ELiTES WP2 + ET R&D WG3 Telecon (15.09.2014)

Attendees:
Julius Komma, Gerd Hofmann, Rene Glaser, Christian Schwarz, Marielle v. Veggel, Ross Birney, Angus Bell, Peter Murray, Stuart Reid, Iain Martin, Karen Haughian, Jessica Steinlechner, Rebecca Douglas, Kentaro Somiya, Dan Chen, Kazuhiro Yamamoto, Geppo Cagnoli, Jerome Degalaix, Harald Lück, Alexander Khalaidovski, Michele Punturo, Ronny Nawrodt

Minutes (by C. Schwarz, R. Nawrodt):
- introduction by R. Nawrodt (see slides)
- individual group reports:

FSU

J. Komma:

- basics on optical absorption (see slides 1-4)
- recent measurement data (minimum in the absorption @ 100K, high absorption @ low temperatures
- number of free carriers explains absorption at temperatures up to 80K (slide 5)
- at temperatures above 80K a significant deviation of theoretically derived data and experimental data has been seen

Questions:

H. Lueck: How to measure mobility?

We will use Hall measurements for a first try. There are several types of mobility defined and we need to see which one agrees best with the measured data.

R. Glaser:

- birefringence imaging setup in Jena
- introduction to the data analysis theory (Stokes vector – see slides)
- first results on birefringence introduced due to mechanical stress and gravity related loads

Questions:

H. Lueck: Current sensitivity limit?

This is the next step. The investigations just started and so far the setup has been developed and characterized.

C. Schwarz:

- current status of high thermal conductivity measurements in Jena (see slides)
- steady-state method to derive the thermal conductivity is not applicable at thermal conductivities above ~10000 W/m/K due to sensor calibration issues

Questions:

G. Cagnoli: Is it possible to avoid these problems by relative temperature measurements?

Glasgow

M. v. Veggel / I. W. Martin:

- strength tests of HCB bonded sapphire and silicon have been performed
- influence of the crystal cut can be seen
- currently testing the influence of curing time (after joining the samples) and thermal cycling of bonded samples
- thermal conductivity measurements on bonded samples down to 77 K reveal bulk values
- indium bond loss seems to be a factor of 100 smaller at 20 K than the HCB loss
- currently testing the HCB loss of joined sapphire parts
- orientation tests for a proper alignment of sapphire crystals in progress
- results on silica/ tantala coated sapphire discs reveal no dissipation peak at low temperatures
- dynamic and static fibre breaking test reveal loads well above the requirements of KAGRA
- homogeneity tests of the absorption in silicon show slightly higher absorptions at the crystal surface

ICRR

D. Chen & G. Hofmann:

- shows cryogenic s sapphire suspension design (and where to use indium)
- mechanical loss measurements on indium bonded sapphire sample (setup description) + how to estimate the intrinsic loss influence
- how will the derived bond loss influence the thermal noise of KAGRA

Questions:

How close are the loss values measured on the bonded samples to the intrinsic loss of indium?

K. Yamamoto:

- near future plan for KAGRA activities
- D. Chen and Y. Sakakibara have to hand in their thesis before Christmas this year and leave around march next year
- setups at ICRR are in use for the next month, after that available for further experiments

Sannio

Innocenzo could not attend the telecom as he was traveling. He provided additional slides with the status of his group. The slides are attached to the minutes.

– Harald will contact the relevant ET R&D people for the mid-term reports.
– The next telecom is scheduled for the **13th October at 10:00 CEST**. Please check if you are available. The next telecon will focus on coating issues (ELiTES deliverable) and status reports of the different groups.

Status Telecon WP2, WG3

ELiTES, ET R&D

15/09/2014

Content

- overview
- reports of individual groups

- AOB ELiTES + ET R&D: ET Symposium, ELiTES annual meeting, mid-term reports in ET R&D

- next telecon

Reminder: Project Background

ELiTES

- exchange program between Europe and Japan
- funding of secondments to Japan

- aim: combine expertise from ET + KAGRA side

ET R&D

- small R&D program of selected European countries (depends on funding of individual nation)
- supports smaller R&D projects in different countries

Reminder: Groups involved

ELiTES

- U Tokyo, Tokyo Tech, KEK
- EGO, University of Rome, Jena, Glasgow, Nikhef, AEI Hannover, Benevento, UWS

ET R&D (full partners)

- Nikhef
- Hannover, Jena
- Birmingham, Glasgow, Cardiff, UWS
- Russian ET Consortium
- Polish ET Consortium

Reminder: relevant WPs

ELiTES

- WP2 „Mirror thermal noise and cryogenics“
- Jena, Glasgow, Rome, Sannio, Tokyo, UWS

ET R&D

- WG3 „Optical properties of silicon at cryogenic temperatures“
- Jena, Hannover, Glasgow, LMA, Russian Consortium, UWS

Reminder: tasks

ELiTES

1. Properties of test mass materials
2. Properties and optimization of mirror coatings
3. Thermal and mechanical properties of suspension elemenets
4. Report on mirrors for filter cavities

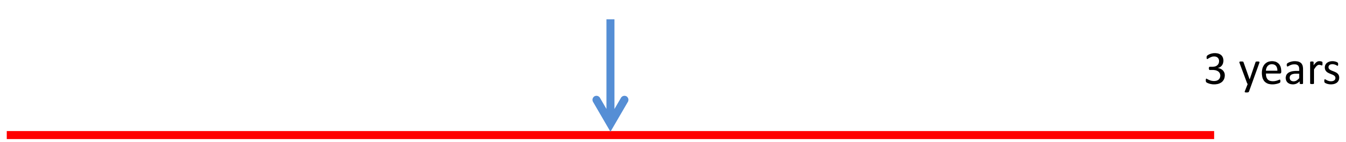
ET R&D

1. Stress induced birefringence
2. Homogeneity of optical properties
3. Surface quality of Si samples
4. Whispering Gallery Mode Resonators to probe optical absorption

Reminder: tasks

ELiTES

ET R&D



Reports of the individual groups

The individual reports are attached at the end.

AOB ELiTES and ET R&D

- ET Symposium, 19th-20th Nov 2014, Lyon
- ELiTES annual meeting, Feb 2015, Tokyo
- mid-term reports in ET R&D

Next telecon

- proposal: 13th October (in 4 weeks) at the same time
- ~4 weeks later: ET Symposium
- after that: new time slot needed

Optical absorption of silicon

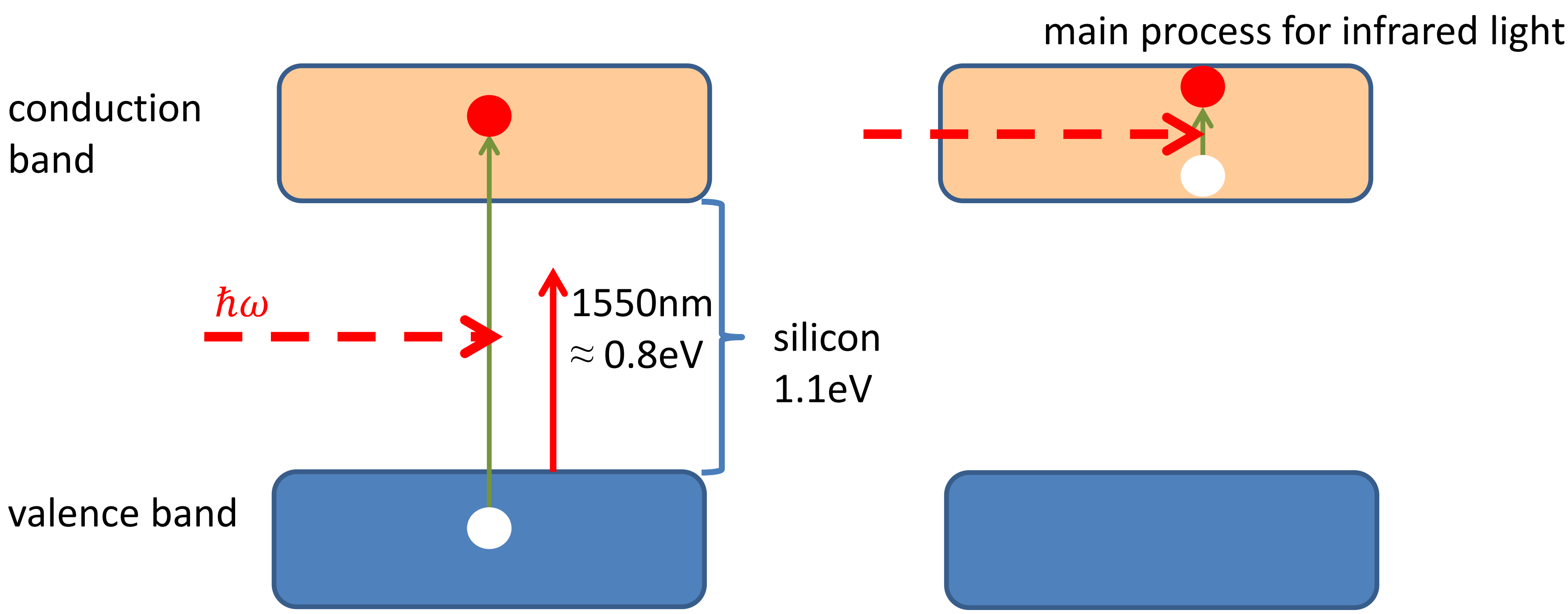
Julius Komma, Daniel Heinert, Ronny Nawrodt (FSU Jena)
Jerome Degallaix (LMA)
Angus Bell, Jessica Steinlechner, Iain Martin (U Glasgow)

15.09.2014

ET optics and thermal noise call

(ELiTES WP2, ET R&D WG3)

Absorption processes inside a semiconductor



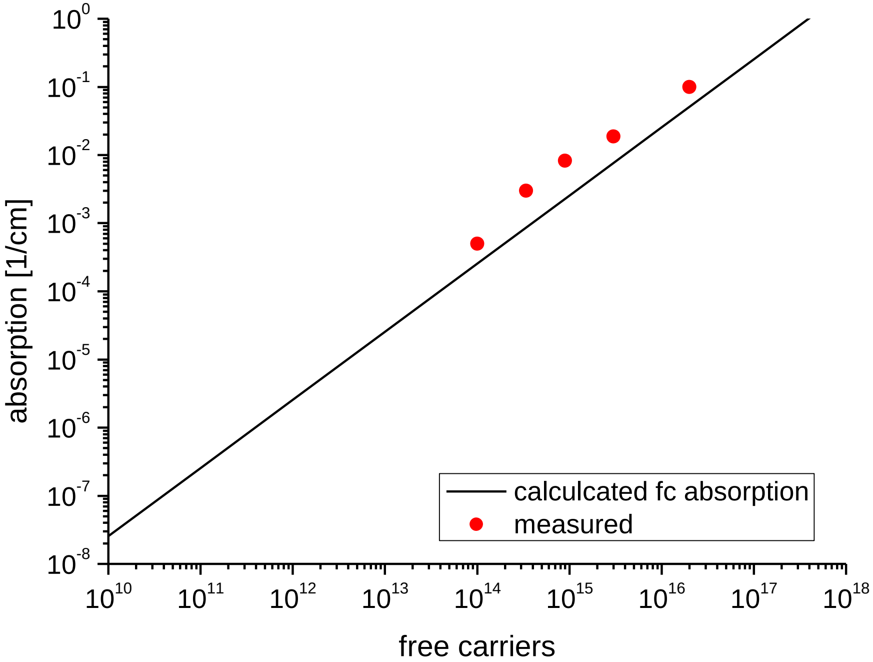
inter band absorption
(band-band abs.)

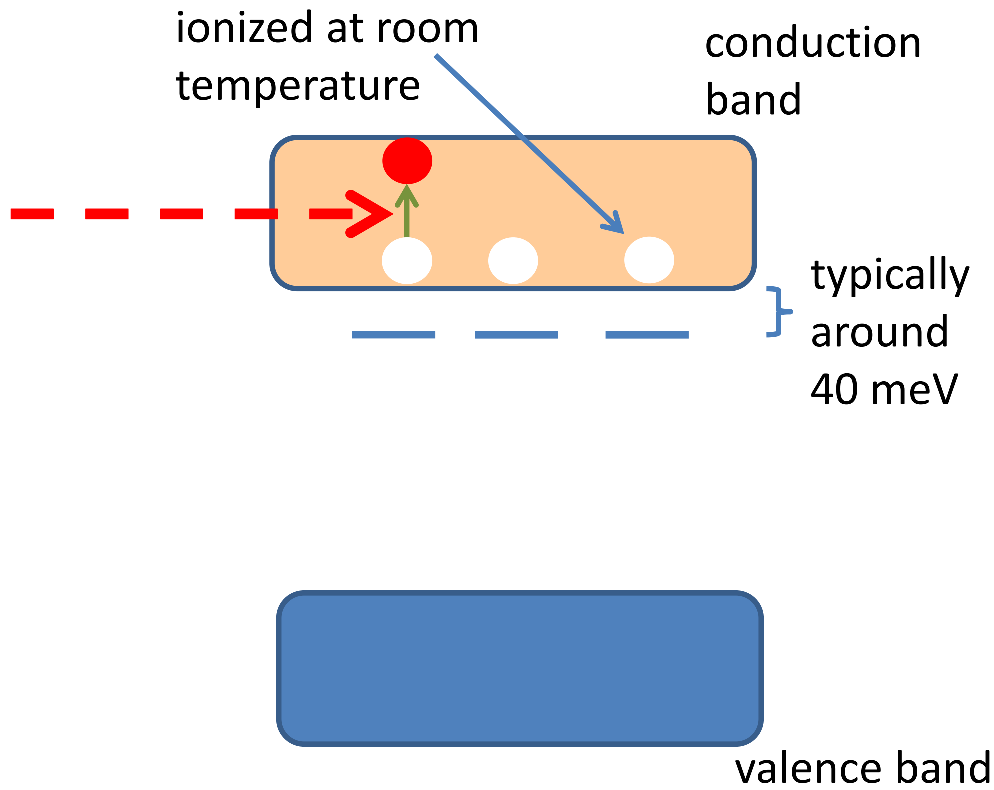
intra band absorption
(free carrier abs.)

$$\alpha_{fc} \sim N$$
$$\alpha_{fc} \sim \lambda^2$$

→ high transmission @1550 nm
→ low absorption

Free carrier absorption (@ 300 K)

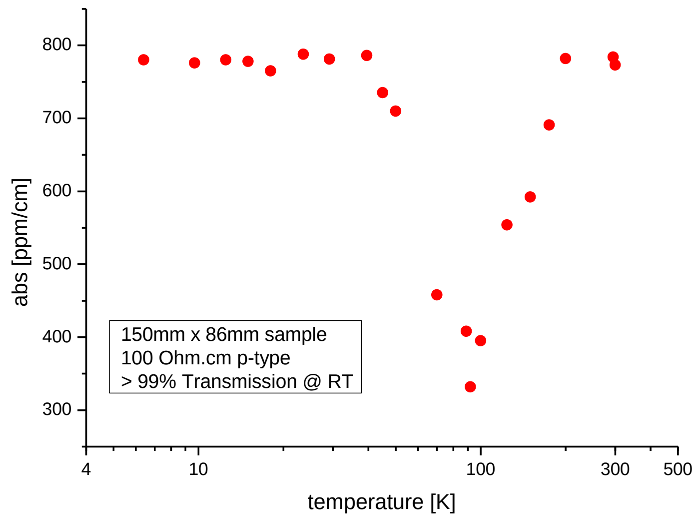


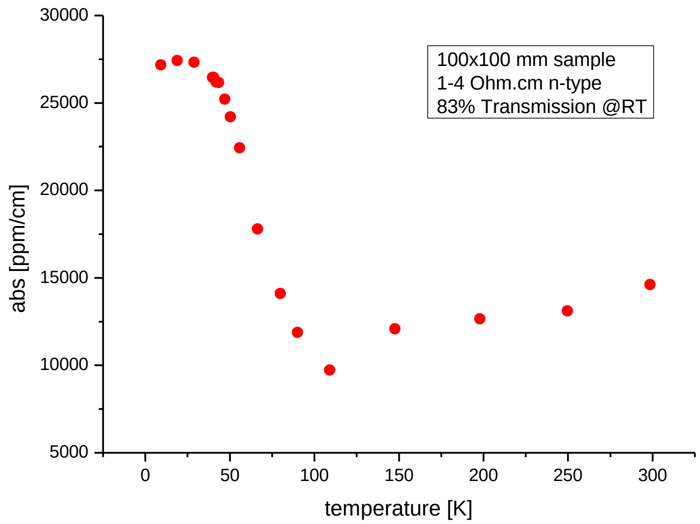


intra band absorption
(free carrier abs.)

$$\alpha_{fc} \sim N$$
$$\alpha_{fc} \sim \lambda^2$$

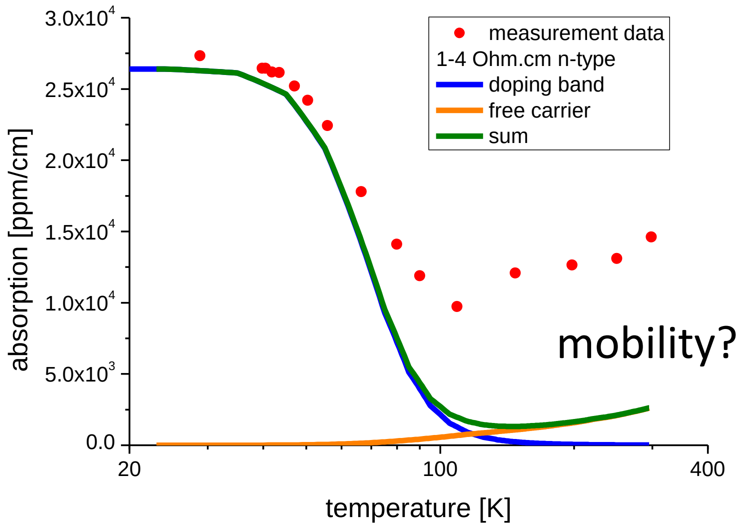
Temperature depended absorption





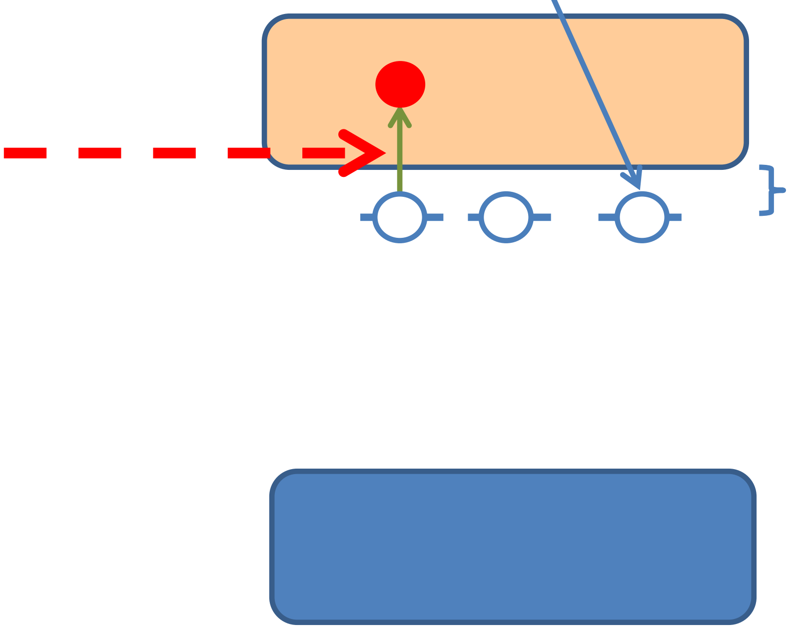
- Decreasing absorption for cooling a silicon sample , followed by an increase for low temperatures is observed at Glasgow, LMA and Jena
- Measured with different setups (Calorimetric, Deflection and Transmission)

Explanation for the minimum?



carrier freeze out at low temperatures

conduction band



typically around 40 meV

valence band

absorption from the doping states into the conduction band

- free carrier freeze out:
  → population of the doping states
  → absorption from the doping states into the conduction band rises

Status on the Thermal Conductivity Measurements on Diffusion bonded Sapphire

C. Schwarz, B. Walter, R. Nawrodt, Uni Jena
D. Chen, K. Yamamoto, Uni Tokyo
T. Tomaru, KEK Tsukuba

Experimental setup to test the thermal conductivity of diffusion bonded sapphire

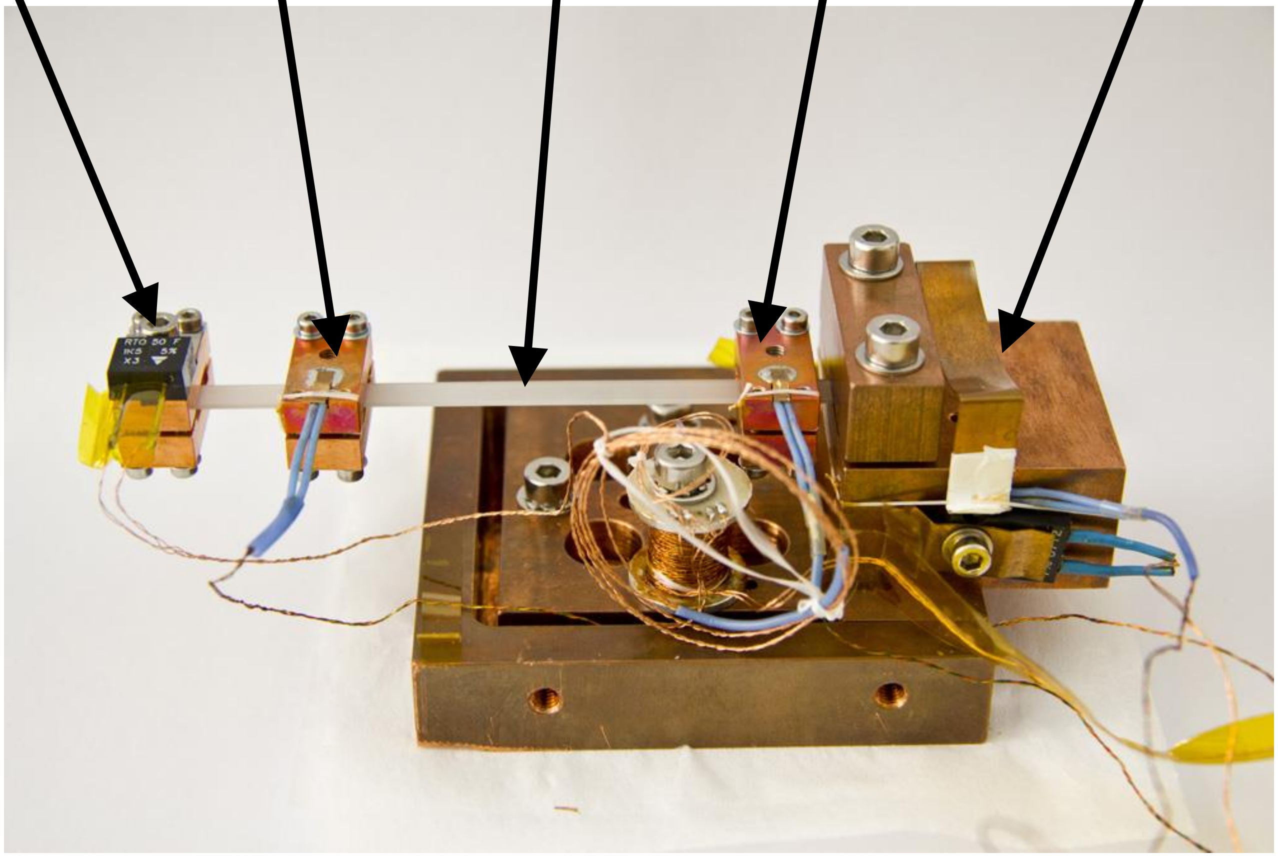
Sample Heater

Temperature Sensor 1

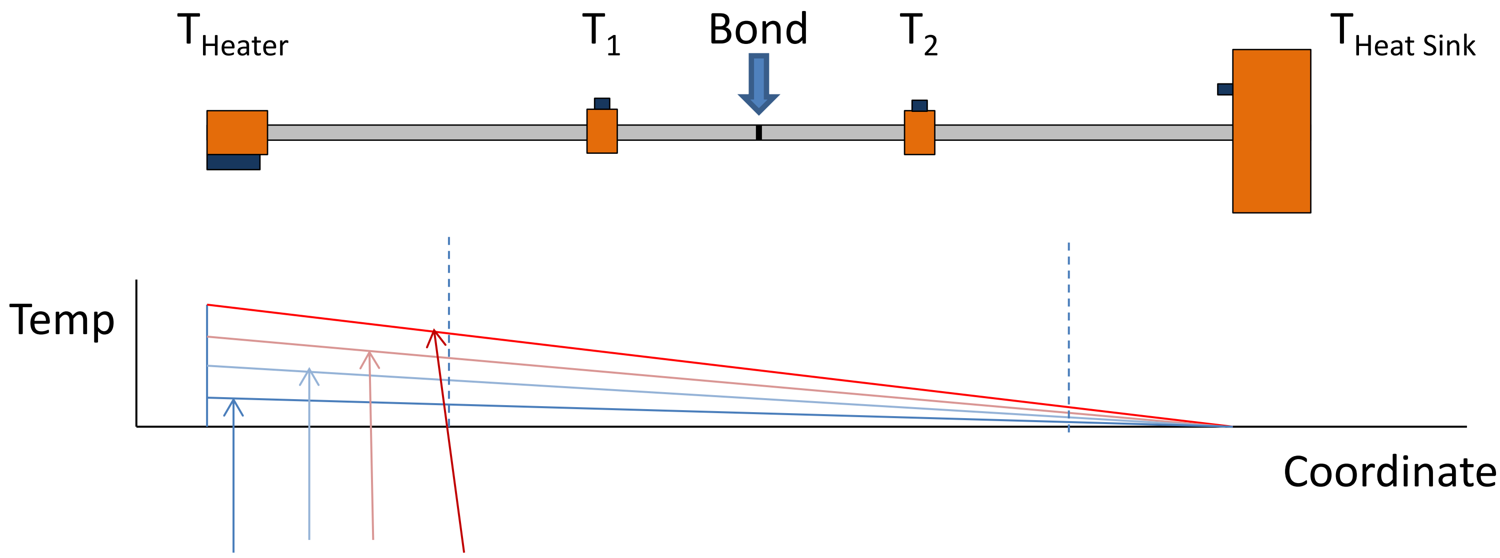
Sample

Temperature Sensor 2

Temperature Controlled Heat Sink



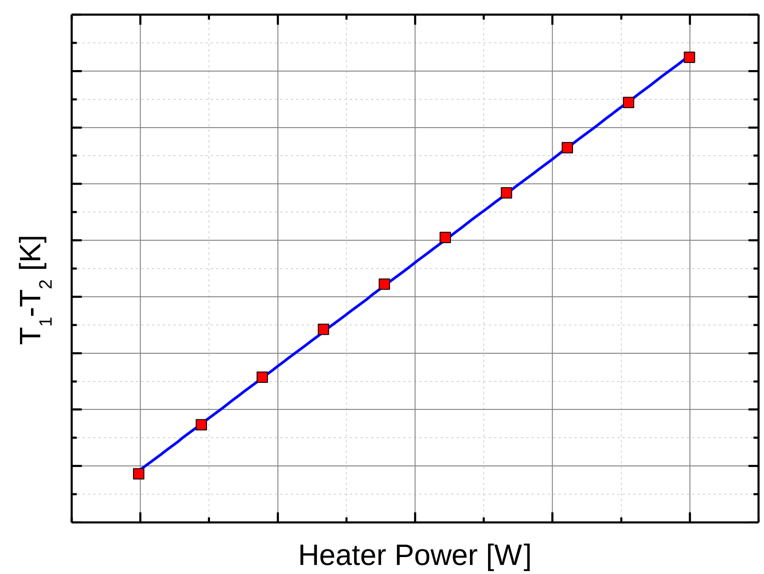
Measurement procedure



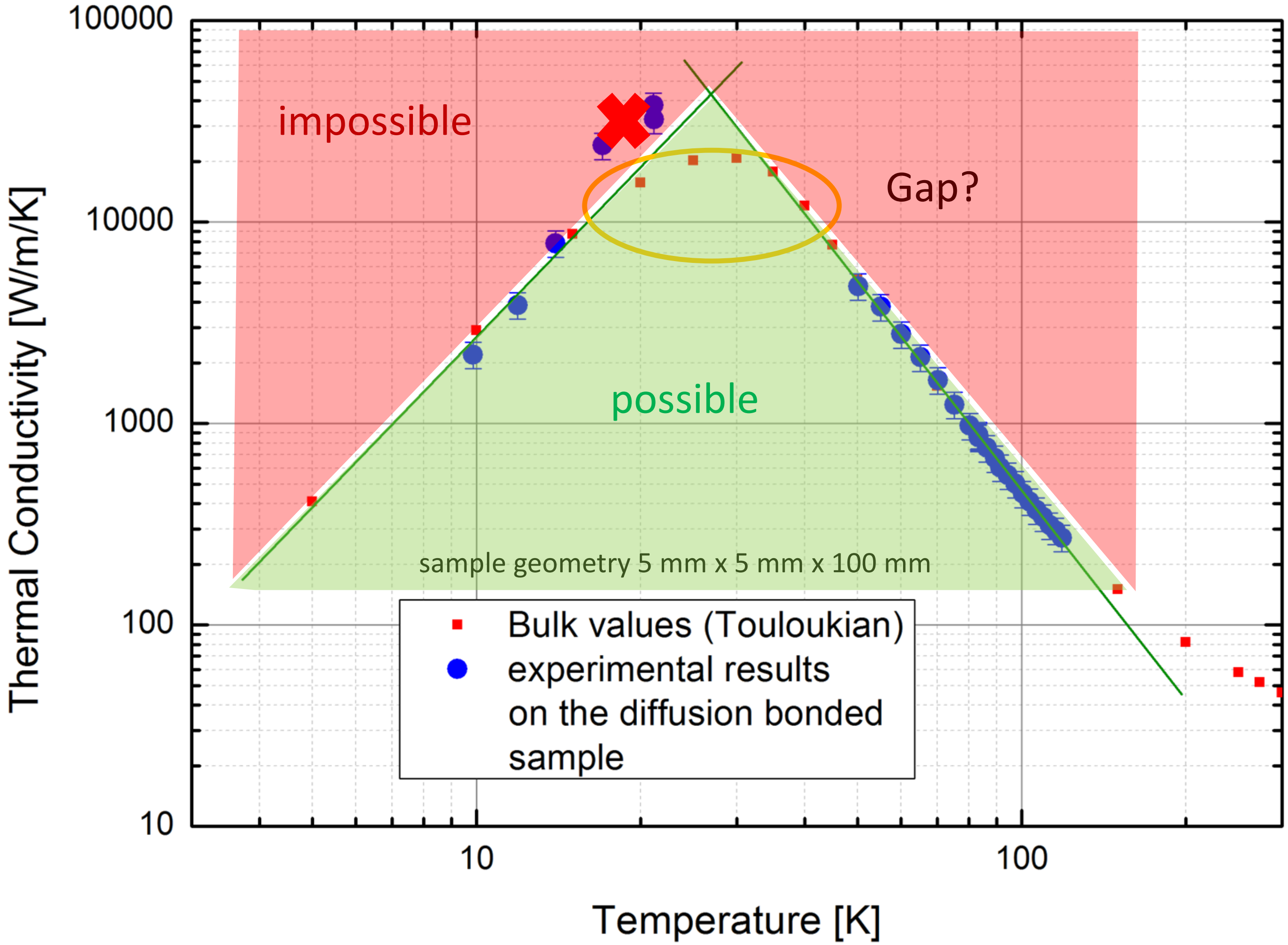
$$P_1 < P_2 < P_3 < P_4$$

$$\Delta T = T_1 - T_2$$

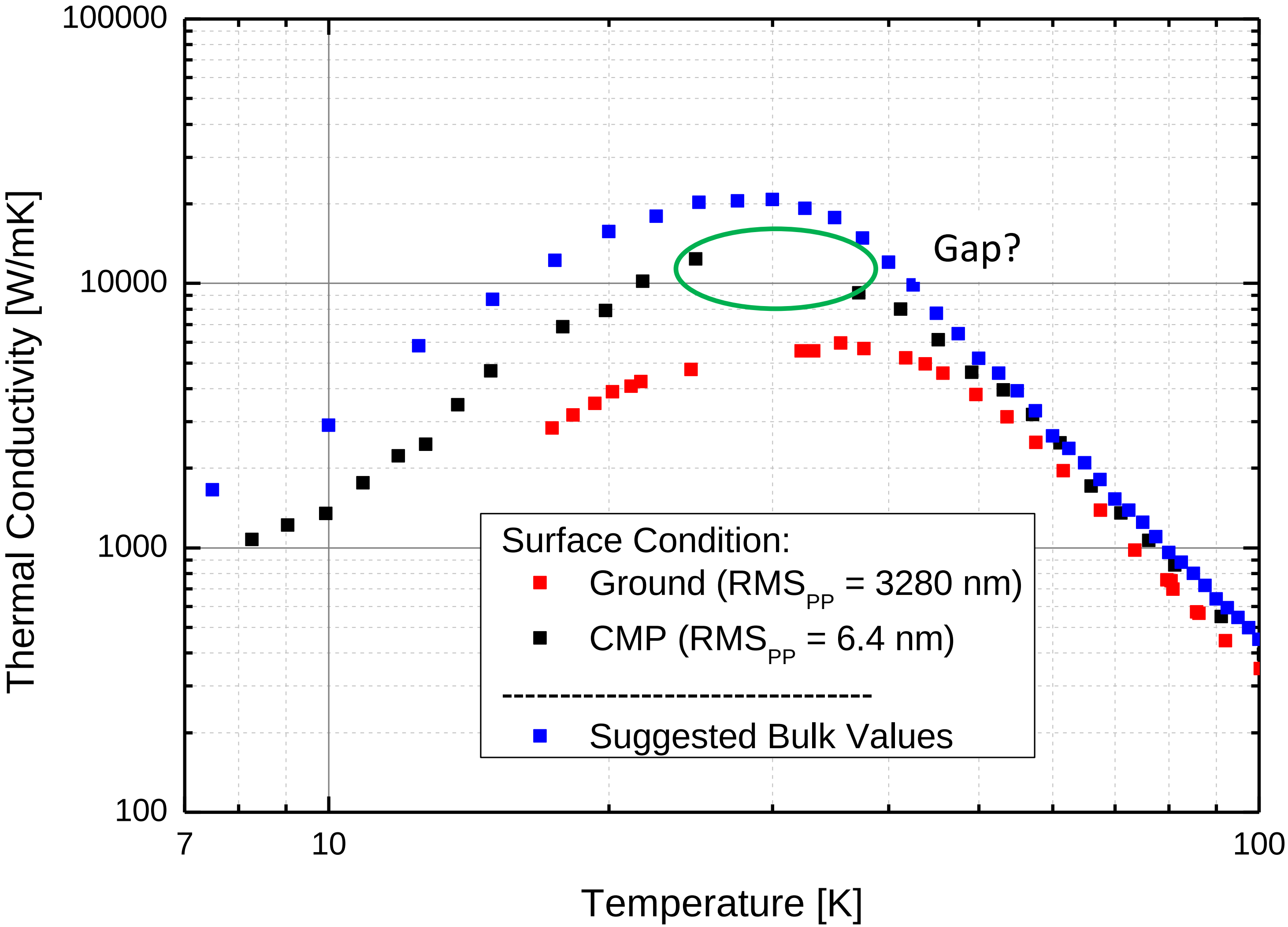
$$\Delta T_1 < \Delta T_2 < \Delta T_3 < \Delta T_4$$



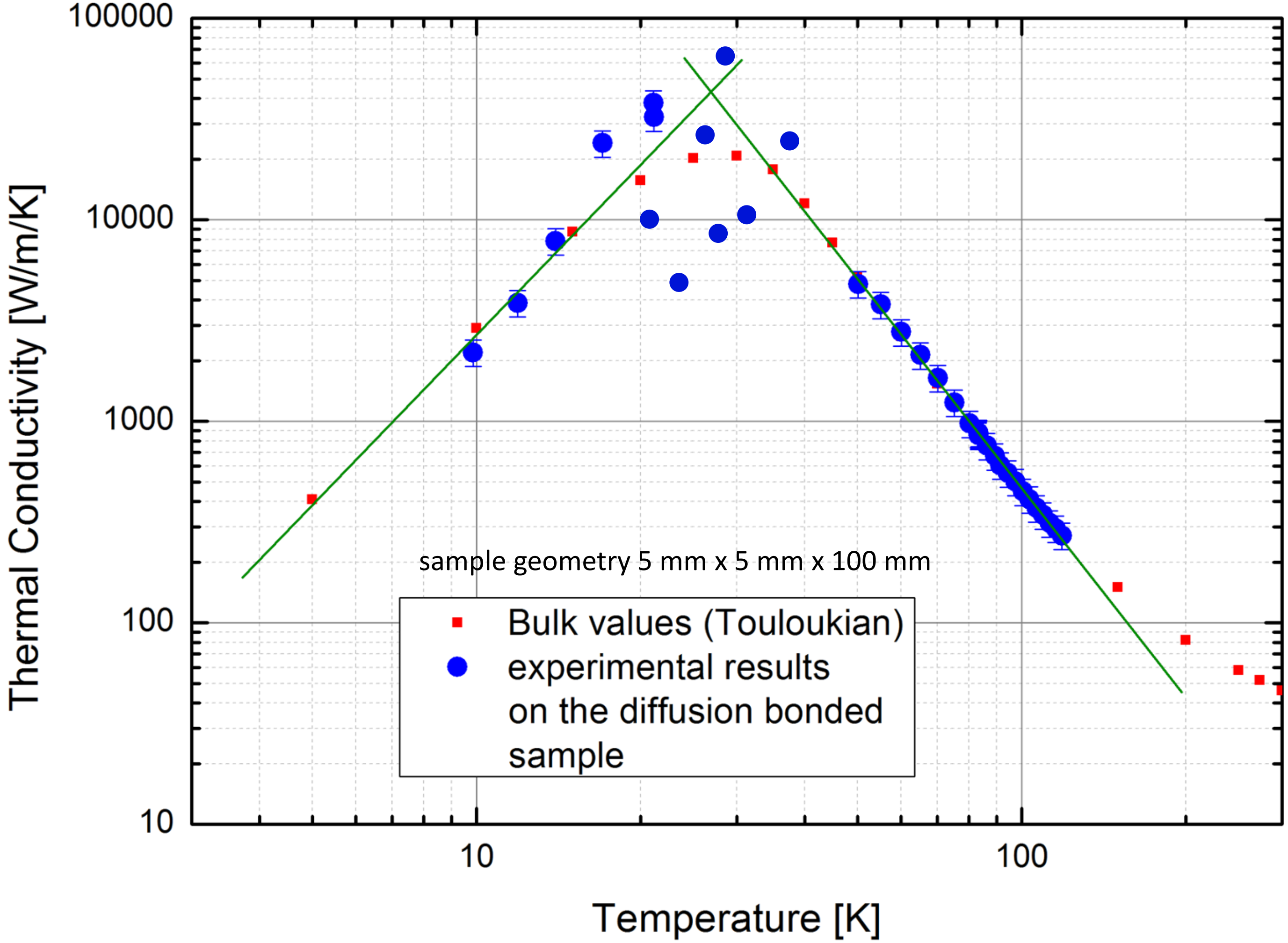
Preliminary results for the thermal conductivity of diffusion bonded sapphire



Results for the thermal conductivity of sapphire ribbons with different mechanical surface treatments



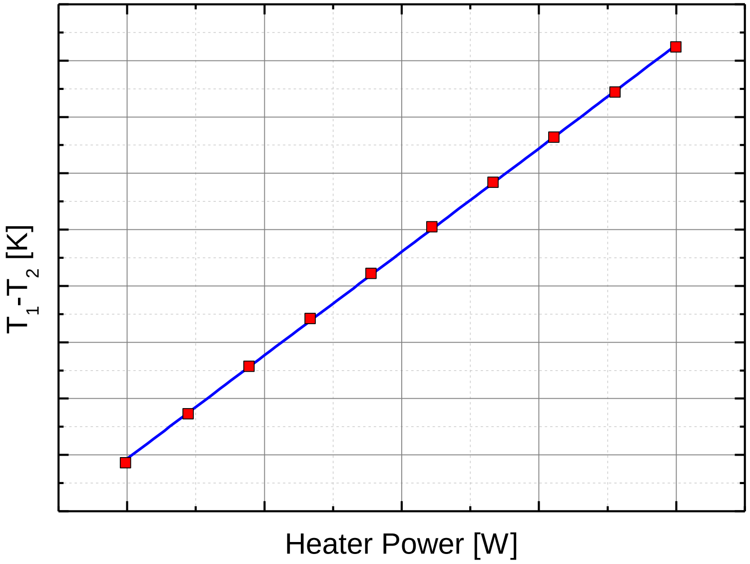
Preliminary results for the thermal conductivity of diffusion bonded sapphire



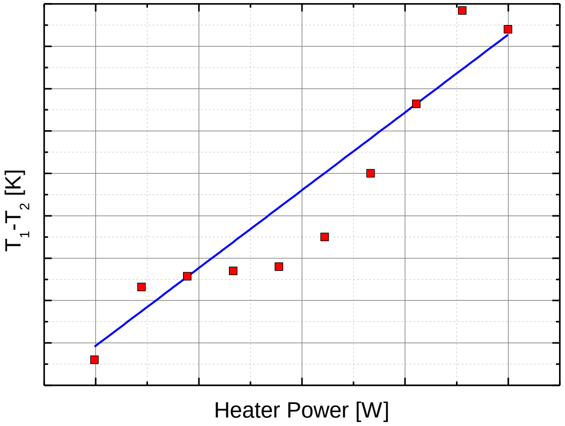
What happened?

Remember how the heater power vs. temperature dependence should look like!

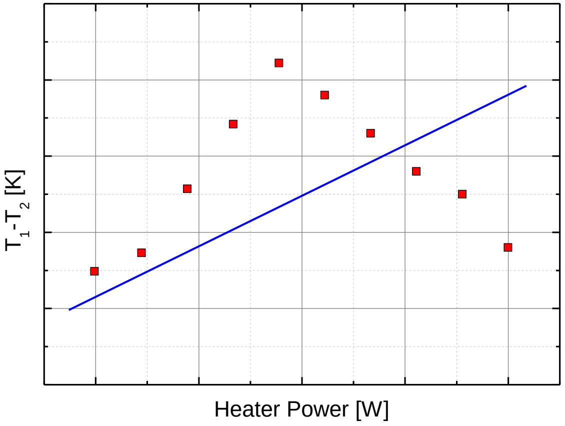
Linear
and ΔT=0K @ P=0W!



data points @ ~ 20K



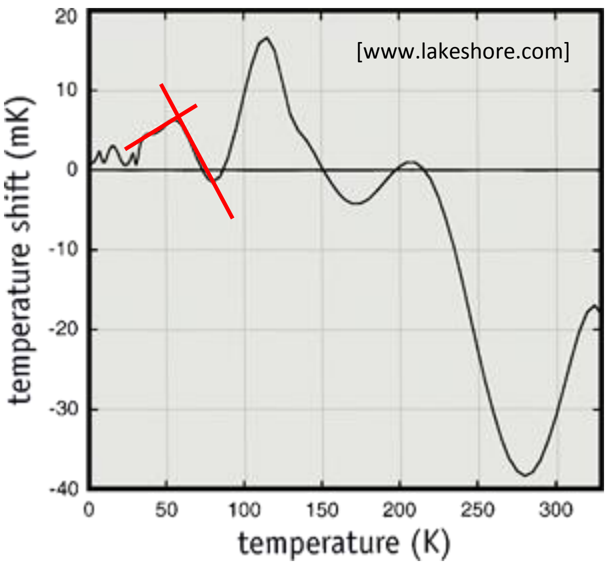
data points @ ~ 29K

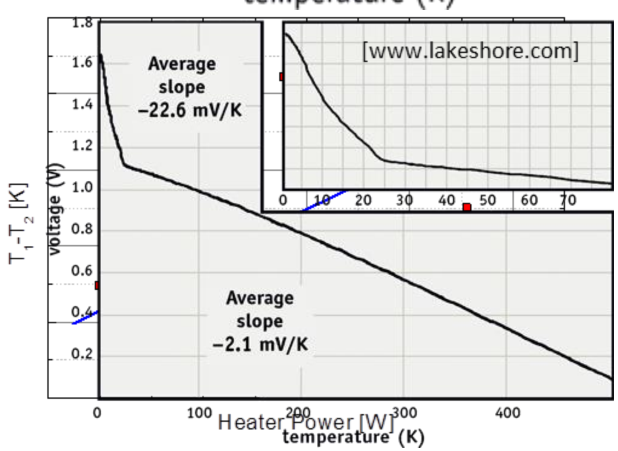


extracted slope is too small/high
⇒ leading to too high/small values for ***kappa***

<u>*What’s the reason for that behavior and how to get rid of it?*</u>

example for the sensor temperature deviation from the manufacturers calibration





How to get rid of it?

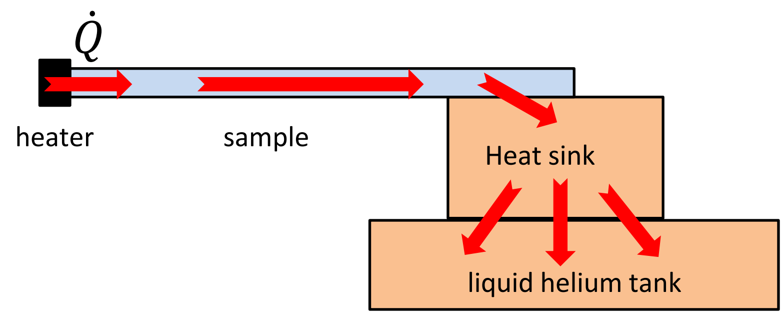
#1:

~~Check for temperature sensors with a different behavior!~~

They behave more or less the same.

#2:

Use (much) more heater power to increase the temperature difference spanning a wider temperature interval!



#1 doesn’t work but what about #2? Does it lead to reliable results?

No, because:

-1-
The temperature difference could be increased by a factor ~10, but still no linear behavior!

-2-
The better the “sample-heat sink“ thermal contact needs to be, the better also the contact “heat sink-helium tank“ needs to be → the more heater power at the heat sink is necessary to keep the experiment at a constant temperature above 4.2 K → difficult to extract that much heat into liquid helium without boiling off all at ones

We need a different method to measure thermal conductivities exceeding ~13000 W/m/K!

Measuring Polarization Using a Rotating Quarter Wave Plate

Stokes vector for describing polarization state of incident light:

$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

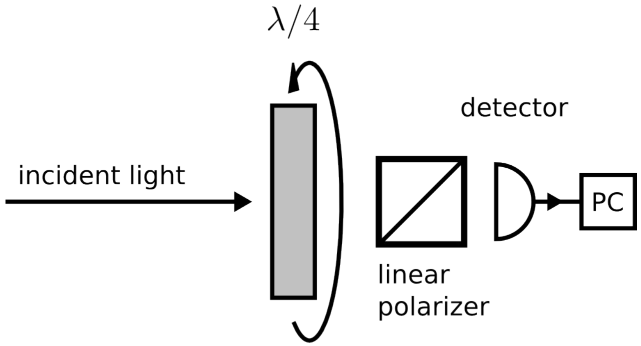
S_0 total intensity

S_1 part of horizontally and vertically linear polarized light

S_2 part of ±45° linear polarized light

S_3 part of right and left circular polarized light

Schematic of the setup:



$$I(\varphi) = \frac{1}{2}\left(\left(S_0 + \frac{1}{2}S_1\right) + S_3 \sin(2\varphi) + \frac{1}{2}S_1 \cos(4\varphi) + \frac{1}{2}S_2 \sin(4\varphi)\right)$$

seit 1558

Actual setup:

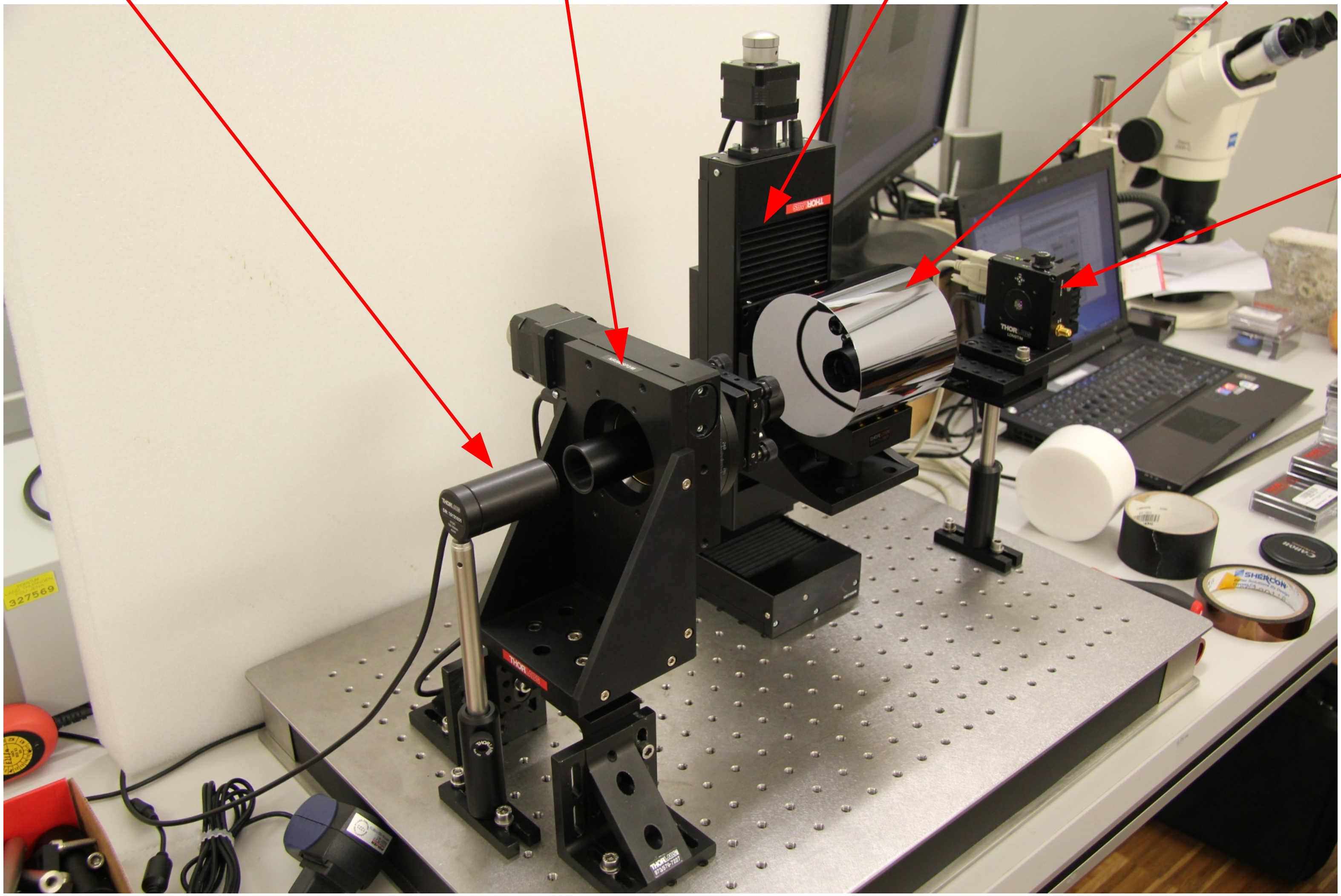
quarter wave plate and motorized rotator

linear polarizer and detector

motorized linear stages

sample

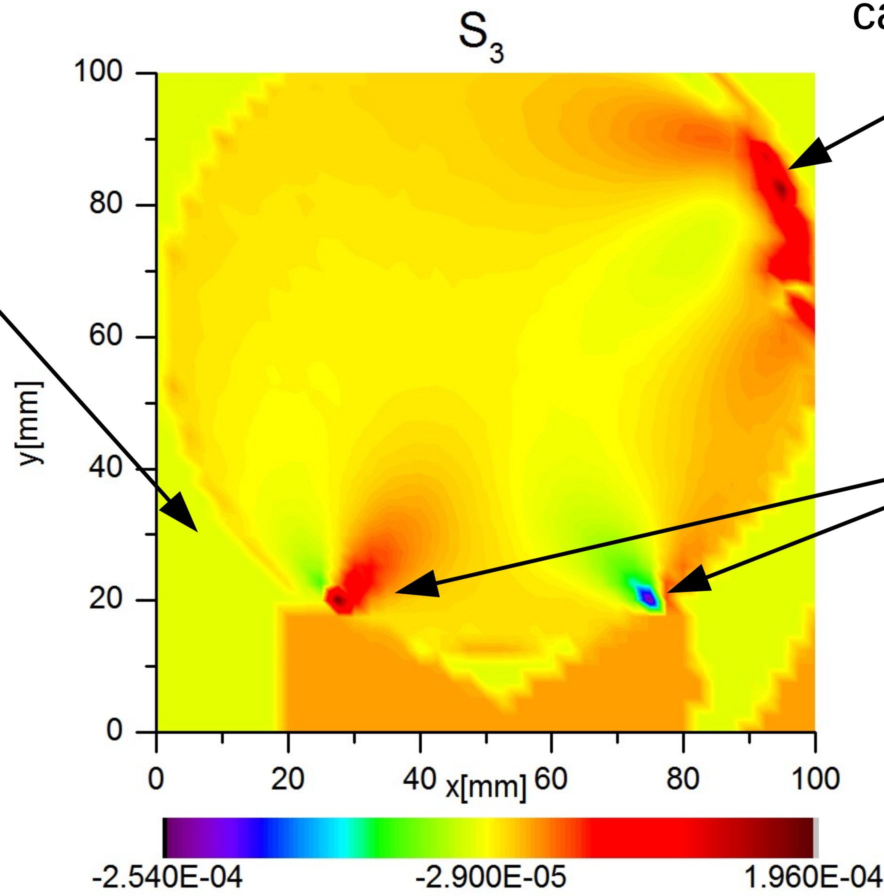
Laser



Sample diagram for fourth stokes parameter

additional circular polarization
caused by intrinsic stress

almost no circular
light in source



additional circular part
caused by stress at support

Elites WP2

• Assessment of the properties and suitability of silicate bonding for bonding sapphire, and comparison with the properties of bonded silicon, to develop techniques for constructing sapphire suspensions for use in LCGT and as a possible alternate suspension material for use in ET

• Investigation of the mechanical loss in both silicon and sapphire bulk materials

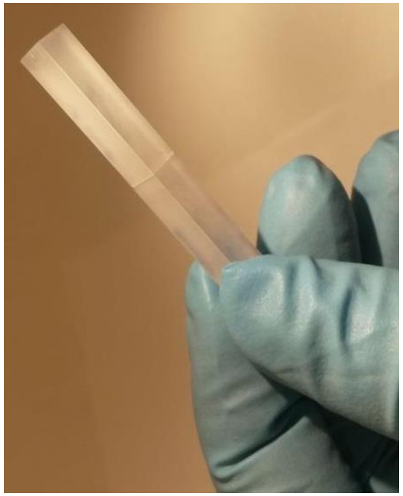
Strength of hydroxide catalysis bonds of sapphire and silicon

What we know:

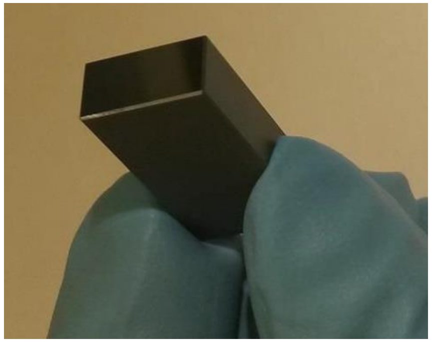
- Hydroxide catalysis bonds between sapphire and silicon are strong, also at 77 K
- Some dependence of strength on crystal orientation for both
  - Paper in preparation
- Samples are re-bondable though with some reduction in strength
  - Paper in preparation

Currently investigating:

- Curing time for sapphire bonds (chemistry is slightly different for sapphire bonds).
  - 2 of 4 sets of 10 bonds have been made. Another set in 1 week, 4th set in 5 weeks. Curing for 4, 8, 12 and 16 weeks. Strength testing all at RT in 9 weeks.
- Influence of thermal cycling on strength
  - Silicon samples in preparation in Glasgow (oxidation ongoing, plan to do thermal cycling in Jena).
  - Sapphire samples in Tokyo.



Bonded sapphire sample
5x5x40 mm
c-axis $\perp$ bonding surface



Oxidised silicon sample
10x5x20 mm
Boron doped P-type <100>
150 nm dry thermal oxide

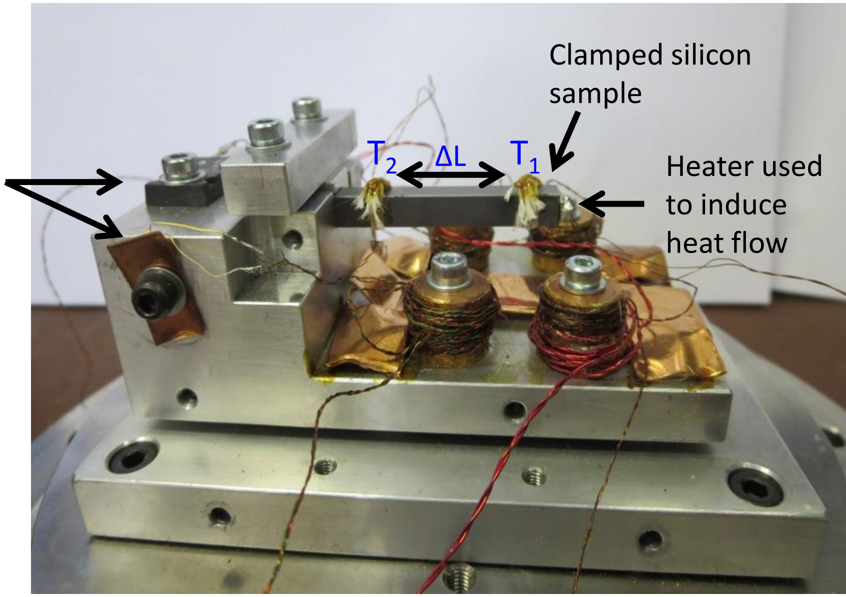
Thermal conductivity

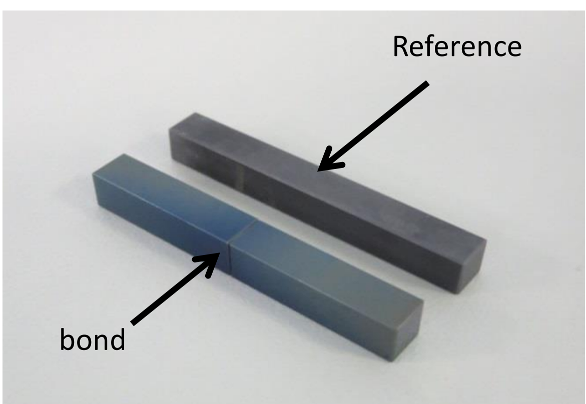
Goal:

Measure thermal conductivity of silicon bonded samples (hydroxide catalysis bonds and indium bonds)

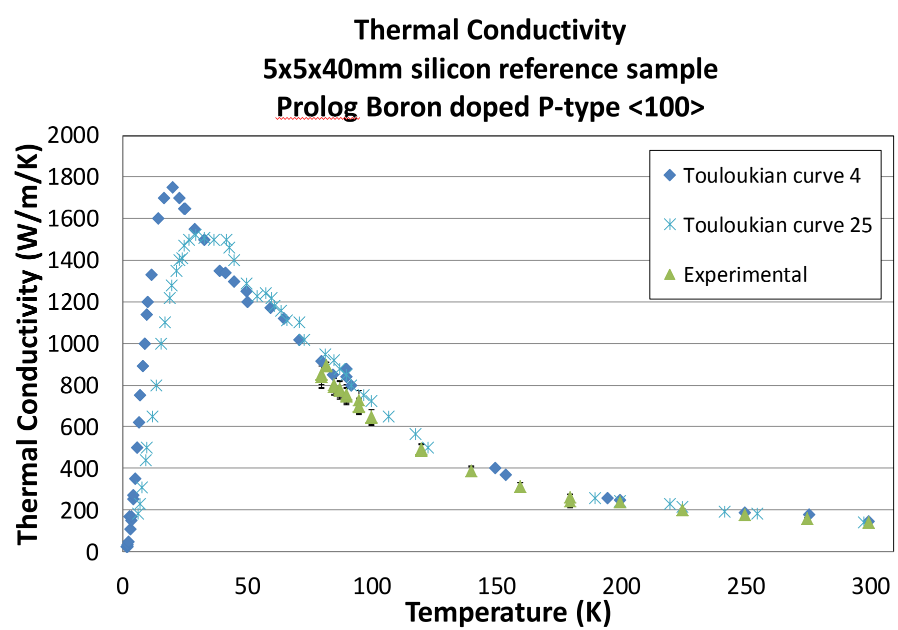
Current status:

- 2 series of measurements on reference sample down to 77 K.
- Measuring hydroxide catalysis bond just now.



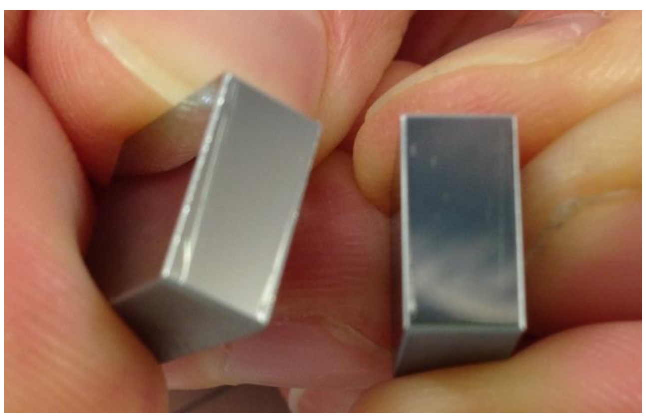


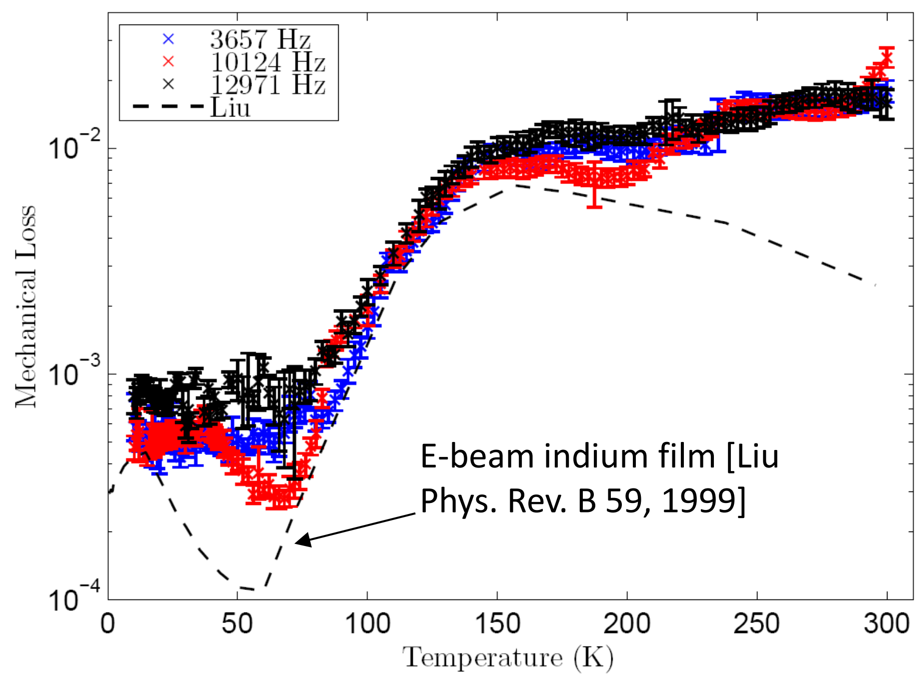
Silicon samples (5x5x40 mm Prolog Boron doped P-type <100>



Indium bonding

- 3 silicon samples and 3 sapphire samples at vendor just now for indium bonding
- We are preparing new vapour deposited indium bonding tests at higher compression loads (total indium layer thickness just 500 nm)
- We have carried out cryogenic mechanical loss measurements of a thermally evaporated indium film
  - At 20 K, loss approximately 100 times lower than a hydroxide catalysis bond between silica pieces at room temperature





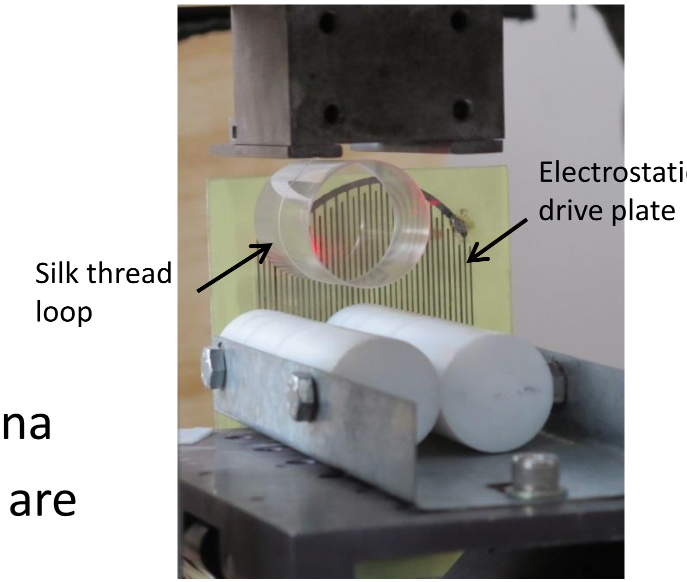
Mechanical loss of sapphire and hydroxide catalysis bonds between sapphire substrates

Goal:

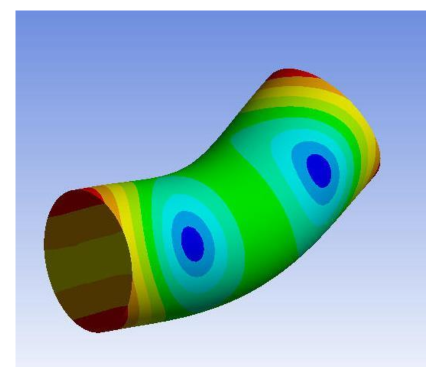
Measure the mechanical loss of a hydroxide-catalysis bond created between two sapphire substrates at cryogenic temperatures

Current status:

- Reference rod has been measured in Jena
- Room temperature loss measurements are being carried out on the two shorter samples to be bonded to check sample quality.
- Orientation measurements have been attempted by PZT excitation and lycopodium. Looking into a different method, possibly x-ray diffraction or crossed polarisers, to accurately orientate the sample to enable proper alignment of the crystal axes when bonding.



Sapphire sample suspended for mechanical loss measurements



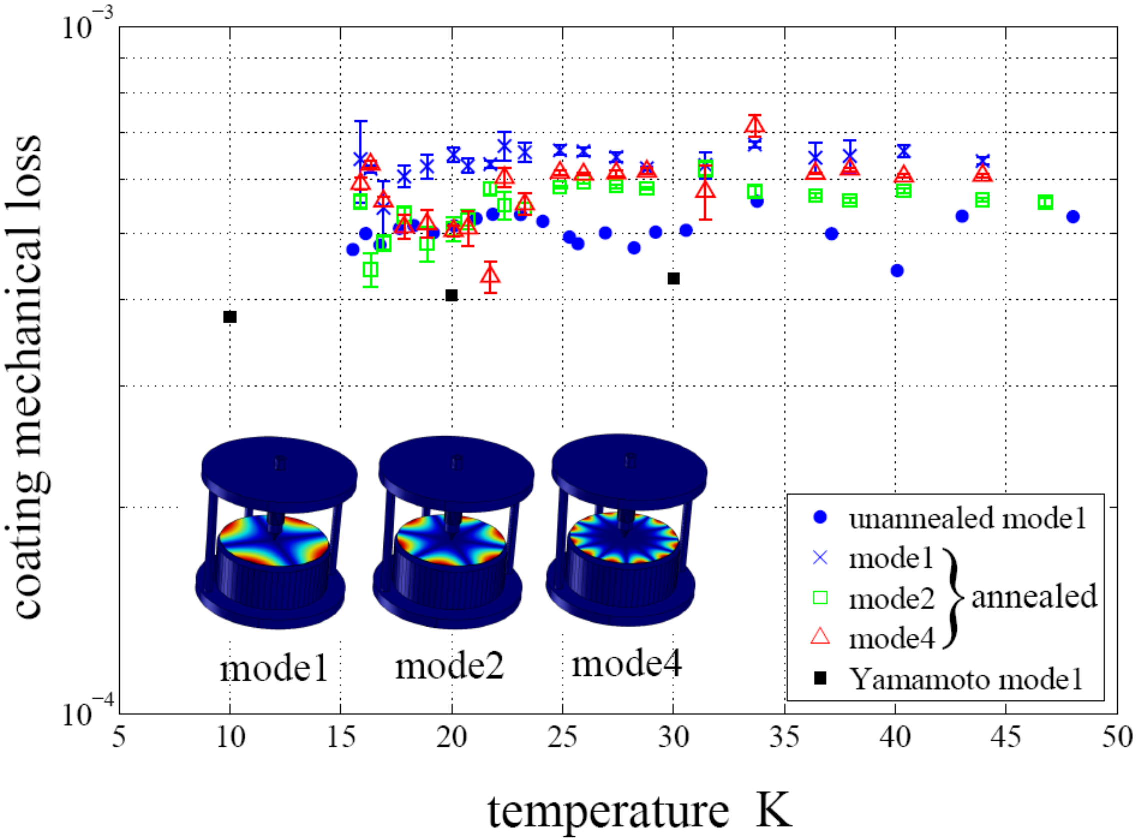
42kHz resonant mode on 30mm diameter, 70mm long sapphire sample

Elites WP2

- Performance of suitable optical coatings on sapphire substrates for the development of the mirrors for LCGT

Loss of silica/tantala mirror coating on sapphire disk

- Measured as-deposited and heat-treated at 500 C for 10 hours



At 20 K:

- Un-annealed:
  - $\Phi_{coating} \sim 5 \times 10^{-4}$
- Annealed:
  - $\Phi_{coating} \sim 6.4 \times 10^{-4}$

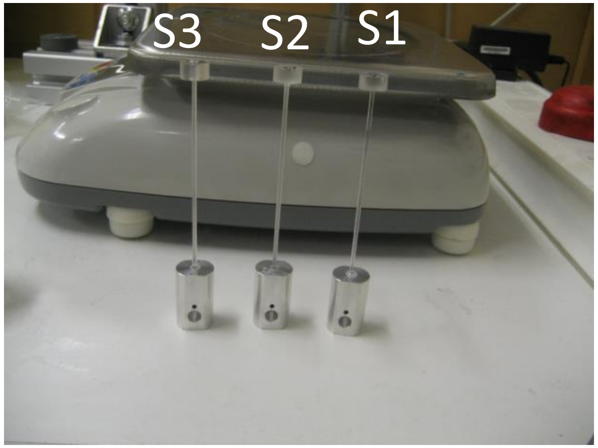
- The mechanical loss was observed to be broadly temperature-independent between 15K and 50 K
- In contrast to some previous measurements, no strong loss peak was observed around 20-30 K. Possibly related to precise heat-treatment temperature?

Elites WP2

- Characterisation of the thermal and mechanical properties of suspension elements (fibres, bond areas, etc.)

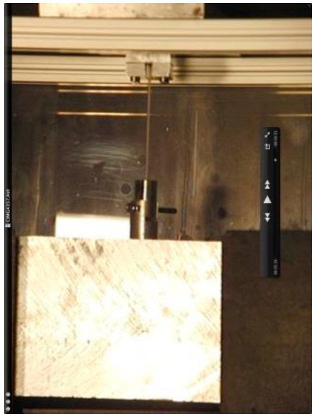
Sapphire Fibre Tests

S1: brazed fibre (technique not specified by IMPEX)
S2: monolithic fibre
S3: brazed fibre (“Heat Exchange Method” with alumina)

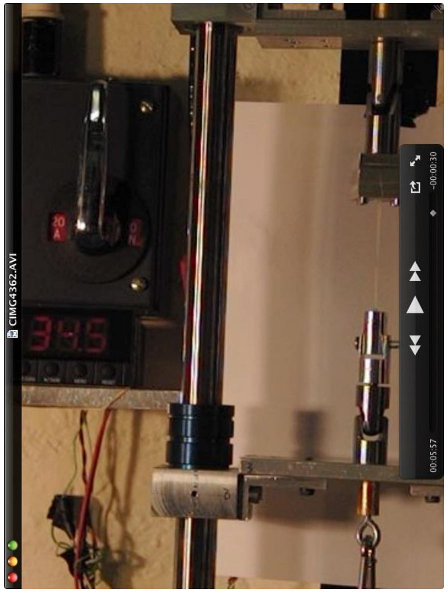


Tensile strength testing

S1 (brazed): 90 kg, without breaking
S2 (monolithic): 56 kg
S3 (HEM): 35.4 kg



Static/Dynamic tests with masses of 6.5 kg and 15 kg
Amplitude 5-7 mm, all fibres OK

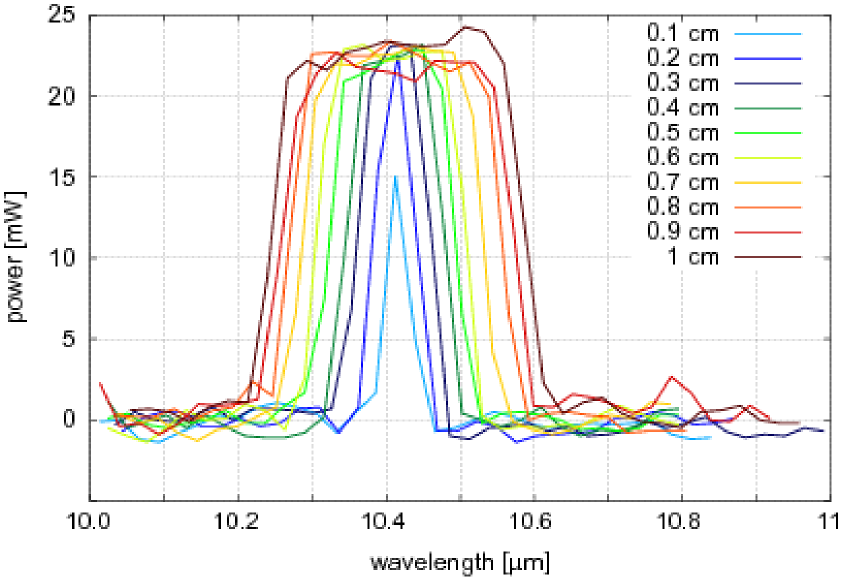


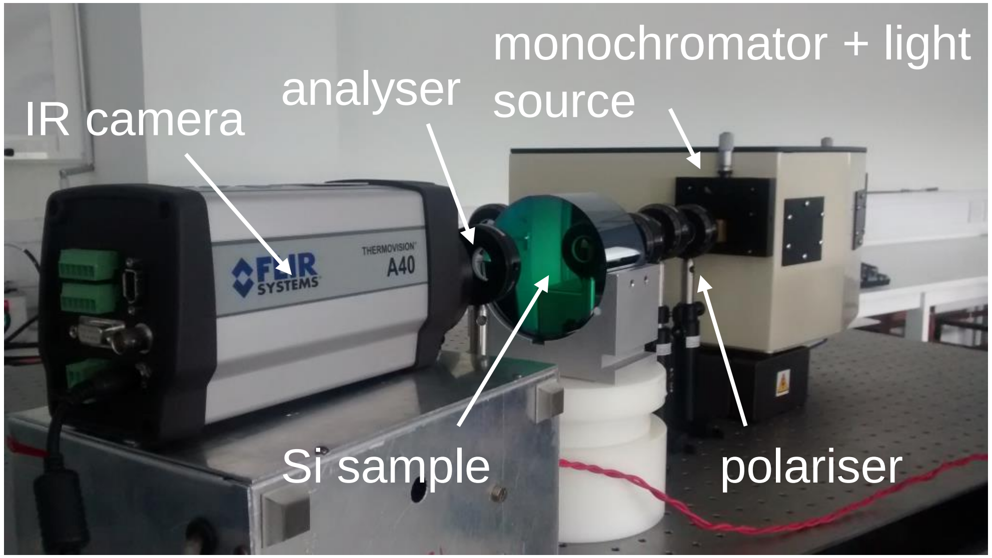
Tensile strength tester

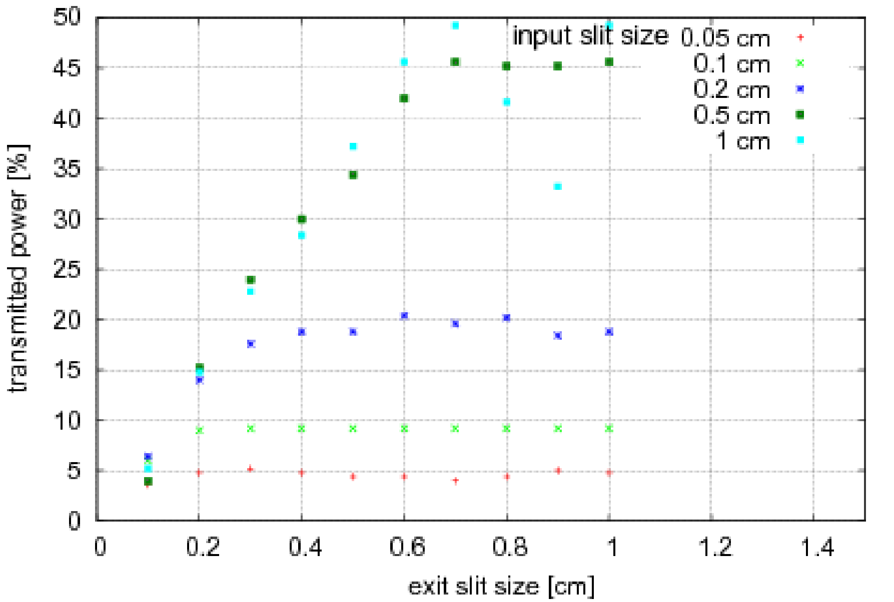
ET R&D WG 3

ET R&D WG 3 – Birefringence

- Polarimeter set up – plan to study stress-induced birefringence in silicon.
  - Including samples stressed by coatings applied at UWS.
- Investigating use of monochromator and suitable lamp to illuminate sample
- Calibration of monochromator using ~10.6 μm laser, suggests can get a 40nm bandwidth with 5% of incident power transmitted



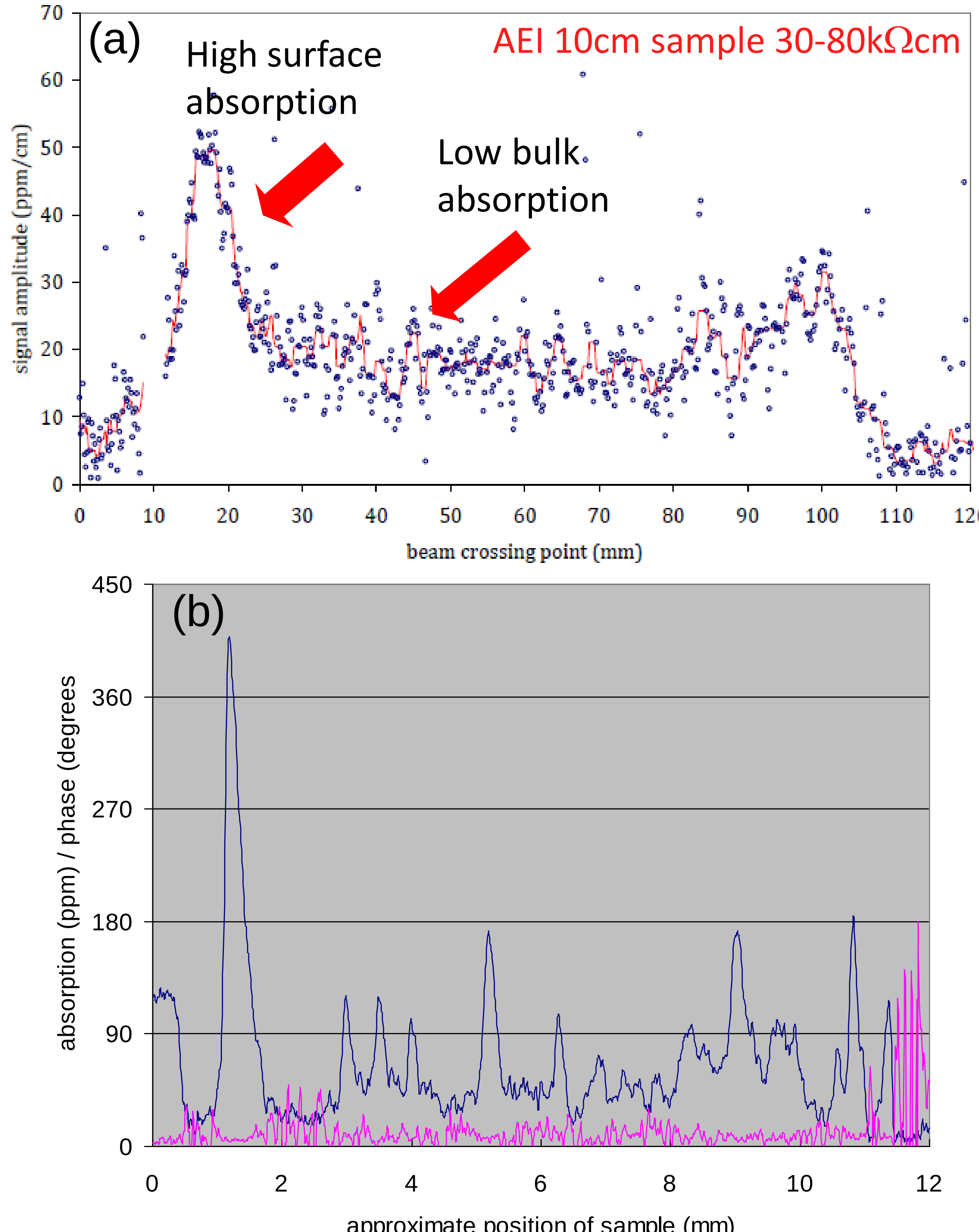




ET R&D WG 3 – Homogeneity of silicon

- Several samples show surface absorption (a)
- Can vary significantly across surface (b)
- Cannot be reduced by:
  - simple cleaning procedures (isopropanol etc)
  - etching with HF to remove oxide layer (few nm)
  - etching with KOH to remove a few 10 nm of material

– Next step: remove more of surface by polishing



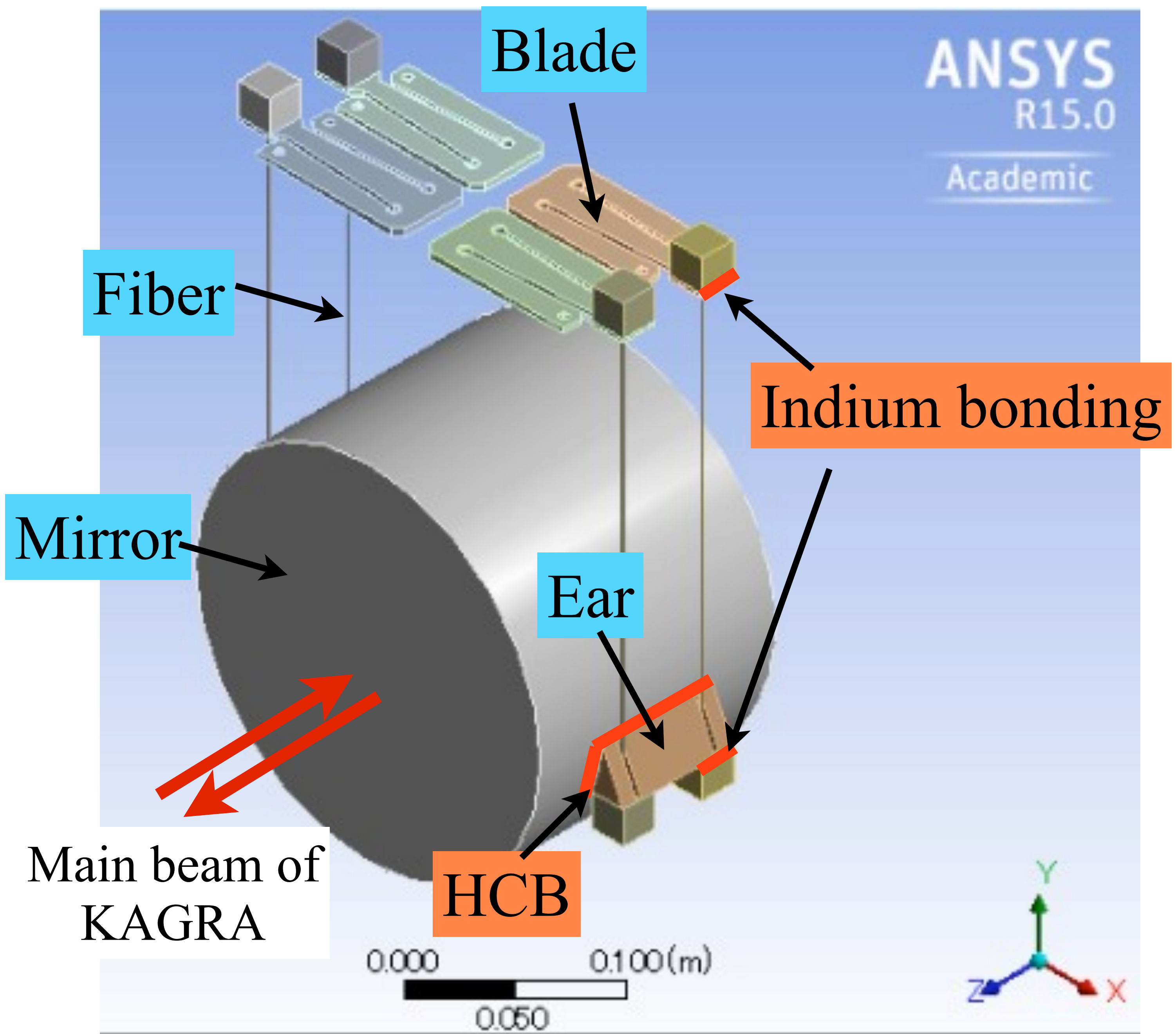
Mechanical loss measurement of indium bonding

Dan Chen [A C], Gerd Hofmann [B], Seiji Kawamura [C], Alexander Khalaidovski [D], Nobuhiro Kimura [E], Julius Komma [B], Rahul Kumar [C], Ettore Majorana [F], Takahiro Miyamoto [C], Ronny Nawrodt [B], Christian Schwarz [B], Toshikazu Suzuki [E], Hiroki Tanaka [C], Takayuki Tomaru [E], Takashi Uchiyama [C], Kazuhiro Yamamoto [C],
KAGRA Collaboration
Astro.S.UT [A], Friedrich-Schiller-University Jena [B], ICRR.UT [C],
Albert Einstein Institut, University of Hannover [D] KEK [E],
Sapienza University of Rome and INFN [F]
ELiTES WP2 15th Sep 2014

Outline

- KAGRA cryogenic sapphire suspension
- Q measurement of bonding between sapphire
- The impact on the sensitivity of KAGRA

KAGRA cryogenic sapphire suspension



Temperature of the main mirror is kept at 20K to reduce the thermal noise.

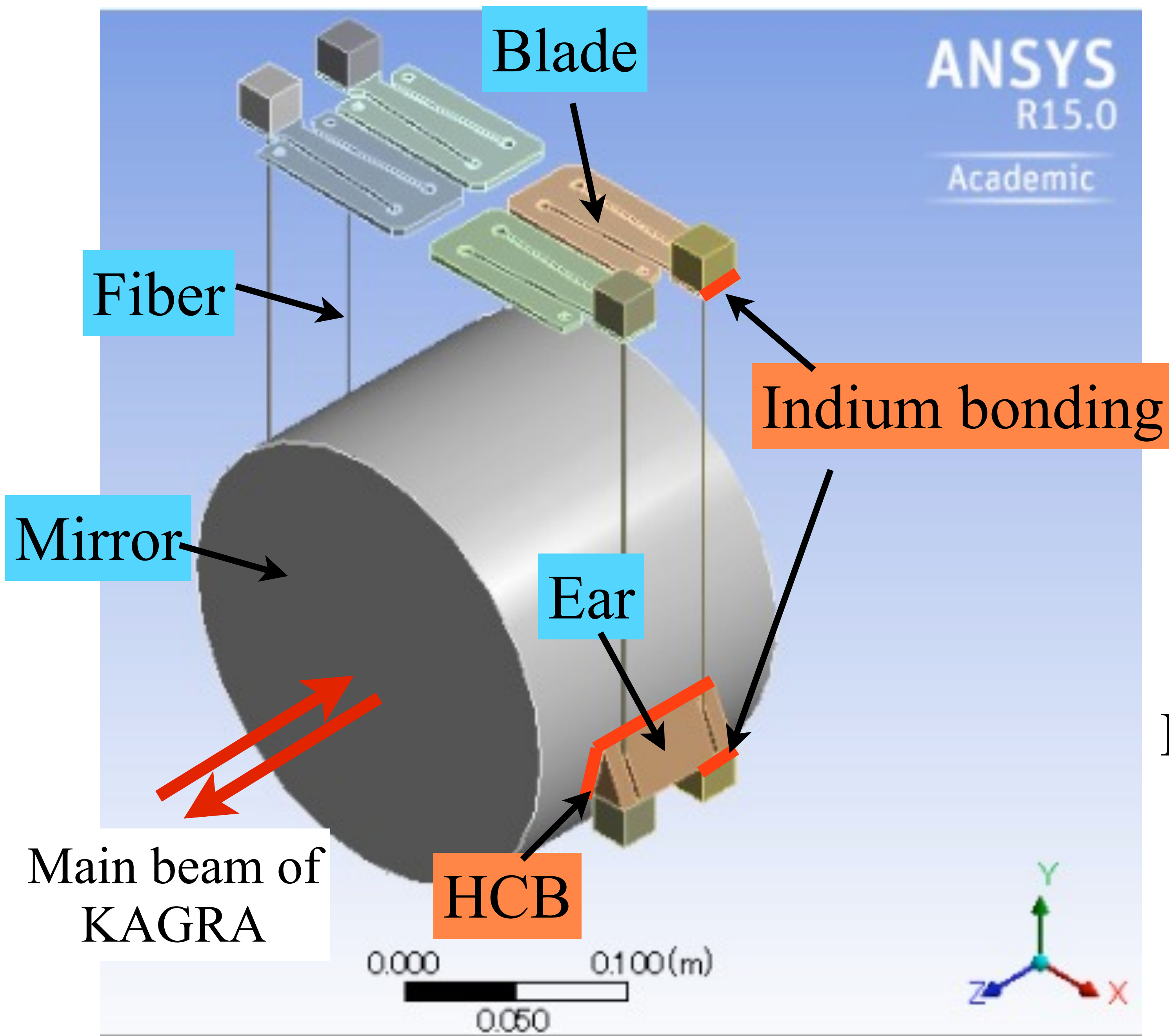
We need...

High thermal conductivity

Low mechanical loss

14年9月18日木曜日

KAGRA cryogenic sapphire suspension



Temperature of the main mirror is kept at 20K to reduce the thermal noise.

We need...

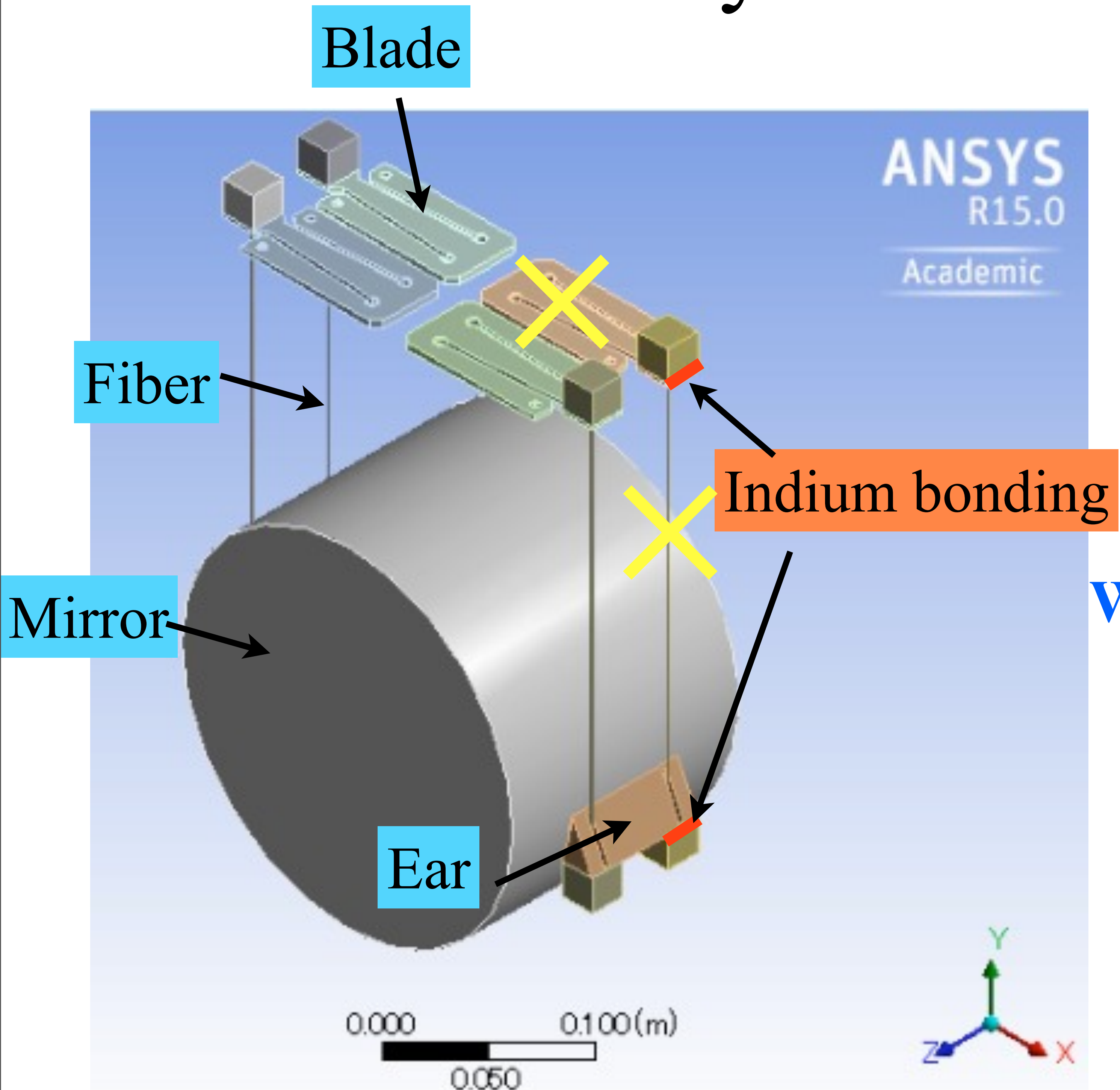
High thermal conductivity
Low mechanical loss

Mirror, ear, fiber and blade are made of sapphire

We have already measured the thermal conductivity and loss of fibers. It is acceptable.

We report mechanical loss measurements of indium bonding in this presentation.

Why indium bonding?



If blades or fibers break !!

We can remove the fiber and blade at indium bonding using heat or acid.

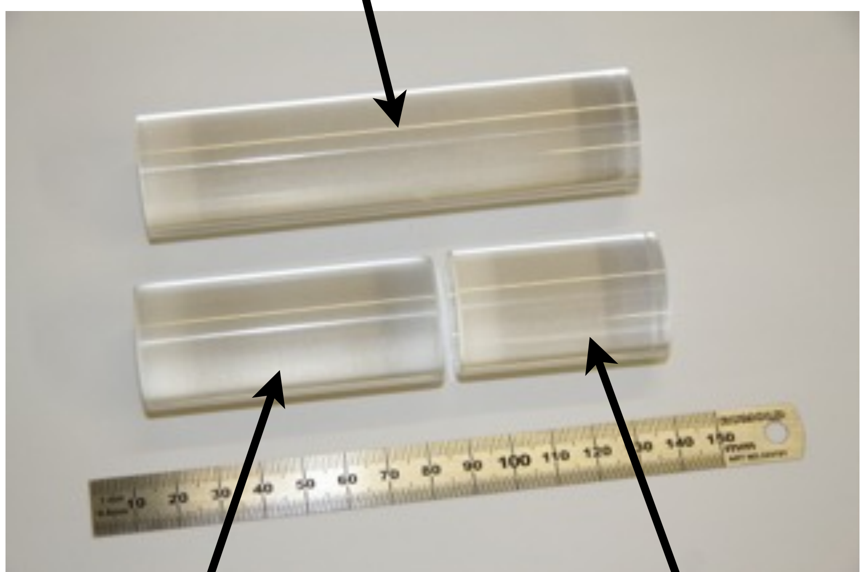
Otherwise we have to throw away our expensive mirror...

But can thermal noise from indium bonding effect sensitivity of KAGRA?

We need to measure the mechanical loss of indium bonding.

Mechanical loss measurement of indium bonding
- Bonding making process -

Reference sample



Sapphire A Sapphire B

Size:

L=70+50=120mm

φ=30mm

Weight on the bond:1743g

Sapphire A

Indium

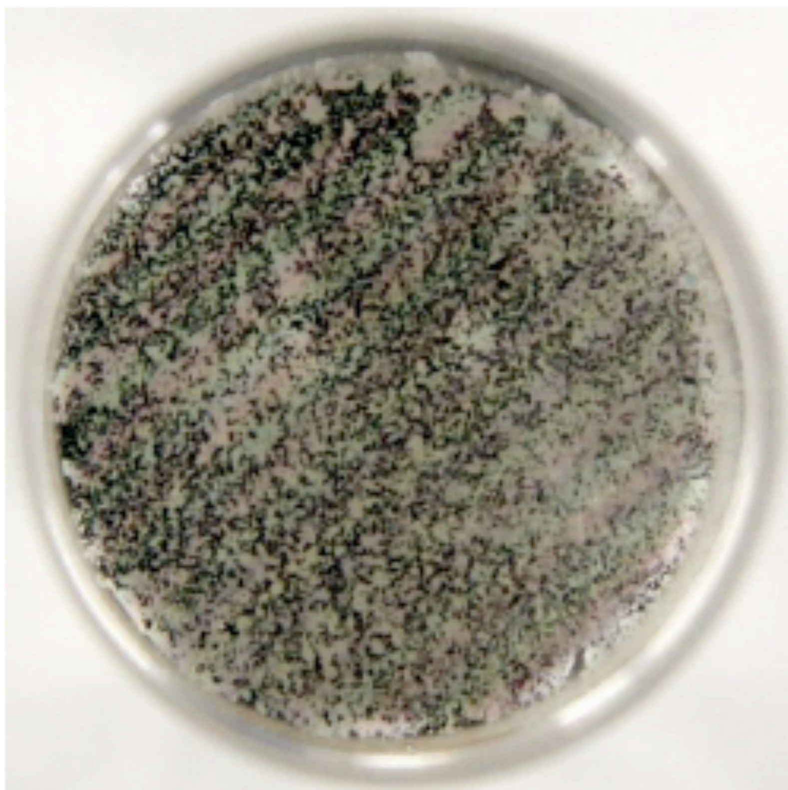
Sapphire B

We made indium bonding twice using same sapphire samples.
At the second time, we evaporated indium (~300nm) on the surface in advance.

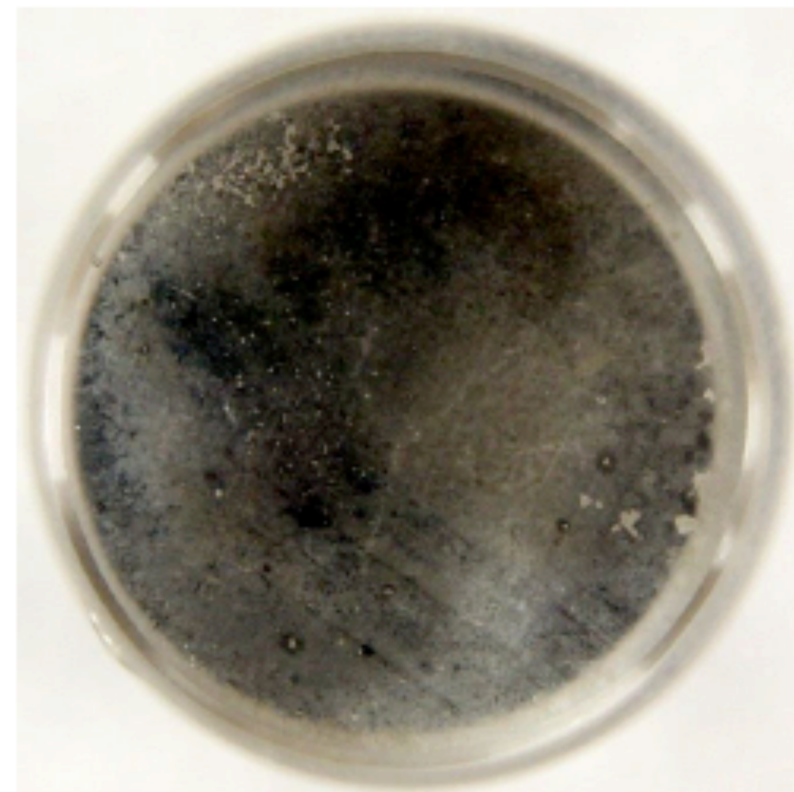
We put an indium foil between sapphire samples and kept the temperature at 200°C for 3 hours.

Indium layer between the samples:

1st bonding (just foil), 40% covered

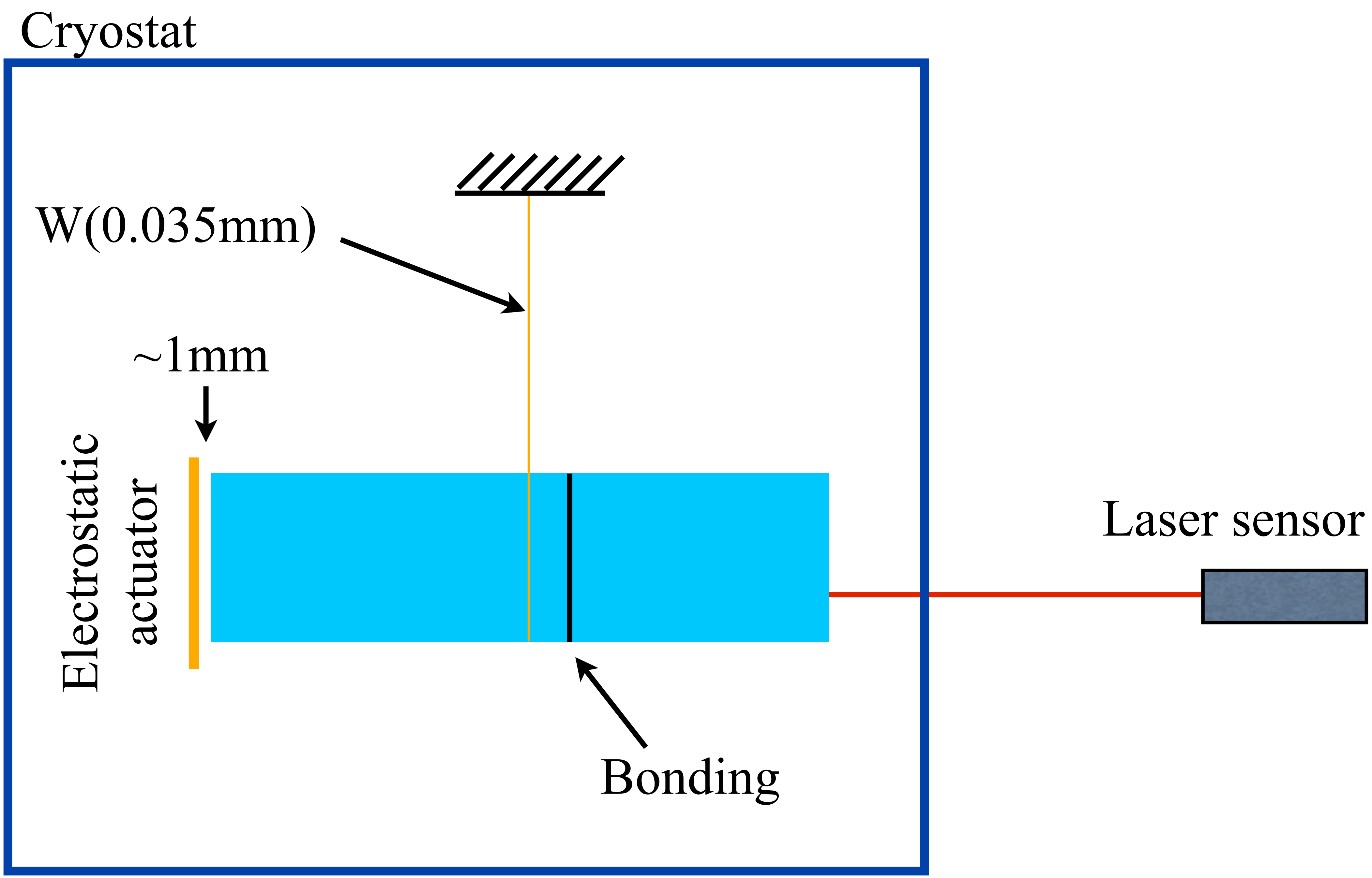


2nd bonding (previous coating), 95%



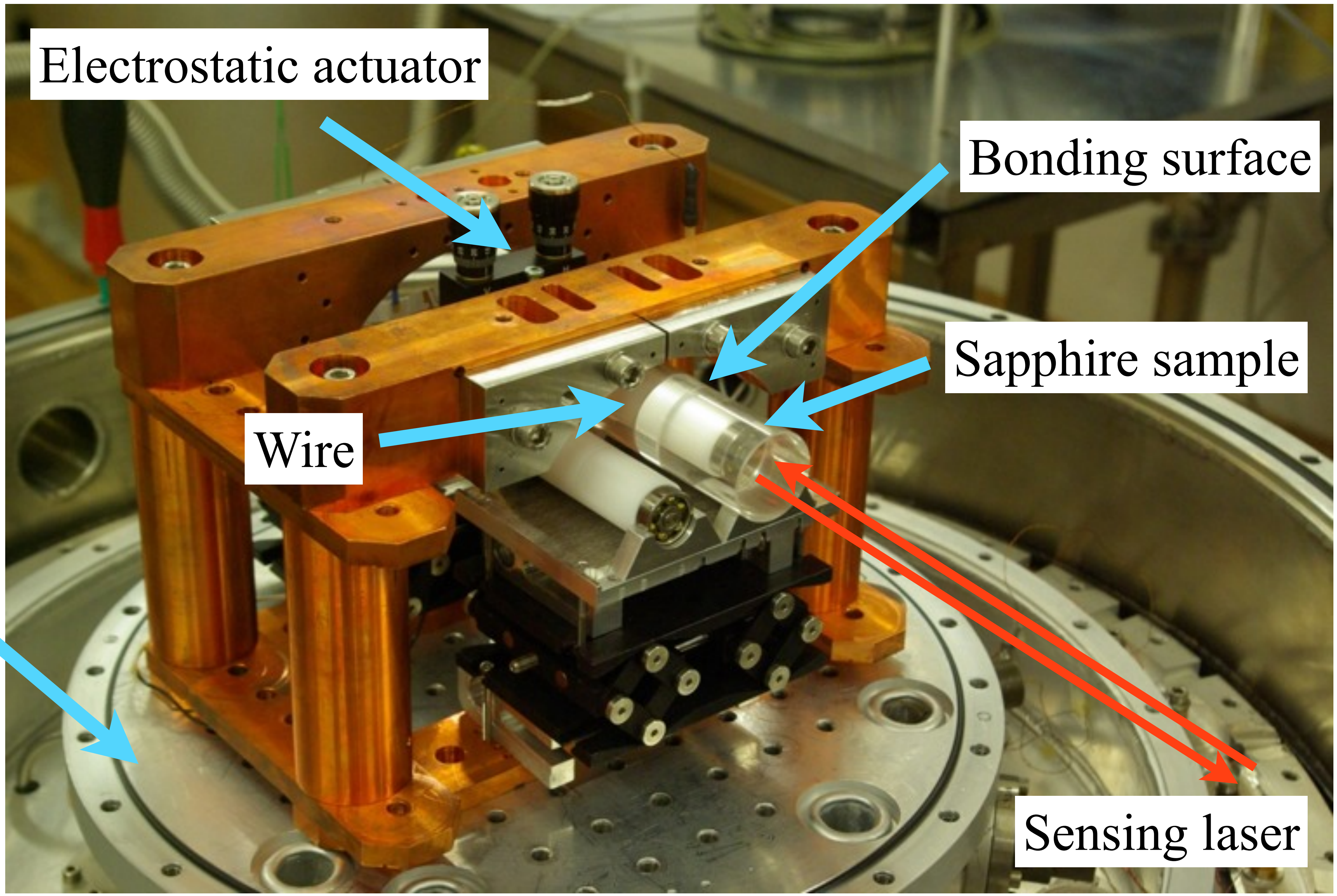
- Layer tilt → numerical calculations suggest no influence
- Effective thickness → 1st bond 3.3 µm, 2nd bond 12.9 µm
  but less indium gives higher mechanical loss?! Quality of bond layer or contact area seems important – experiences from HCB?

Measurement setup

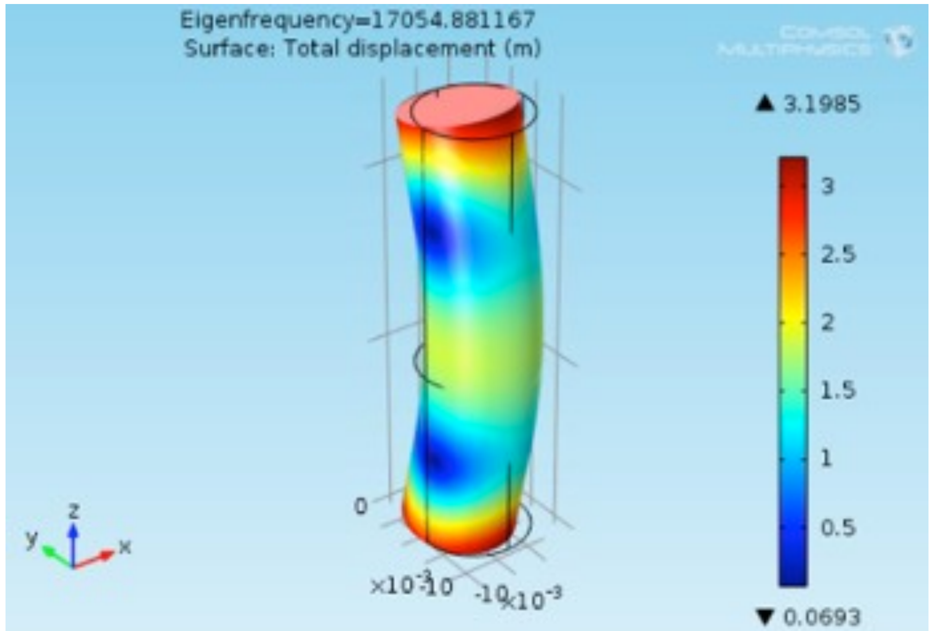


We used an electrostatic actuator to excite modes of the sample.
We estimated the loss from decay curves of the vibration.

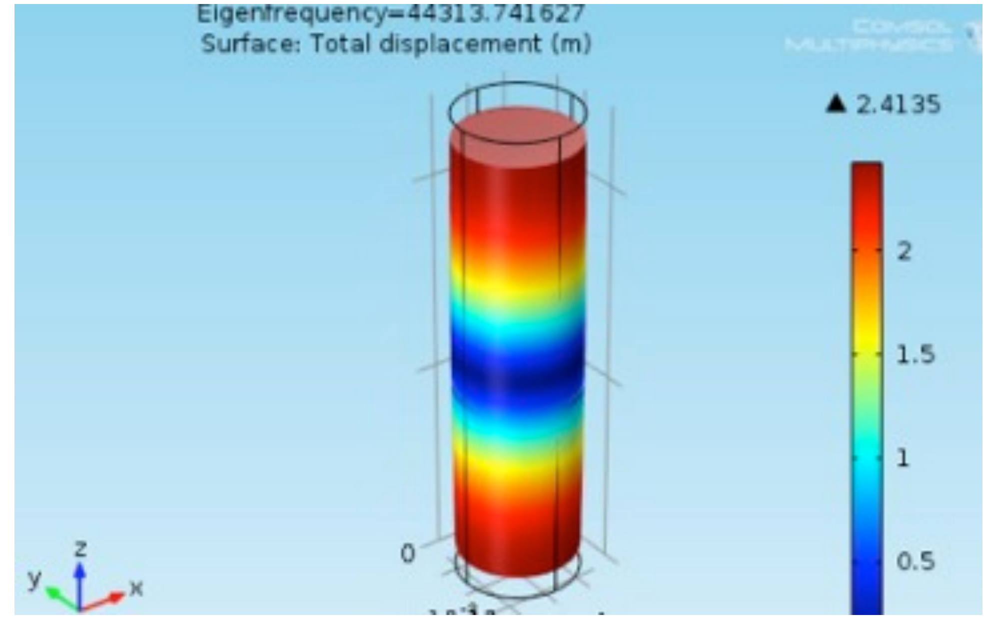
Measurement setup



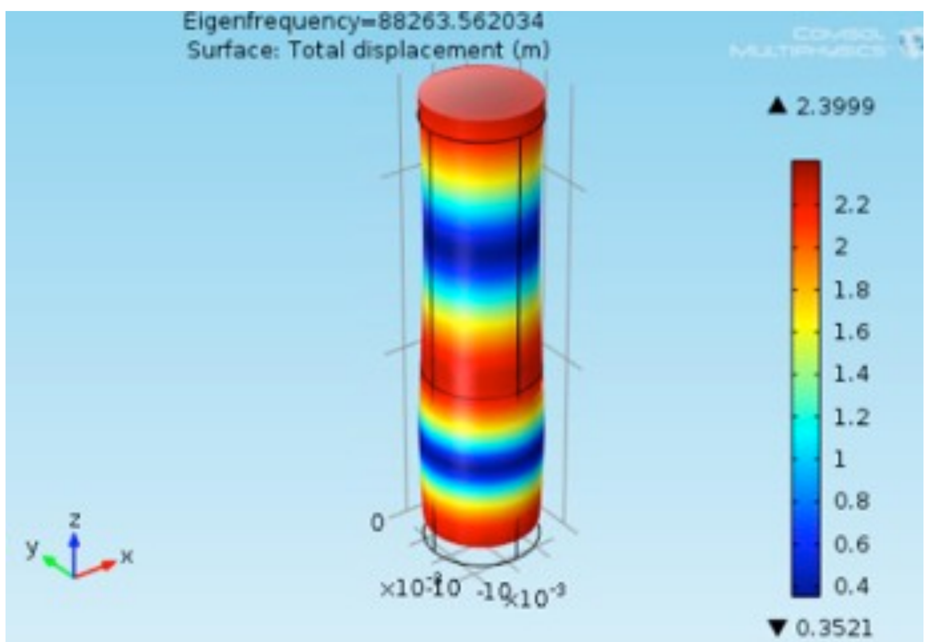
Resonant frequency



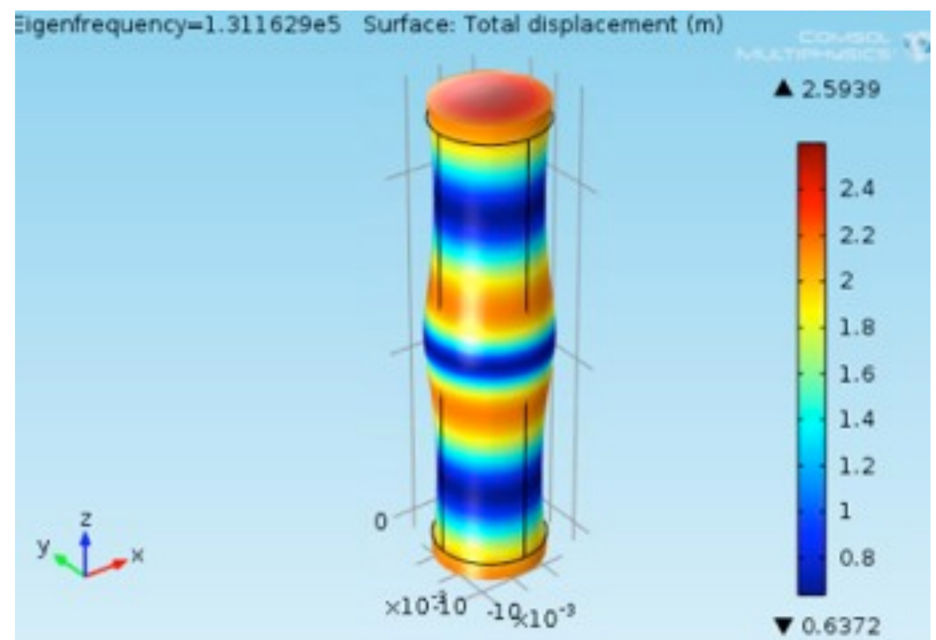
Mode1=17kHz



Mode3=44kHz



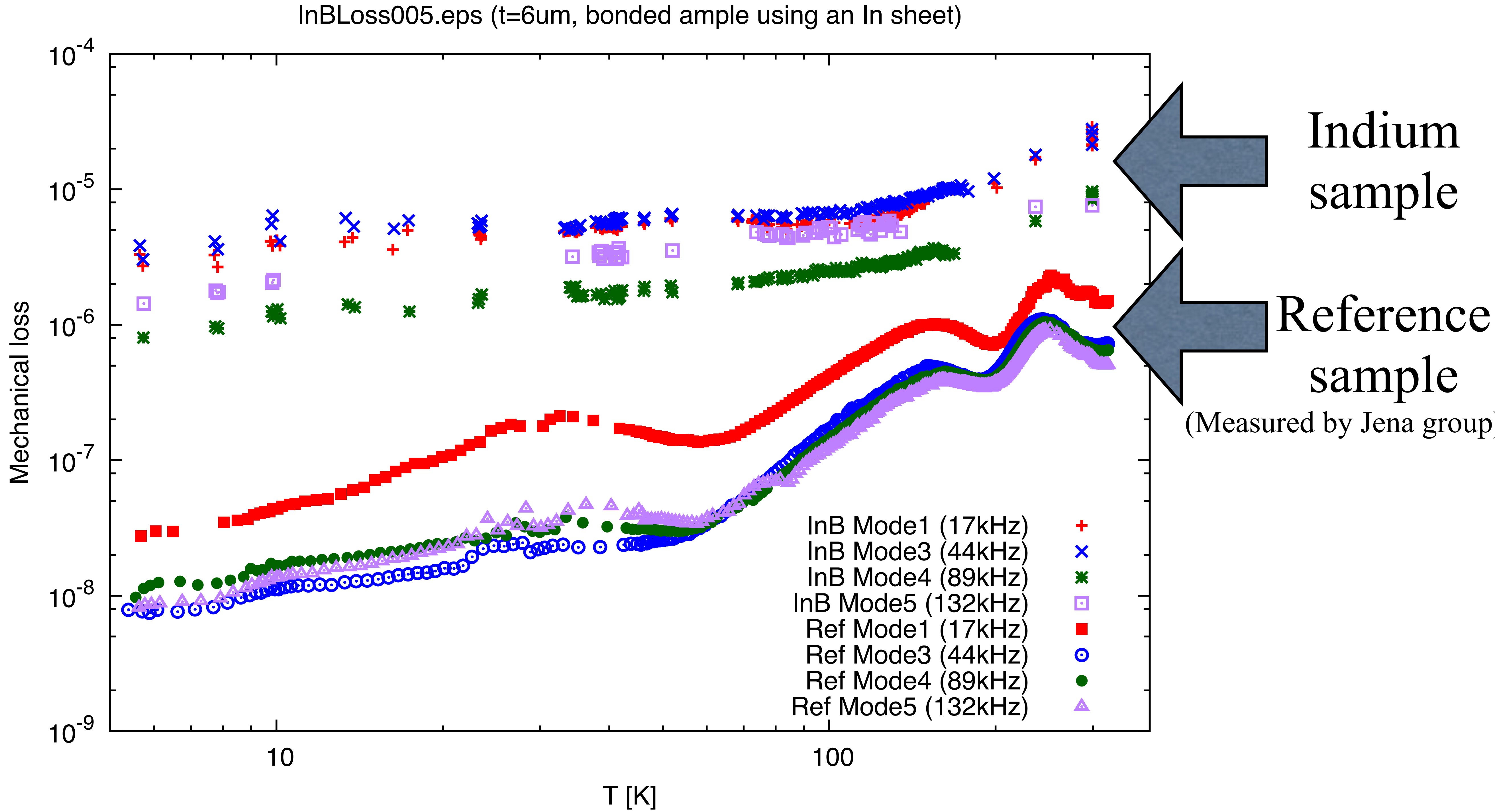
Mode4=89kHz



Mode5=132kHz

We measured loss of these 4 modes.

Measurement result



This data shows the loss of sapphire sample which includes indium bonding. We need estimate the loss of indium bonding from this data.

How to estimate the loss of bond?

measured loss — substrate loss — bonding loss

$$\phi_{meas}E_{tot} = \phi_{sub}E_{sub} + \phi_B E_B$$

total energy — energy in sub — energy in bond

$$\frac{E_B}{E_{tot}} << 1 \qquad \frac{\phi_{sub}}{\phi_{meas}} << 1$$

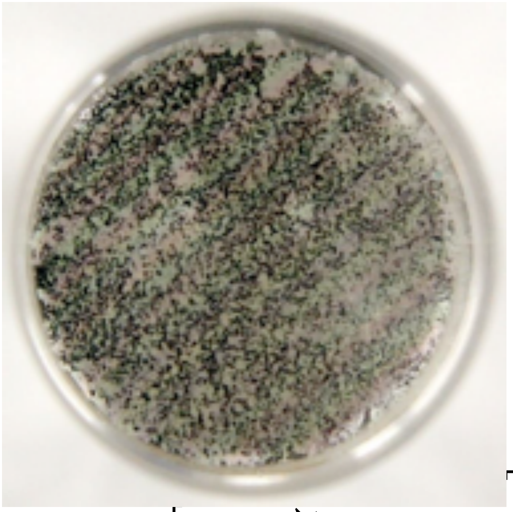
Loss of indium bonding

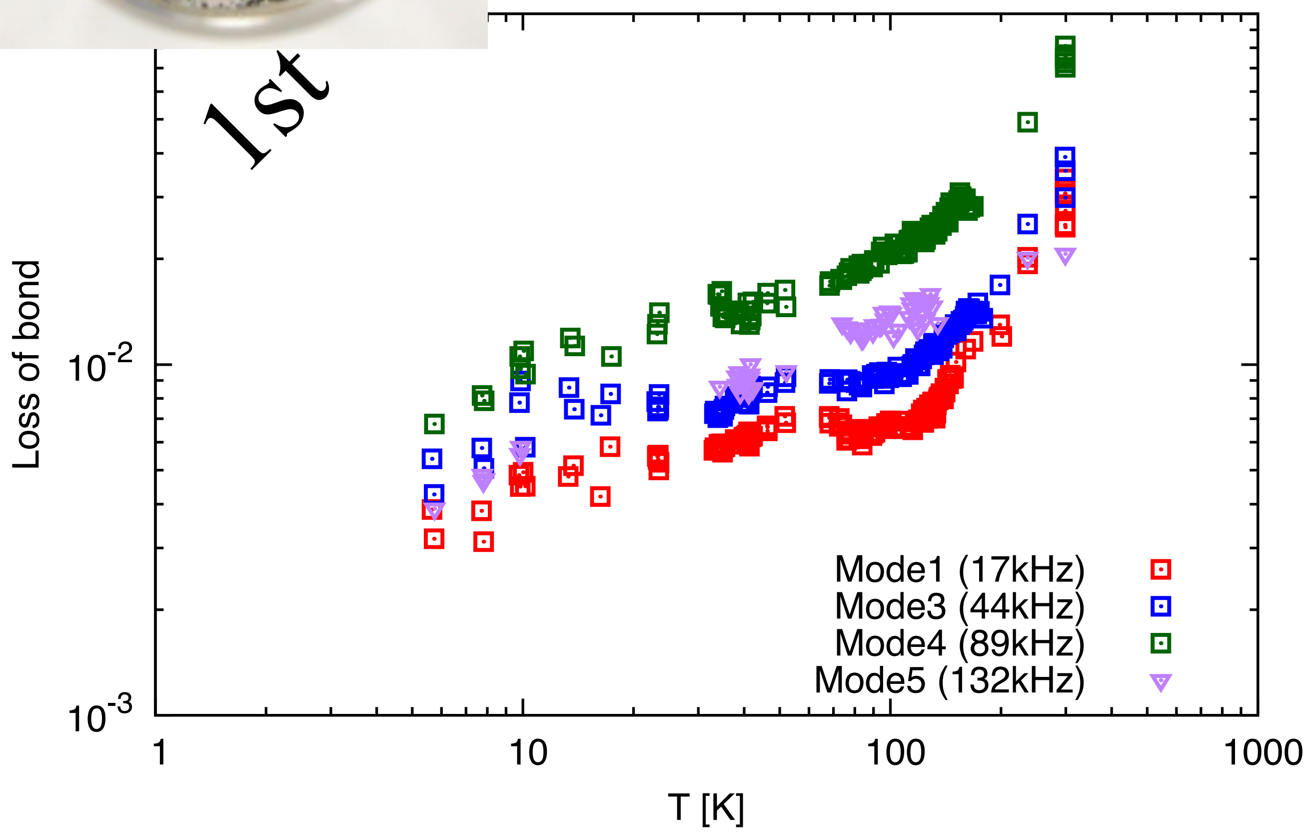
Loss we measured

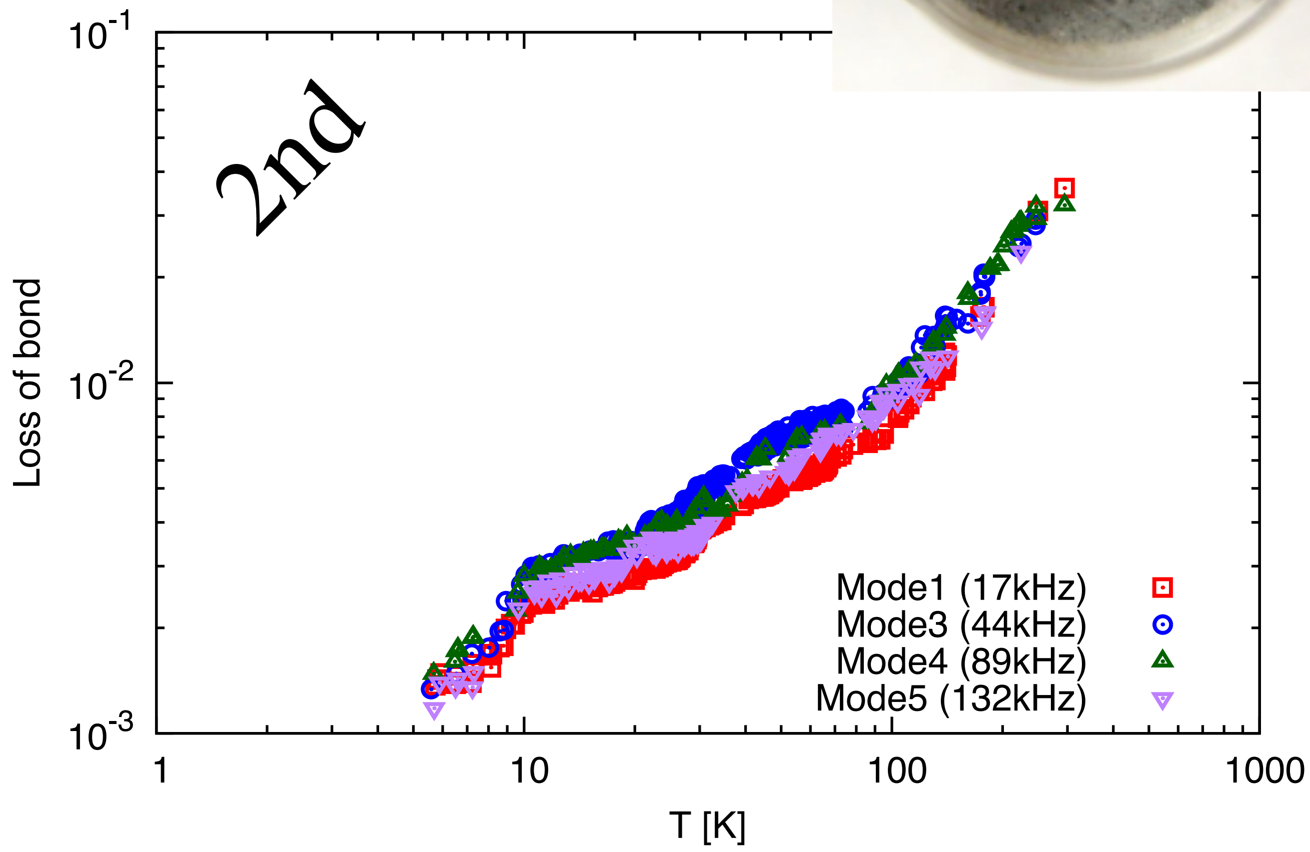
$$\phi_B \simeq \frac{E_{tot}}{E_B}\phi_{meas}$$

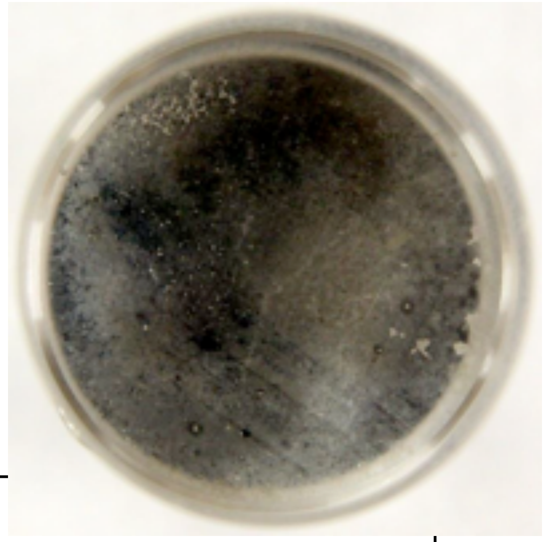
We calculated this ratio by FEM

Loss of bonding









We made indium bonding twice using same sapphire samples.
The bonding quality can effect the mechanical loss.

Loss of indium bonding at 20K: $3\sim7\times10^{-3}$

Can this effect the sensitivity of KAGRA?

Thermal noise calculation

We used Levin's way to calculate thermal noise.

Yu. Levin PRD (1998) **57** 659

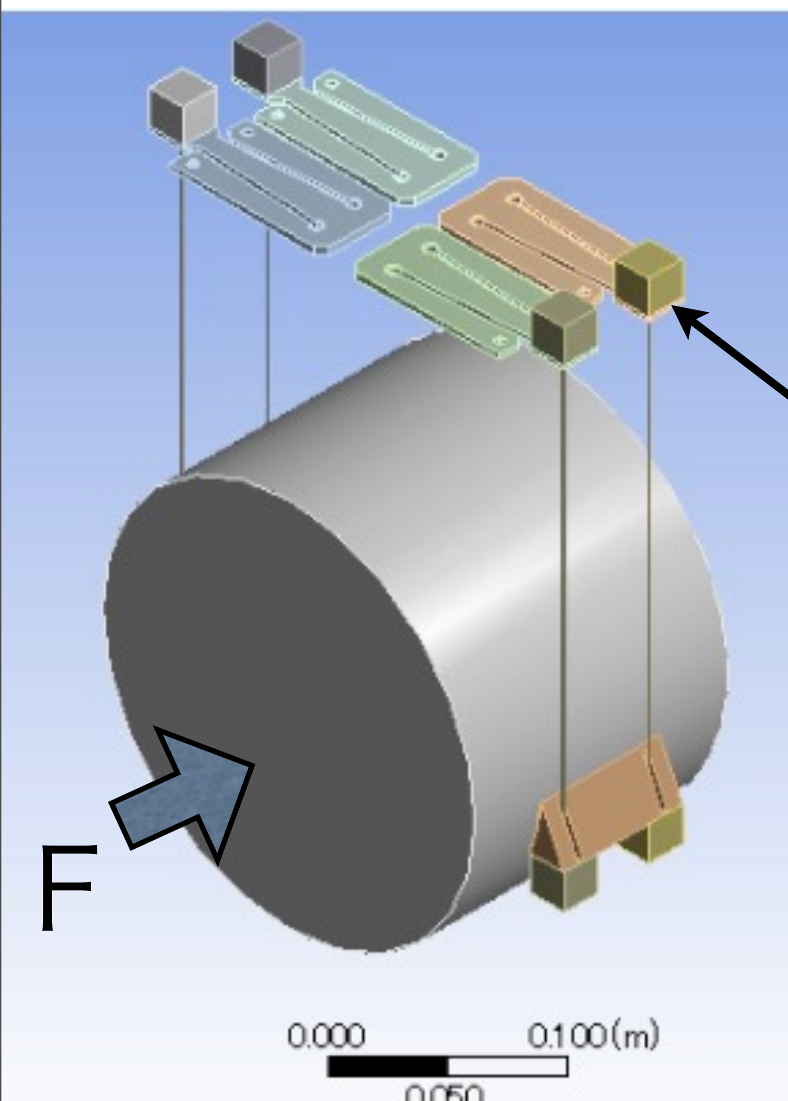
Thermal noise:

$$S_x(f) = \frac{2k_BT}{\pi^2 f^2}\frac{W_{diss}}{F_0^2}$$

$$W_{diss} = 2\pi f \int u(\vec{r})\phi(\vec{r})\mathrm{d}V$$

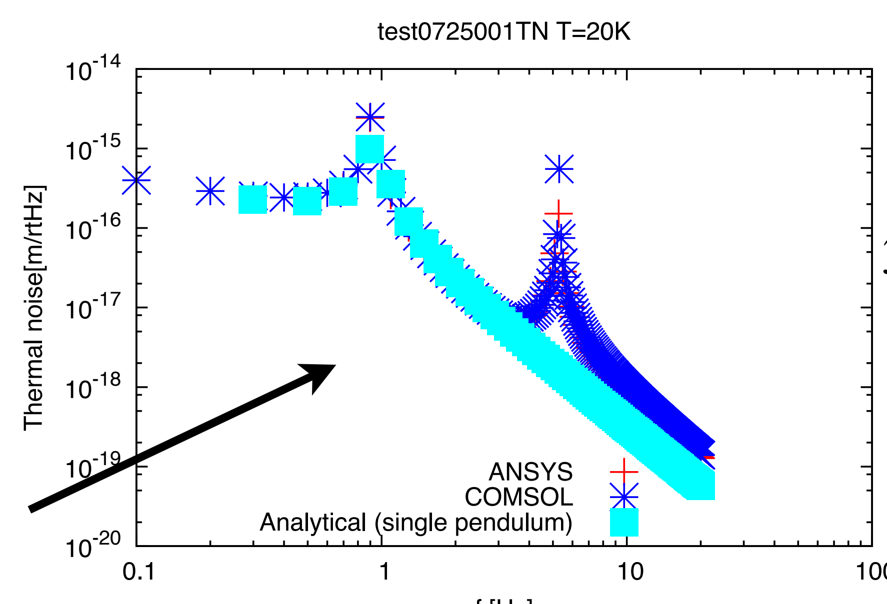
Energy density at each point

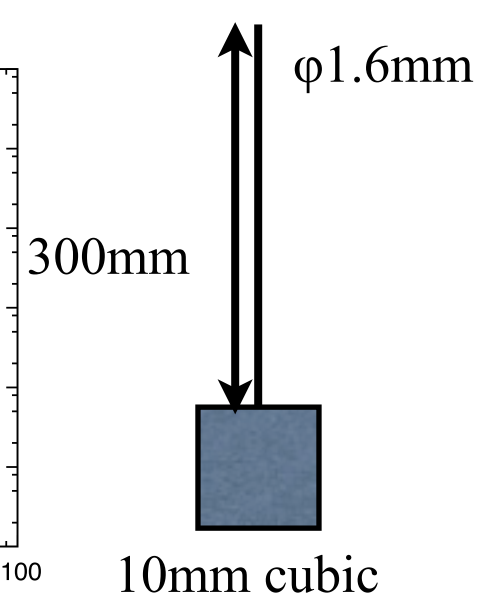
FEM



Indium bonding

Example:

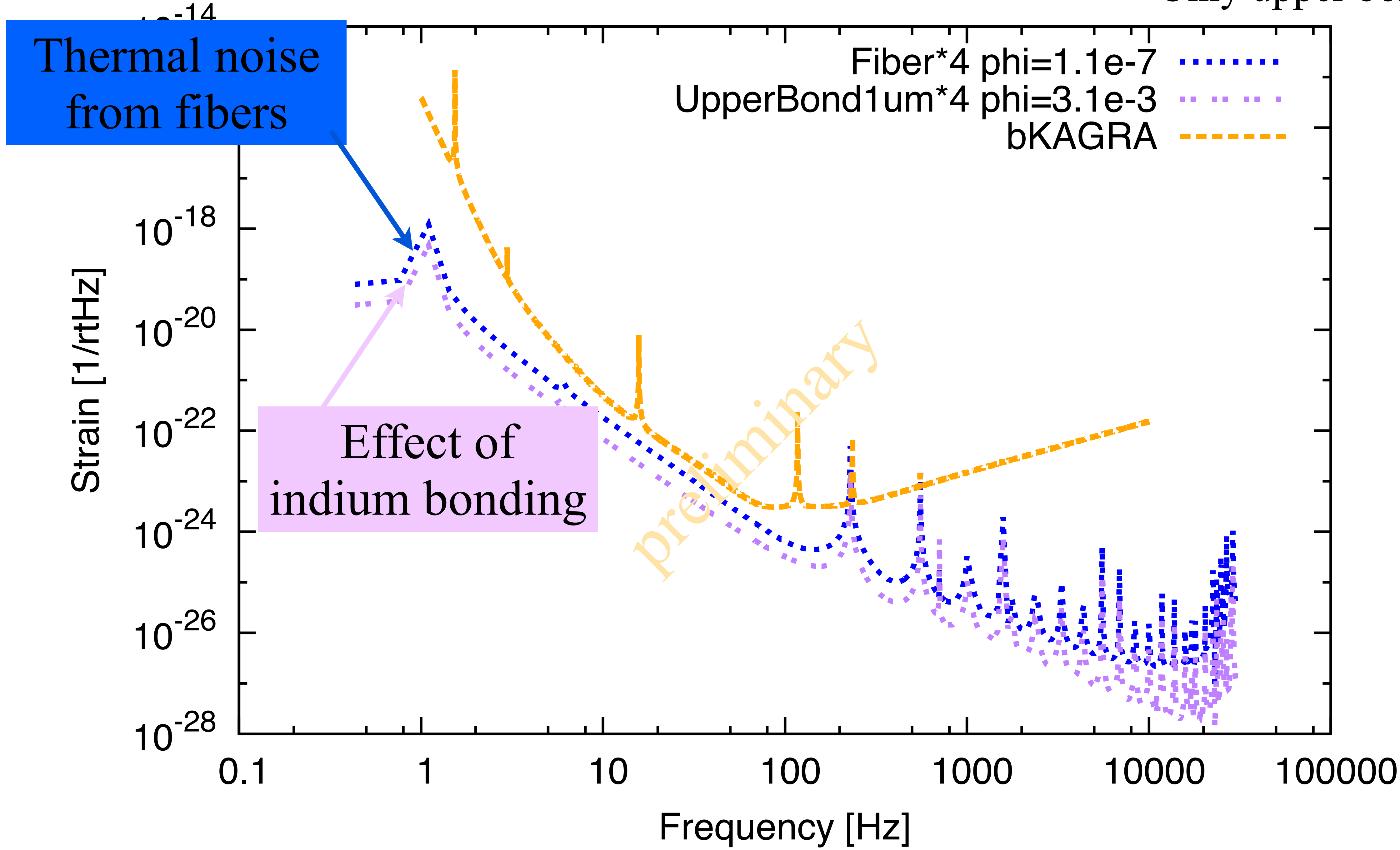




The results are consistent with each other.

The impact of the sensitivity of KAGRA

Indium thickness = 1um
Only upper bond



Thermal noise from indium bonding will not limit the sensitivity.
(We need more detailed calculation.)

Summary

- We made indium bonding twice using same sapphire samples.
- The bonding mechanical loss we measured were 3-7x10^{-3}.
- According to the first calculation, thermal noise because of the indium bonding will not limit the sensitivity of KAGRA. Calculation is going on.

End

Near future plan

Kazuhiro Yamamoto

Institute for Cosmic Ray Research, the University of Tokyo

15 Septmeber 2014
ELiTES WP2 meeting

First of all …

KEK and ICRR are responsible for KAGRA cryogenic payload.

KEK: 1/4 cryostat and so on (“Large” cryostat)
ICRR: Two “small”cryostats

Kazuhiro explains possible near future plan in ICRR.

Cryostats in ICRR

Small one : No vibration reduction system, Shorter cooling time (half day)

Middle one : Vibration reduction system, Longer cooling time (2 days)

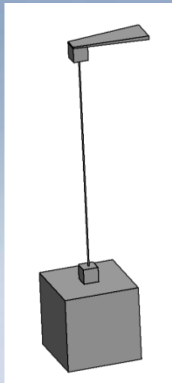
Current status

(1)Sapphire suspension R&D :

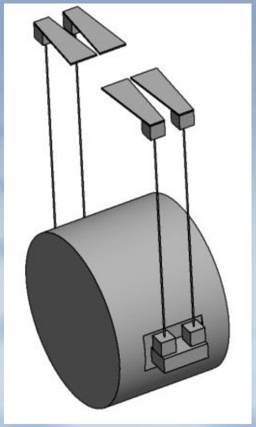
Some issues are still open.

(2)Sapphire suspension prototype

One fiber



Full size



Preparation is in progress.

(3)Material : Some issues about heat links and wires are still open.

Human resources

Yusuke and Dan :
They must submit their Ph.D. thesis before Christmas. Defense is in January. They leave on the end of March.

Tanaka-kun and Miyamoto-kun (fresh persons) join.

Although Rahul left on the beginning of September, he comes back on the beginning of November (KEK).

KEK : Suzuki-san will retire on March 2015 and Takayuki Tomaru will succeed as chief of Cryogenic sub group.

Human resources

KAGRA needs your support !

Schedule

Sep 2014

Small cryostat : Thermal conductivity (Cu, Yusuke)

Middle cryostat : Q of sapphire fiber (Dan, Tanaka)

Before middle of Oct 2014

One fiber prototype assembly (Ettore visit).

Middle of Oct – Middle of Nov : Dan will be at Jena.

December : Yusuke and Dan will submit Ph.D. thesis.

January : Defense of Yusuke and Dan.

Delivery of sapphire bulk for full size prototype ?

Open issues

Sapphire suspension R&D
Sapphire fiber Q, Indium bonding manufacturing, blade spring test, glue for magnet, coating mechanical loss (Mirror subgroup), …

Prototype (one fiber and full size prototype)
Assembly, performance test …

Material
Q of metal wires and heat links, rigidity of heat link, thermal resistance at end of heat link …

Open issues

Investigation on European side

Q value of long (300 mm length) fiber

Simulation
Eddy current in metal mass, Magnetism in metal mass, Vibration transfer function of heat links, …

ELITES WP2 TELECON

September 15 2014

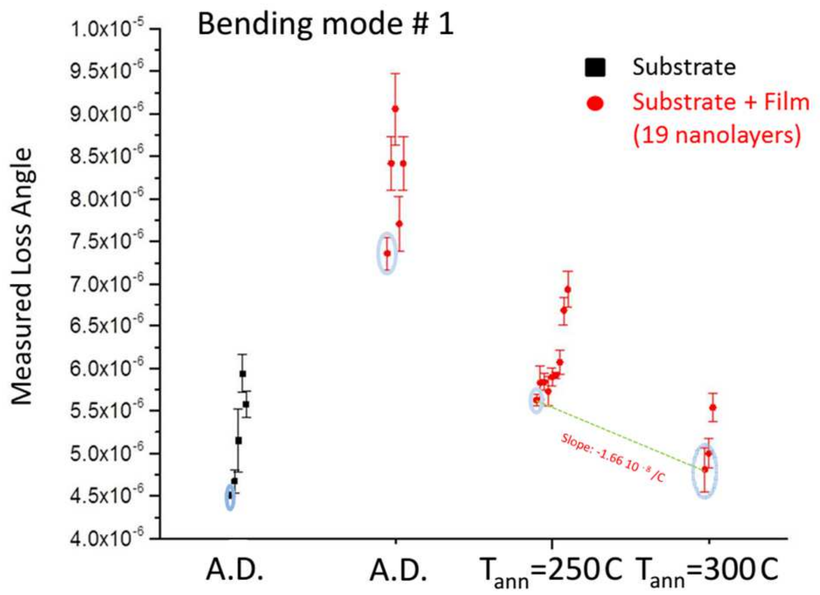
UniSannio WP2 Progress Report

I.M. Pinto

USannio Deliverables Update

- Extensive experiments aimed at assessing maximum annealing temperature of nm - layered composites vs nanolayer thickness completed [LIGO - P14 00122, submitted to Optics Express]

- Preliminary measurements of loss angle of annealed nm-layered Silica/ Titania composites on silicon substrates   [LIGO – G1401055]



	Loss Angle	
T_{ann}	μ	σ/μ
A.D.	$7.36\ 10^{-6}$	0.082
250	$5.64\ 10^{-6}$	0.074
300	$4.81\ 10^{-6}$	0.074
substrate + film (19 layers)		

	Loss Angle	
T_{ann}	μ	σ/μ
A.D.	$4.48\ 10^{-6}$	0.073
250	$4.32\ 10^{-6}$	0.044
300	$4.55\ 10^{-6}$	0.046
substrate only (Silicon)		

USannio Deliverables Update

The loss angle of the Silica-Titania nm-layered composite is retrieved from

[Pierro et al., LIGO-T060173]

Young modulus of substrate (169 GPa, Silicon 100)

thickness of substrate ($92 \pm 1\ \mu$)

$$\phi_{nlc} = \frac{Y_s h_s}{3 Y_{nlc} h_{nlc}} (\phi_{coated} - \phi_{naked})$$

measured loss angle of naked cantilever (substrate)

measured loss angle of coated cantilever

thickness of nanolayered composite (112.5 nm, for the 19-layer prototypes)

Young modulus (Voigt) of nanolayered composite

$$Y_{nlc} = z_1 Y_1 + (1 - z_1) Y_2$$

Volume (thickness) fractions of composite ingredients (0.654 for TiO_2, for the 19-layers prototypes)

Young moduli of composite ingredients (165Gpa for TiO_2, 72 Gpa for SiO_2)

$\phi = 1.04\ 10^{-3}$ (as deposited)
$\phi = 4.3\ 10^{-4}$ (after annealing 24h @ 250 C)
$\phi = 1.3\ 10^{-4}$ (after annealing 24h @ 300 C)

Preliminary

USannio Deliverables Update, contd.

Started working on updated version of our coating thickness optimization code. Main changes/improvements

- include models of "mixture" materials (cosputtered (EMT) as well as nm-layered)

- include mixture parameters (dopant concentrations) among optimization variables

- allow for alternative (better ?) coating noise models [Hong et al, PRD 87 (2013) 082001]

USannio Secondments (April – August 2014)

I.M. Pinto	05/14 – 05/28
L. Troiano	05/14 – 05/28
D. Castellano	05/14 – 06-28
A. Stabile	06/24 – 07/23
P. Daponte	
F. Picariello	07/03 – 07/10
+ 2 postdoc	

Total ≈ 4.5 FTE