in amplifier.
  But it is not relevant for the physics of the model.
- The important thing is the ratio between surface and bulk absorption, that cancels this scale factor out.

Ratio between surface and bulk	
Measurements	Simulations
3.9±0.7	4.4±1.4

Crystalline coating absorption

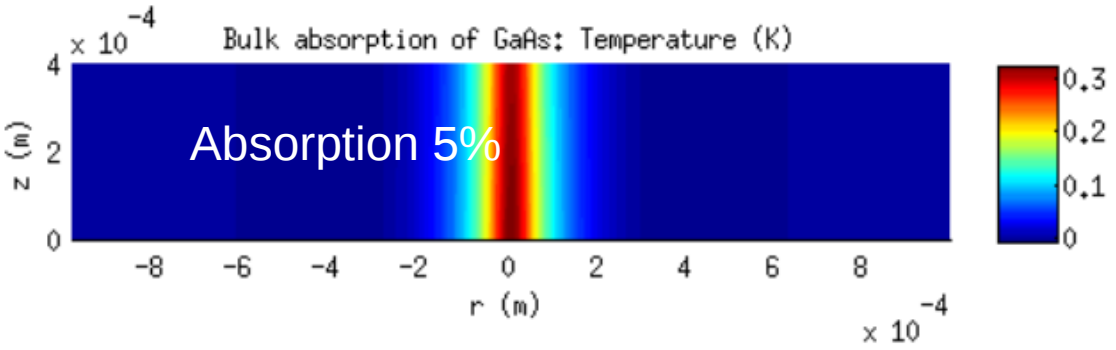
- Crystalline coatings are candidates for future upgrades of KAGRA to reduce coating thermal noise.
- AlGaAs coatings are attached on GaAs substrate.

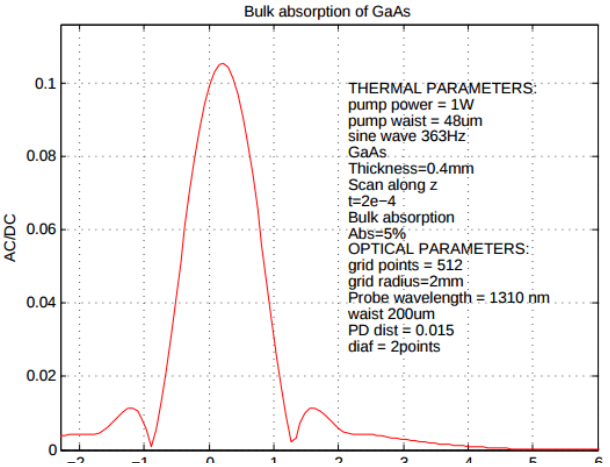

GaAs substrate sample

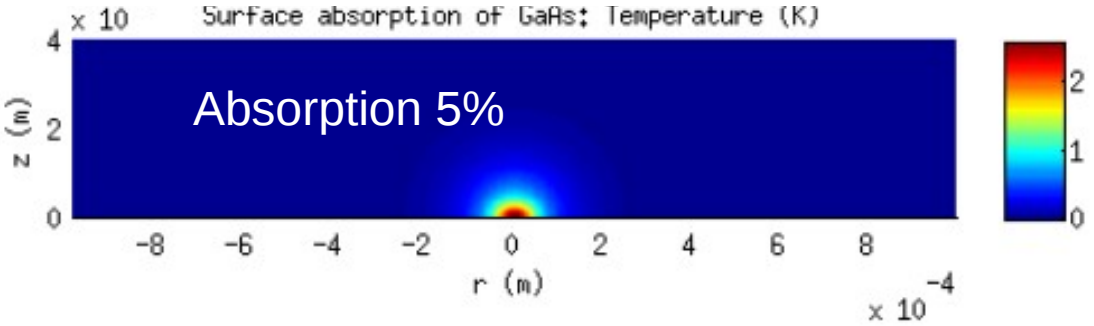
- The idea is to measure the calibration of **bulk absorption** of GaAs and use the simulation to calculate the calibration of **surface absorption**.

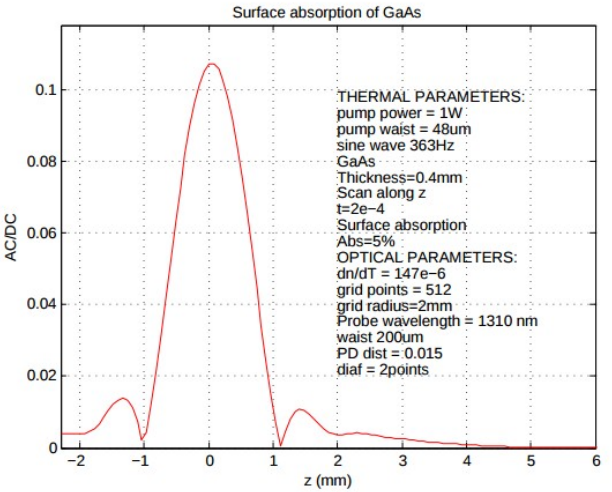
Crystalline coating absorption

SIMULATIONS







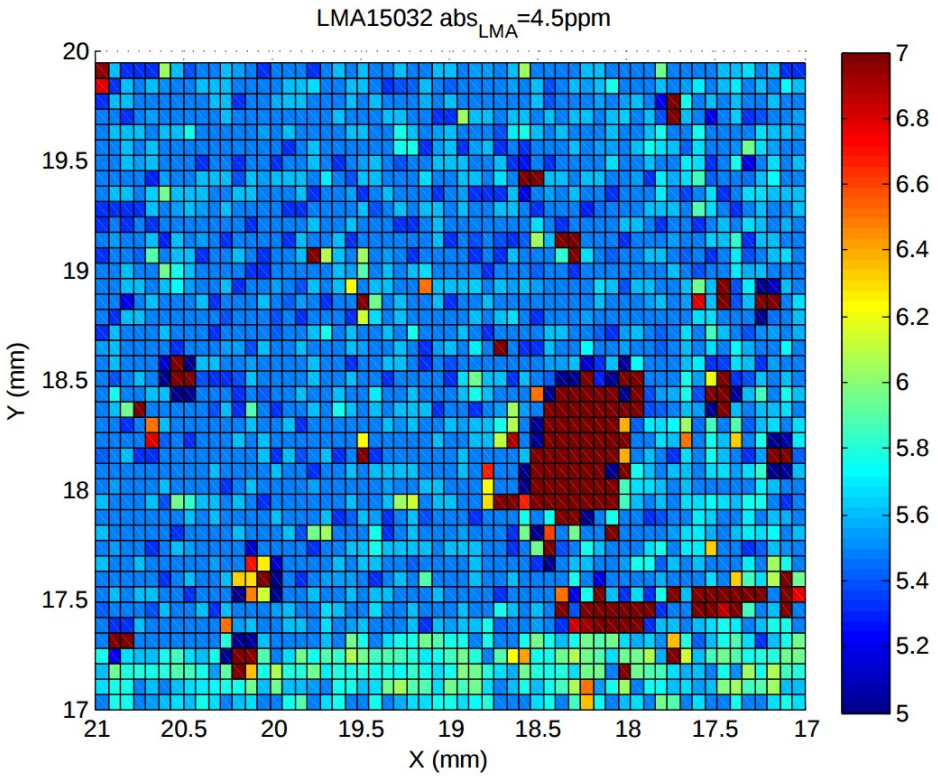


RESULT: For same amount of absorption but different distribution we get the same signal

Measurements results:

SURFACE ABSORPTION MAP

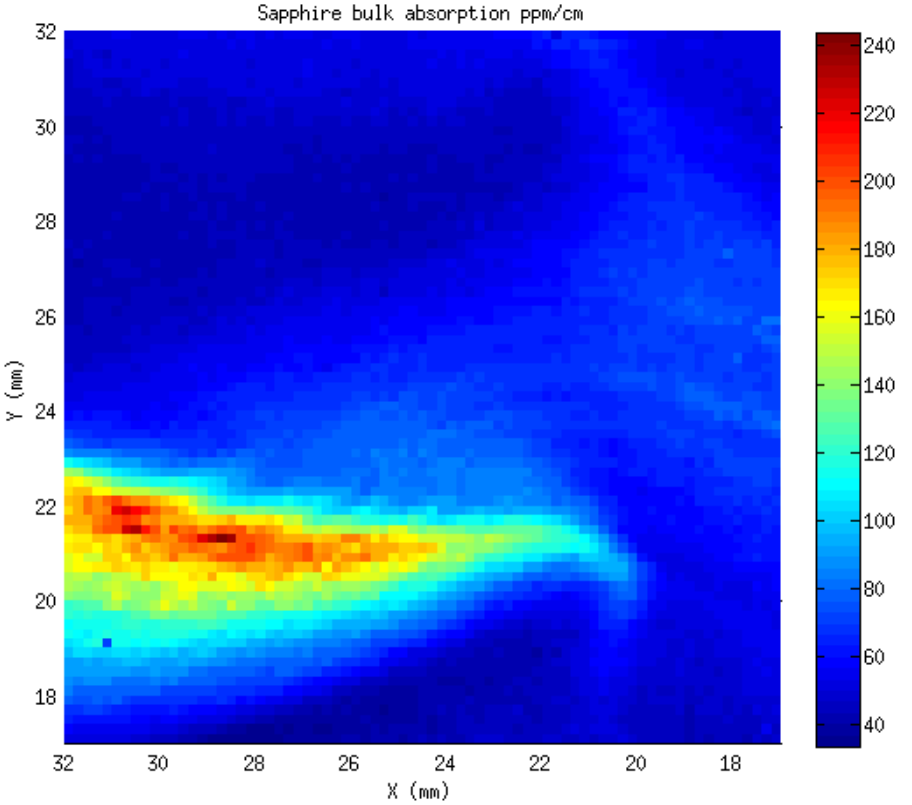
High reflection coating
on silica substrate:



We found many coating defects

BULK ABSORPTION MAP

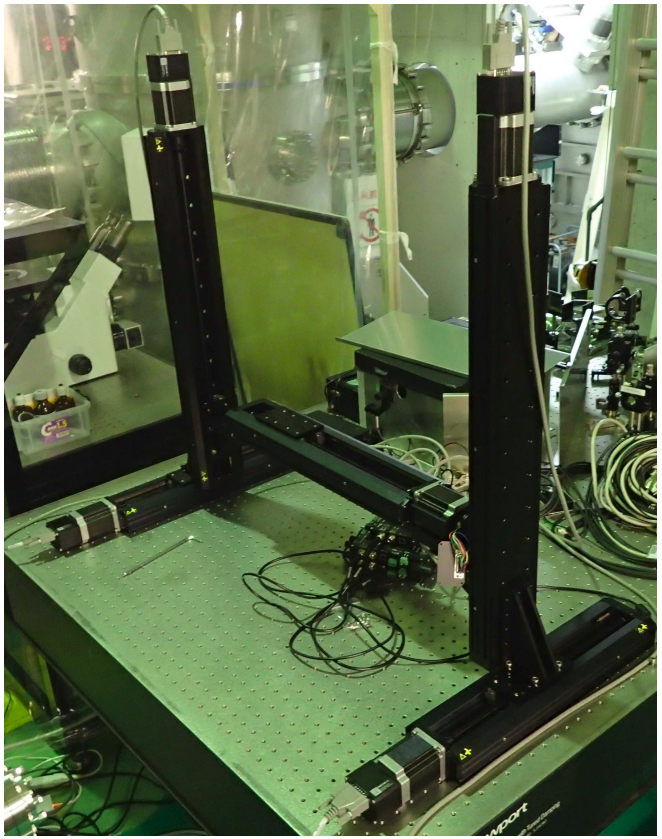
Looking for good sapphire:
- Need to be <50ppm/cm
- Need to be homogeneous



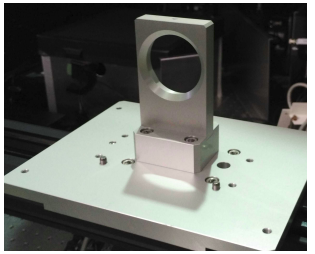
The material of this sample is not homogeneous:
range from 30 to 240 ppm/cm

Next upgrades of the absorption measurement system

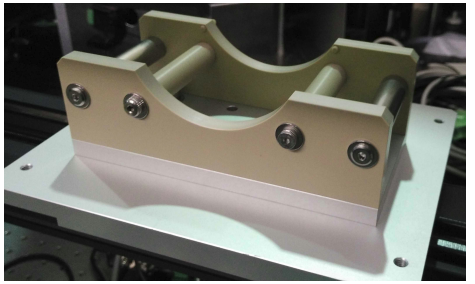
- Install a large translation stage to measure bigger mirrors



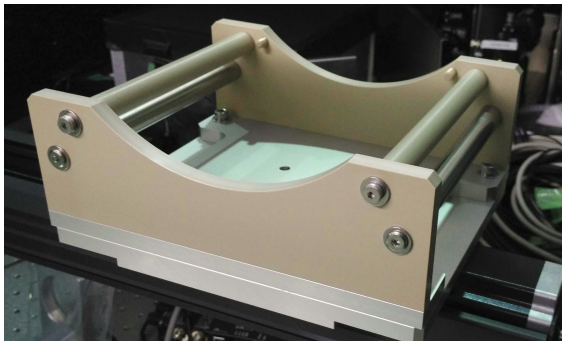
- Install different mounts for different sizes



- 1 to 2 inches



- Ø100mm x 60mm (Tama300 size)



- Ø220mm x 150mm (KAGRA size)

- Install a 1310 nm laser probe to measure GaAs samples

Conclusions:

- The absorption system works fine,
  with a sensitivity better than 1ppm/cm.
- We measured the absorption scan and maps of small silica and sapphire samples.
- By using the simulation we calculated the calibration correction factor between GaAs substrates and AlGaAs crystalline coated samples.
- We will install 1310nm laser probe to measure GaAs samples
- We will install large translation stage to measure the absorption of KAGRA mirrors

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KAGRA

Thank you for the attention

東京大学
THE UNIVERSITY OF TOKYO