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DIRECT LN2 COOLED DOUBLE CRYSTAL MONOCHROMATOR

Tetsuro Mochizuki†, Kazuteru Akiyama, Katsumi Endo, Hirotsugu Hara, Takumi Ohsawa, Junki Sonoyama, Tetsuya Tachibana, Hisataka Takenaga, Koji Tsubota, TOYAMA Co. Ltd., Kanazawa, Japan
Klaus Attenkofer, Eli Stavitski, BNL, Upton, Long Island, New York, USA

Abstract

A liquid-nitrogen-cooled (LN) X-ray double crystal monochromator has been designed and built for the high power load damping wiggler beamline of the NSLS2. It was designed as the direct LN first crystal to dissipate the max heat load of 2 kW and the second is in-direct-braid LN. It is designed to operate for beam energy 5 to 36 keV with fixed exit beam mode, and for QEXAFS compatible with channel cut mode. It is designed to rotate the Bragg axis with using AC servo motor and achieve up to 10 Hz scan.

INTRODUCTION

Directly fin-cooling cryogenic crystal is designed and built for the first crystal of NSLS-II ISS beam line monochromator. The ISS damping wiggler source incident power to the first crystal is total power of 2 kW and its power density of 7 W/mm^2.

Directly water cooled silicon crystal was designed and built for use in high power synchrotron radiation beamlines. The fin-cooling crystal used at KEK-PF BL16 multi pole wiggler source beamline showed its cooling effectiveness at the total incident power up to 1.6 kW and power density up to 0.7 W/mm^2 [1]. The total heat load is comparable to the incident power of ISS monochromator but the power density is one tenth.

Another crystal cooling method of direct LN2 cooling was designed and used for cooling the high heat load and high power density source at AR-NE3 in-vacuum undulator beamline [2, 3]. The maximum heat load is 800 W and the power density is 4.2 W/mm^2. The crystal is cooled by LN2 pool boiling. The power density is comparable to that of the ISS crystal but the total power is about half.

Cryogenic internal cooling and side cooling crystals were tested at NSLS on beam lines X25 and X17[4]. The tests are carried out for power density: 150 W/mm^2, total power: 75 W and power density: 0.5 W/mm^2, total power: 100 W. The power density is very high but the total power is small.

As cryogenic silicon crystal is adequate thermo-mechanical property for cooling the high power density radiation source and directly fin-cooling crystal can handle the high heat load, a new direct fin-cooling cryogenic silicon crystal was designed and fabricated for the ISS monochromator first crystal. The design of this crystal depends on critically on a number of mechanical dimensions. One is the Si thickness between the diffracting surface and the top of the LN2 channel. As this thickness is reduced, but the temperature and the heat flux on the LN2 channel are increased. If the temperature of the channel exceeds the starting point of nucleate boiling, LN2 boiling begins on the cooling channel surface. When the heat flux go through the critical heat flux, the heat transfer is suddenly decreased, and part of the channel surface is insulated with a vapour film and then the cooling of the crystal fails.

The individual widths of the cooling channels and Si fins, and the geometry of the crescent inserts influence the effectiveness and uniformity of the cooling, and should be matched to the parameters of the cooling system.
The Si top thickness, the channel widths, the geometry of inserts, the over-all Si thickness and the coolant flow rate were optimized by the simulation with using FEA analysis.

DESIGN OF SI CRYSTAL

The Si (111) first crystal is a cylindrical shape and has a disc shape thick flange in the middle of it with which it is mounted to a manifold and seals the vacuum. The cooling semi-circular channels are cut into the backside through which LN2 is circulated. The size of the crystal is 62.5 mm in height, 77 mm in top surface diameter, 125 mm in flange diameter.

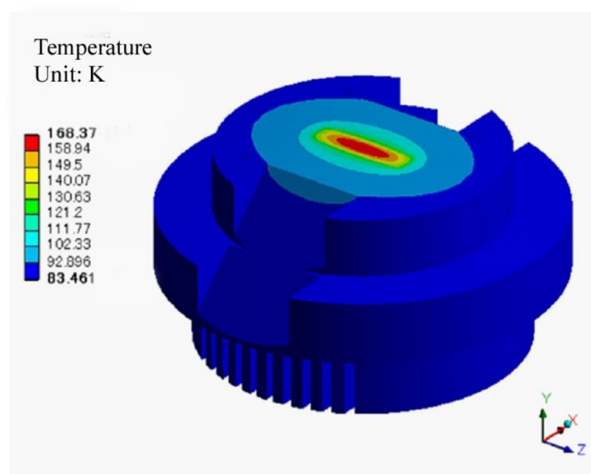

Figure 1: Temperature profile of the first crystal. Total heat load=2 kW; power density=7 W/mm^2; foot print=33.6 mm x8.51 mm (H x V); T-LN2=80 K; h=0.0103 W/mm^{2}K. This calculation model is for the thermal design phase.

† mochizuki@toyama-jp.com

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Thermo-mechanical analyses were carried out by using FEA software ANSYS and the results are shown in Fig. 1 and Fig. 2.

The heat load on diffraction surface is 2 kW and the heat flux is 7 W/mm^2. The LN2 flow rate is 0.52 l/min for each channel and its temperature is 80 K. Figure 1 shows the temperature profile of the crystal, the maximum temperature is 168.4 K at the diffraction surface and the minimum is 83.5 K. Figure 2 shows the temperature profile at top of cooling channels and the maximum is 97 K. The calculated maximum heat flux of cooling channel is 0.18 W/mm^2 which is much smaller than the critical flux of 1.4 W/mm^2 estimated by using the CHF correlation [5, 6].

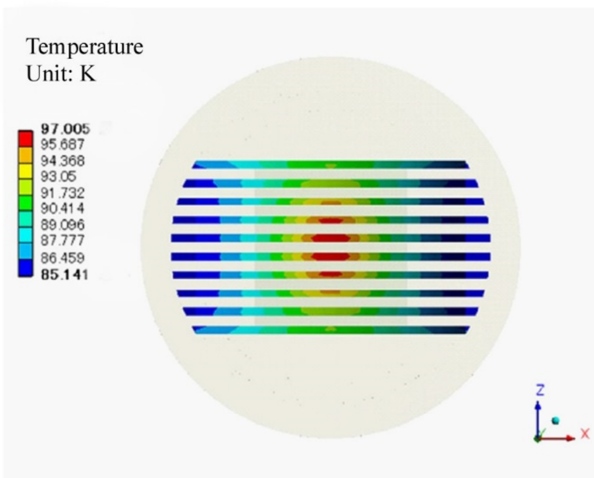

Figure 2: Temperature profile of the top of channel. The maximum heat flux of the channel is 0.18 W/mm^2.

Thermal deformation profile perpendicular to the crystal surface is shown in Fig. 3. Figure 4 shows the thermal slope error of the crystal is much smaller than the angular width of the reflectivity curve (Darwin width).

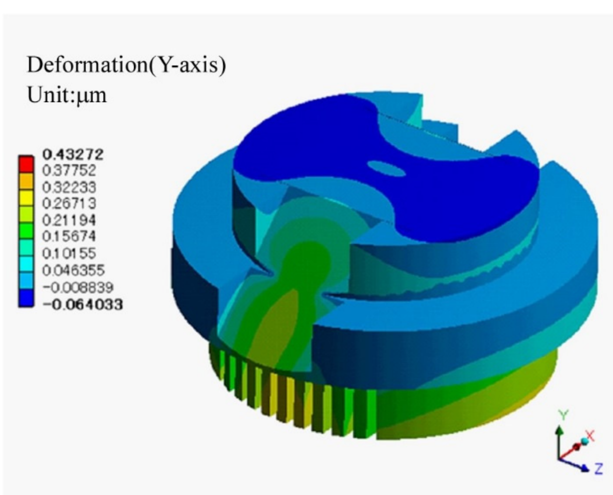

Figure 3: Deformation profile in perpendicular to the diffraction surface. Reference temperature for the calculation of thermal deformation=83.5 K. LN2 pressure=0.5 MPa absolute.

The appropriate size and shape of DCM first crystal and the shape of its cooling channel were evaluated by FEA analysis of various crystal designs.

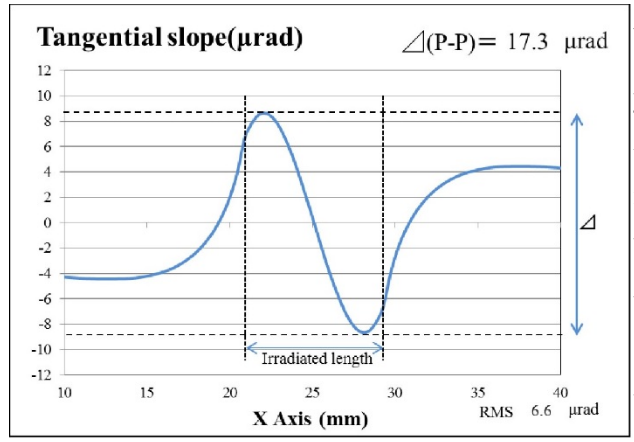

Figure 4: Tangential slope error of Si first crystal.

The final crystal shape is slightly different from the FEA model. From the reviewing the range of Bragg angle to be used, the notches in the upstream and downstream portions of the diffraction surface were unnecessary and it was enough to chamfer the peripheral portion. The final first crystal shape is shown in Fig. 5 and Fig. 6.

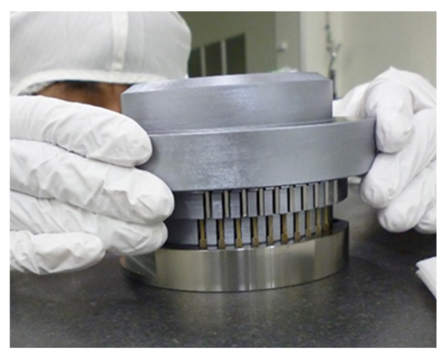

Figure 5: Si first crystal and crescent inserts assembly.

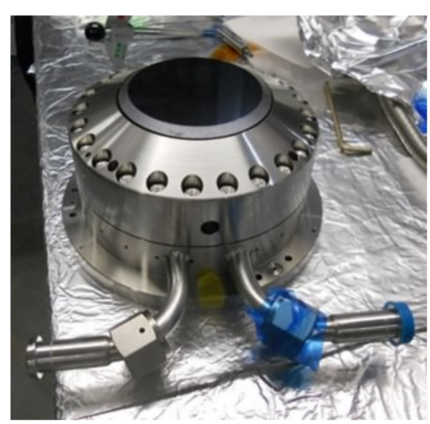

Figure 6: Si first crystal mounted to the manifold.

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Figure 5 shows the engagement check of Si first crystal and the crescent inserts assembly. Figure 6 shows the assembled crystal mounted to the manifold. The vacuum seal between the crystal and the manifold is kept with using Indium wire.

SUMMARY

A directly LN2 cooled crystal for double crystal monochromator has been designed and built for the damping wiggler source ISS beamline of NLSL-II. It is in successfully operation.

The full heat load condition is 2 kW of total power and 7 W/mm^2 of the power density. The maximum heat flux on LN2 cooling channel is 0.18 W/mm^2 which is 13 % of critical heat flux at full heat load condition.

This crystal is installed in the ISS DCM and the scan mode was tested up to 10 Hz.

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