Mechanical loss of optical coating at low temperature

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0. Abstract

In order to evaluate the thermal noise of LCGT ....

(i) we measured the mechanical loss

of the reflective coating of the mirror

at low temperature.

(ii) we measured the mechanical loss

of the CaF_2, alternative material of the mirror,

at low temperature.

Contents

1. Introduction

LCGT : future Japanese project to construct

the interferometric gravitational wave detector

Thermal noise suppression in LCGT : cool mirror (20 K)

Thermal noise also depends on the mechanical loss.

Sapphire (material of mirror) : sufficiently small loss
(T. Uchiyama et al., Phys.Lett.A 261(1999)5.)

Loss of the reflective coating ?

measurement of the loss of the coating
at low temperature

2. Outline of Experiment

(i) Sapphire disk with and without coating

(ii) Measurement of decay time of resonant motion
at low temperature ⟶ Q-values

(iii) Estimation of coating loss from the measured Q-values

Advantage of this experiment

(i) Thin disk : large effect of coating loss

(ii) Resonant frequencies (>500Hz)

are near the observation band (about 100Hz).

2-1. Sapphire disk and coating

Sapphire disk : ϕ100 mm t 0.5 mm and t 1 mm

commercial polish (both sides)

Shinkosya (Japanese company)

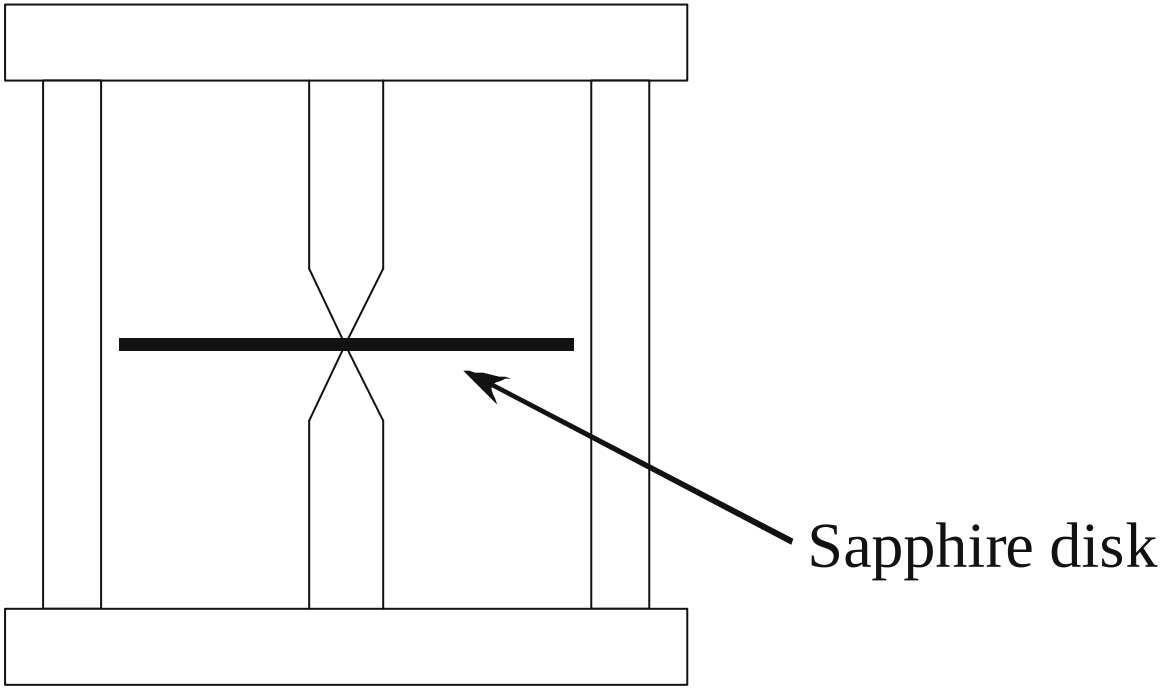
Coating : IBS @ National Astronomical Observatory of Japan
(K.Waseda)
and Japan Aviation Electronics Industry, Ltd.
(TAMA mirror coating by JAE.)

Ta_2O_5/SiO_2 (31 layers) : typical material

Reflectivity is the same
as that of typical end mirror (>99.99%).

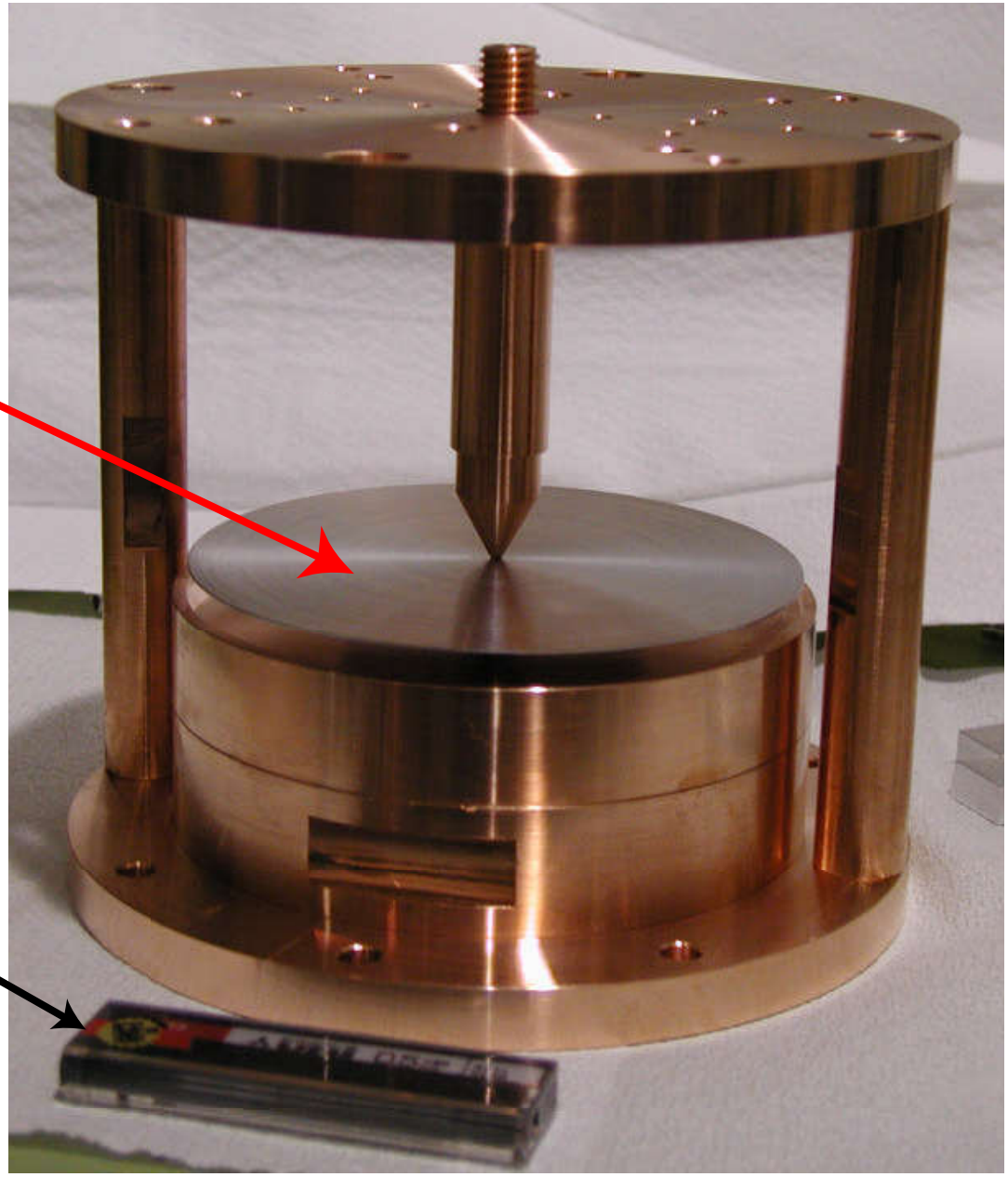
2-2. Support system

Nodal support system (K.Numata et al., Phys.Lett.A 276(2000)37.)



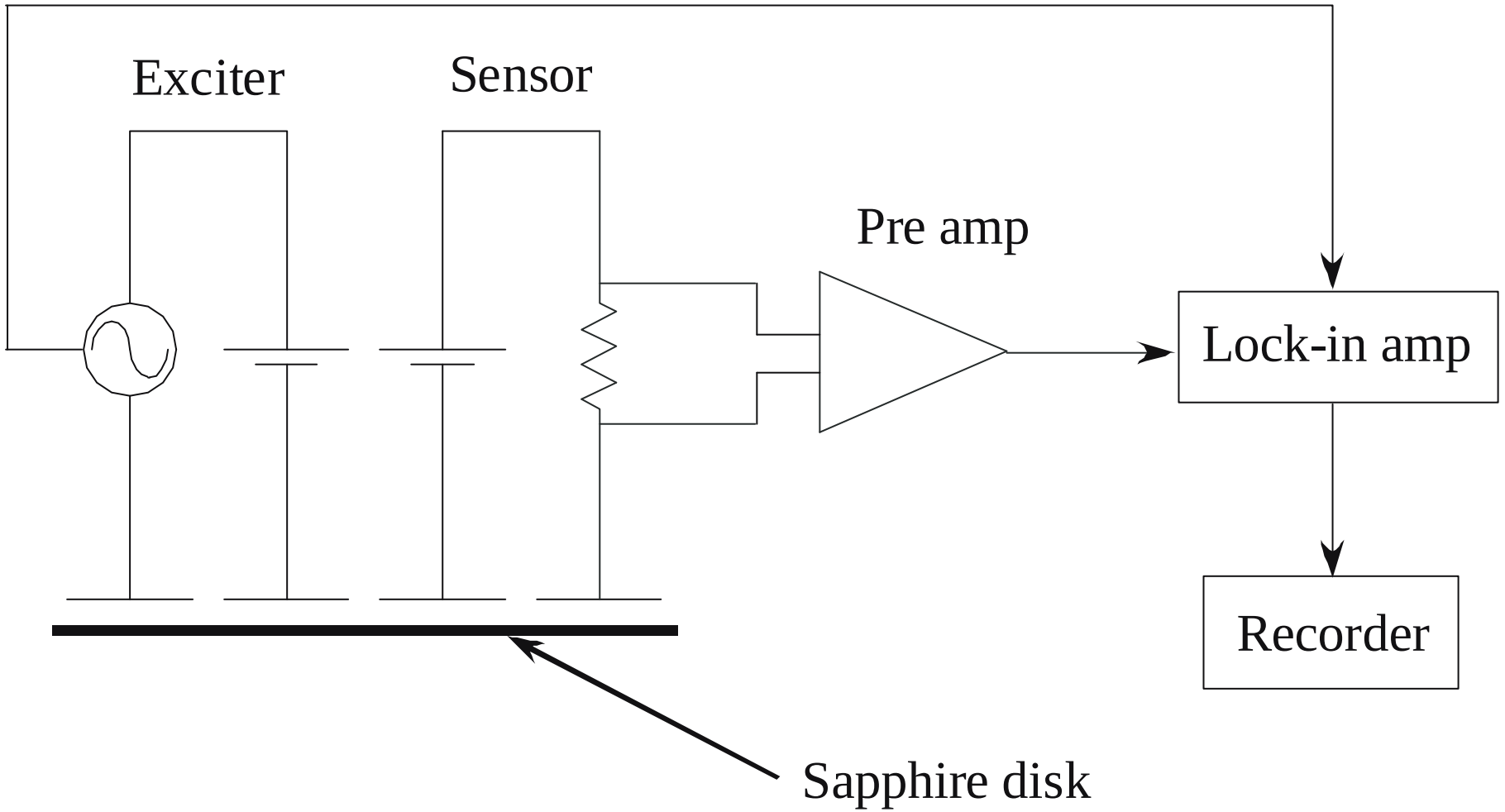
Our system : Copper (for cooling)

Nodal support system

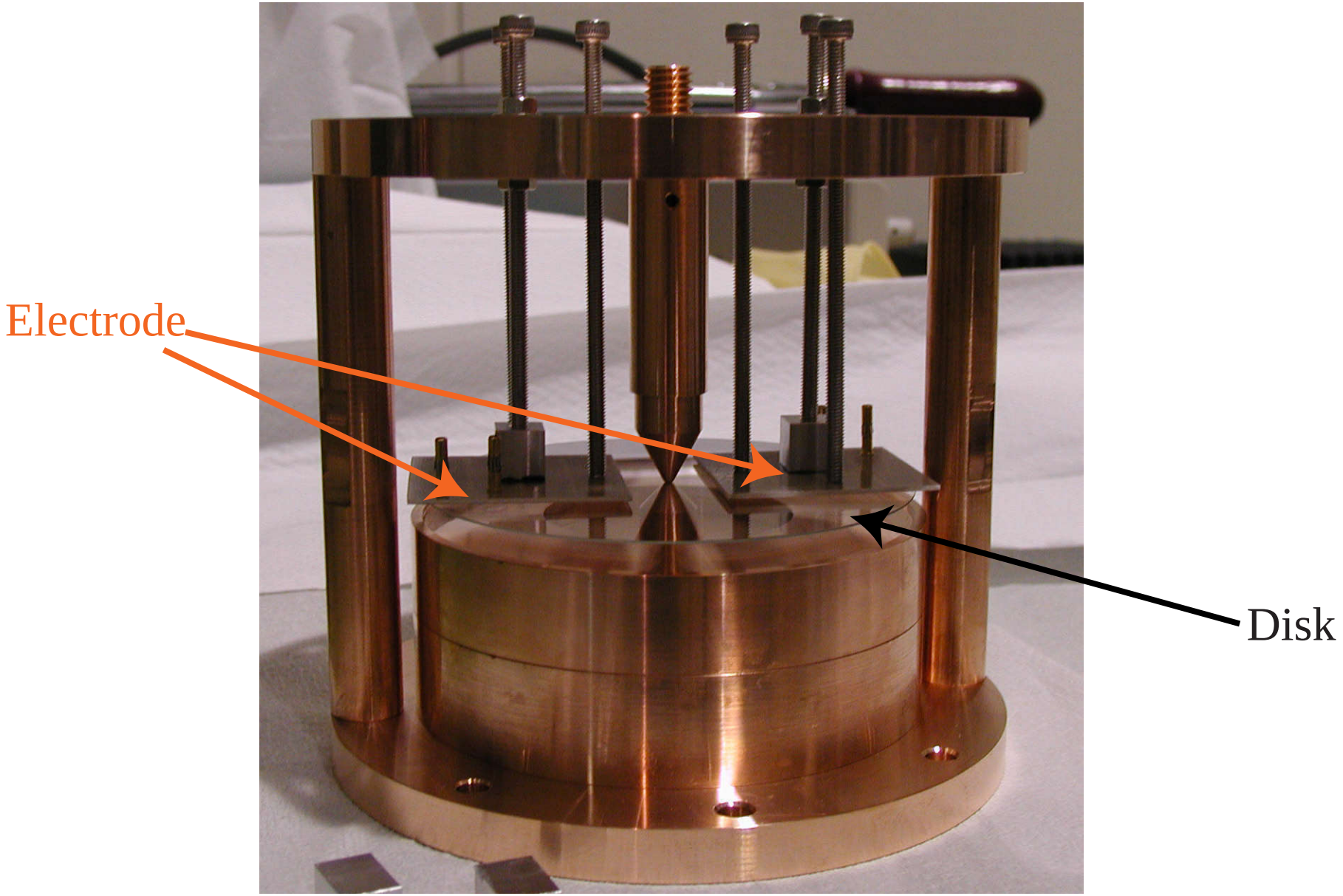


2-3. Exciter and sensor

electrostatic actuator and electrostatic transducer



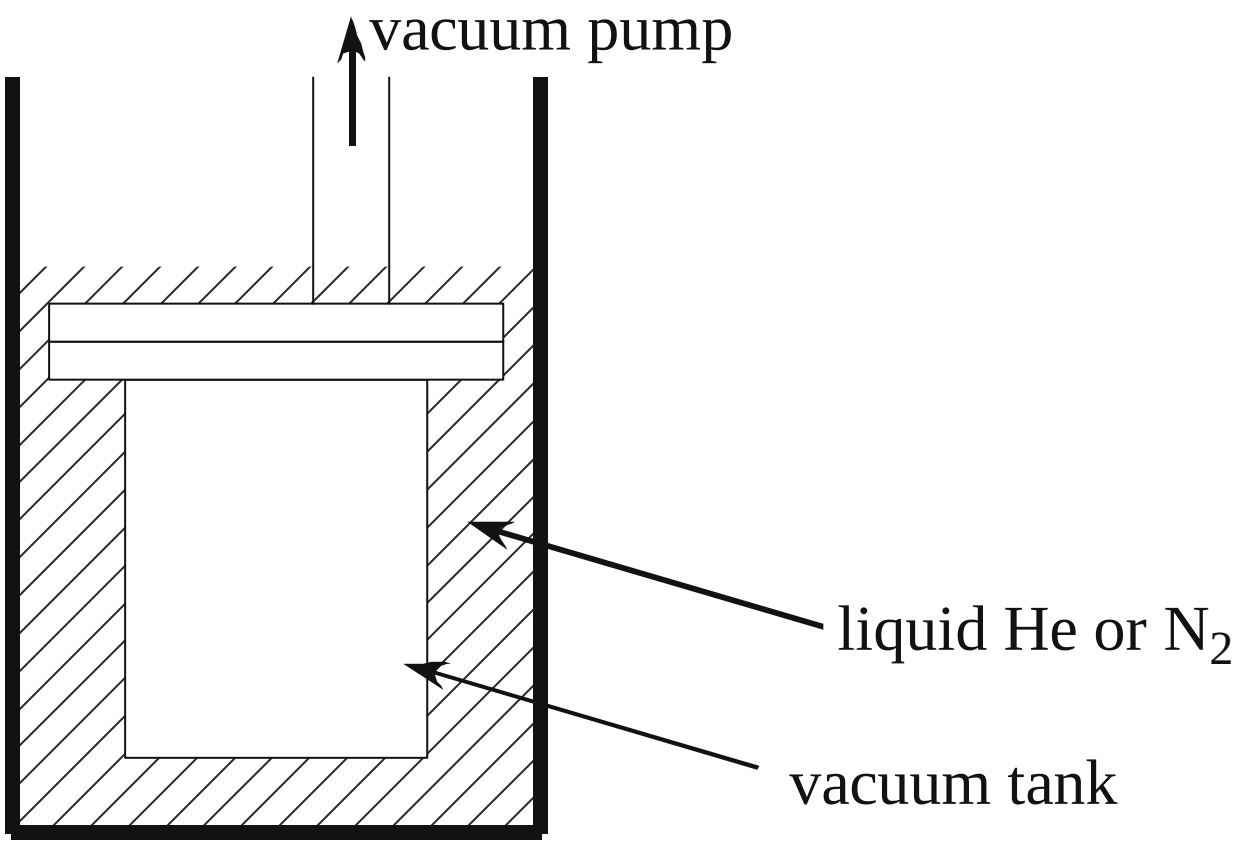
Exciter and sensor



2-4. Cooling

Vacuum tank in liquid He or N_2

at KEK(High Energy Accelerator Research Organization)



3.Result

3-1. Samples

measured sapphire disks

NAO coating : t 0.5, 1 mm disk , without annealing

JAE coating : t 1 mm disk , with and without annealing

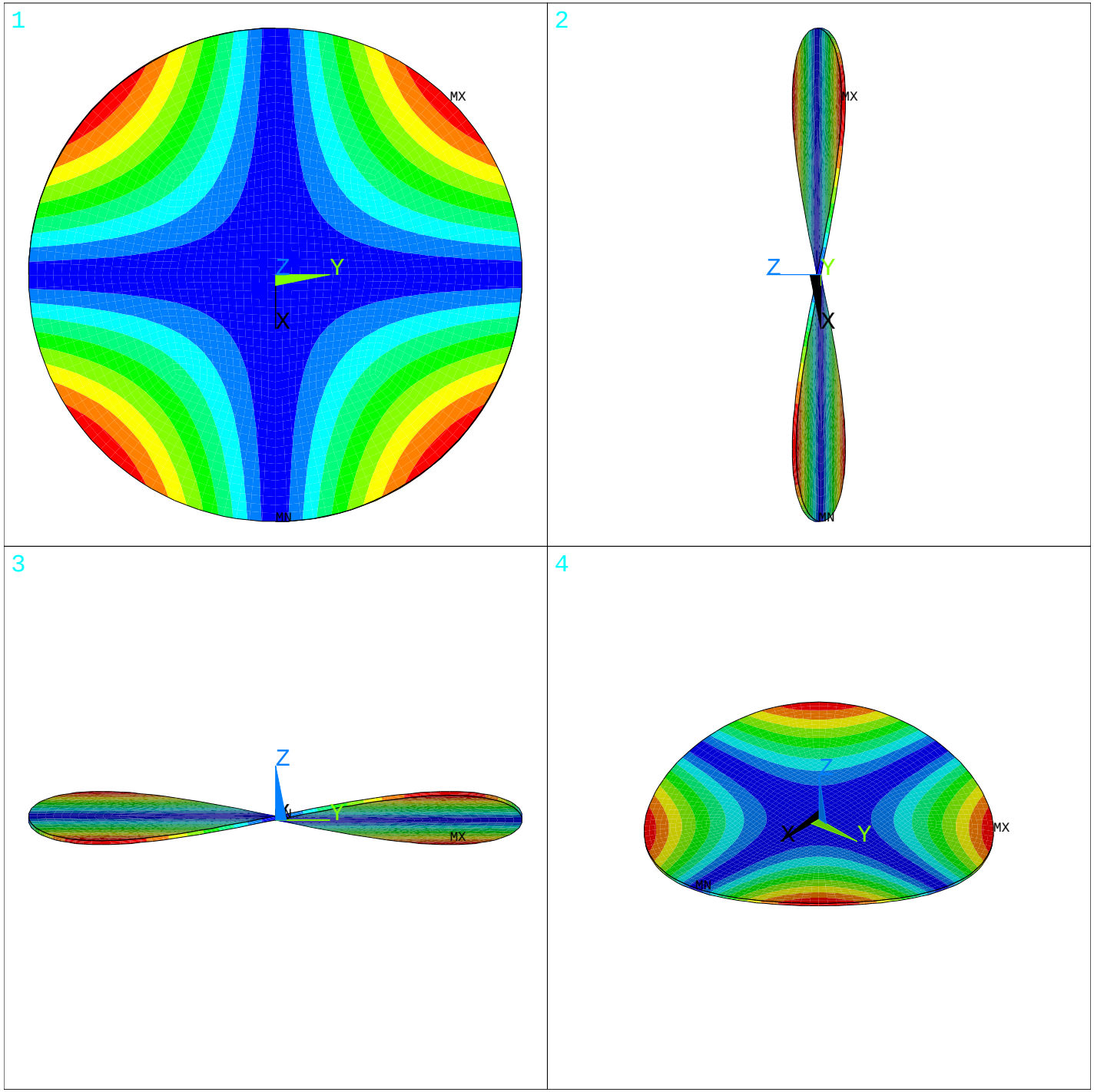
no coating : t 0.5, 1 mm disk

measured modes : first and third mode

	first mode	third mode
t 0.5 mm	520 Hz	1200 Hz
t 1 mm	1100Hz	2500 Hz

K. Numata measured Q-values of fused silica disk at room temperature.

(NAO coating)



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SMX =10.099

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5.61
6.732
7.854
8.977
10.099

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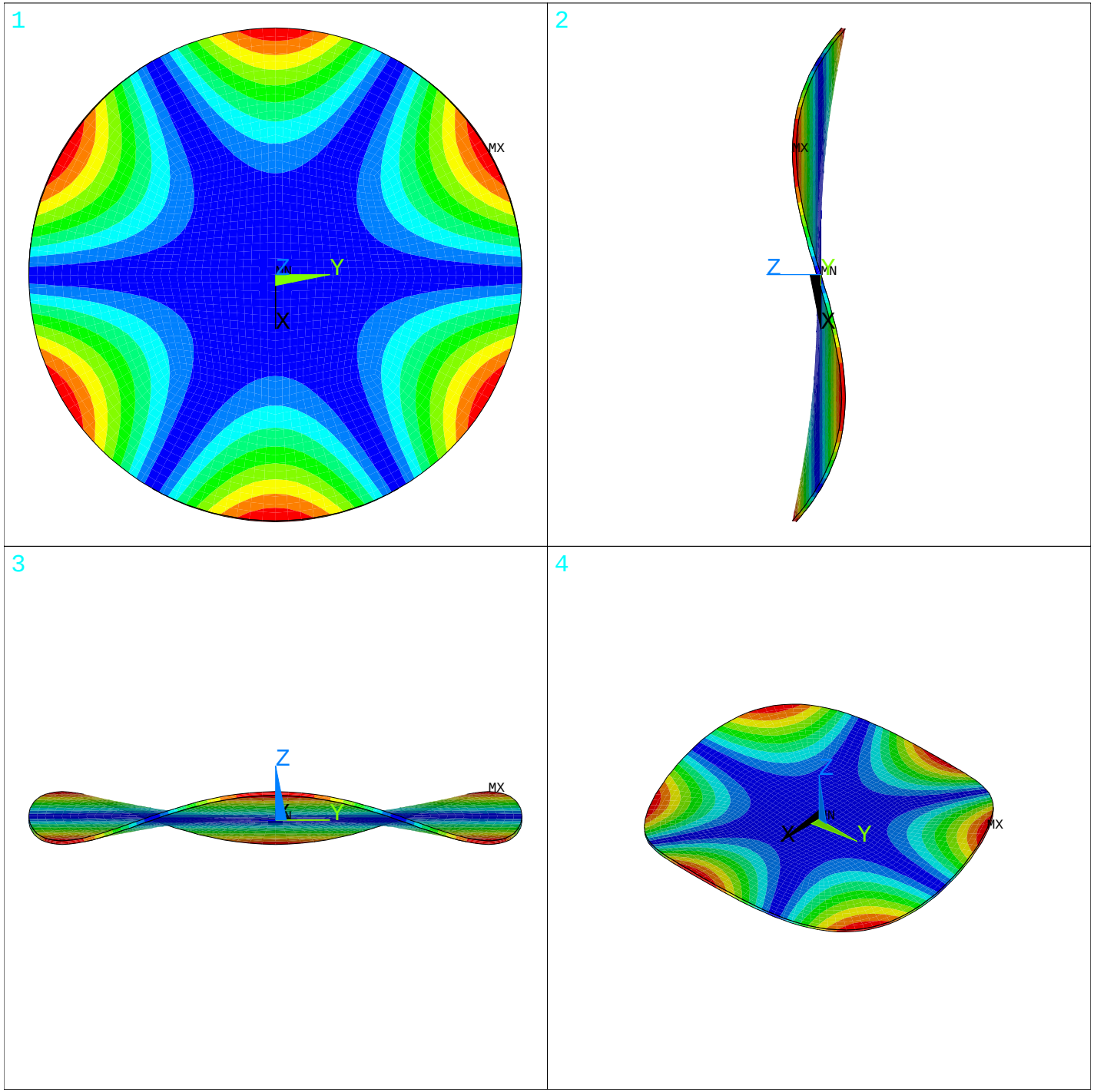

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6.161
7.393
8.625
9.857
11.09

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9.857
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.197E-05
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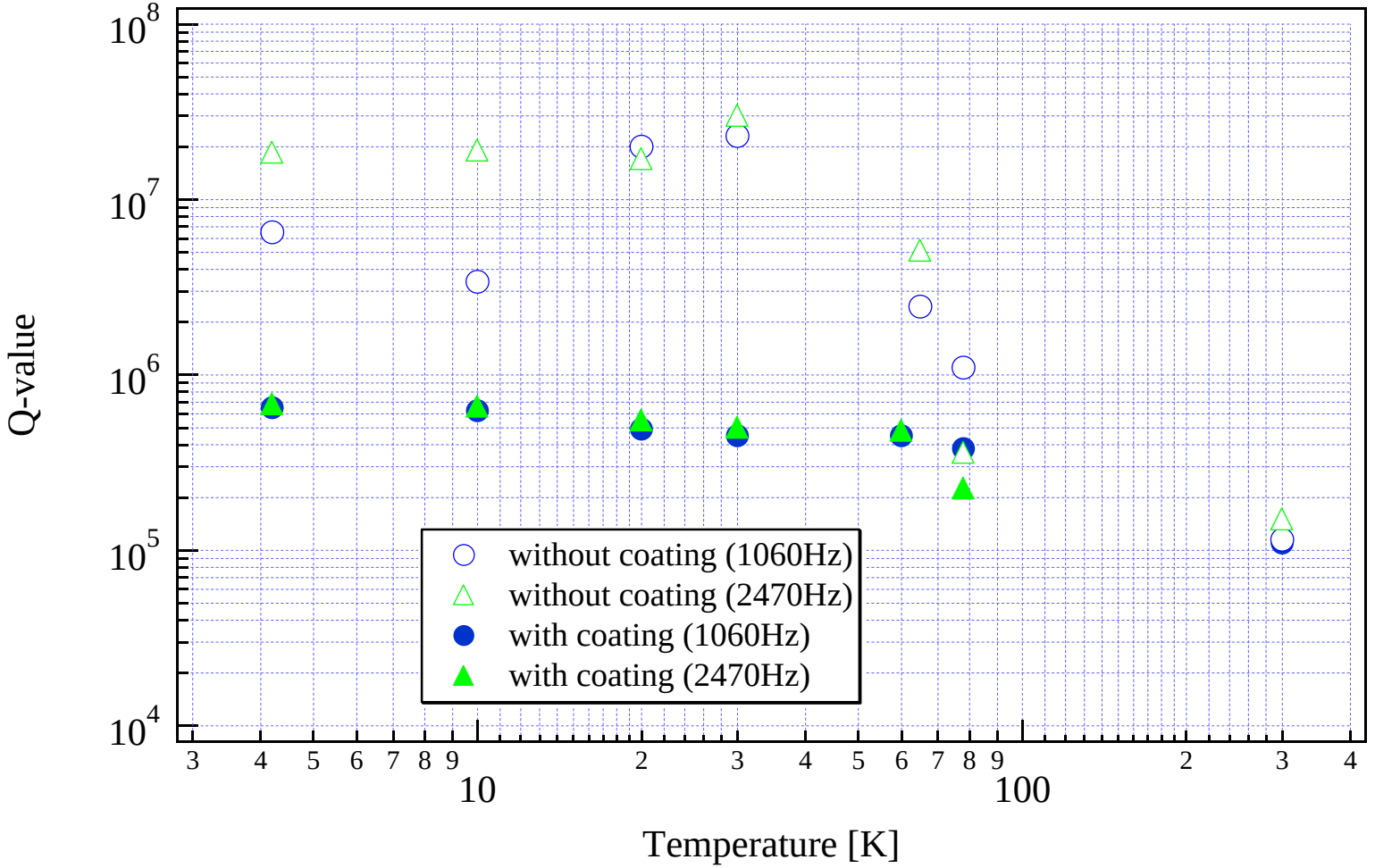
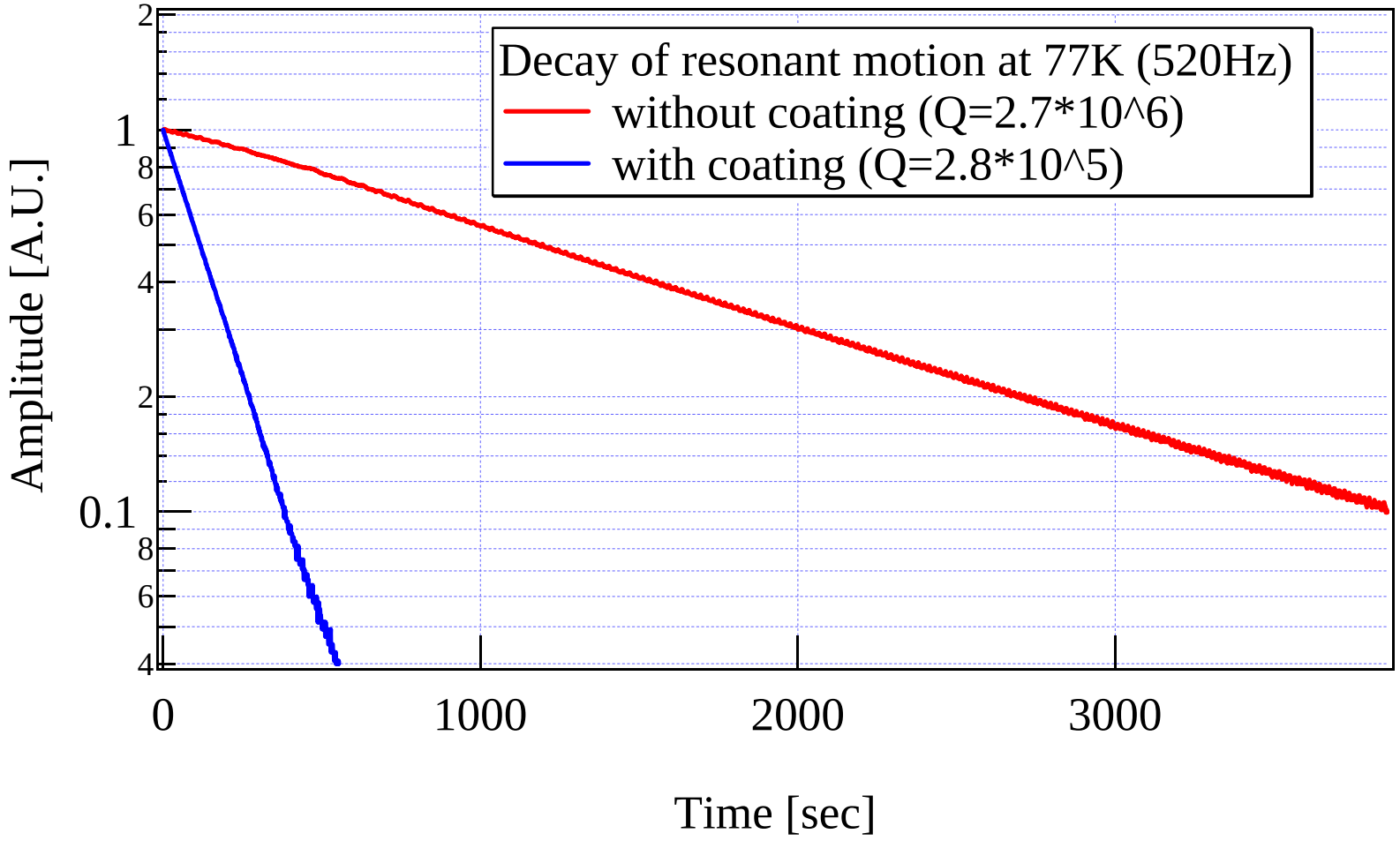
8.625
9.857
11.09

3-2. Measured Q-values

JAE coating on t 1mm disk with annealing

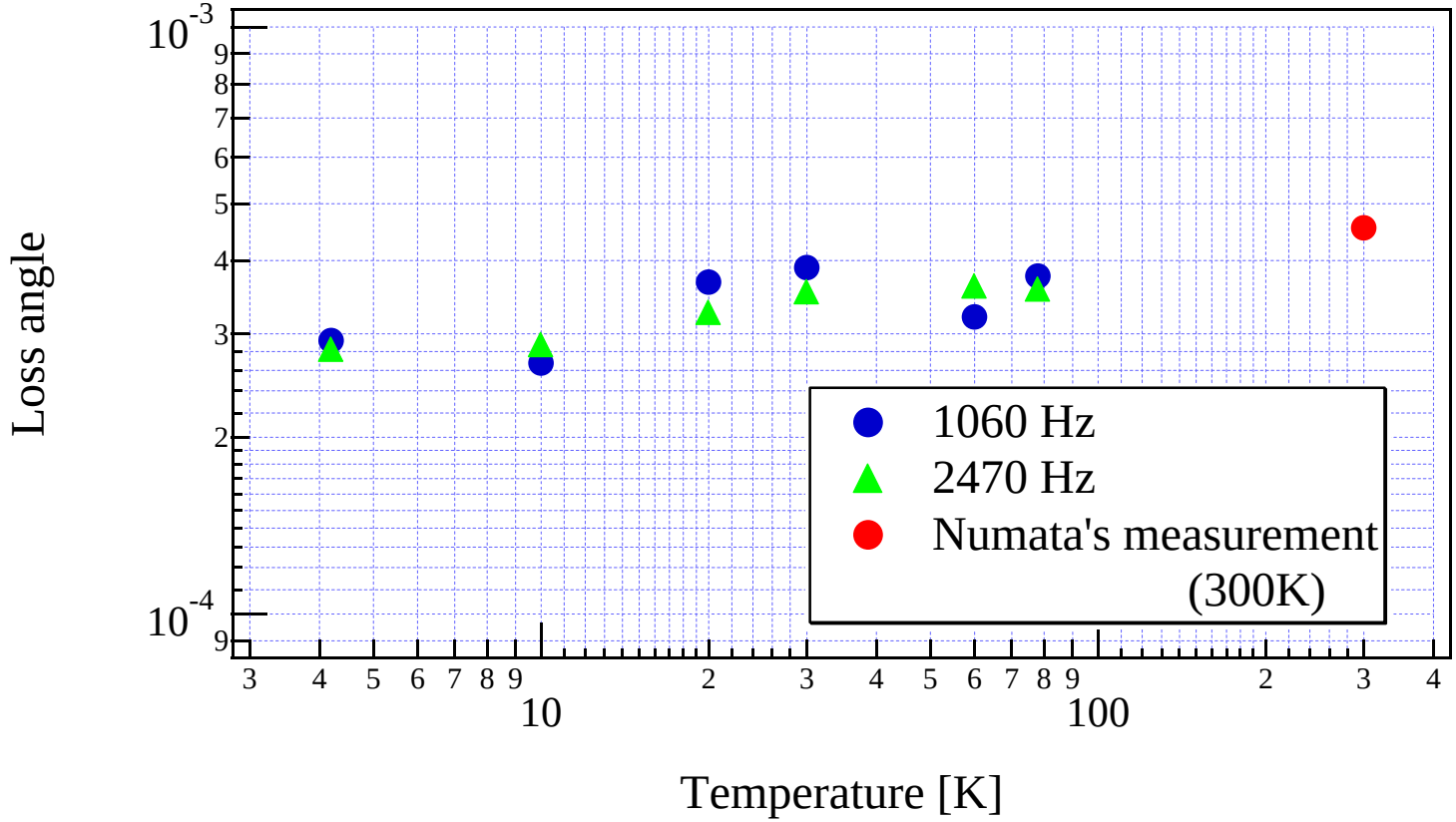


Decay of resonant motion

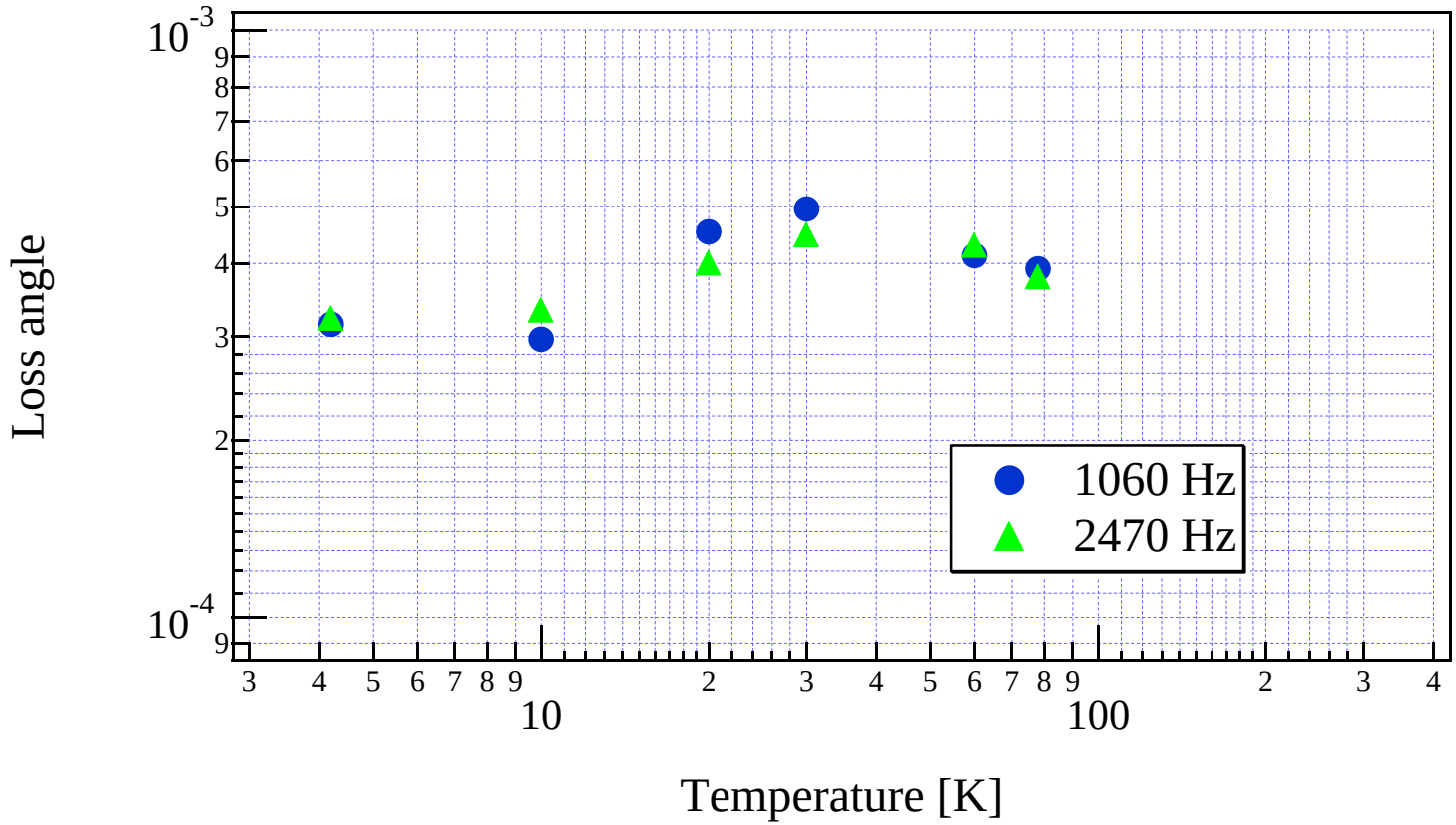


3-3. Loss angle of coating

NAO coating on t 1mm disk
without annealing



JAE coating on t 1mm disk
with annealing



3-4. Summary of results

(i) Loss angle of coating is about $4*10^{-4}$.

This value is not so good.

Measurement of other groups at 300K : $6*10^{-5}$ -$4*10^{-4}$

(ii) Loss angle of all samples in all cases are the same.

Loss of JAE coating is as large as that of NAO coating.

Loss angle of coating does not depend on temperature, resonant frequency, thickness of sapphire disk.

Annealing does not affect loss of coating.

4. Discussion

4-1. Property of coating loss

(i) Loss angle is independent of temperature (4.2K-300K).

Thermal noise of coating loss is proportional to $T^{1/2}$.

ex.) (thermal noise at 20 K) = (thermal noise at 300 K) /4

→ advantage of cryogenic interferometer

(ii) Loss angle is independent of temperature (4.2K-300K).

Expectation : Coating loss becomes larger at low temperature

because loss of cool SiO_2 is large.

↓

Coating loss is not dominated by intrinsic loss of SiO_2.

(iii) Loss angle is independent of resonant frequency and mode.

→ Structure damping model is valid.

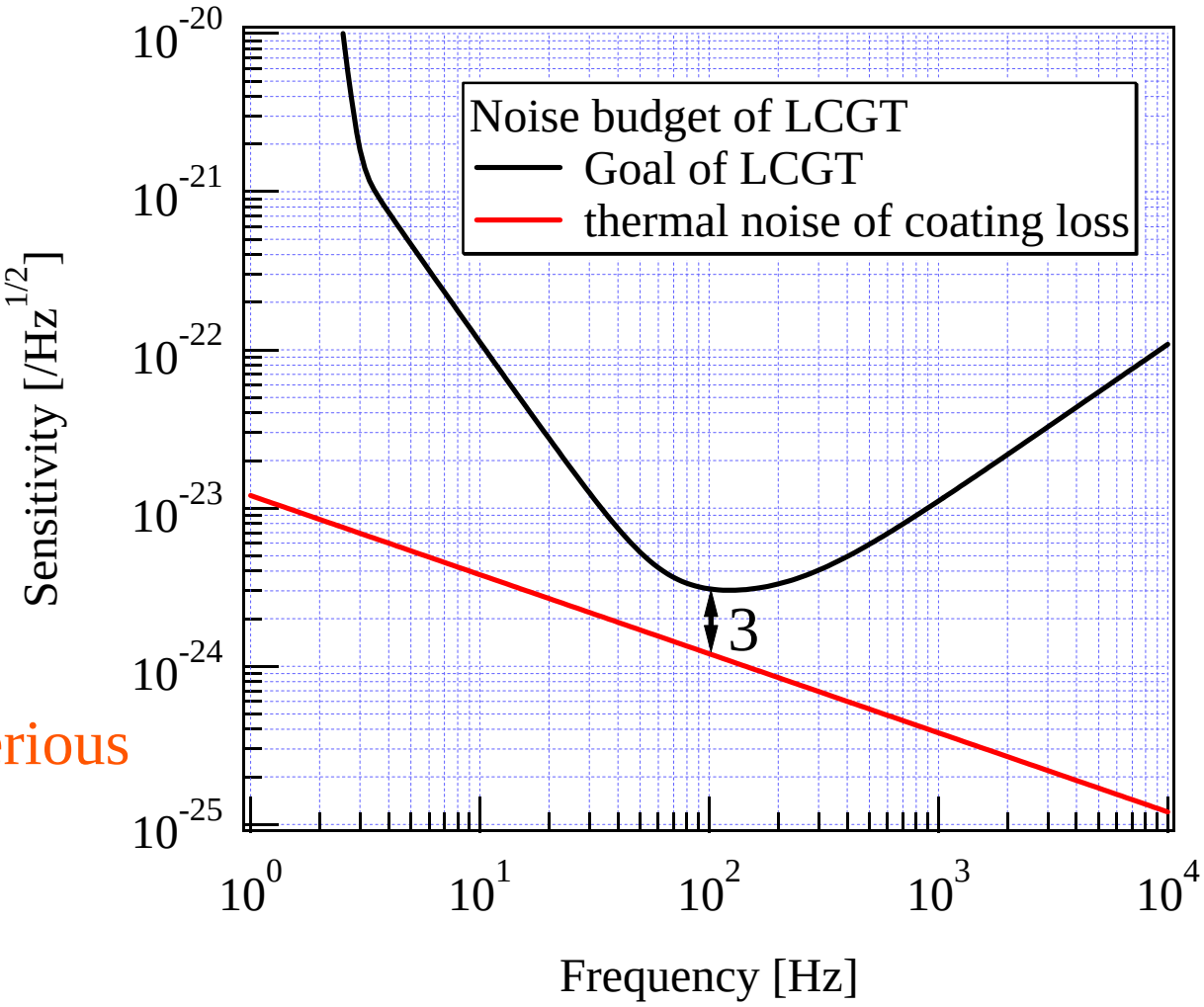
(iv) Loss angle is independent of thickness of disk.

→ Strain does not increase loss.

(v) Annealing does not change the loss angle.

→ Strain does not increase loss.

4-2. Thermal noise in LCGT



coating loss : not serious

5.Q-values of CaF_2

5-1. Motivation

sapphire : material of mirror in LCGT

small thermal noise, but large heat absorption (20ppm/cm, about 1W)

Alternative material ?

Material of future European project ? → CaF_2

small heat absorption (2ppm/cm, about 0.1W)

Is thermal noise is small ?

→ measurement of Q-values of CaF_2 at low temperature
using same apparatus for coating loss

5-2. Sample and experimental apparatus

CaF_2 disk : ϕ 100 mm t 3 mm

Both sides are polished.

Ouyou-kouken (Japanese company)

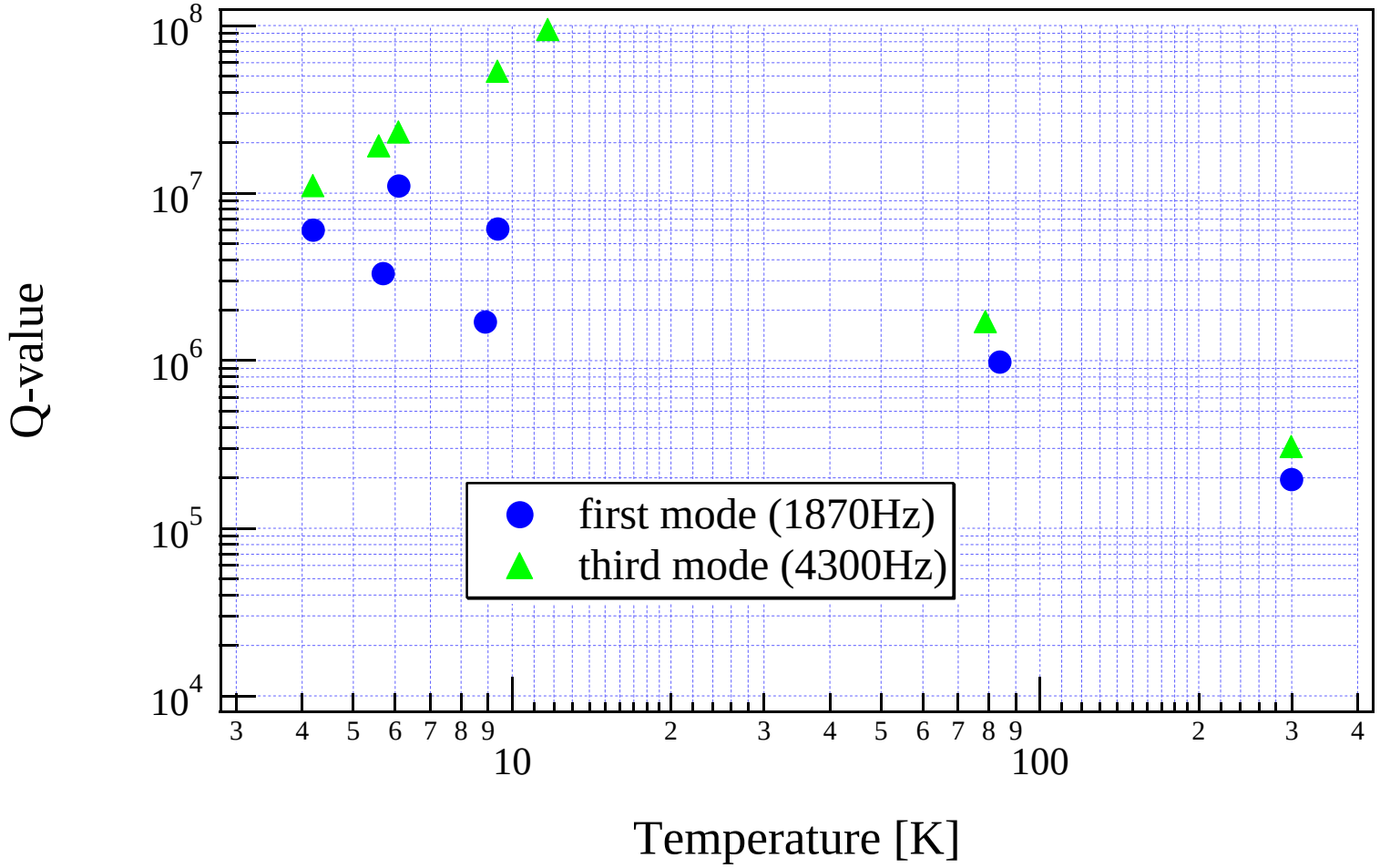
measured modes : first and third mode

	first mode	third mode
t 3 mm	1870Hz	4300 Hz

Experimental apparatus is the same as that for coating loss.

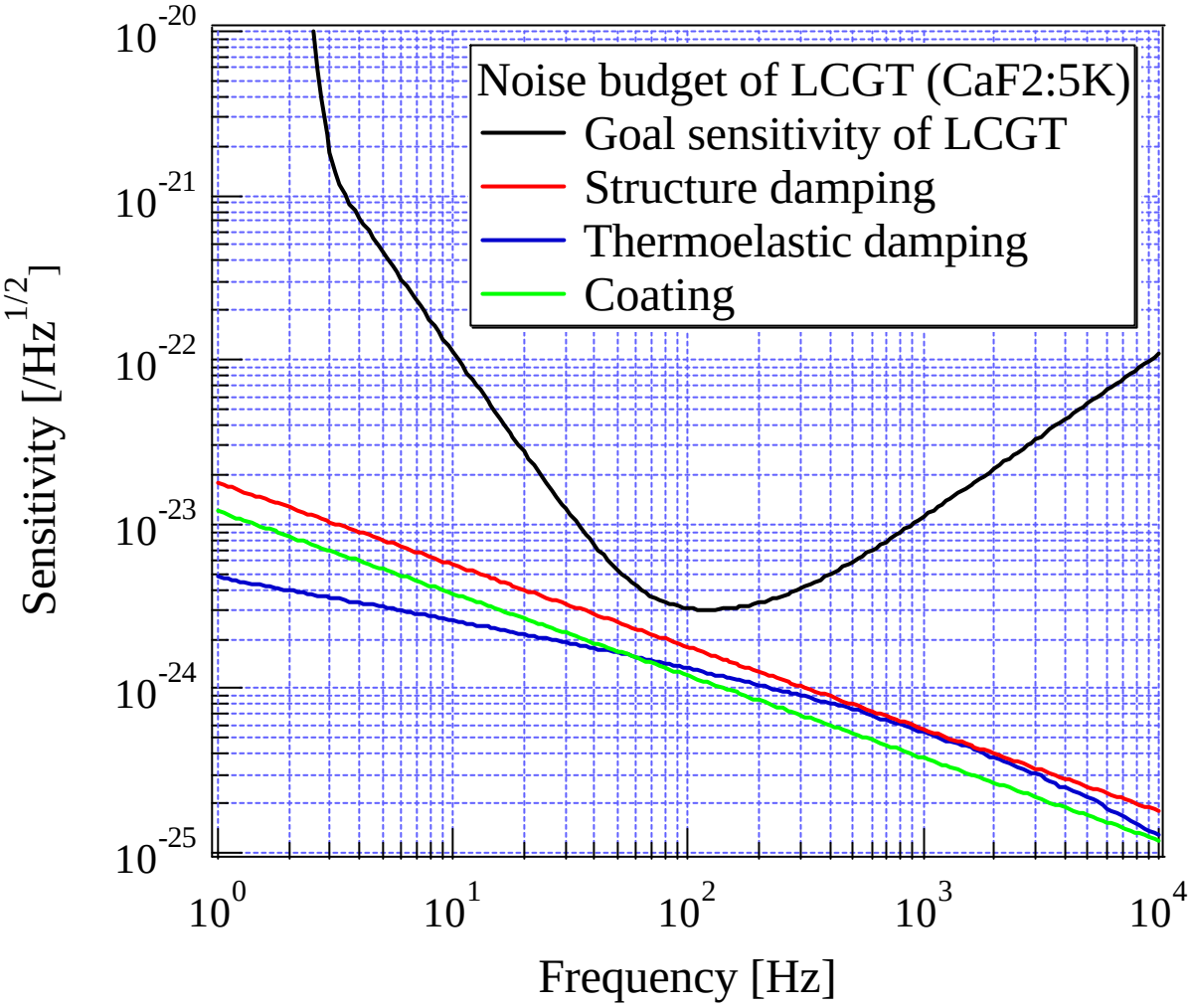
5-3. Result

Q-values is 10^7 at least below 10K.



5-4. Thermal noise of CaF_2 in LCGT

Temperature : 5K



6.Summary

(1) Coating

(i) Measurement of mechanical loss of reflective coating at low temperature.

(ii) Coating loss is independent of temperature (4.2K-300K).

→ advantage of cryogenic interferometer

(iii) Coating loss is not a serious problem in LCGT.

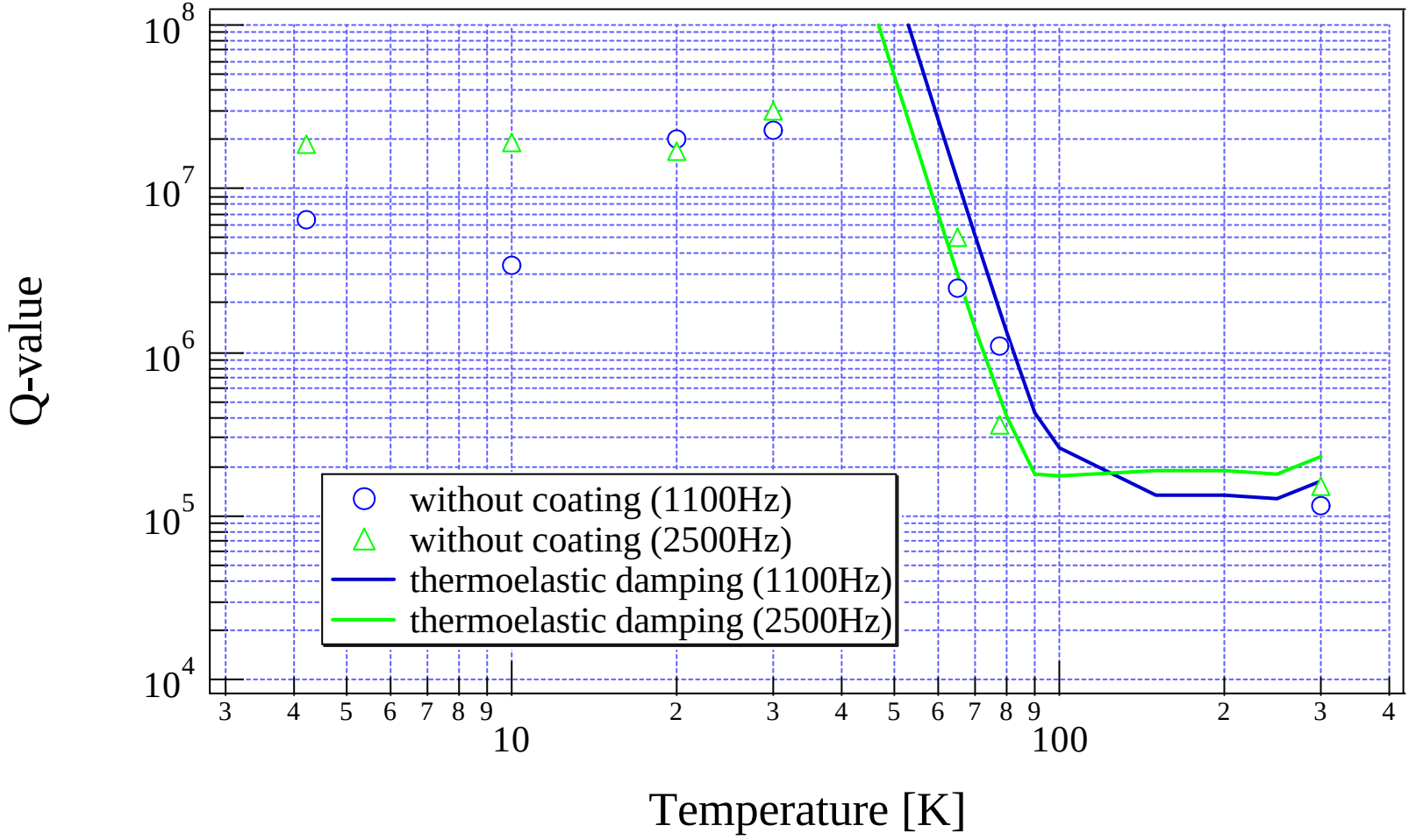
(2) CaF_2

(i) Measurement shows that Q-values below 10K are 10^7 at least.

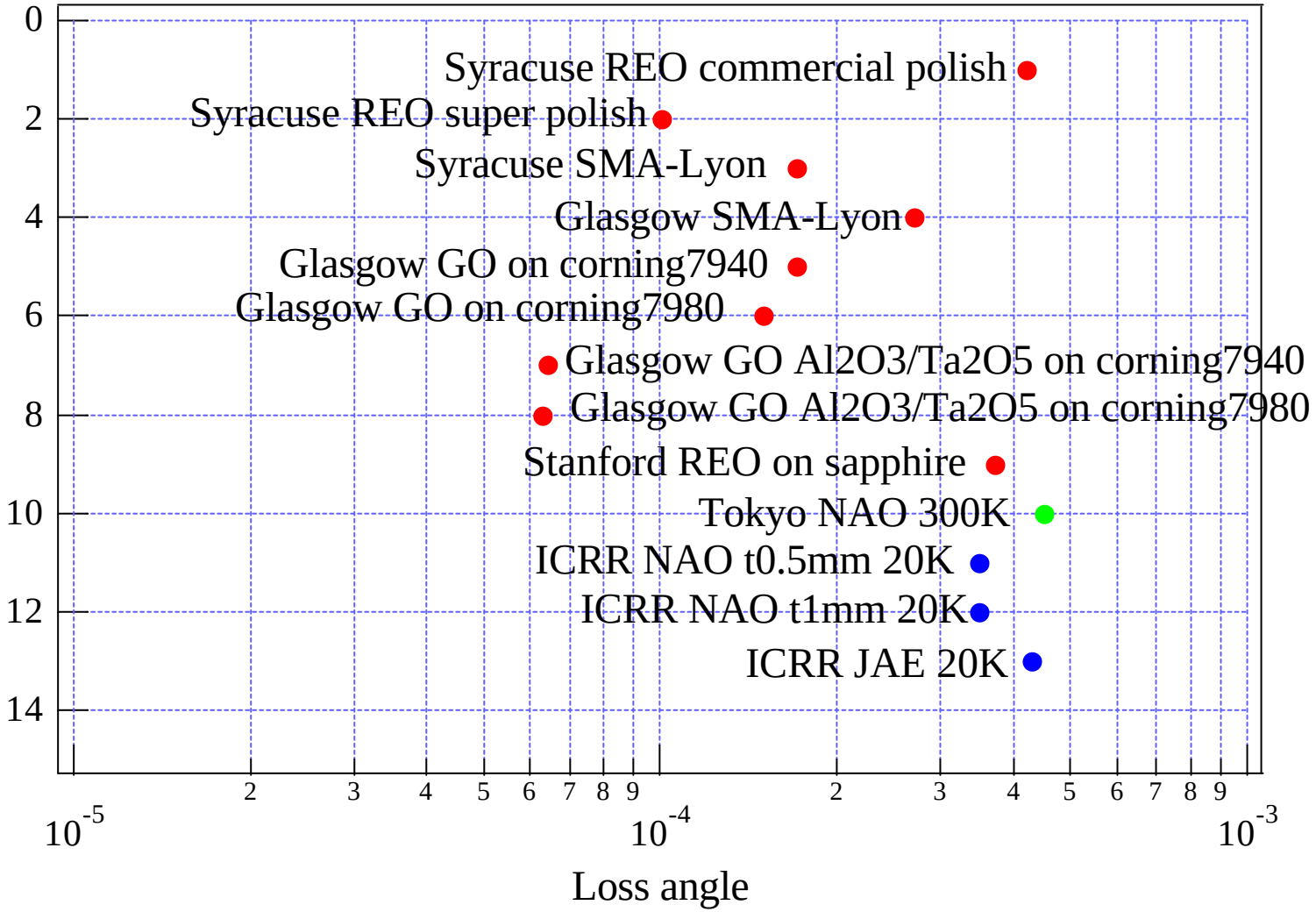
(ii) Temperature of CaF_2 must be 5K in LCGT if it is used.

Thermoelastic damping

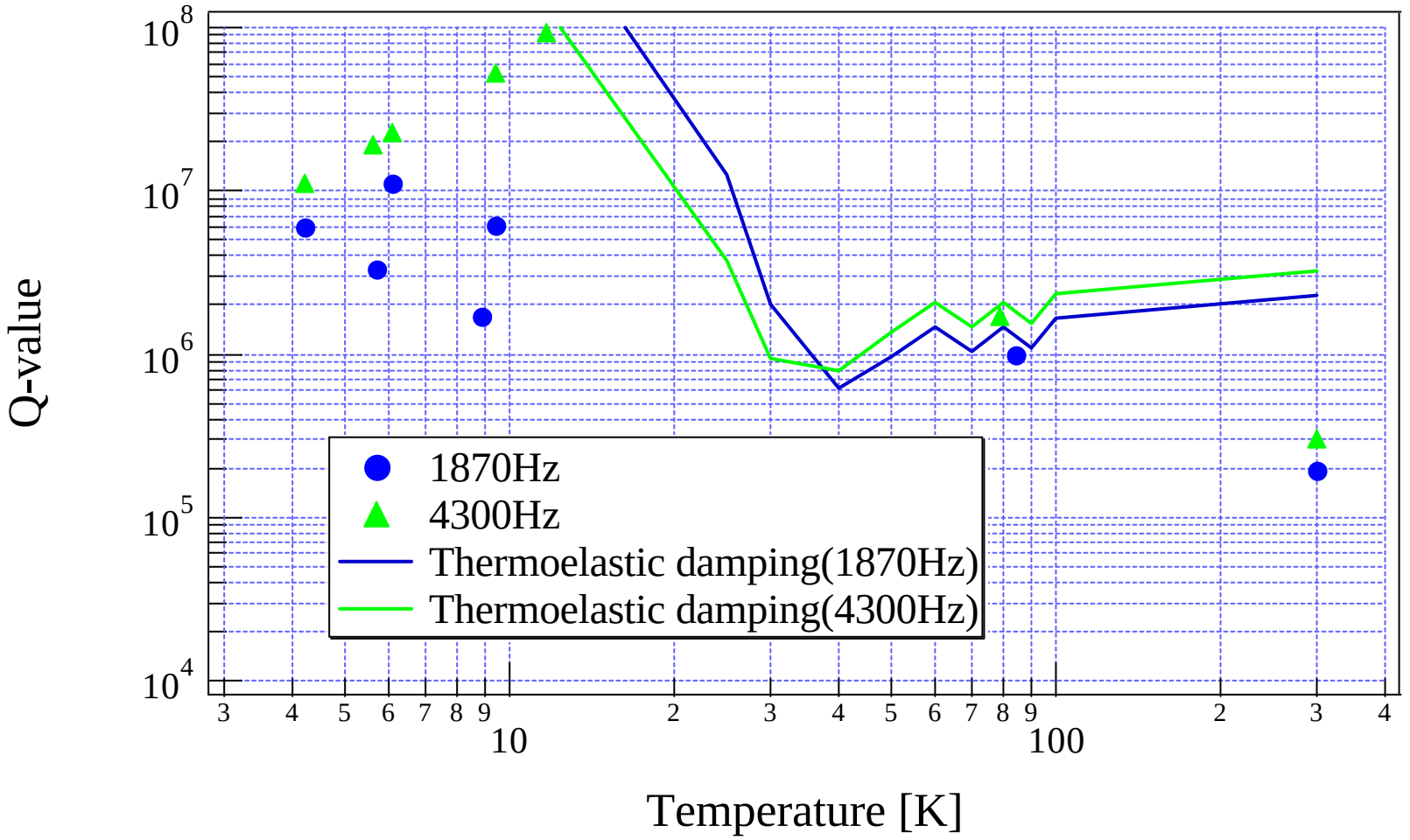
t 1 mm



Measurement of other group



Q-values of CaF2



Thermal noise of CaF_2 in LCGT

Temperature : 10K