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

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

Photo-thermal Common-path Interferometer

Probe laser (200μm)

Pump laser (70μm)

Sample

High Power Meter

Photo Detector

Lenses

Diaphragm

modulated thermal bump

probe pump

perturbation

fringe pattern
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 abs=116%/cm at 1064 nm](#)

**Calibration factor:**
\[ R = 11 \text{ W}^{-1} \]
Power used: 30mW
Repeatability = 10%

BULK Reference sample:
Schott glass NG-12
Silica substrate
Known absorption: **116%/cm** at 1064 nm

**Calibration factor:**
\[ R = 0.5 \text{ W}^{-1} \]
Power used: 30mW
Repeatability = 5%

- 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

SILICA: Temperature Distribution (K)

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

\[ E(x, y) = E_0(x, y)e^{ikOPL(x,y)} \]

FFT code:
- Propagation up to detector distance
Reference samples simulation and measurements

**MEASUREMENTS**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Bulk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.068\pm0.008$</td>
<td>$0.0175\pm0.001$</td>
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</table>

**SIMULATIONS**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Bulk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.022\pm0.005$</td>
<td>$0.0051\pm0.0005$</td>
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- 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

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Simulations</th>
</tr>
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<tbody>
<tr>
<td>$3.9\pm0.7$</td>
<td>$4.4\pm1.4$</td>
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Crystalline coating absorption

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

- 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

**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
Thank you for the attention