Mirror

LCGT

Technical advisory committee

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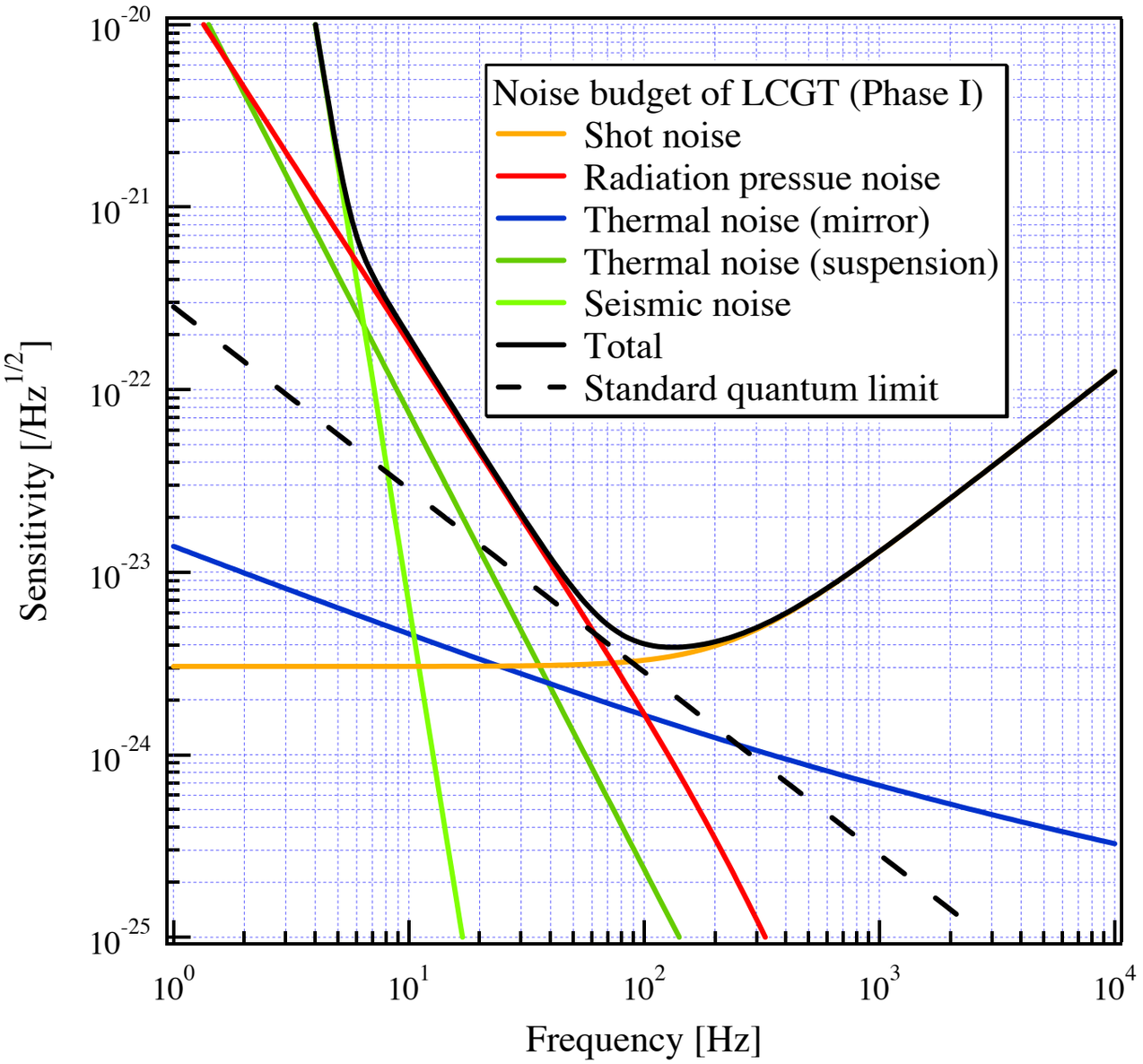
LCGT mirror

- LCGT uses sapphire mirrors.
- Sapphire: Φ250×150、 30kg.
- Coating: SiO2/Ta2O5.
  - Front mirror 99.6% reflectance.
  - End mirror 99.995% reflectance.
- End mirror has curvature of several km.
- Cooled at 20K.

Mirror thermal noise

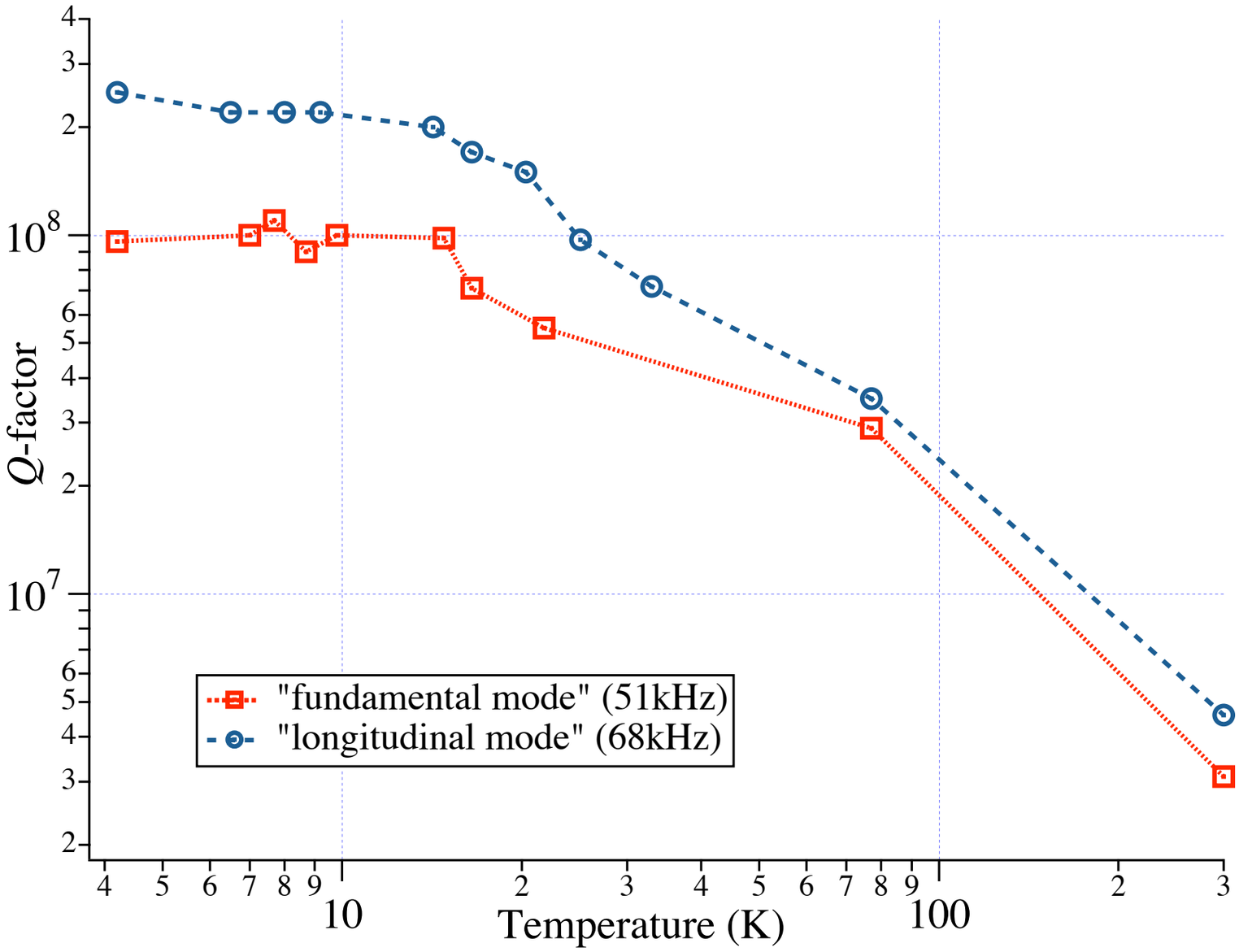


Cryogenic cooled sapphire mirror makes possible low mirror thermal noise level.

Mirror thermal noise 2

- There are three kinds of mirror thermal noise.
- Structure damping in the substrate.
  - Low T and high mechanical Q.
- Structure damping in the coating.
  - Low T and low Dissipation.
- Thermoelastic damping in the substrate.
  - Low T and thermal expansion ratio.

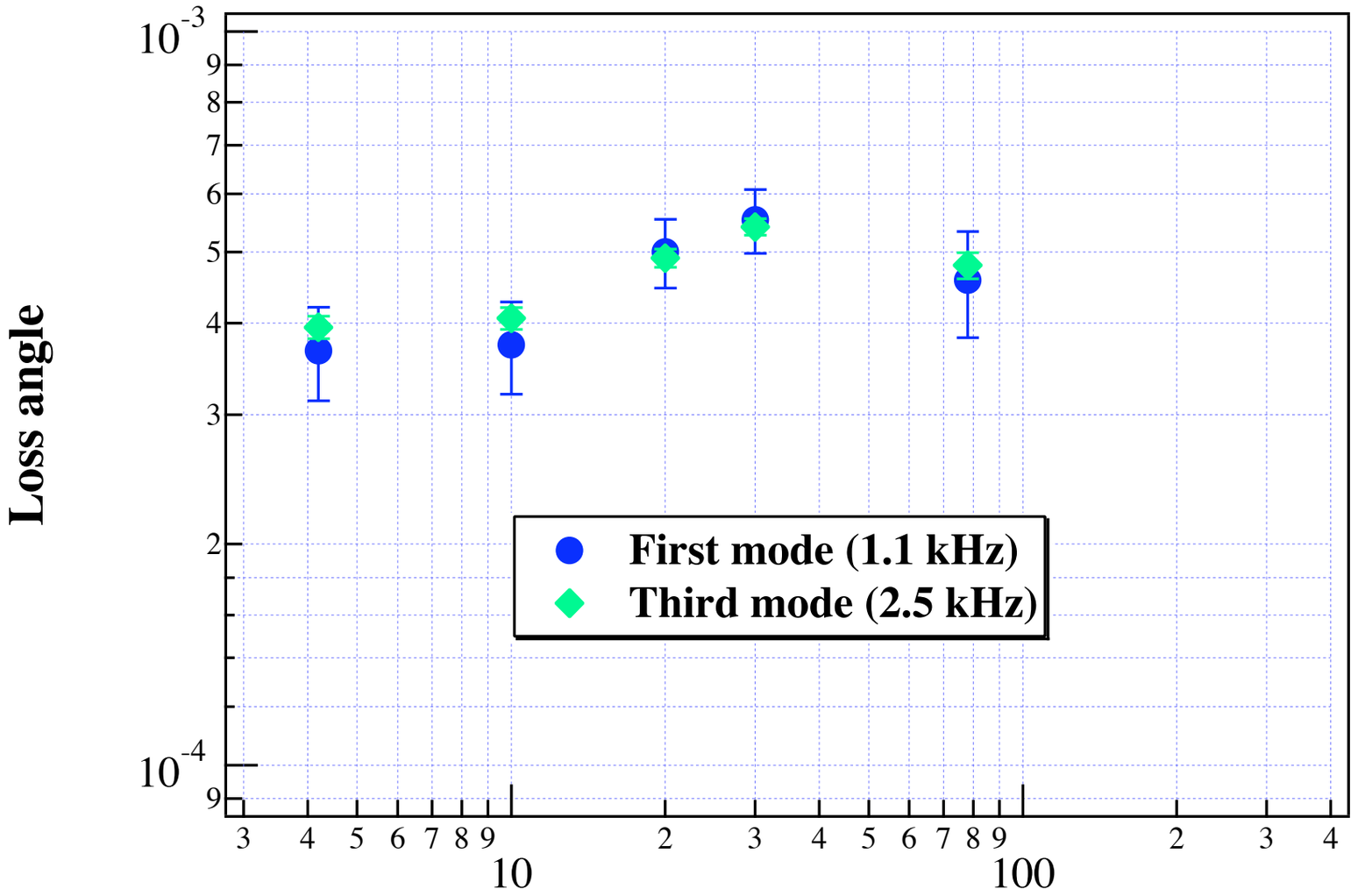
Mechanical Q



T. Uchiyama

Mechanical Q of sapphire cylinder.
Reached to 10^8

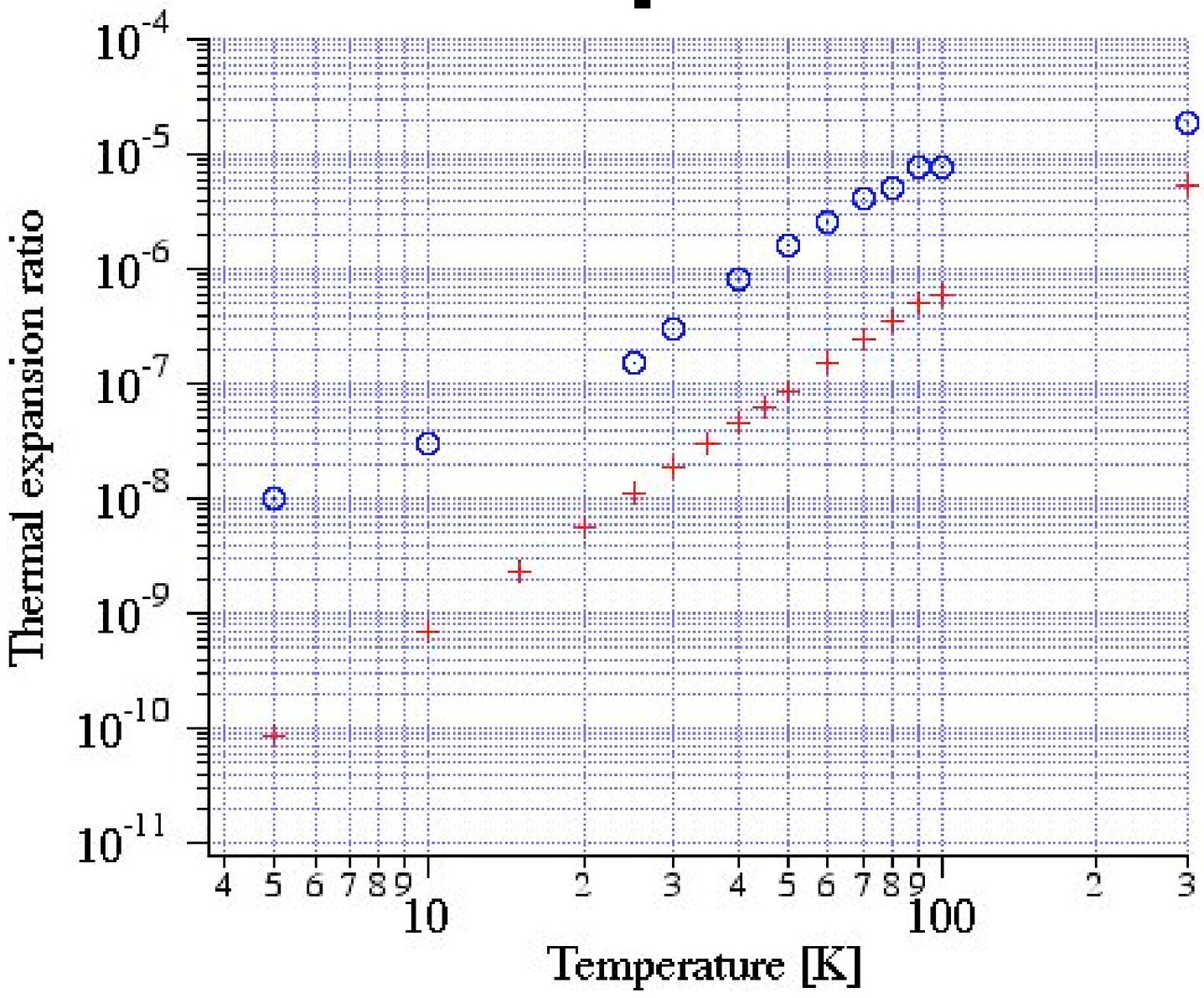
Dissipation



K. Yamamoto

Dissipation of the coating on a sapphire disk.
Temperature independent.

Thermal expansion ratio

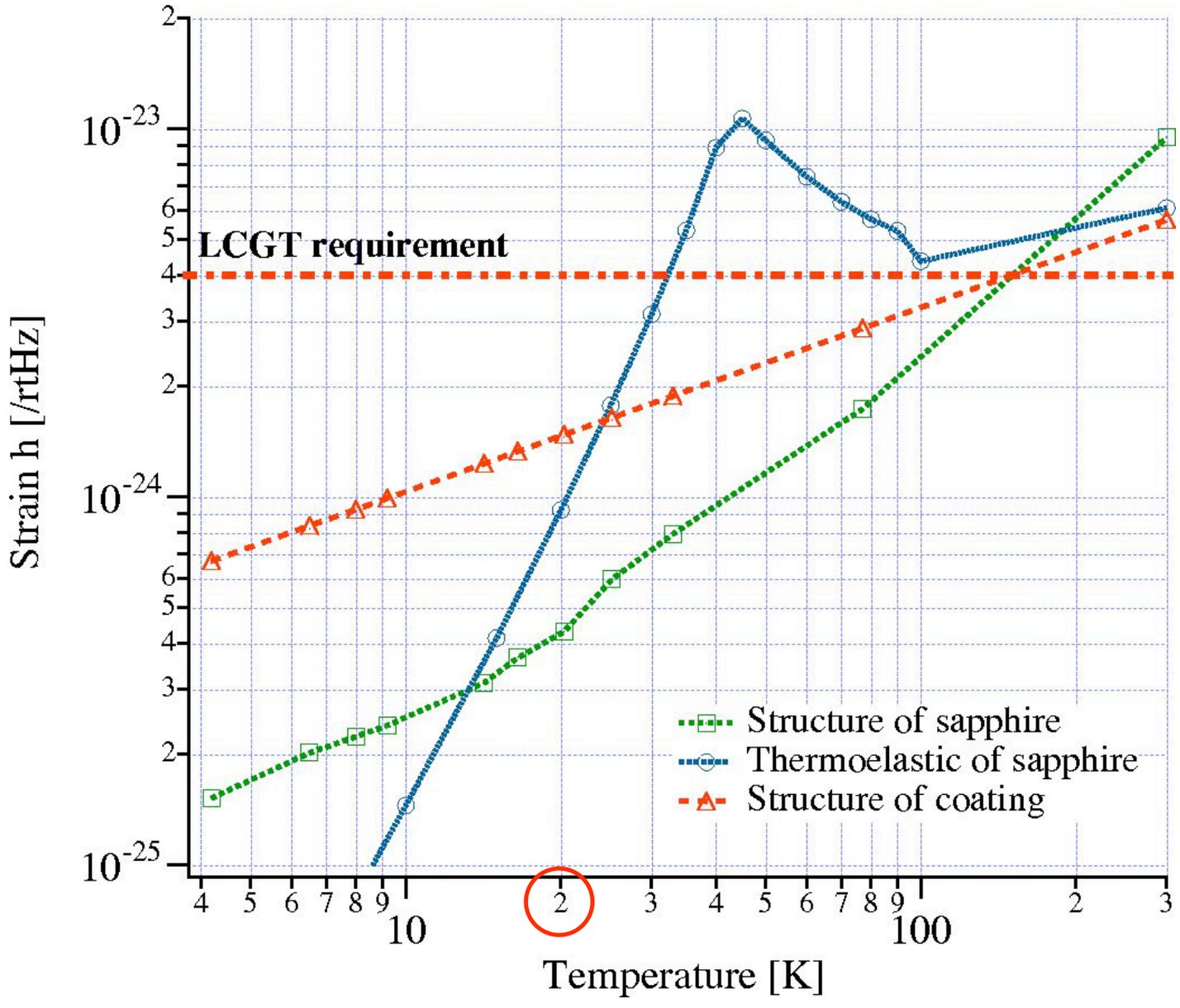


CaF2

Sapphire

Sapphire is very small expansion ratio in cryogenic temperature.

Cryogenic



Temperature dependence of the mirror thermal noise at 100Hz

20 K is the target temperature.

Thermal lensing

- Thermal lensing effect
  - High power laser makes temperature gradient in the mirror.
  - Refraction index changes with temperature.
  - Refraction index gradient will appear. It act as a lens.
- Sapphire mirror
  - High thermal conductivity: 4×10^{3}W/m/K at 20K.
  - Low temperature dependence of refraction index:
    - $\beta < |9\times10^{-8}|$ /K at 20K$_{(T.Tomaru)}$.
- 10000 times smaller than in room temperature !!

Optical property
- absorption -

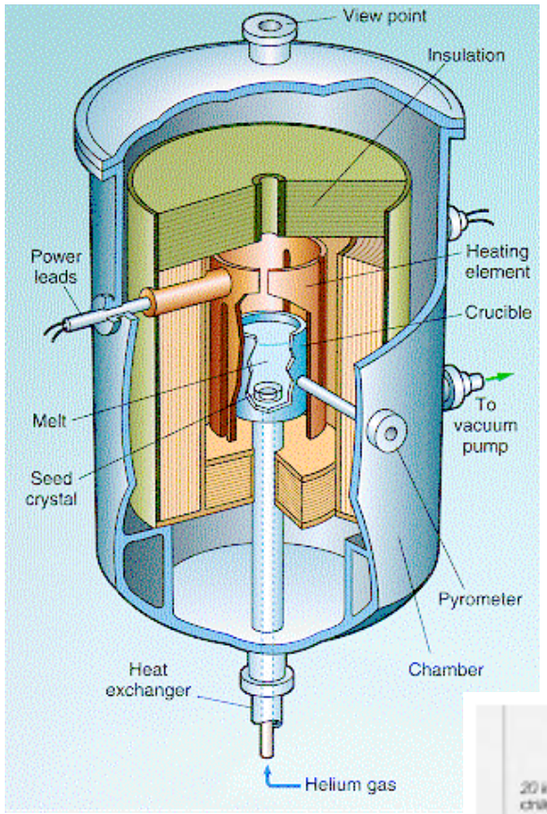
- Laser absorption is important factor for cooling.
- LCGT target
  - Substrate: 20ppm/cm → 250mW
  - Coating: 1ppm → 40mW
- Current status
  - Substrate : 40 - 60ppm/cm (CSI Hemex white grade)
  - 20 - 30ppm/cm (use annealing) (R. K. Route et al., LIGO-G040084-00-Z)
  - Coating: 1ppm (R. K. Route et al., LIGO-G030023-00-Z)

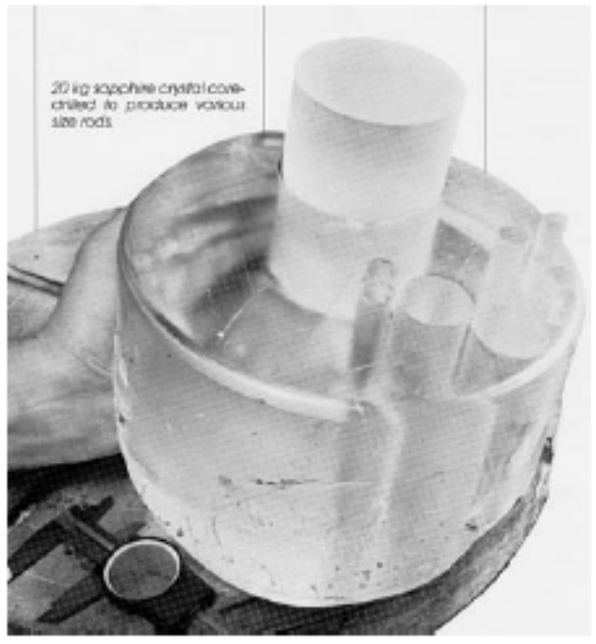
Absorption is close to the target value even now.

Our current cryogenic design is possible to cool the mirror, even if the substrate has 60ppm/cm absorption.

Make the mirror 1
- substrate -

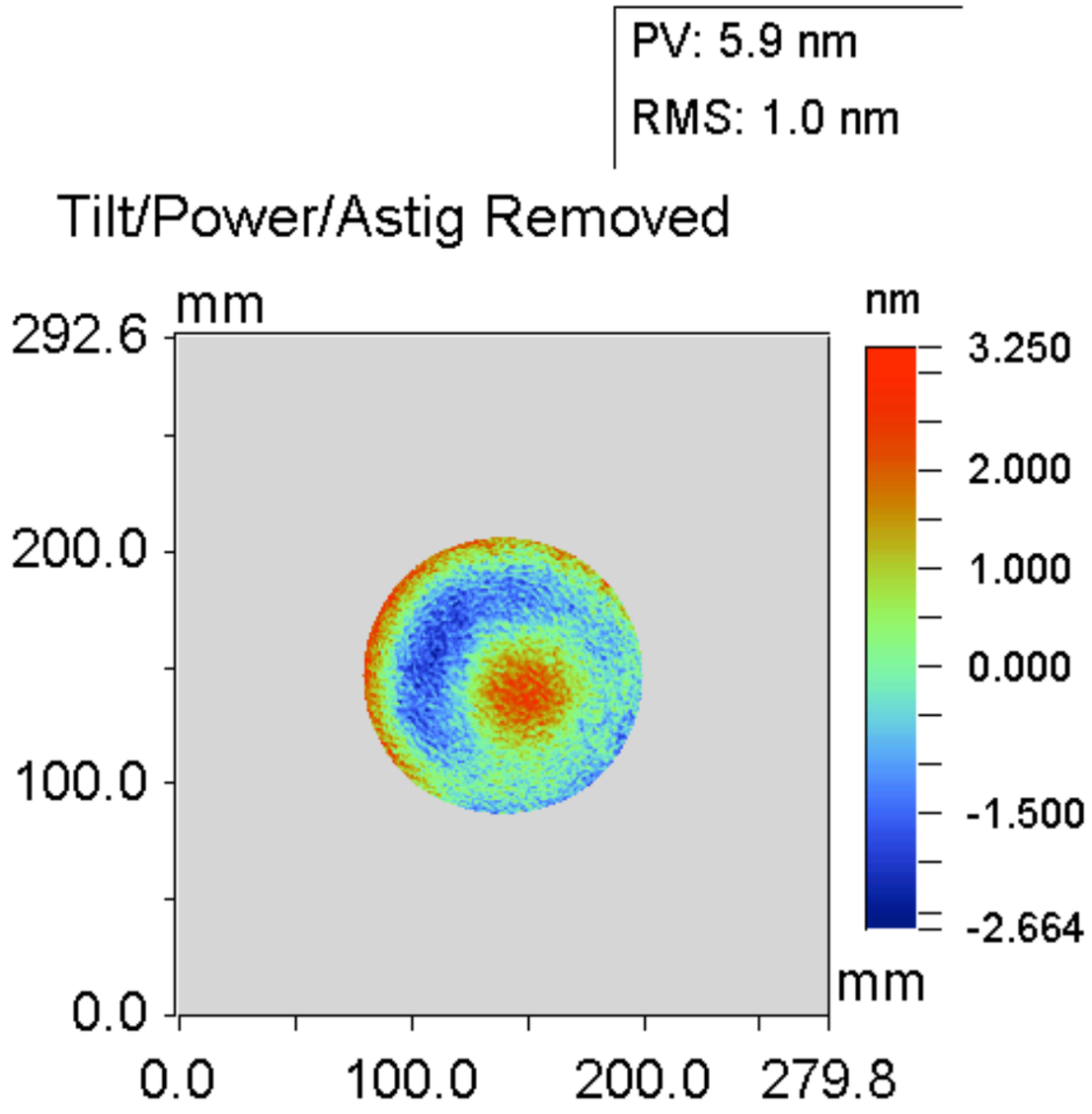
- Substrate (Φ250×150).
- Crystal Systems Inc.
- Heat Exchanger Method.
- Φ330, 65kg sample is possible.
- Effort for the quality up is still valuable.





Make the mirror 2
- polish -

- CSIRO or Canon Inc.
- Micro roughness < 1Å
- RMS 1.0nm.
- Curvature of 9000m has been made for TAMA power recycling mirror (fused silica).



CSIRO sapphire polish

(G. Billingsley et al., LIGO-G030007-01-D)

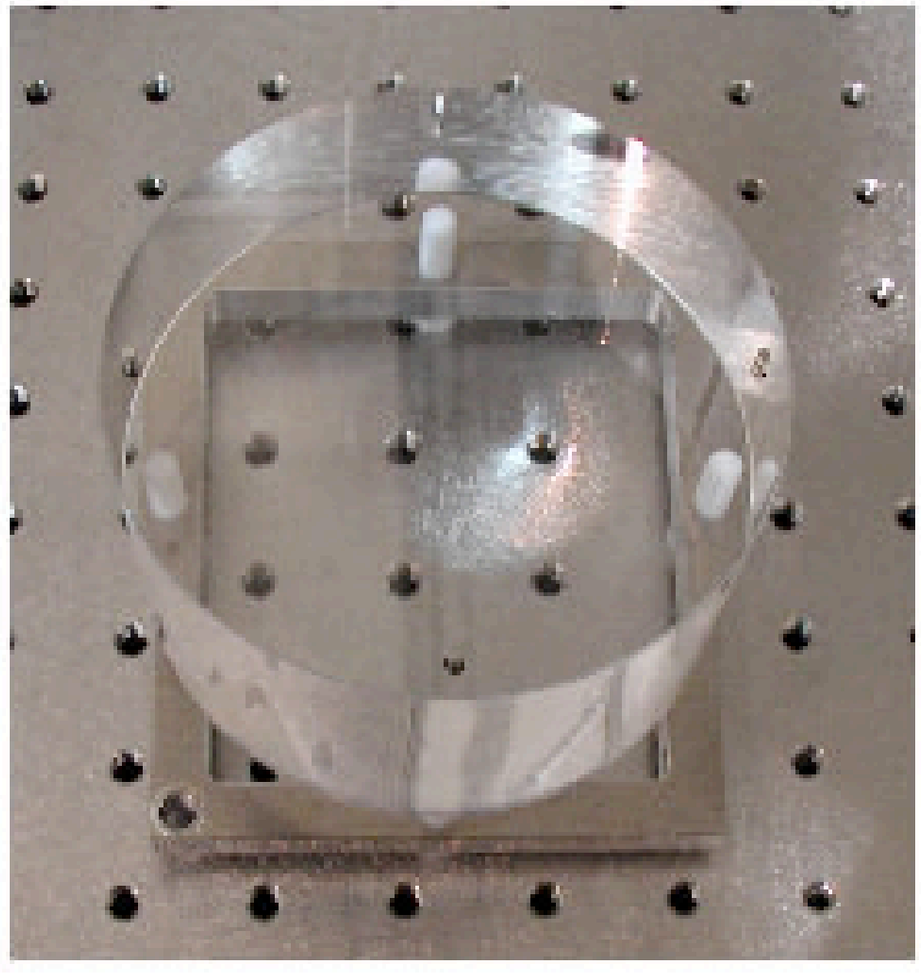
Make the mirror 3
- coating -

- Japan Aviation Electronics Industry Ltd.
- Ion beam sputtering machine.
- Φ250 sample is possible.
- Finesse of 25000 has been achieved (fused silica).
- Low loss and high reflective coating is possible.

IBS at NAO

Make the mirror 4
- Sapphire mirror for CLIK -

- Cryogenic Laser Interferometer in Kashiwa.
- 7m Fabry-Perot cavity.
- Sapphire mirror Φ100×60 (CSI).
- R=30286mm (30m requested) has achieved (Canon).
- Waviness < λ/4.
- Roughness < 10 Å.
- Finnese of 3142 and reflectivity of 99.9% have achieved.



Summary of the mirror

- LCGT uses the sapphire mirror.
- The mirror thermal noise is much lower than the design sensitivity, when the mirror is cooled at 20K.
- Technical issues for realizing the LCGT mirror are overcome in study of the past projects.
- We are ready for making the mirror.