Improvement of mechanical loss measurement system of sapphire fibers for the cryogenic suspension system of KAGRA II

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Outline

- In KAGRA, Q value of the sapphire fiber must be larger than 5×10^6.
- Highest measured Q was 10^7. However, recent measurement for the same fiber shows Q-values is much lower, less than 5×10^6.
- We expect that the loss of clamp for fibers makes "measured Q of fibers" smaller.
- We investigated the loss of the clamp system.

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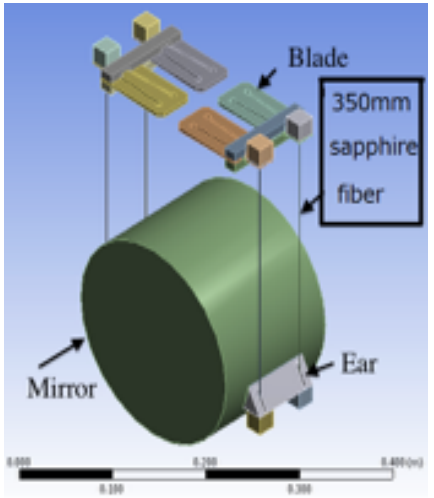
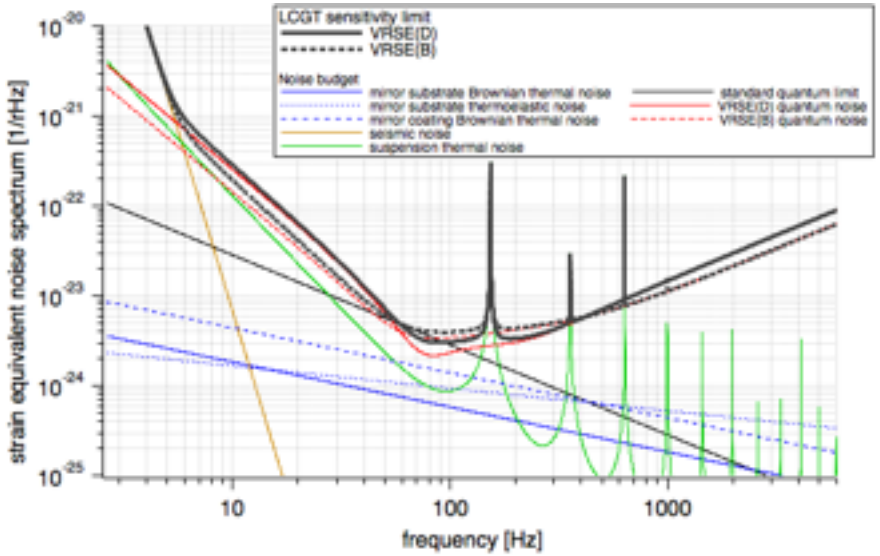
1-1. KAGRA



- To detect the gravitational wave, km-scale interferometer KAGRA is being constructed in Kamioka.
- The mirrors must be free→It is suspended!
- The reduction of the thermal noise of the pendulum motion is one of the most serious issues.



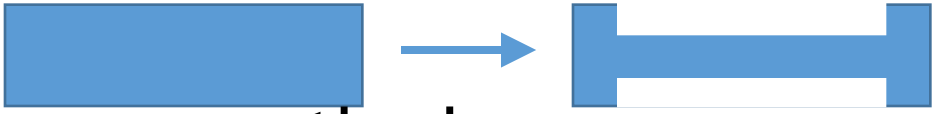
1-2. Thermal noise

- The thermal noise of pendulum is smaller at the lower temperature and with smaller mechanical loss in fiber.
- Mirror temperature of KAGRA should be around 20K.
- The mirrors are suspended by four 350mm sapphire fibers because the mechanical loss of sapphire could be extremely small at low temperature. (cf. Physics Letters A, 273(2000),310, T. Uchiyama et al)
- The Q value (reciprocal of the mechanical loss) of the sapphire fibers must be higher than 5×10^6.
- We should check the Q value of the actual 350mm sapphire fiber for KAGRA sapphire suspension. We are measuring Q value of the test piece.

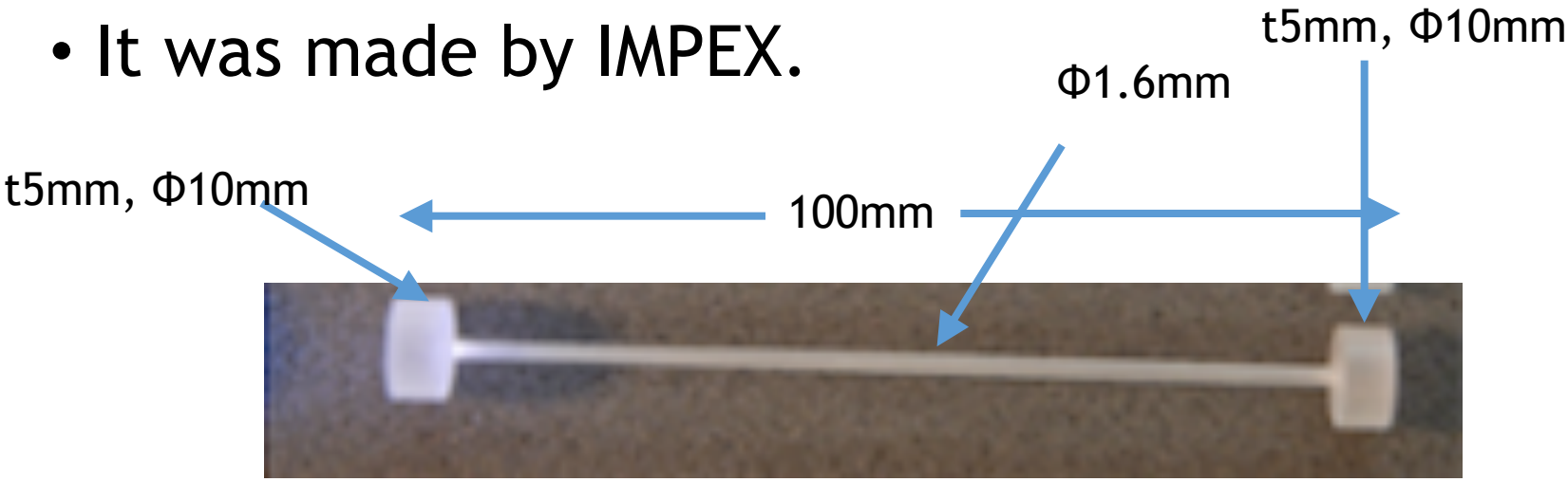
Contents

2-1. Test piece

- 100mm length test piece of the fiber.
- monolithic fiber…First, the rod (Φ10mm) was made from the sapphire bulk. Then the rod was scraped off.

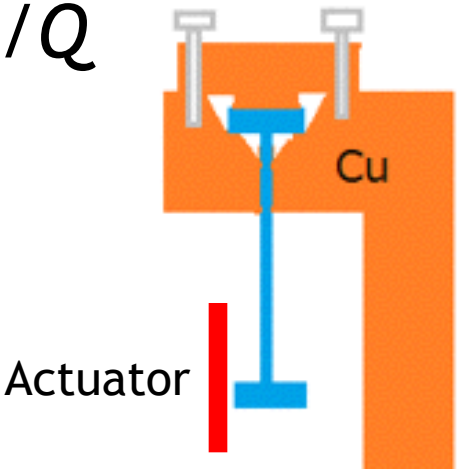


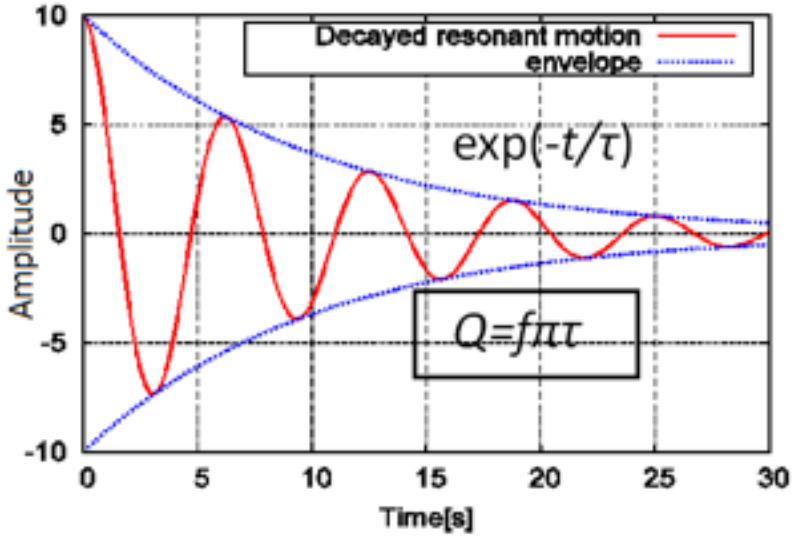
- It is made by Stepanov method.
- It was made by IMPEX.



2-2. Measurement

- The resonant elastic vibration of sapphire fiber is excited by an actuator. After that, we stop the excitation of the actuator.
- Then we measure the decay time(τ).
- Q value is defined as $Q=f\pi\tau$. (f:resonant frequency)
- $\varphi=1/Q$

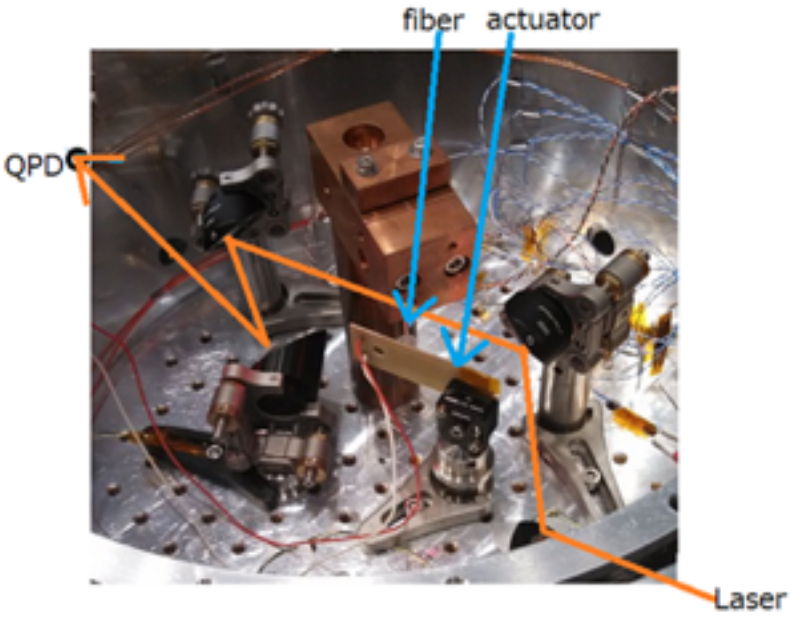


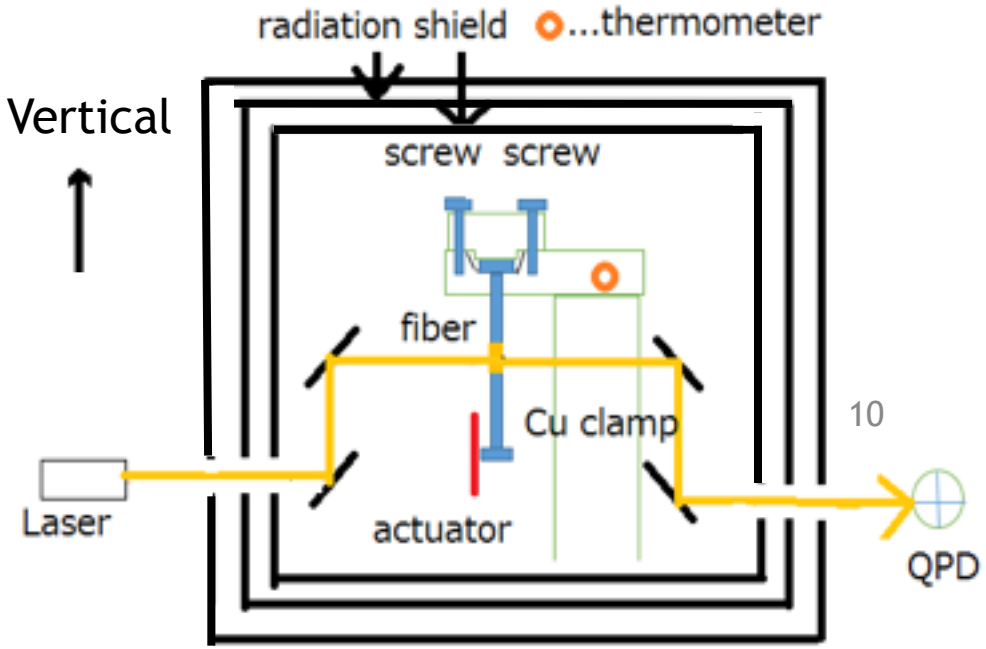


2-3. Experiment apparatus in ICRR

We constructed the apparatus in the cryostat in ICRR and measured the Q value of the fiber.

We adopt the electrostatic actuator and the shadow sensor to monitor the decay motion.



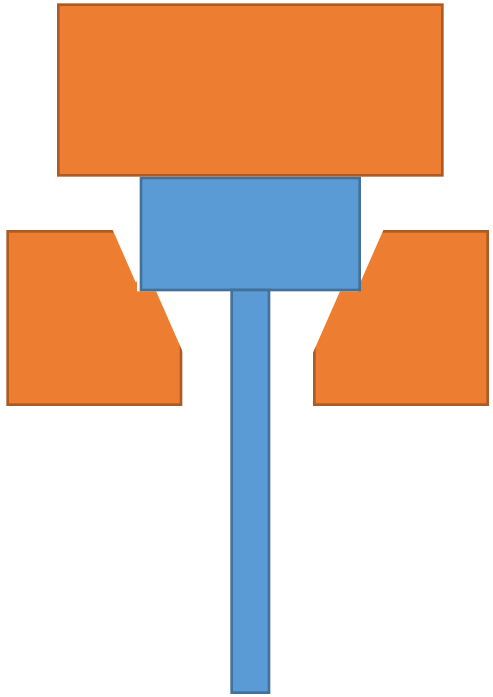


2-4. Clamp loss

- So far we measured the Q values of shorter fibers as test pieces.
- The highest measured Q value was 10^7(by Dr. Chen in Rome).
- In ICRR, even if we measured exactly the same fiber, the Q value was less than 5×10^6.

2-5. Clamp loss

- We expect that the measured Q value is dominated by the loss in clamps.
- The distortion of the fiber head and the friction between the fiber head and the clamps could reduce the measured Q value of the fiber.
- We are investigating the clamp loss of the support system in order to measure the intrinsic Q value of the fiber.



Contents

3-1. Copper clamp (In ICRR)

- As the first step, we measured the Q value of the fiber using the copper clamp in ICRR (fig.1).

- The measured Q value of the fiber was less than 5×10^{6} , KAGRA requirement.

- 1st mode (pendulum mode)…7.4×10^{5} at 5K

- 2nd mode (violin mode)…4.8×10^{5} at 5K

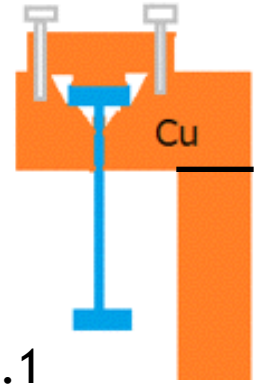


fig.1

3-2. Copper clamp (In Jena)

Jena (Germany) group (leaded by Dr. Ronny Nawrodt) is one of our collaborators.

In Jena, Dr. Gerd Hofmann measured the Q value of the similar sapphire fiber in almost the same clamp as ours.

The Q value was high (4×10^{6} for 2nd mode at 5K).

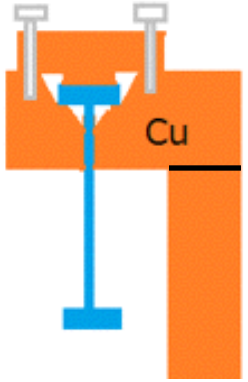


fig.1

3-2. Copper clamp (In Jena)

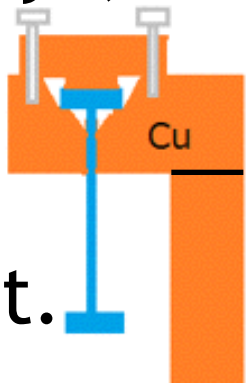
We brought our fibers in previous measurement to Jena this summer and measured its Q value with their copper clamp.

This measurement was done in the thermal noise workshop in Jena (organized by Dr. K. Somiya, Dr. R. Nawrodt).

After I went back to Japan,

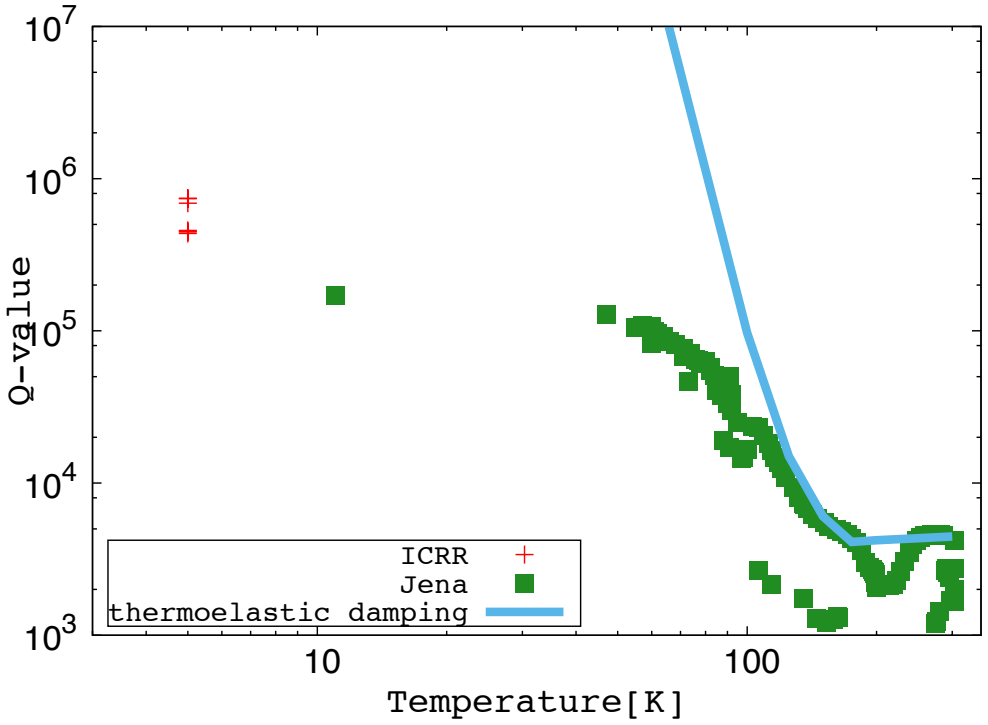
Dr. R. Nawrodt continued the measurement.

fig.1



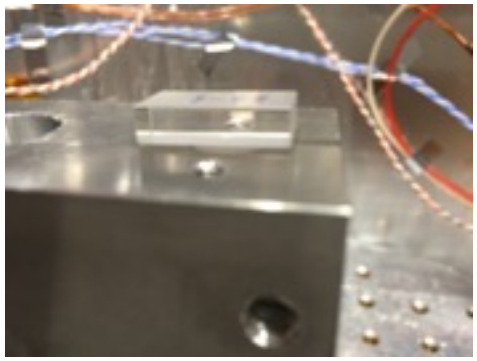
3-3. Result (copper clamp)

- We measured the Q value of exactly the same fiber in Jena and in ICRR.
- Unlike our expectation, the Q value of the fiber measured in Jena was lower than that measured in ICRR (the graph is the Q value of the 1st mode).
- There is no reproducibility, measured Q of fibers are not intrinsic Q of fiber, but loss depends on details of clamp.



3-4. Clamp by sapphire block

- One of the details in the clamp which reduce the Q value would be the deformation of the clamp.
- In order to reduce the deformation loss of the clamp, we adopt the sapphire block because the sapphire is hard and its Q value is high.
- We assembled the clamp system as fig.2 because it it easy to assemble the clamp by what we have in ICRR.



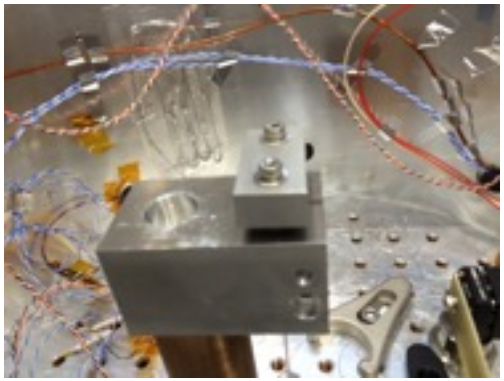
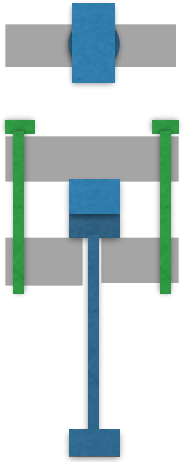
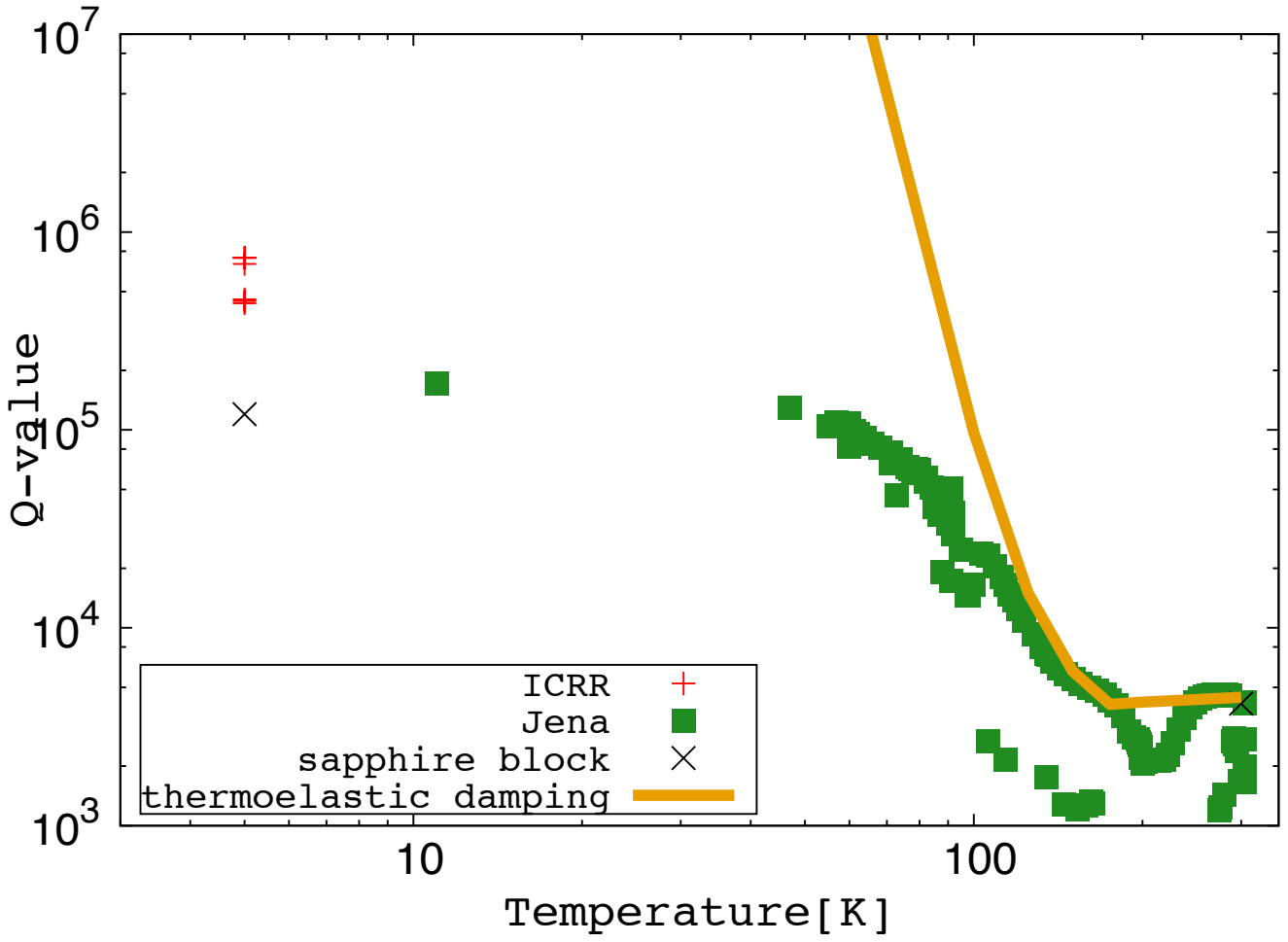


fig.2



3-5. Result (1st mode, 91Hz)

- When we used the sapphire block, the measured Q value was lower.



4. Discussion

- In Jena, the Q value measured in 2013 was 4×10^6, but this time it was 6×10^5.
- We think that there is no reproducibility of measurements with copper clamps.
- We will clamp with sapphire blocks using the new clamp (fig.3)

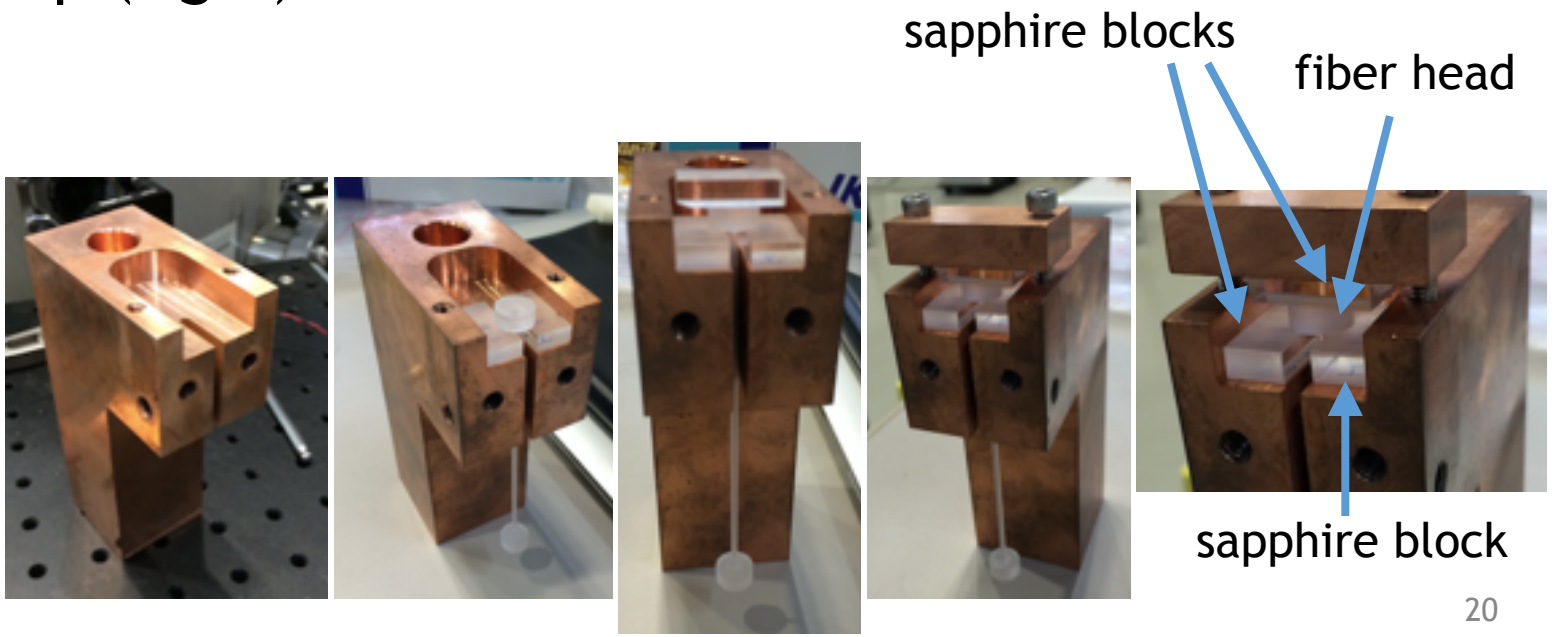
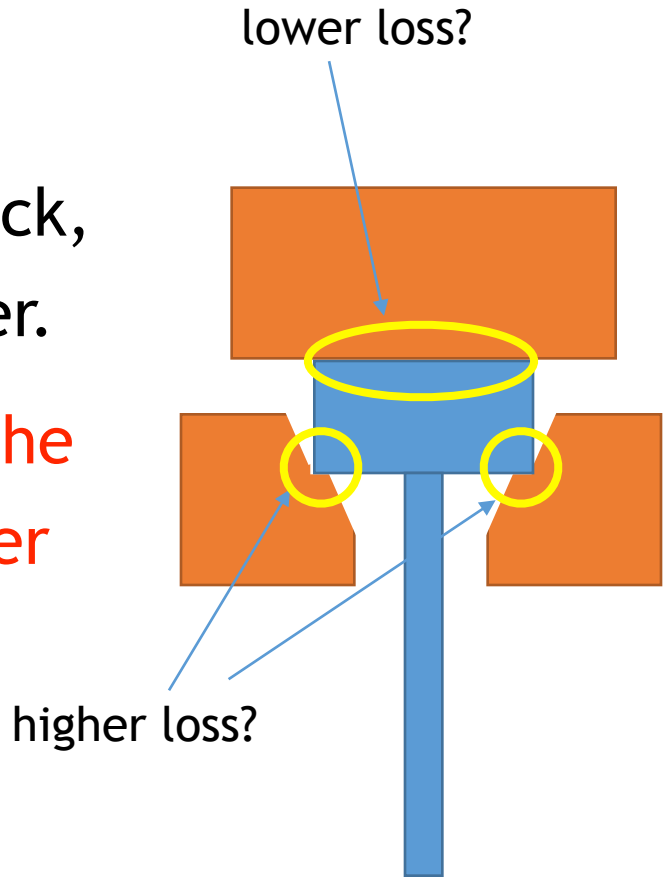


fig.3

4.Discussion

- When we used the sapphire block, the measured Q value was lower.
- Possible reason would be that the loss of the clamp under the fiber head is higher than that on the fiber head.



5. Future work

- We will clamp with the sapphire blocks using the new clamp.
- We will simulate the loss between the fiber head and the clamp.
- As the next step, we will measure the Q value of the long fiber.

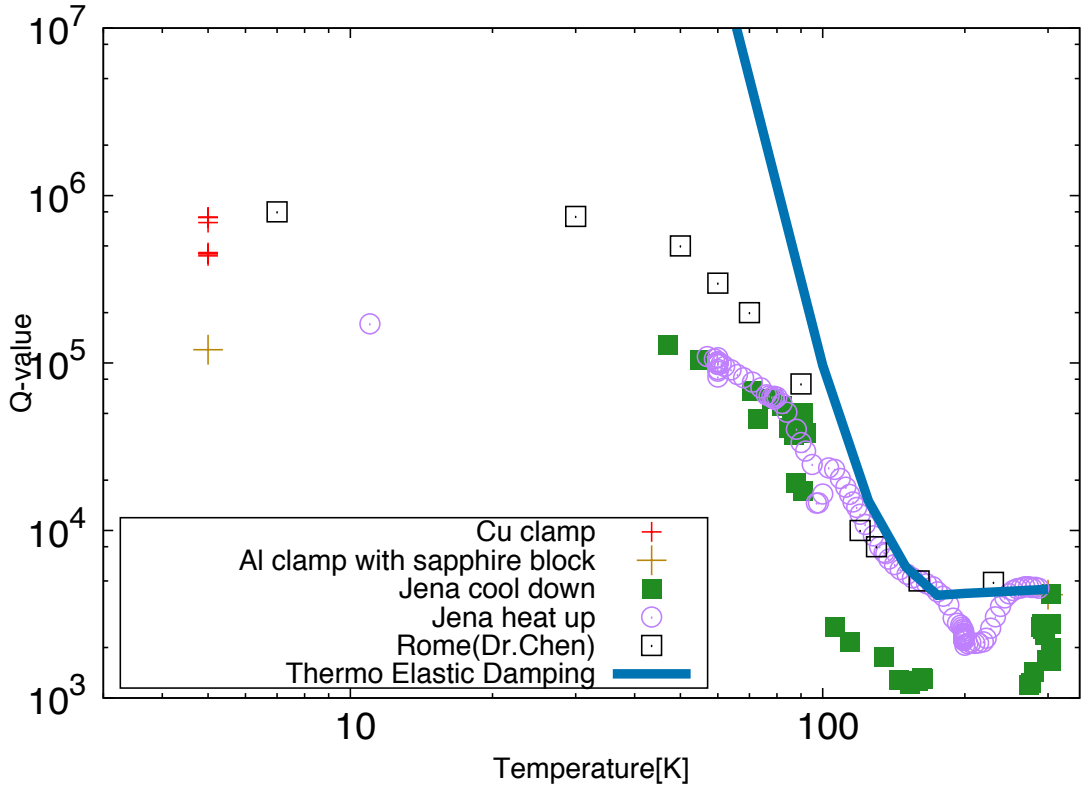
6.Summary

- We measured the Q value of the fiber with almost the same clamp in ICRR and in Jena and found that there is no reproducibility of measurement in copper clamps.
- When we used the sapphire block, the measured Q value was lower.
- As the next step, we will measure the Q value of the 350mm fiber.

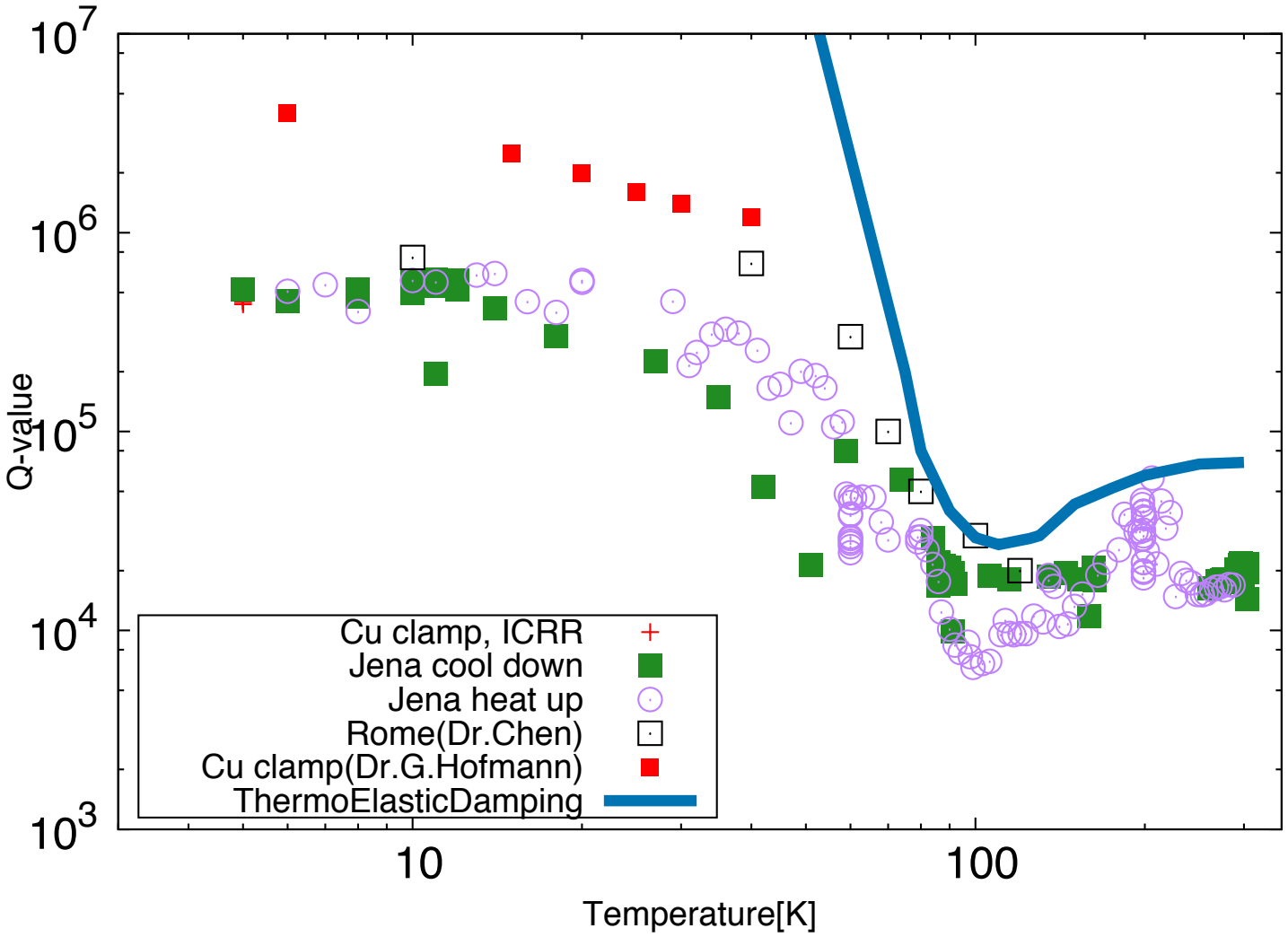
Thank you!

2-3.Result (In Jena)

- We measured the Q value of exactly the same fiber in Jena and in ICRR.
- Unlike our expectation, the Q value of the fiber measured this time was lower than that measured in ICRR (the graph is the Q value of the 1st mode).
- There is no reproducibility, so the loss depends on some details in the clamp.



2nd mode, 1220Hz



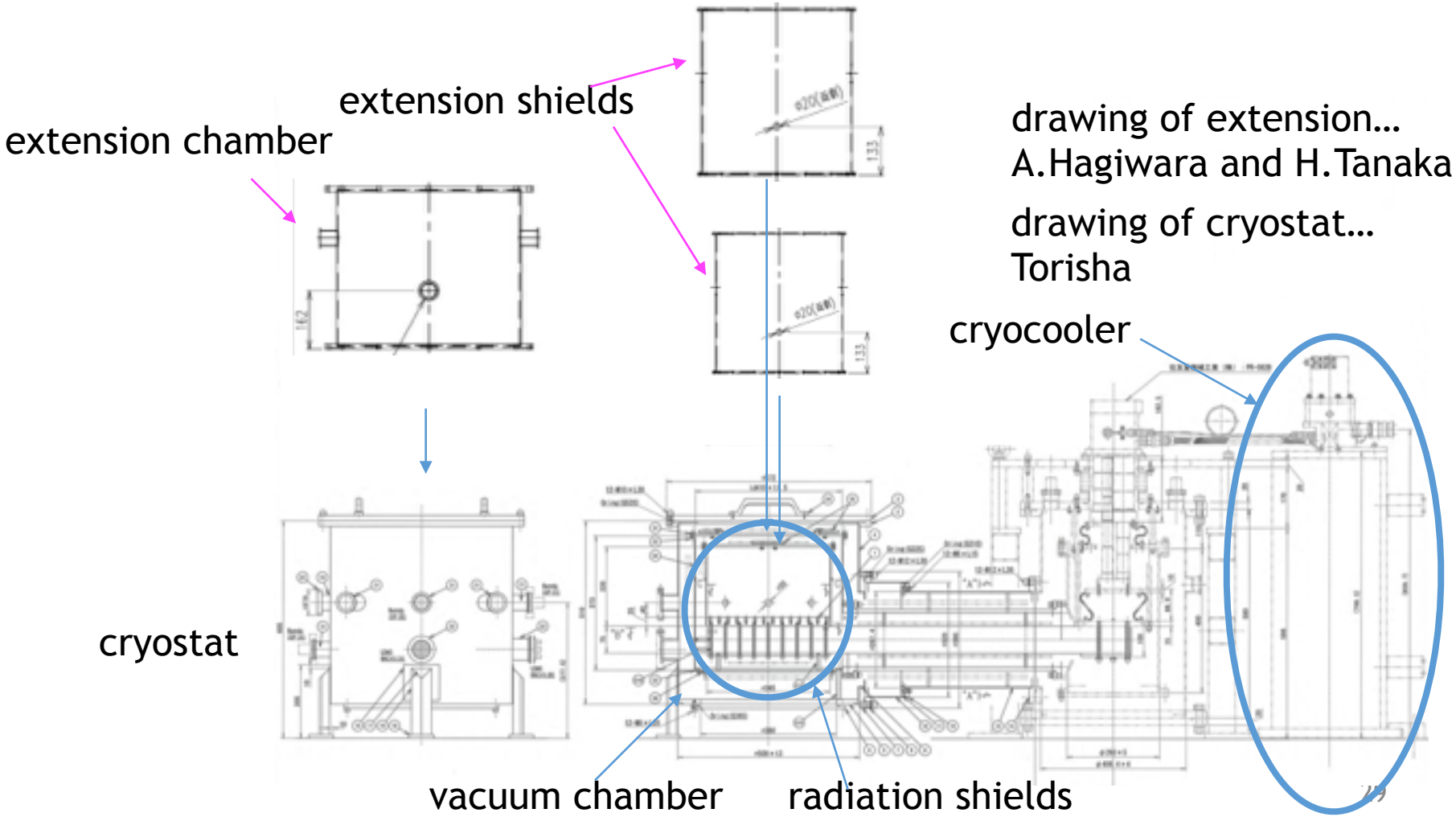
1.Introduction

1-5.Extension of the cryostat

- We will measure the Q-value of the 350mm sapphire fiber in ICRR.
- The cryostat in ICRR is too small to install the 350mm fiber.
- We asked Mechanical Engineering Center in KEK to construct the extension of the cryostat. They will be delivered on the end of October.

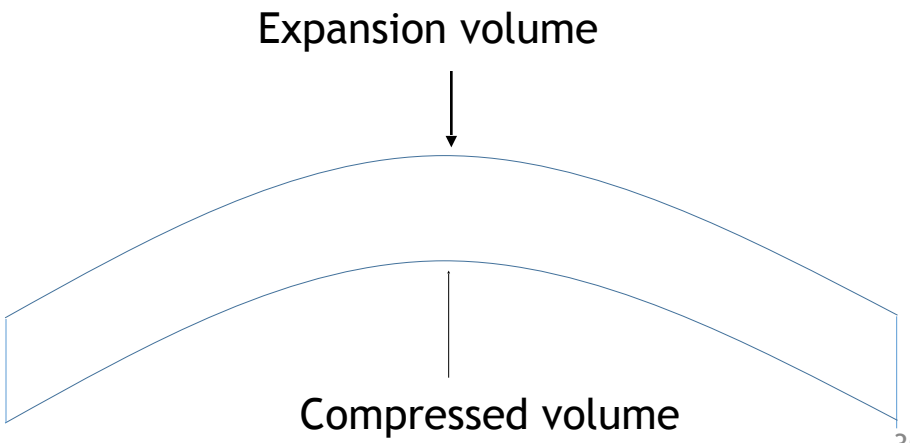
1.Introduction

1-5.Extension of the cryostat



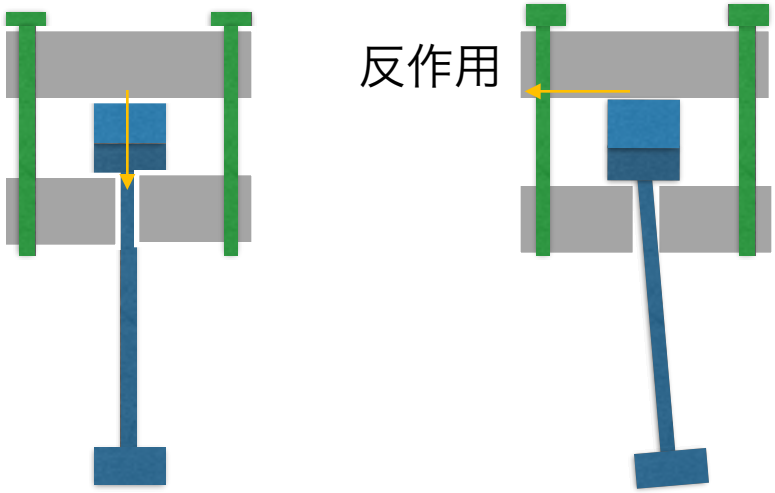
Thermoelastic damping

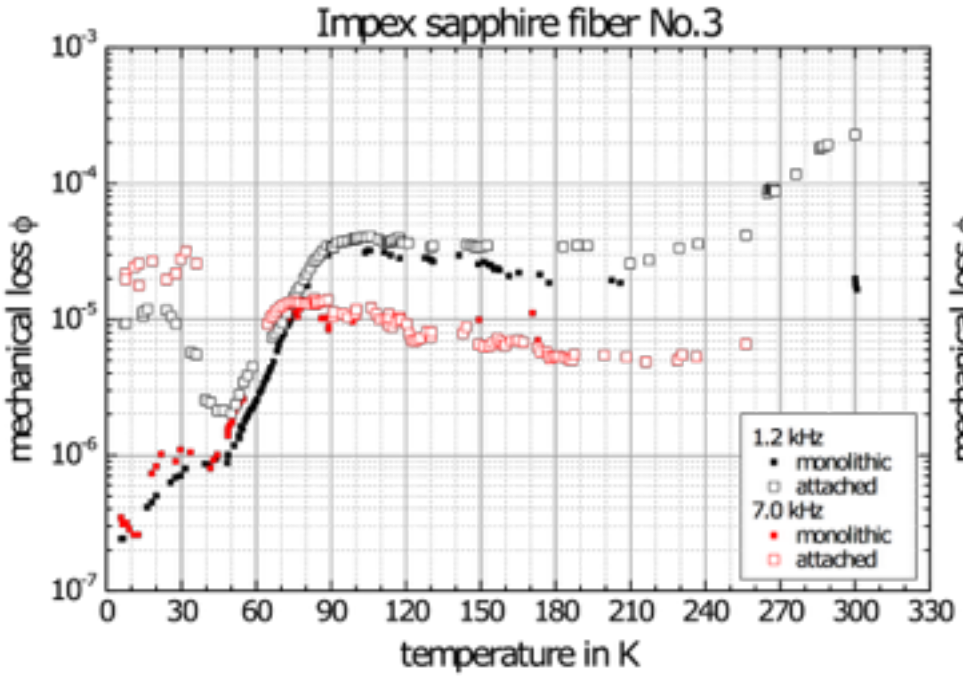
- When the fiber is bended, temperature gradient appears between the compressed volume and the expansion volume.
- Heat flow between the compressed and expansion volume to relax the temperature gradient. This is a source of the loss.

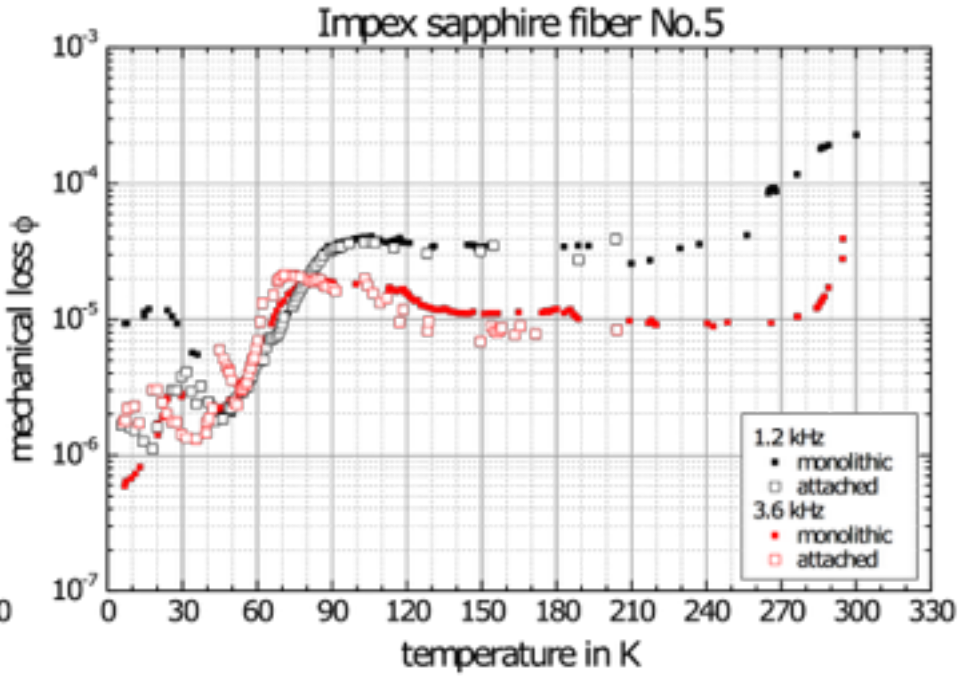


Al clamp and sapphire block

0.75N・mだと上のクランプがrecoil lossで揺れ、Q下がったかも

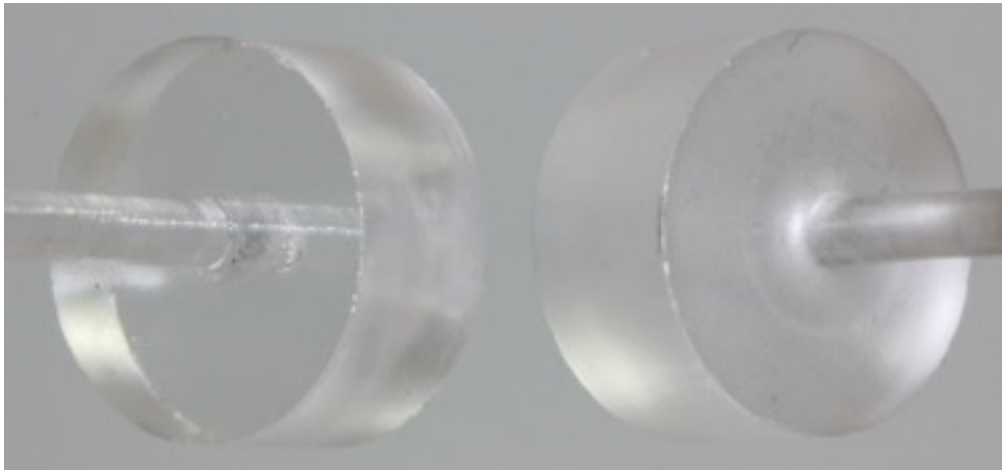






Comparison of two double nailhead fibers clamped at the monolithic (filled symbols) and the attached head (open symbols). At low temperatures it seems like the monolithic head provides lower losses.

Attached head



Monolithic head

Measurement in Rome