Study of the thermal noise caused by inhomogeneously distributed loss

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0.Abstract

(1)Our experiments show that ...

when the loss is distributed inhomogeneously

the traditional method to estimate thermal noise is invalid.

(2) The thermal noise of

mirror with inhomogeneous loss

was calculated using new valid methods.

Contents

1.Introduction

○ Thermal noise of mirror

→ fundamental noise of GW detectors

→ It is important to estimate thermal noise

○ Modal expansion

→ traditional method to estimate thermal noise

(thermal noise of system)
= Σ (thermal noise of each resonant mode)

However ...

new estimation methods (direct approaches)
suggest that modal expansion is invalid
when the loss is distributed inhomogeneously.

○ Direct approaches (Levin, Nakagawa, Tsubono)

→ without modal decomposition

○ Suggestion of direct approaches

⟶ Serious problem !

However, this problem has not been researched fully.

This problem is main theme of this speech.

○ The two topics of this speech

(1) Experimental check of estimation methods

modal expansion : invalid

direct approach : valid

(2) Estimation of thermal noise of the mirror with inhomogeneous loss using direct approaches

2.Experimental check of estimation methods

2-1.Outline

○ Experimental check of modal expansion and direct approaches

→ Measurement of the thermal noise of the mirror with inhomogeneous loss

● Direct measurement of thermal noise of real mirror: difficult

(i) Mechanical model of mirror : drum

(ii) Measurement of mechanical response

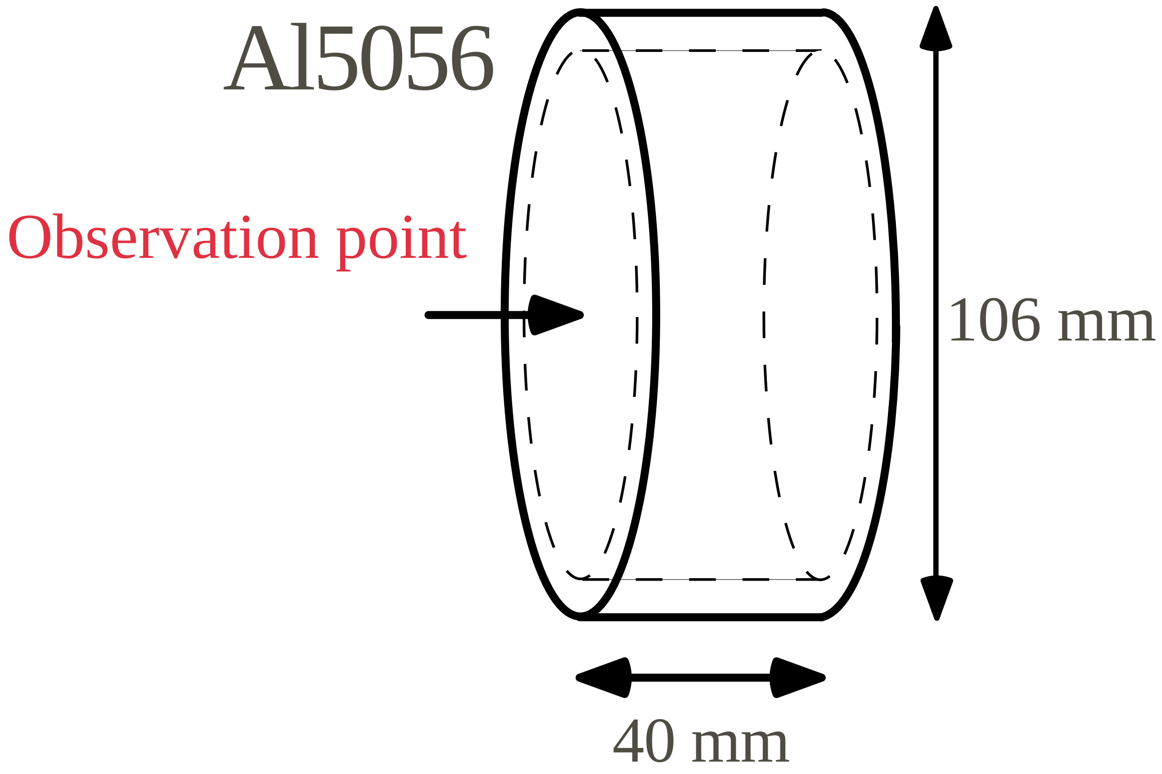
→ Fluctuation-dissipation theorem

first experimental check

using oscillator like mirrors

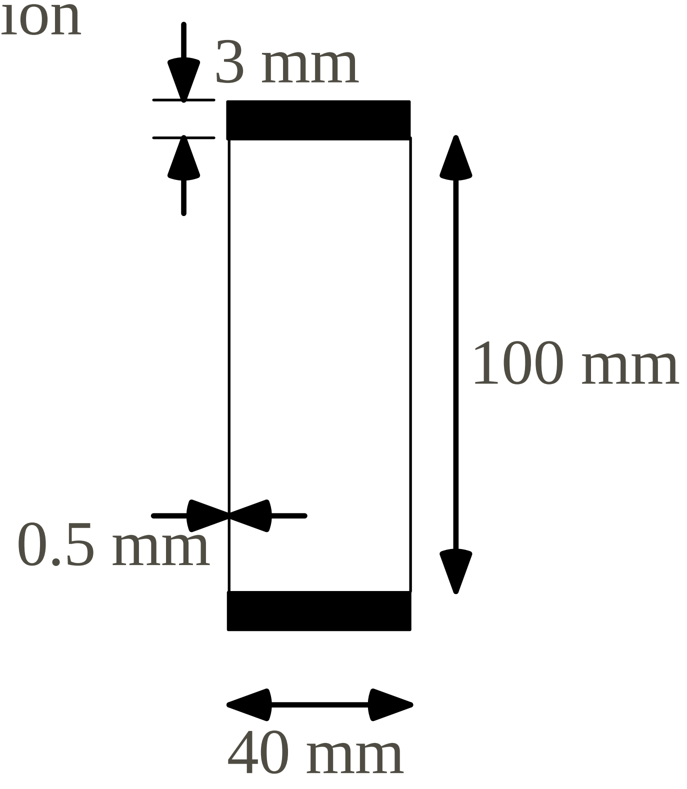
2-2.Experiment

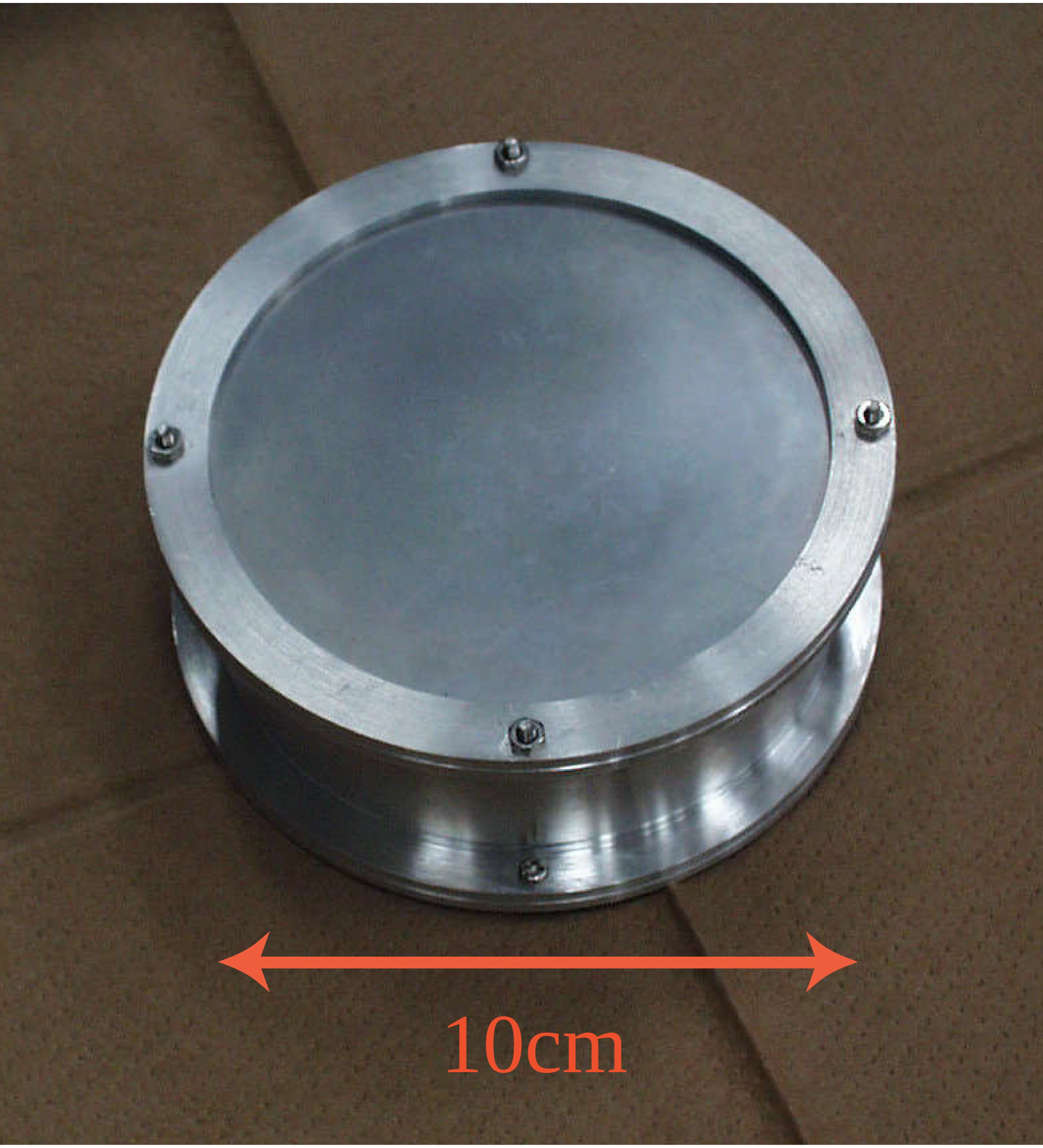
○ drum



Observation band : lower than resonant frequencies

● Cross section

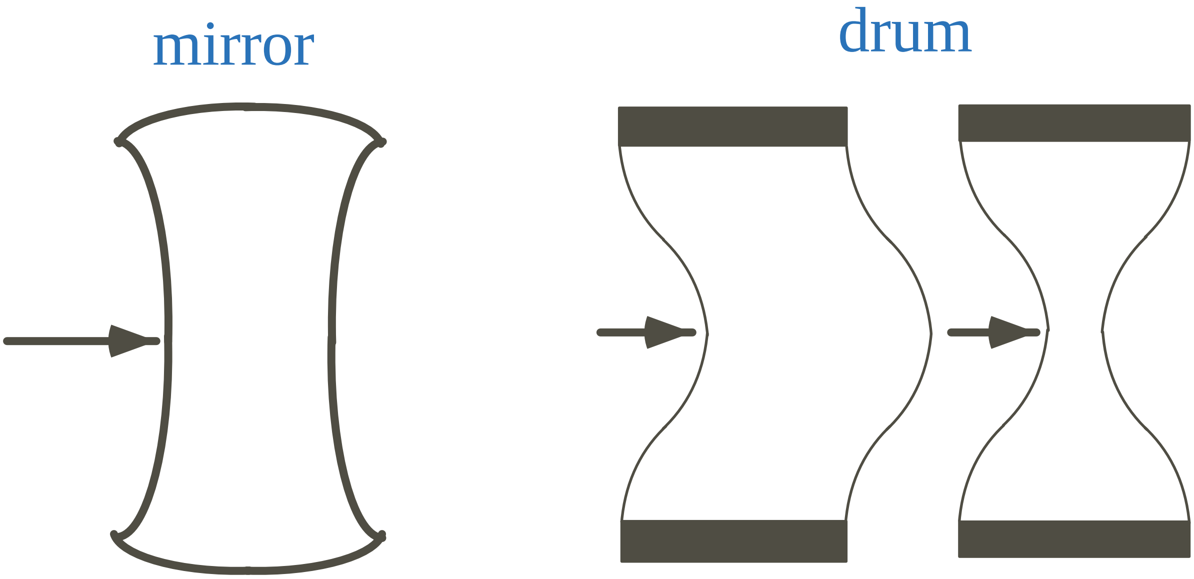




Drum (front view)

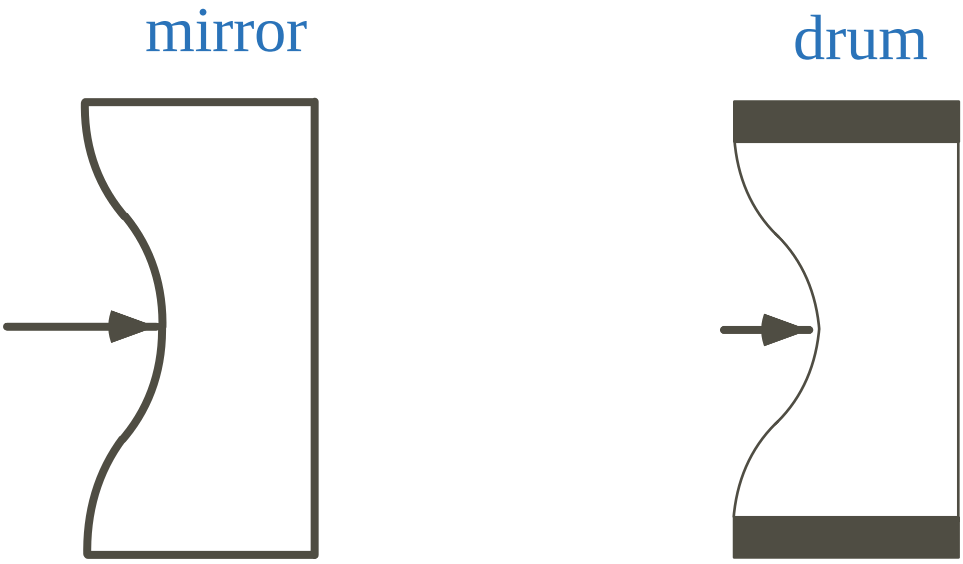
- comparison between mirror and drum

(1) At resonant frequencies



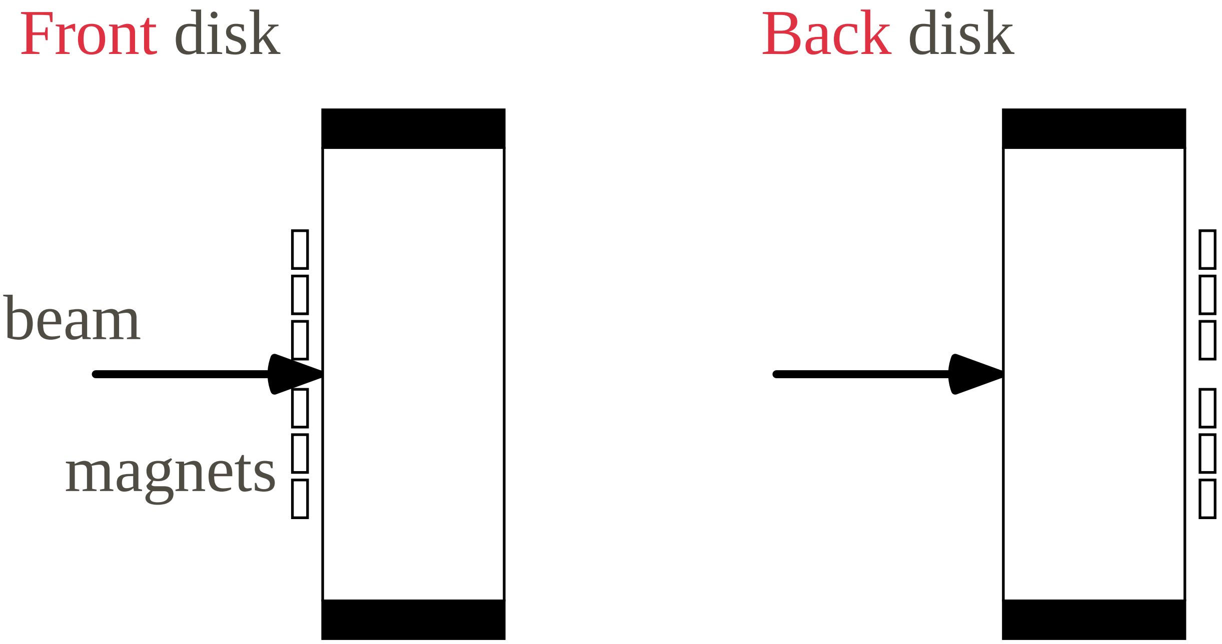
Both sides vibrate.

(2) In observation band (<<resonant frequencies)

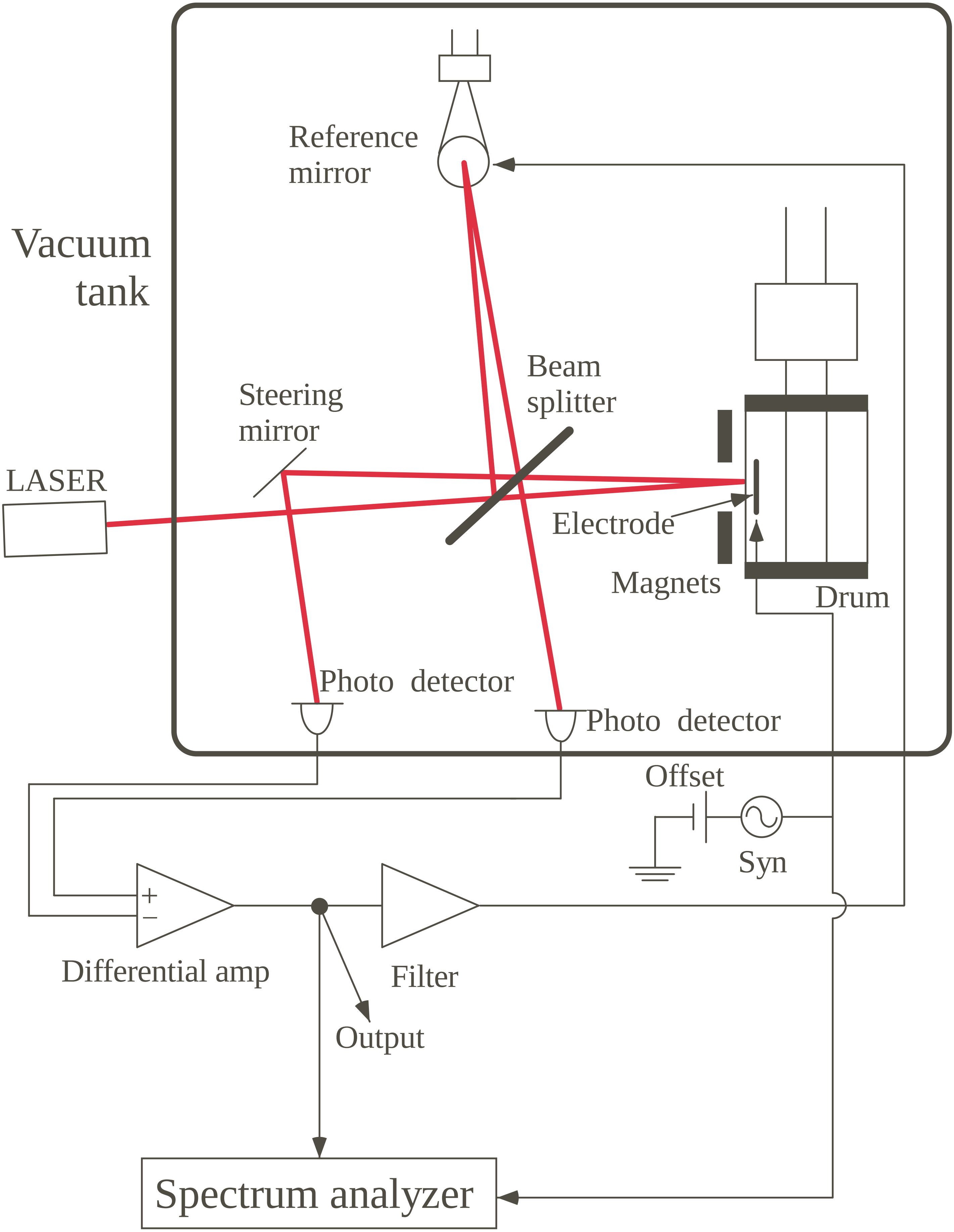


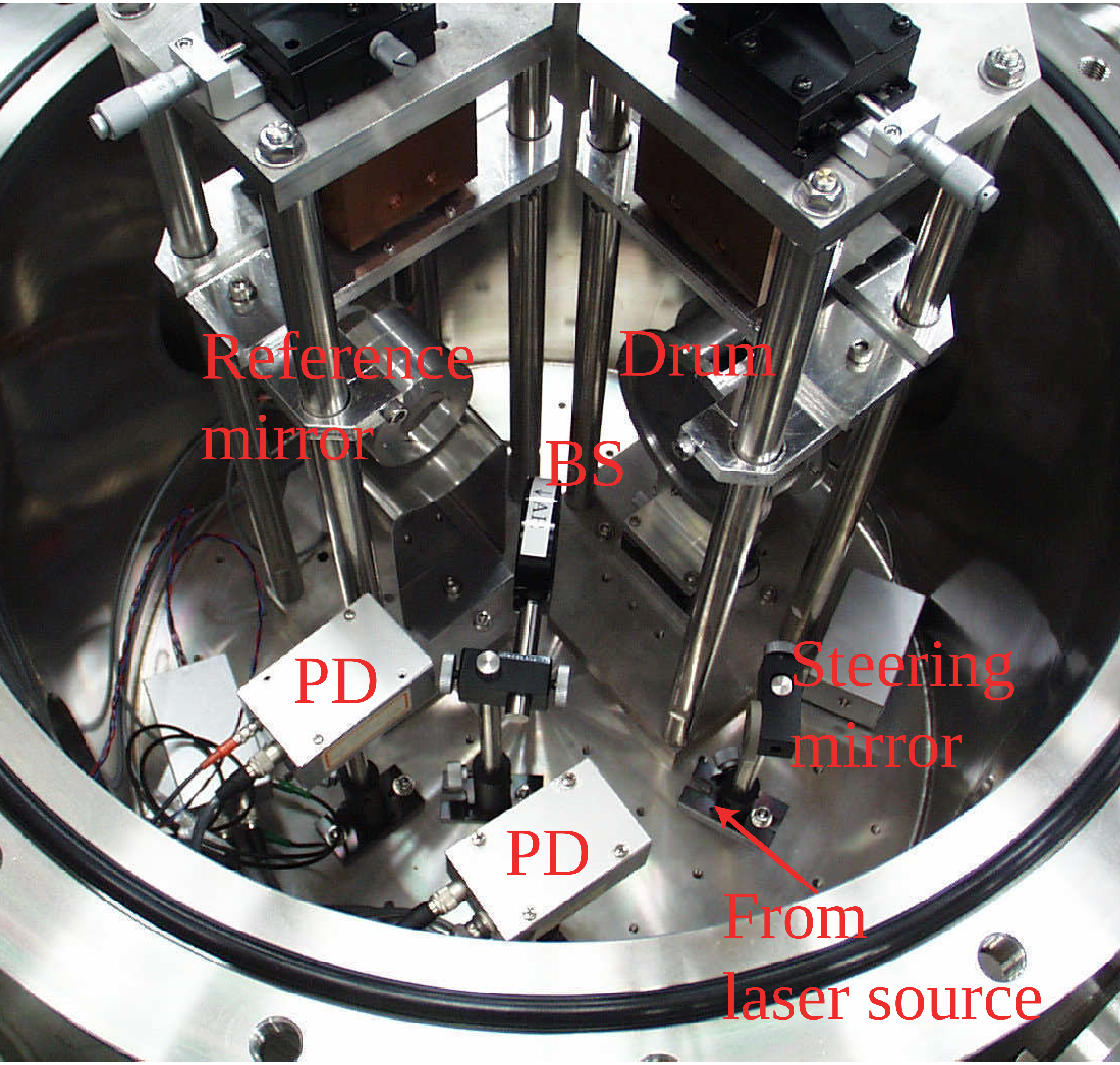
Only one side vibrates.

- loss distribution



○ Experimental apparatus



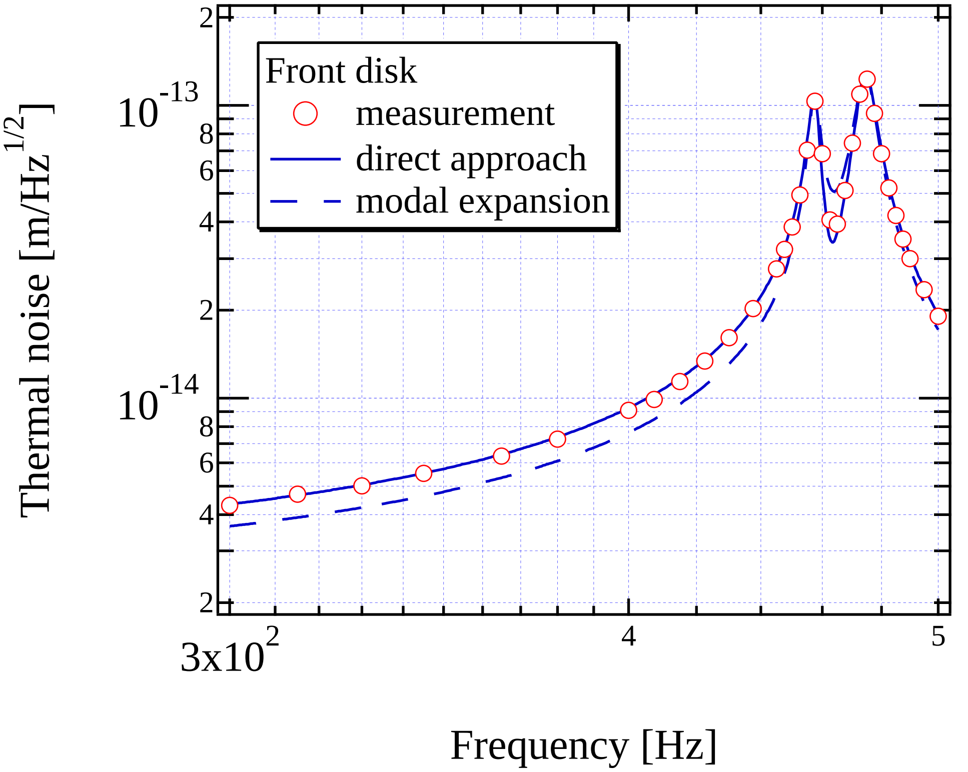


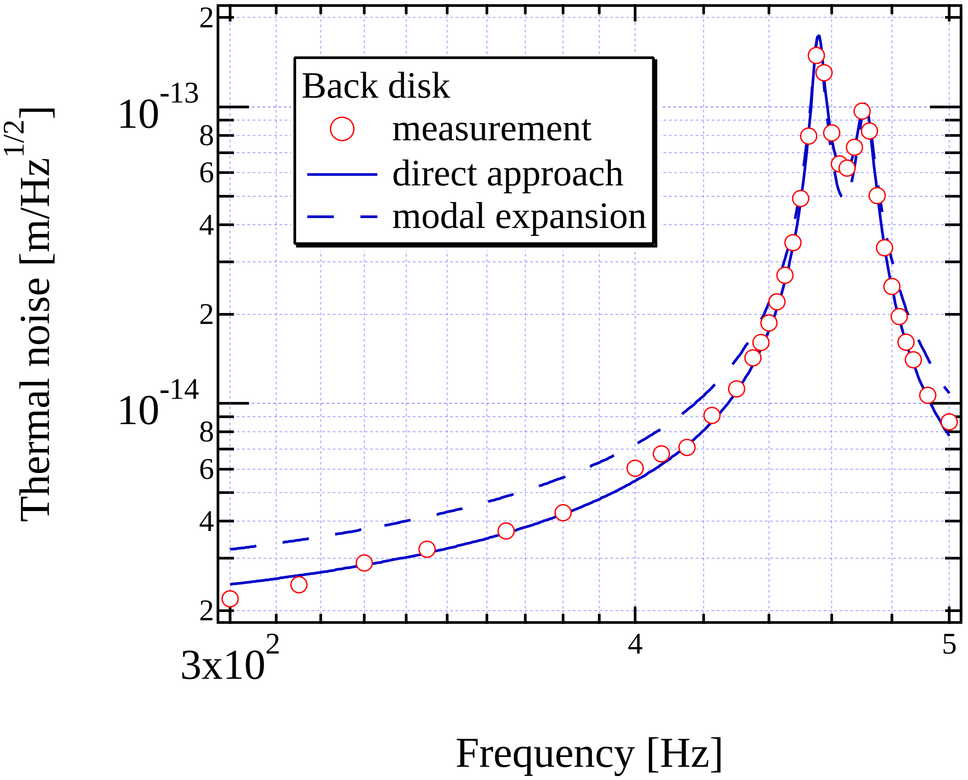
Interferometer
in vacuum tank

2-3.Results

direct approach: valid

modal expansion: ***invalid***



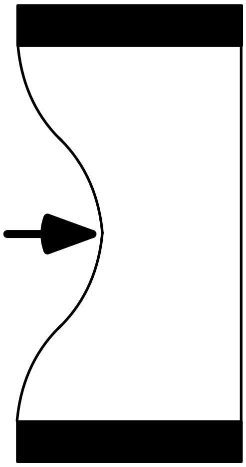


○ Why is modal expansion invalid ?

(1) real thermal noise

Fluctuation-dissipation theorem :
power of thermal motion
is proportional to dissipated energy

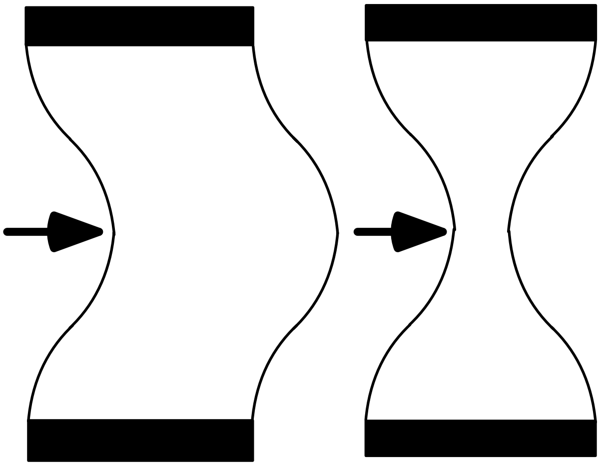
observation band << resonant frequency



Only one side vibrates.

loss : Front disk > Back disk

(2) modal expansion (summation of resonant mode)



Both sides vibrate.

loss : Front disk = Back disk

3.Calculation of thermal noise of the mirror with inhomogeneous loss

3-1.Outline

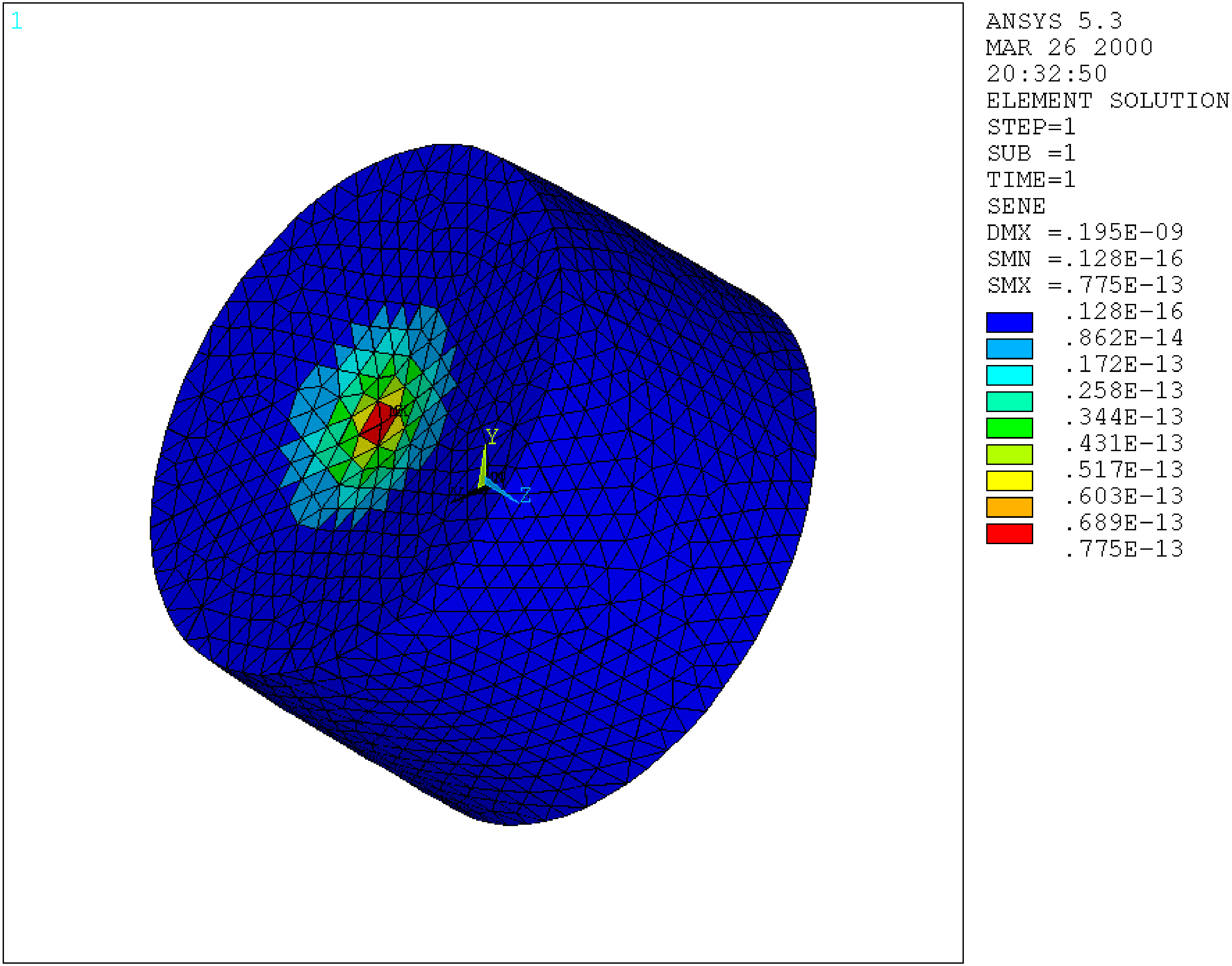
The thermal noise of real mirror

with inhomogeneous loss

is calculated using direct approach.

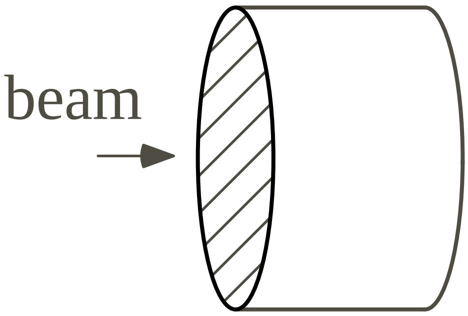
Calculation : difficult

→ Finite element method


1
ANSYS 5.3
MAR 26 2000
20:32:50
ELEMENT SOLUTION
STEP=1
SUB =1
TIME=1
SENE
DMX =.195E-09
SMN =.128E-16
SMX =.775E-13
.128E-16
.862E-14
.172E-13
.258E-13
.344E-13
.431E-13
.517E-13
.603E-13
.689E-13
.775E-13
Y
Z
MX

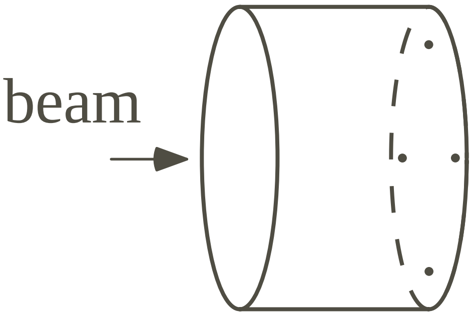
3-2.Loss distribution

two extreme case



Coating

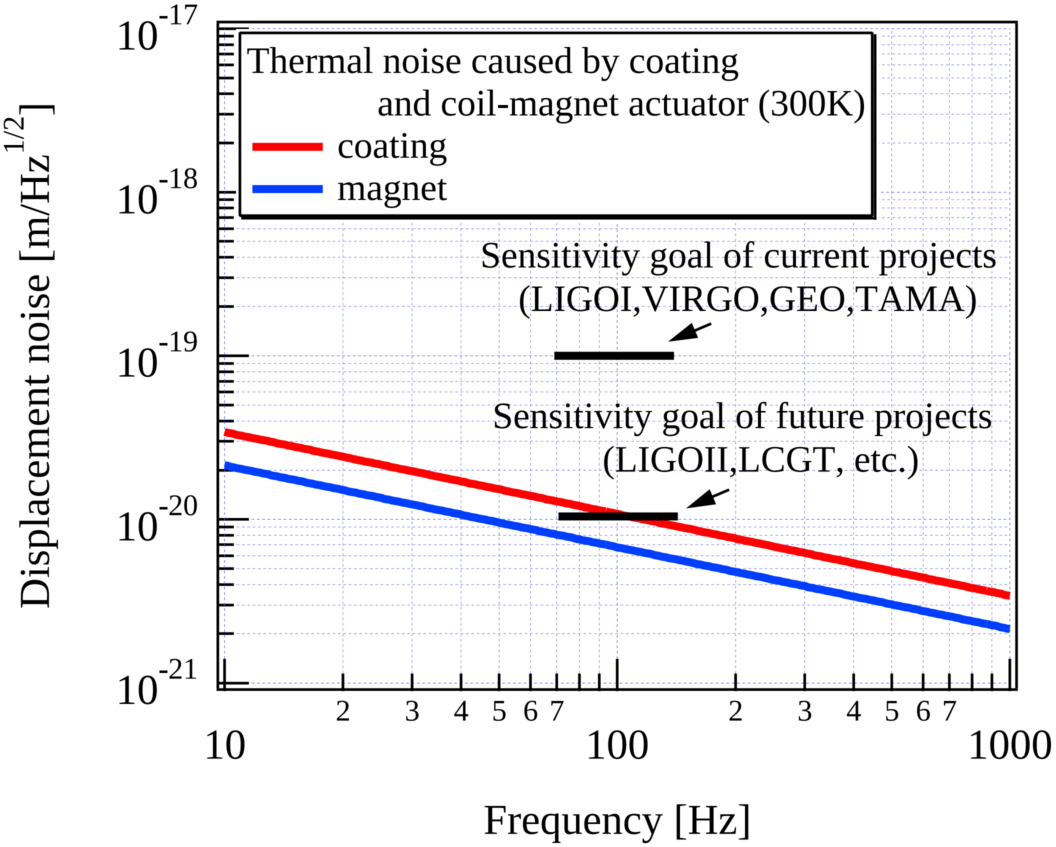
(thermal noise)
>(modal expansion)



Coil-magnet
actuator

(thermal noise)
<(modal expansion)

3-3.Results



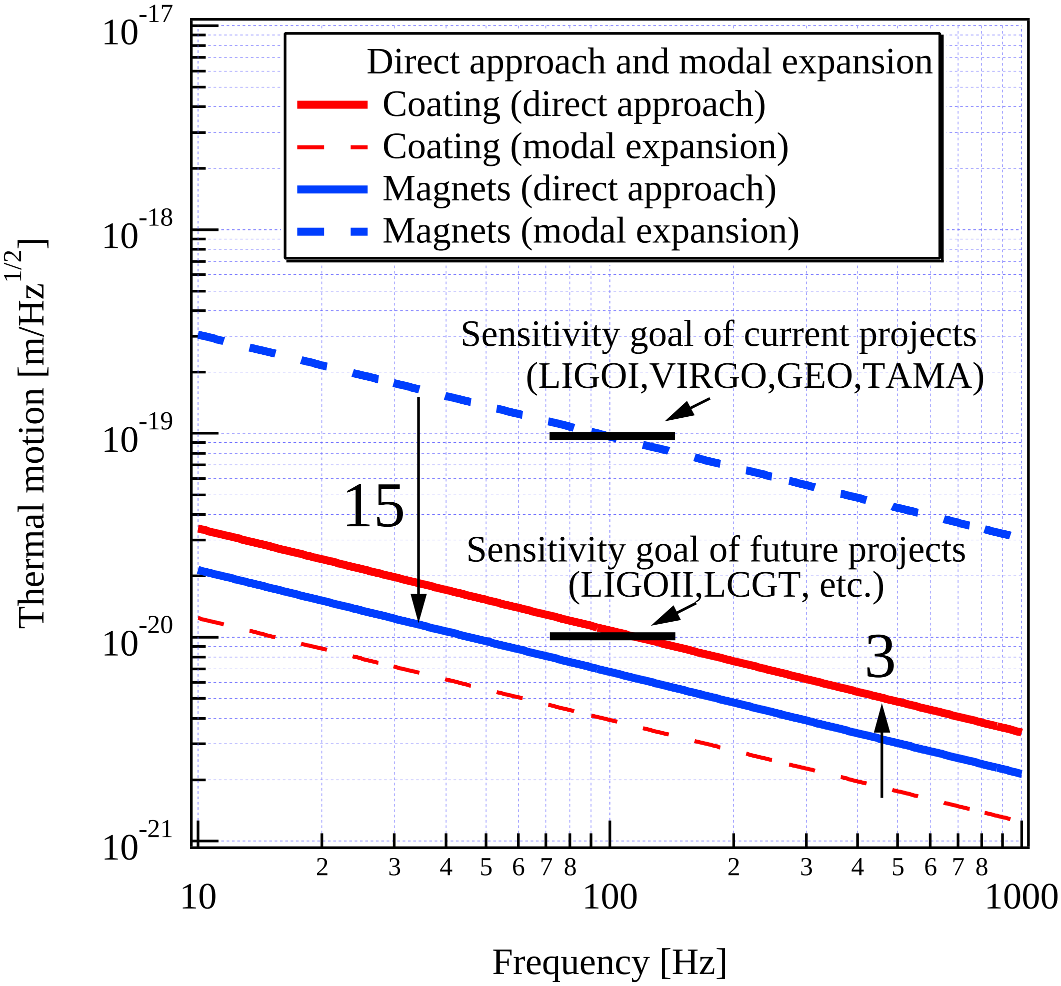
In future projects ...

coating and magnet : comparable with goal

→ low loss coating and actuator ?

cooling ?

Direct approach and modal expansion



coating : 3 times

magnet : 1/15 times

large difference

between the thermal noise

and modal expansion

4.Summary

(1)Our experiments show that ...

when the loss is distributed inhomogeneously

modal expansion (traditional method) is invalid.
direct approaches (new methods) are valid.

(2) The thermal noise of mirror with inhomogeneous loss is calculated using direct approaches.

coating and actuator : comparable with goal of future projects

large difference between thermal noise and estimation of modal expansion