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

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Outline

- In KAGRA, Q(reciprocal of the mechanical loss) of the fiber must be more than 5×10^6 in order to reduce the thermal noise.
- At the first experiment in Rome, the measured Q-value of the test piece was 10^7. However in our lab(ICRR), the measured Q-value of the same piece was less than 3×10^6.
- We expect that the support system of the fiber has problems.
- We developed three types of support system and compared Q-values of the fibers of them.

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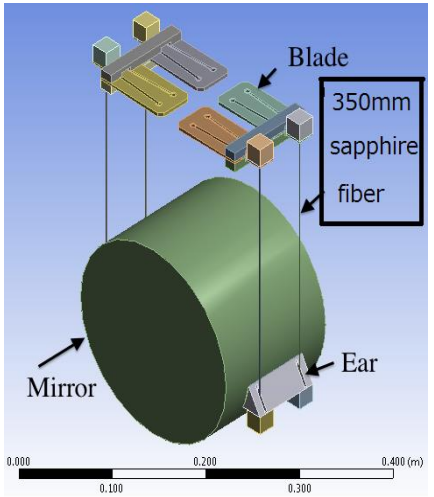
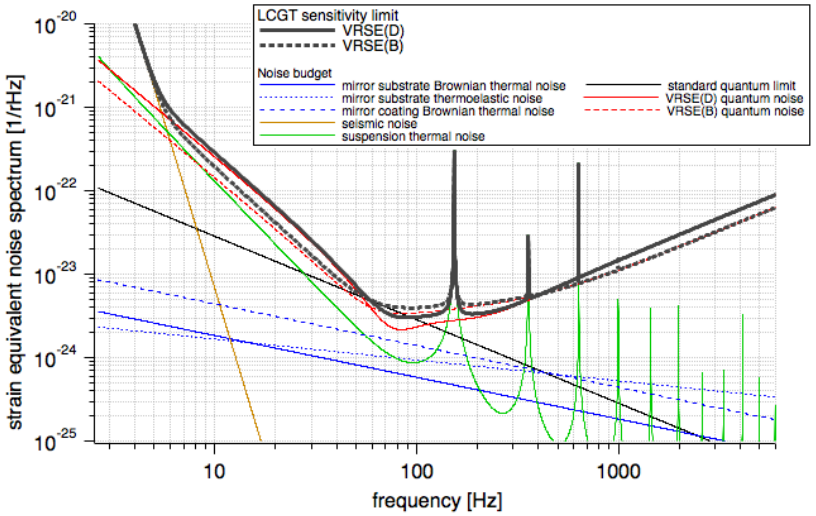
1.Introduction

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 is one of the most serious issues.



1.Introduction

1-2.Thermal noise

- The thermal noise is smaller at the lower temperature and with smaller mechanical loss in fiber.

＜In KAGRA＞

・T=20(K)

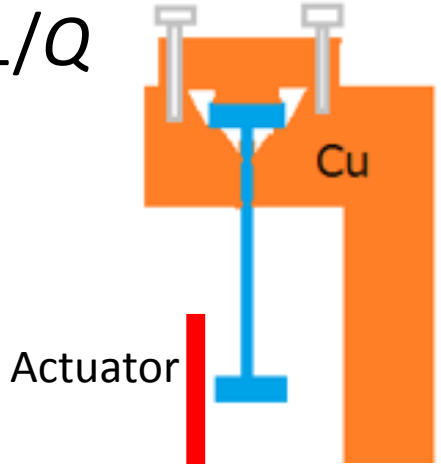
・The mirrors are suspended by sapphire fibers(350mm length) because the mechanical loss of sapphire could be extremely small at low temperature. (cf. Physics Letters A, 273(2000),310, T. Uchiyama et al)

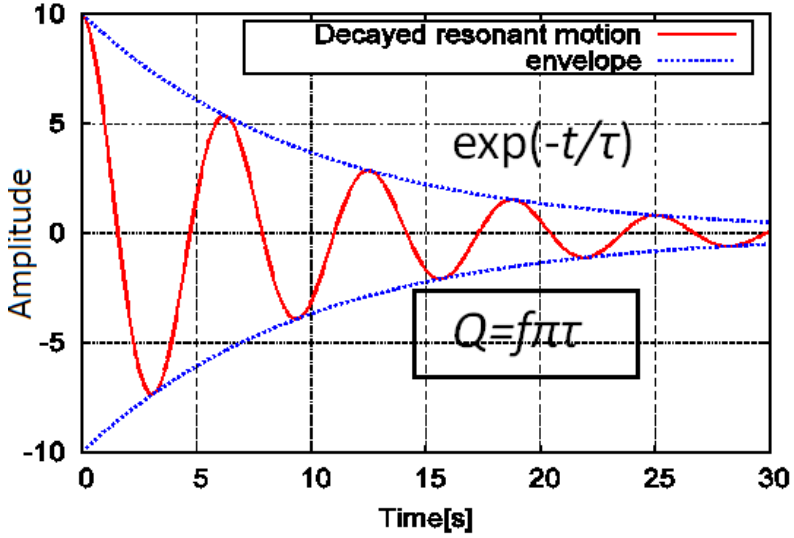
・We should check the Q-value of the 350mm sapphire fiber for KAGRA sapphire suspension.

1.Introduction

1-3. Measurement

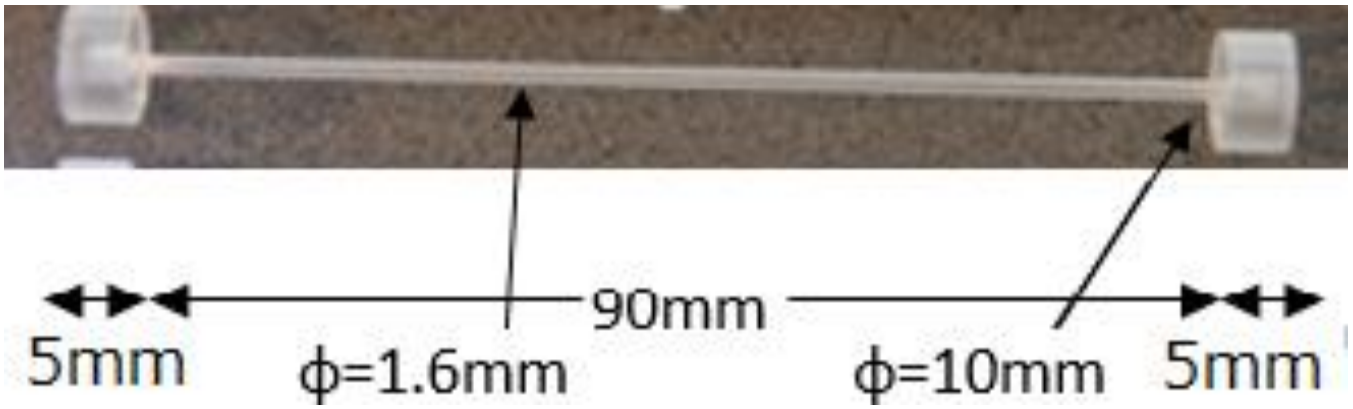
- The resonant elastic vibration of sapphire fiber is excited by an electrostatic actuator. After that, we stop the excitation of the actuator.
- Then we measure the decay time(τ).
- Q-value is defined as $Q=f\pi\tau$.(f:resonant frequency)
- $\varphi=1/Q$





1.Introduction
1-4.test piece

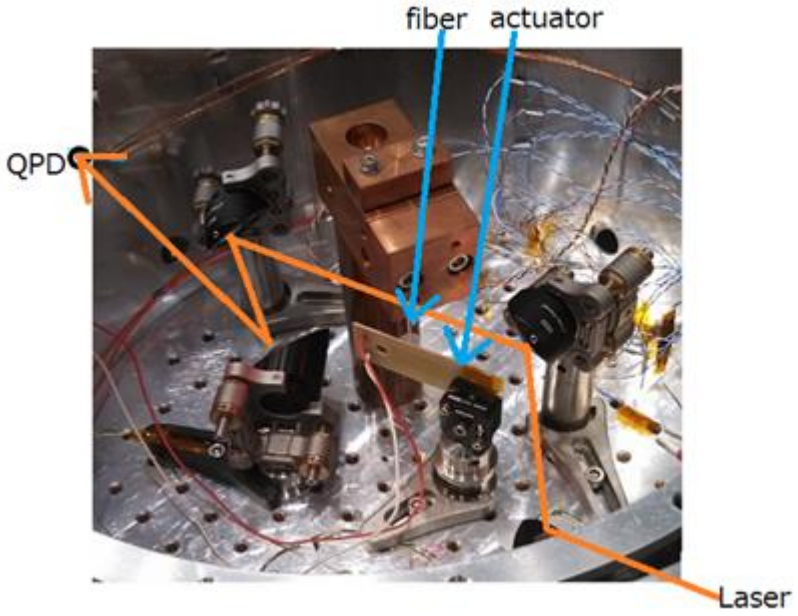
- Shorter test piece of the fibers.
- Sapphire heads are welded to the sapphire (HEM) pole.
- It was made by IMPEX.
- The highest Q-value was 10^7 (measured by Dr. D.Chen in Rome) (cf. requirement…5×10^6)

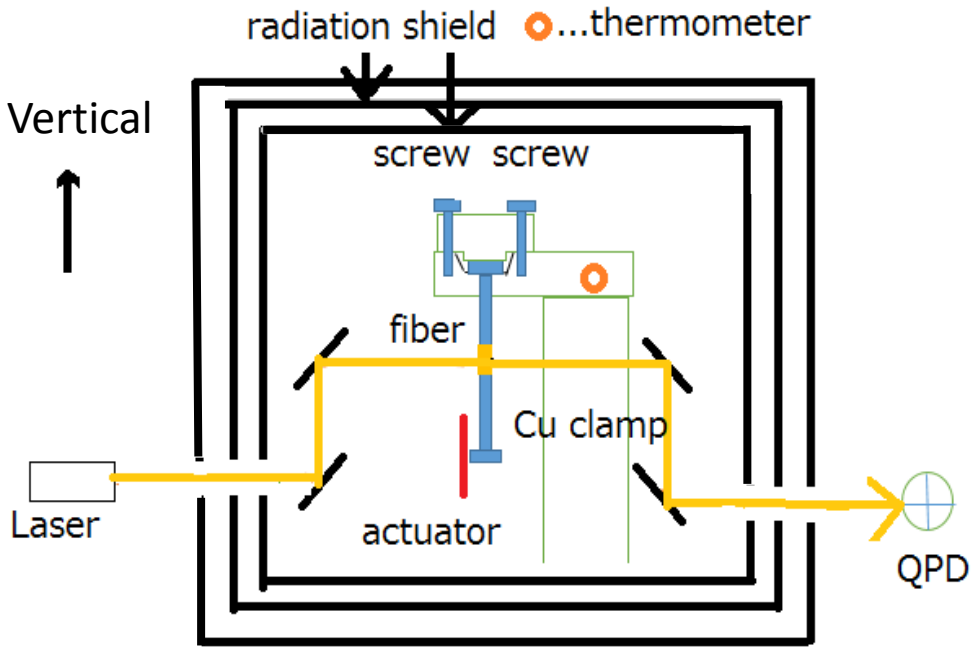


1.Introduction

1-5.experiment apparatus in ICRR

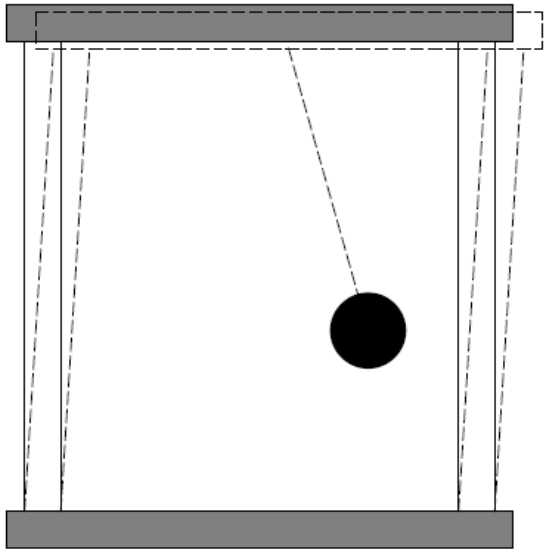
We constructed the apparatus in ICRR and measured the Q-value of the fiber whose Q-value was measured by Dr. D.Chen.





1.Introduction
1-6.Issue

- In ICRR, the Q-value of the fiber was less than 3×10^6.
- We expect that the recoil loss is an issue.
- Measured Q-value depends on not only sapphire fiber itself but also the loss of the support system.
- It is necessary to develop the support system where the recoil loss is absolutely small and the measured Q satisfies KAGRA requirement.

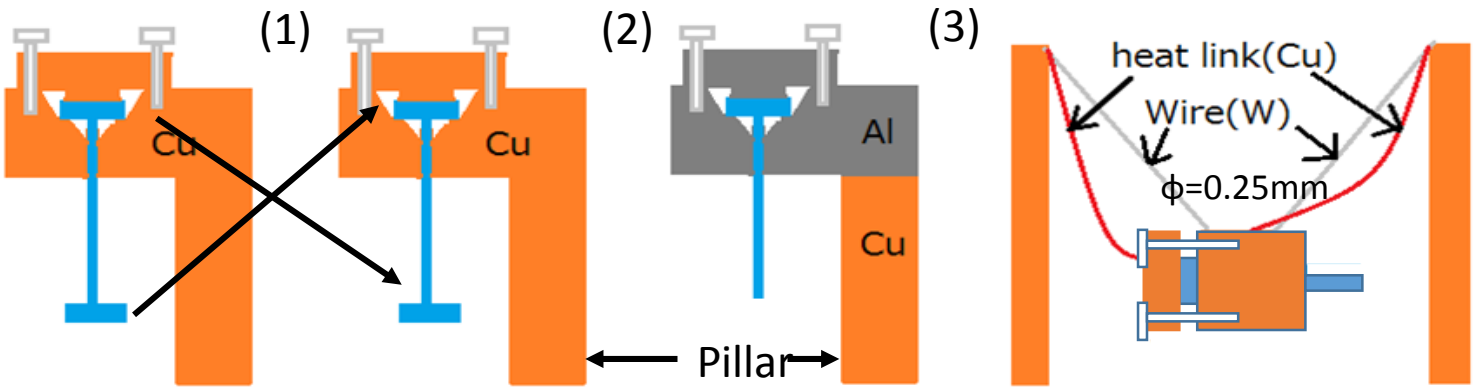


2.Experiment

(1)The Q measured at first was low→We turned the fiber upside down.

(2)The copper clamp could make mechanical loss larger:Cu→Al5056(Just before changing, the lower head was broken.)

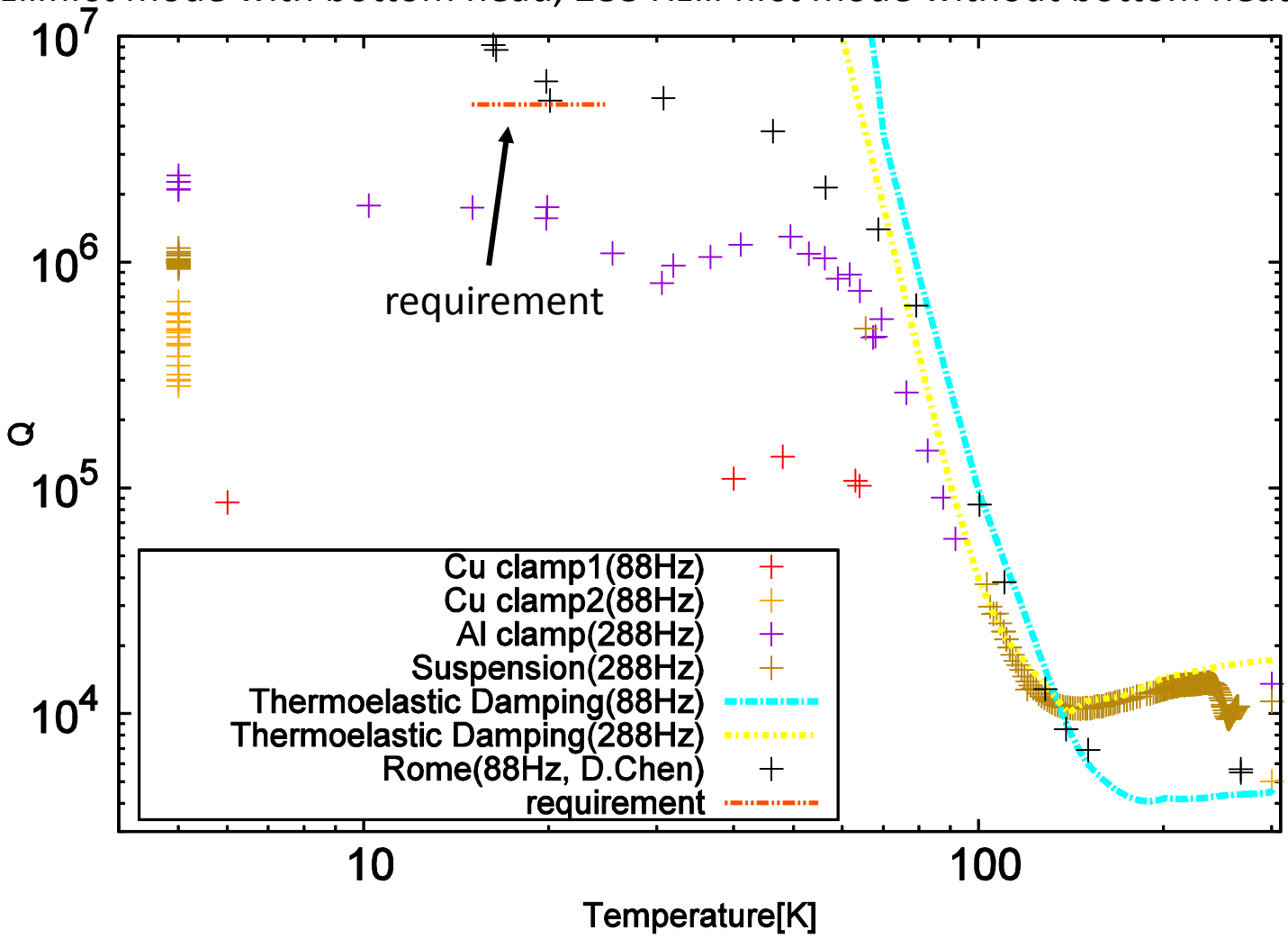
(3)The mechanical loss in copper pillar could limit Q measurement:Pillar→Suspension



3.Result(1st mode)

3-1.Result

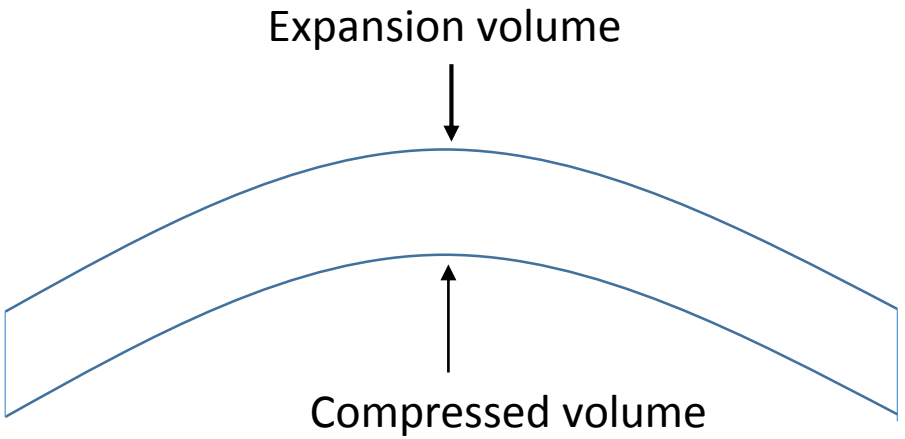
88 Hz…first mode with bottom head, 288 Hz… first mode without bottom head



3.Result(1st mode)

3-2.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.



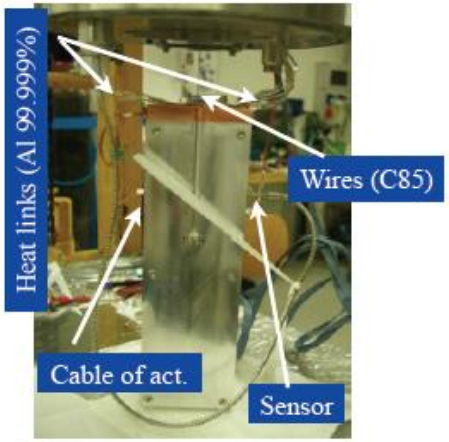
4.Discussion

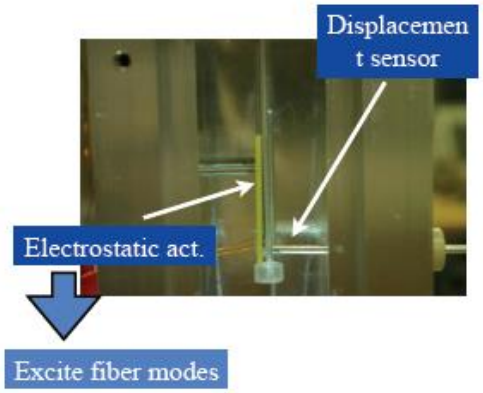
- Above 100K, Q-value can be comparable with that by thermoelastic damping.
- The loss of the copper clamp could be large because the Q-value was lower than that measured by D.Chen even after we turned the fiber upside down.
- The Q-value of Al clamp case is the highest. However, the surface of Al5056 clamp was dented by the fiber easily.
- The Q-value with the suspended copper clamp is higher than that with the fixed copper clamp. We will improve the copper clamp suspension system. For example, we will develop a heavier clamp.

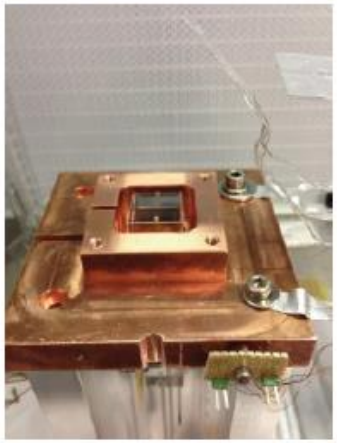
5.Summary

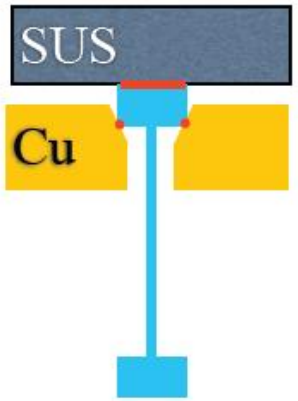
- We must measure the Q-value of the sapphire fibers for KAGRA.
- The fiber Q-value(10^7) measured in Rome is high enough for KAGRA. However the Q-value ($<3 \times 10^6$) measured in ICRR is lower because of the recoil loss.
- We measured the Q-values with fixed copper clamp, fixed Al5056 clamp and suspended copper clamp.
- As the next step, we will investigate suspended copper clamp (for example heavier).

Measurement in Rome

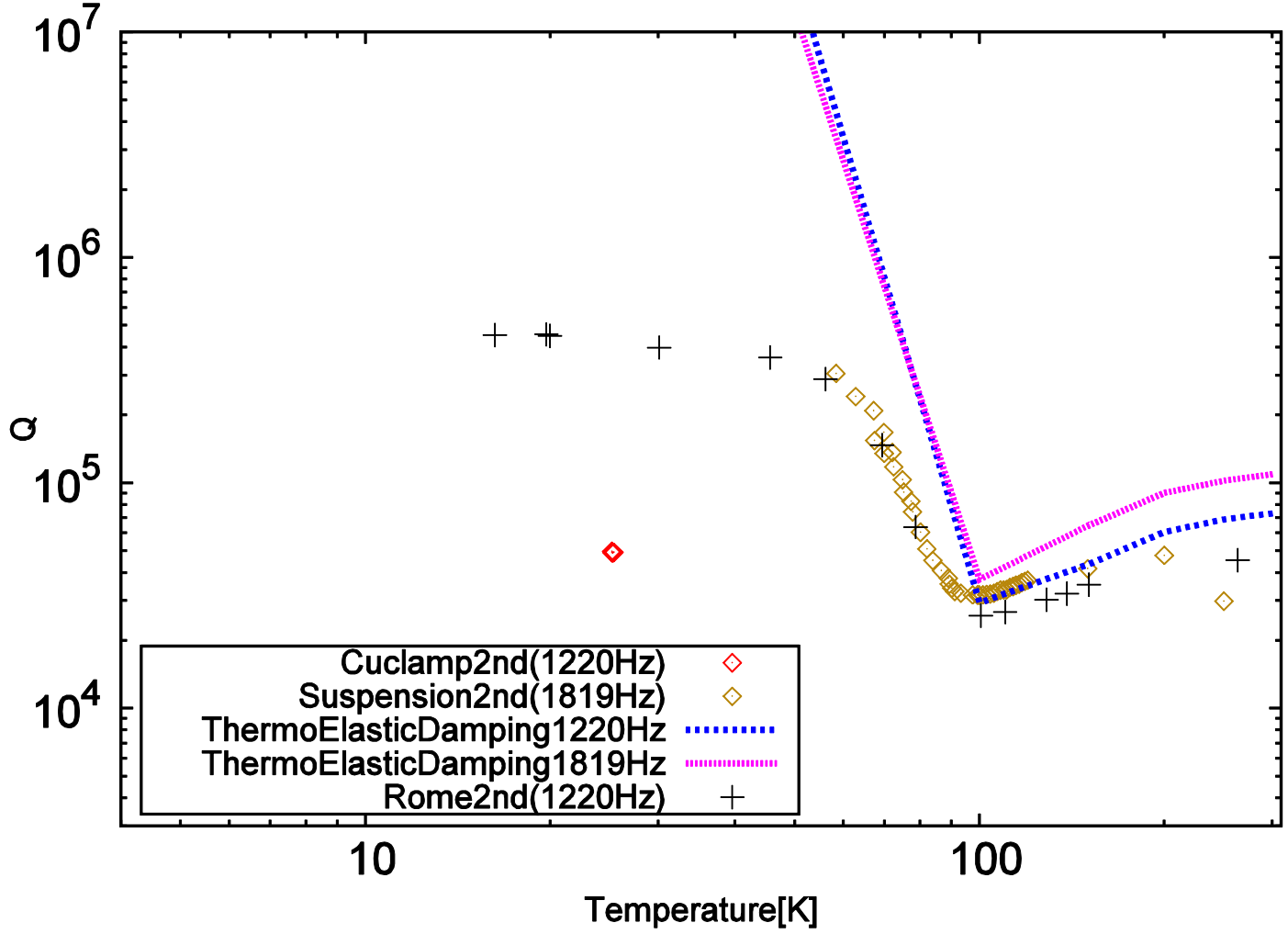








2nd mode


Q
Temperature[K]
10
100
Cuclamp2nd(1220Hz)
Suspension2nd(1819Hz)
ThermoElasticDamping1220Hz
ThermoElasticDamping1819Hz
Rome2nd(1220Hz)

Suspension 1st~3rd