Design of a V-shaped Crystal Monochromator

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1. Introduction

In the APS and ESRF, they have been devising their own monochromators for undulator beamlines, e.g., a combination of inclined silicon crystals and a liquid gallium cooling technique at APS [1], and a cryogenic cooling technique at ESRF [2]. A rotated inclined monochromator has been developed in the SPring-8 Project Team [3]. Difficulties in solving the high heat load problems with monochromators originate from the plate-like shape of crystals. One side of the plate is exclusively heated by the incident photon beams and the other side cooled with water or liquid metal, causing a temperature gradient normal to the crystal surface. This causes serious crystal-lattice deformations classified into the three modes of a)lattice expansion, b)bump, and c)bowing. Thus, we tried to design a bulky shape for the crystal to overcome this problem.

2. Design of a V-shaped Monochromator

We designed a new type of double crystal monochromator as shown in Fig. 1. Two crystals of concave and convex V-shapes are coupled to configure the monochromator system. The (left or right) half part of the V-shape can be regarded as the inclined geometry employed at the APS. The concave structure is adopted for the first crystal, on which the undulator beams are incident. The initial size of beam cross-section is preserved in the monochromated beams by use of a convex V-shaped second crystal with the same geometrical property as the concave one.

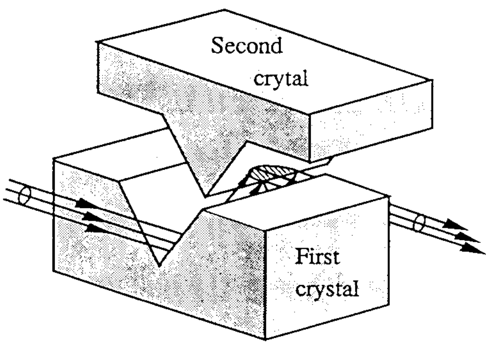

Fig. 1 V-shaped crystal monochromator.

Heat transfer and lattice deformation around the bottom line of the valley are expected to appear as schematically illustrated in Figs. 2a) and b), and the V-shaped structure will suppress the three modes of deformations mentioned above by the reasons that

1)the heat flux on the crystal surface is reduced by the inclination,
2)the cooling efficiency is improved by doubling the cooling zone around the heated spot,
3)the displacement is decreased by forming a bulky or massive structure around the irradiated area, and
4)the displacements are directed in the horizontal plane by cutting the crystal inclined to the reflecting lattice plane.

3. Thermal analysis and results

We calculated the temperature-rise and the strains of crystal surface around the irradiated area with ANSYS (ver. 5.0) on the model illustrated in Fig. 3. The calculations were conducted under several kinds of conditions of different inclination angles, α, and the radiation powers. Other geometrical parameters were fixed as indicated in Fig. 3. We let the beams be incident downward upon the V-shaped crystal. We used a radiation with a cross-sectional distribution: $P=P_{max}\exp[-x^2/(2\sigma_x^2)-y^2/(2\sigma_y^2)]$, σ_x=0.0015m and σ_y=0.0018m. Fig. 4 shows the dependence of the surface distortion along the z axis on the angle, α, and the photon density, P_{max}. Typical resutls for the temperature-rise and deformation are given in Figs. 5a) and b). The heat transfer coefficient between the crystal and the cooling water was taken to be 35×10^3 W/(m^{2}K), which was experimentally determined elsewhere [4].

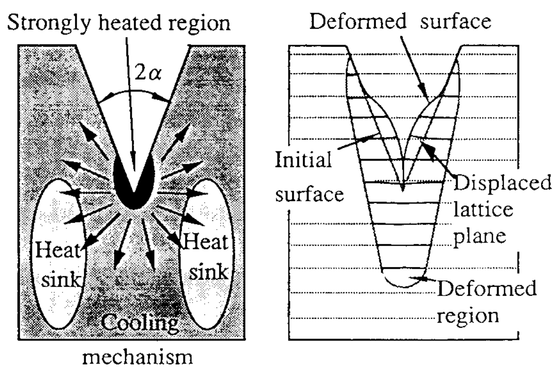

Fig. 2 a)Heat flow and b)thermal deformation in the V-shaped crystal.

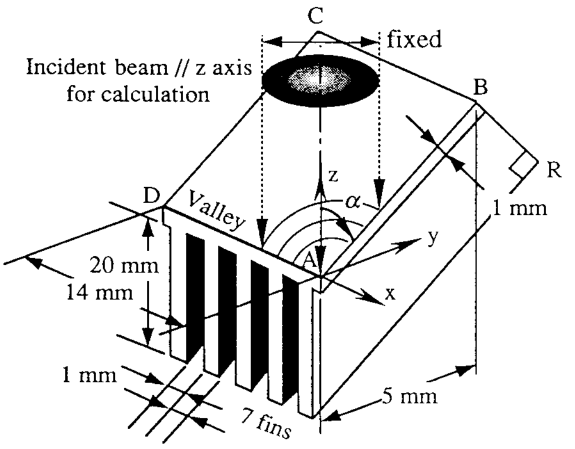

Fig. 3 Structure model for ANSYS calculation. A quarter of the whole block is adopted from the symmetry.

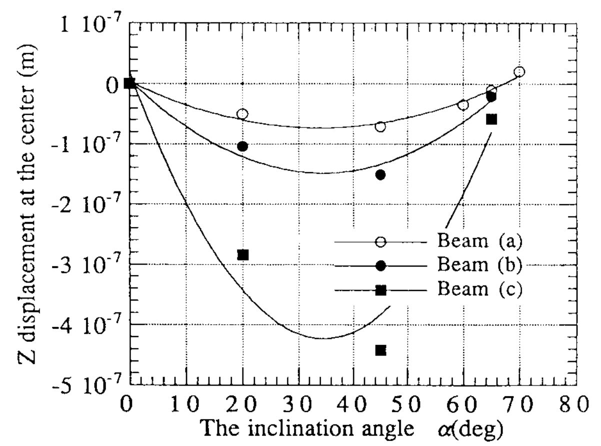

Fig. 4 Surface distortion in the z direction at the central position of irradiation against the inclination angle, α. P_{max}=(a)3×10^6, (b)6×10^6, and (c)1.5×10^7 W/m^2.

We can see in Fig. 5a) that the position of the maximum temperature is deviated by 0.003m from the center on the AB line in Fig. 3. We also see in Fig. 4 that there are two kinds of inclination angles, at which there is no displacement at the center indicated as A in Fig. 3.

4. Discussion

There is the narrowest limit at α=0, but it is impossible to be realized. It would be approximately embodied around α =a few degrees. Even if the difficulties in the fabrication of the narrower V-shaped crystal would be overcome, the alignment of the crystal on the beam axis would require more sever adjustment. The other optimum angle, α=65 degrees, is wide enough to ease the fabrication of the V-shaped structure.

The optimum angle will be determined by the fin-arrangement on the crystal, thickness of crystal plate, etc. The valley-shape would be modified in practical fabrications, such as, into parabolic, circular, elliptical, and other structures.

References

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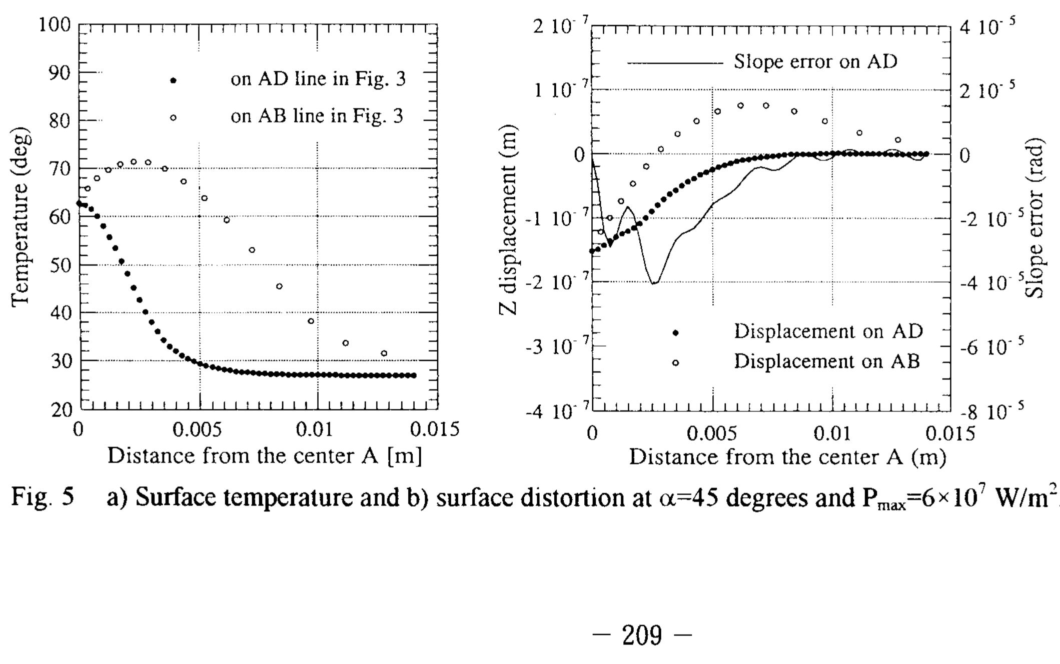

Fig. 5 a) Surface temperature and b) surface distortion at α=45 degrees and $P_{max}=6\times10^7$ W/m^2.