Performance of Water-Cooled Silicon Crystal with Pin-Post Cells

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1. Introduction

The pin-post cell water cooling system[1] combined with rotated-inclined diffraction geometry[2] is one of the most suitable solutions to overcome high heat load problems on silicon monochromator crystals at SPring-8 undulator beamlines. Here we describe results of recent progress in the R&D program for this system.

2. Design of a Prototype Crystal

The cross flow propagated in the pin-post cell water cooling system is so similar to that in cylinder-array geometry that we have estimated the performance of the system with a tube-banks model. According to this estimation, the pin-post cell water cooling system satisfies both high heat transfer and low pressure drop of coolant. We have designed a prototype of monochromator crystal for SPring-8 undulator beamlines, as shown in Table 1. In this design, we have assumed the flux of water through the crystal to be kept at 20 l/min and the pressure of water in the pin-post area under 3 kgf/cm^2 to prevent crystal breakage. At this flux, the designed prototype will provide the pressure drop less than 1 kgf/cm^2 and the heat transfer coefficient more than 100000 W/m^2/K.

Table 1 Parameters of the prototype crystal

Crystal size [mm]	[L] 140, [W] 70, [H] 15
Area of one cell [mm]	[L] 10, [W] 50
Number of cells	12
Number of pins in one cell	16 x 82
Pin arrangement	In-line
Pin diameter [mm]	0.3
Pin height [mm]	0.2
Pin pitch [mm]	0.6

3. Performance of the Prototype

In order to check the reliability of our design, we fabricated a test model which had almost the same size as the prototype crystal, and examined correlations between the flux of water and the pressure drop over the system.

Figure 1 compares the pressure drop of the test model between the experimental data and the analytical results. The experimental data includes the pressure drop all over the cooling channel of the model, but the analytical results only include that in the pin-post area. The pressure drop all over the test model was 0.9 kgf/cm^2 at the flux of 20 l/min. This result indicates that our design is reliable at the estimation of the pressure drop in the crystal.

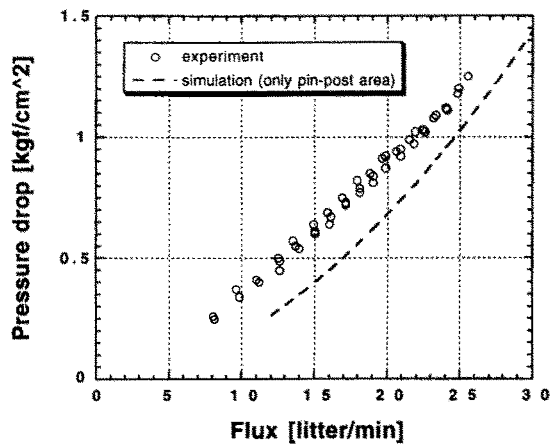

Fig. 1 Pressure drop versus flux for the prototype

Optical performance of the prototype crystal depend on thermal distortions caused of synchrotron radiation. The thermal distortion was estimated by means of the finite element method. We used some simplified models of the prototype crystal and calculated the temperature distribution and displacement of the crystal with ANSYS[3].

The heat transfer coefficient was assumed to be 50000 W/m^2/K, a half of the simulated value. Absorbed heat load (356 W)[4] rather than the input heat load (509 W) was considered for the ANSYS calculation. The ANSYS results indicate that, when the water temperature is 25 ℃, the maximum temperature on the crystal surface will be about 33.5 ℃. The crystal is bowed by the thermal stress, but the rocking curve of the crystal is not so affected, being similar to that of the perfect crystal, because the bowing will occur in the direction nearly perpendicular to the diffraction vector in rotated-inclined geometry.

4. Manufacturing Process

The crystal for the pin-post cell water cooling system will be fabricated in manufacturing process under development. In the process, there are two important stages; one is the fabrication of pin-post cells, and the other is the bonding of silicon plates.

In order to make pin-post arrays, we have tested the sand-blasting method. By means of this method, it is possible to make almost the same pin-posts with the designed ones except diameter. The diameter is gradually changing from the top to the bottom. The strain induced by the sand-blasting will be removed by chemical etching before the bonding process.

The silicon-to-silicon bonding has to satisfy the following requirements: (1) strain free; (2) strong enough against the water pressure; (3) vacuum compatible; (4) resistant to radiation. We have tested the Au/Si-eutectic bonding technique. This technique has the following merits: (1) the strain induced by the bonding will be small because this technique requires relatively low temperature and pressure; (2) gold is so stable material that the bonding state is kept to be constant for long time.

We bonded two silicon plates of 5 inch diameter and 8 mm thickness with this technique. One of the two plates was processed an array of pin-posts on the surface, and a sheet of gold foil was sandwiched between them. After bonding, the crystal was polished until the thickness from the surface to the bottom of pin-posts became about 0.5 mm. We surveyed the conditions of temperature and pressure, and selected the best condition for bonding. The lower temperature and pressure gave the smaller strain to the crystal.

5. Test for Trial Manufacturing

The bonded silicon plates was examined via X-ray diffraction. We measured the rocking curve and topography of Si(400) symmetric Bragg reflection on a double-crystal setup, as shown in Fig. 2. Figure 3 shows the rocking curve of a bonded sample, measured with Mo Kα1 radiation. The width of the rocking curve is 2.5 arc seconds. Because that of the perfect crystal measured on the same setup is 1.9 arc seconds, the value spread by the strain is only 0.6 arc seconds. The topographic data measured at different points on the rocking curve are shown in Fig. 4. The local strain induced by bonding is not observed in these images.

6. Summary

We have designed a prototype crystal with the pin-post cell water cooling system and estimated its performance. The results of the simulations and the experiments indicate that the prototype is suitable for use in the undulator beamlines of SPring-8. The sand-blasting method and Au/Si-eutectic bonding technique have been progressing in the manufacturing process of the crystal with pin-post cell.

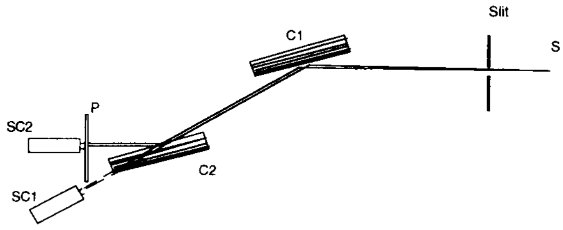

Fig. 2 X-ray optics for topography

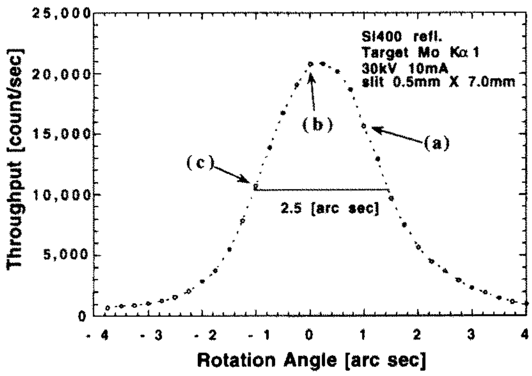

Fig. 3 Rocking curve of a bonded sample

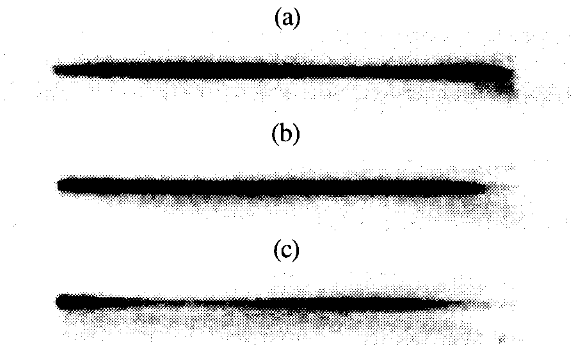

Fig. 4 Topographic images at different points shown in Fig. 3

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