Investigation of Thermal Contact Conductance for Monochromator Crystal


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  SPring-8 x-ray crystal monochromator, crystal holder

- Thermal contact conductance (TCC)
  at low contact pressure, under LN2 cooling

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  under LN2 cooling, with high power laser

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Double crystal monochromator at SPring-8

Monochromator

1st crystal

2nd crystal

Crystal holder (1st)

Copper blocks (Ni-plating)

Plate spring

Silicon

Indium sheets

LN2 paths
In this study

Better cooling efficiency → High TCC (high contact pressure) → Low contact pressure → Less strain

To select contact material and optimize contact pressure, we made two apparatus for quantitative measurements of TCC and surface deformation.

TCC apparatus
- 0.1-1.0 MPa
- LN2
- Thin foil
- In, graphite, gold

Surface deformation
- Fizeau
- 1nm / 100mm
- LN2
- Fiber laser
- Heat load up to 1kW

Better cooling efficiency leads to high TCC (high contact pressure), which results in less strain and low contact pressure.
Thermal contact conductance (TCC) measurements
Previous works of TCC measurements

Low contact pressure region

300 K:

...

77 K:

...
Apparatus of TCC measurements

Cooling (77 - 300 K)

1) Overall TCC
\[ \frac{1}{h} = \frac{\Delta T}{q} \]

2) interface – inserted material contact
\[ \frac{1}{h_c} = \frac{2}{h} \left( 1 - \frac{t}{\lambda_{ins}} \right) \]

The reproducibility of TCC measurements at room temperature is \( \pm 10\% \).
Experimental conditions for TCC measurements

Oxygen free Copper with Ni-plating
The contact interface:
roughness 0.2μm (Ra)
flatness 2μm (P-P).

The uniformity of contact pressure:
Fujifilm-PrescaleTM film
(0.2- 0.6 MPa)

Samples:
- Indium: 50μm, 100μm, 200μm
- Gold: 20μm (annealed at 800°C for 1 hour)
- Pyrolitic Graphite: 100μm
TCC results of LN2 cooling

Liq. N2 cooling
Q=16.5W

Thermal contact conductance [W/K/m²]

Contact pressure [MPa]

Gold
Indium
Pyrolytic graphite
Observation of thermal deformation on Si crystal
Test bench for high heat load

Thermal source

Fiber laser
wavelength: 1.07 um
CW,
Single mode
Power: 0 - 1 kW
Beam diameter (D4s): 0.5 ~ 2.5 mm

Laser

Fizeau interferometer

LN2

FO-1000 (Mitsui Electronics Inc., Corelase)

Surface figure

AccuFiz (4D Technology)

Dynamic mode
Experimental conditions for surface deformation with heat load

LN2 cooling
Flow rate: 4.85 L/min
Laser power: 0-300W

Contact pressure:
0.2 MPa and 0.4 MPa
Inserted in indium 100 μm foil

Uniformity of contact pressure

0.2 MPa
35 mm

0.4 MPa
90 mm
Typical deformation by heat load

Raw surface figure of Fizeau interferometer

Surface figure at 300W

Surface figure at 0W

Differential figure
(deformation by heat load)

\[ \Delta z = 2000 \text{nm} \]

\[ \Delta z = 500 \text{nm} \]

The surface figure under irradiating of the laser were measured after 2 hours for stable temperature.
Power dependence of thermal deformation at 0.4 MPa

Surface deformation increased as higher laser power.

Concave shape is observed, because of Si has negative thermal expansion in low temperature region.
Contact pressure dependence of thermal deformation

with 300 W heat load

0.2 MPa

0.4 MPa

Surface deformation: \(0.2 \text{ MPa} < 0.4 \text{ MPa}\)

Thermal contact conductance: \(0.2 \text{ MPa} < 0.4 \text{ MPa}\)

The clamping pressure of 0.4 MPa distorts the surface figure of crystal.
Conclusion

To improve performance of monochromator crystals for high-heat load, we developed two apparatus to measure thermal contact conductance at low contact pressure and thermal deformations of crystals for high heat load at the liquid nitrogen temperature.

Thermal deformations depended on the clamping pressures. The clamping pressure of 0.4 MPa distorts the surface figure.

For the next plan, Using these results, cooling system of crystal will be re-designed to suppress the deformation.
Thank you for your attention.

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