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Design of an adaptive cooled first crystal for an x-ray monochromator

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Abstract: We report here on the design of the first crystal in an x-ray monochromator for E.S.R.F. beam lines. This crystal is a thin silicon foil bonded to a cooled beryllium support. A system of piezoelectric actuators is used to counterbalance the deformations induced by synchrotron beams.

This work was carried out by the C.E.A. in collaboration with the E.S.R.F. and the LASERDOT Company (Aérospatiale Group).

1. INTRODUCTION

The development of third generation synchrotrons with a wide spectral range and high brightness requires adequate instrumentation. Several studies have shown that the high power (several kilowatts) and high power density (several watts per mm²) produced by these sources induce heat-load effects in the optics [1,2,3]. These result in overall bending, a local bump and an alteration of the d-spacing in a crystal monochromator. Its optical performance (angular divergence of monochromatised beam and energy resolution) is consequently affected.

Many solutions have been considered to overcome these problems [4,5]. An adaptive optics concept employed in astronomy was recently used as the basis for the construction of a cooled mirror for x-rays [6,7] (E.S.R.F./LASERDOT collaboration). In this application, the optical surface of the cooled adaptive mirror is controlled by two rows of piezoelectric actuators.

We are applying a similar concept to a monochromator to compensate for the crystal deformations generated by synchrotron beams.

We summarise here our study of a cooled crystal and its adaptive system and give the sources parameters, a description of the thermo-mechanical simulation and the adaptive cooled crystal design.

2. SOURCES PROPERTIES

The monochromator is designed for use with two different E.S.R.F. beam lines. The first source is a bending magnet [8] and the second source is the I.D.11 wiggler (BL 2 Material Diffraction) [9]. The general characteristics of the two beam lines are summarized in Table 1.

	Bending magnet	Wiggler I.D.11
Ec	19 keV	28,8 keV
P	0,42 kW	5.3 kW
Po	< 1 W/mm ²	< 30 W/mm ²
Σv	0.1 mrad	0.1 mrad
Σh	6 mrad	2 mrad

Table 1: Sources parameters. Ec: critical energy, P: total power, Po: peak power density at a distance of 30 m from the source, Σv : vertical divergence at critical energy (FWHM for Full Width at Half Maximum), Σh : horizontal divergence (FWHM).

3. SIMULATION

3.1. Materials selection

The aim of this work was to obtain a crystal with a slope error less than 5 μ rad in the x-ray direction. This value corresponds to a 10% increase in the silicon 111 Darwin width.

We carried out a thermo-mechanical analysis with a finite element code (I-DEAS) and determined the temperature distribution, thermal distortion and shape of the adaptive cooled system.

The slope errors associated with the overall bending and the thermal bump of the crystal are a function of the heat load, ϕ , and α/κ , where α is the thermal expansion coefficient and κ thermal conductivity. As we had to take into account the selective absorption of x-rays by materials, we decided to simulate a thin crystal foil (silicon) bonded to and supported by an x ray transparent material. We chose beryllium for the latter because of its lower absorption in the 5-60 keV range. Although the beryllium α/κ value is 2.5 times greater than that of silicon, its x-ray absorption for 1 mm is 6 times smaller.

3.2. Model

The results are for our silicon/beryllium system. We considered a 10 μ m thick silicon foil [10] crystal bonded to a cooled beryllium structure (Fig. 1). The overall external dimensions are 70 mm x 70 mm and the beryllium thickness is 2.3 mm. Cooling is provided by water flowing through 1 mm x 1 mm channels drilled in the beryllium support under the silicon foil. A peripheral actuator and 20 pinpoint actuators are connected to the backside of this support.

The thermo-mechanical calculations were made for a peak power density of 1 W/mm² and for incident beam energies of 5 and 23 keV with a low energy titanium filter (Table 2).

	5 keV	23 keV
Incident power	420 W	960 W
Absorbed power in silicon foil	24 W	90 W
Absorbed power in beryllium support	76 W	490 W
Total power absorbed in material*	24%	60%

Table 2: Power absorbed in silicon and beryllium

* we used a denal (tungsten) shield to absorb the residual power

3.3. Results

The maximum difference between the ambient and the crystal temperature is at the centre of the front of the support. We calculated this to be 4 K at 5 keV and 5 K at 23 keV.

In the x-ray direction, the computing slope errors are less than 3 μrad and in the transverse direction they range from 3 to 8 μrad at 5 keV and from 1 to 27 μrad at 23 keV.

These results are consistent with the expected value of 5 μrad in x-ray direction.

4. DESIGN OF THE CRYSTAL

4.1. Crystal description

The final design of the first crystal of the monochromator is shown in Fig. 1. The geometry and the dimensions of the beryllium support are based on a study in collaboration with the SAGEM company, which constructed a full scale mock-up of this support for us. This has an active thickness of 2.3 mm, an active area of 70 mm x 70 mm and a total area of 120 mm x 90 mm. It is cooled by water flowing through 35 1.3-mm diameter, 120-mm long channels. To transmit the movement of the 20 pinpoint actuators to the Be support and thus to the Si foil, these actuators are bonded to 5-mm diameter, 10-mm high cylinders. These cylinders act on the support through 1-mm diameter, 1-mm thick disks. To avoid adhesion problems, cylinders, disks and support are machined from a solid Be block. To protect the actuators from the hard x-rays, a 10 mm cooled denal (tungsten) shield is placed between the cylinders.

Figure 1: Adaptive cooled crystal schematic

4.2. Adaptive system description

The adaptive optics principle had been described previously [6,7,11]. It is a loop system consisting of a warped mirror, a wavefront analyser and a control processor.

In our study, the warped mirror is the beryllium support. A peripheral actuator and pinpoint actuators connected to the backside of this support can change its shape and, consequently, the shape of the silicon crystal. The wavefront is analysed by a Shack-Hartmann sensor (Fig. 2). As a result of the heat-load deformations, the shape of the crystal modified the incident wavefront. The image displacement, y , on the CCD retina, is a fonction of the local slope, α , of the surface and the focal length of the microlences. The crystal shape is modified through the matrix relation between the wavefront slope and the actuators action.

Figure 2: Wavefront sensor principle

5. CONCLUSION

By means of a thermo-mechanical simulation, we have shown that silicon/beryllium system is theoretically suitable.

The next step is to find a suitable silicon/beryllium bonding method. This method doesn't induce mechanical or thermo-mechanical stress in crystal which could alter x-ray optical properties (rocking curve) of the monochromator. In collaboration with SAGEM, we are testing samples using gluing, brazing or molecular adhesion. We bond thick silicon foils to a beryllium support and reduce the thickness of the silicon crystal by steps with testing of its rocking curve between steps. Molecular adhesion has given the best results to date but further work is required to reach a definitive conclusion.

This adaptive cooled crystal is designed to counterbalance crystal deformations generated by synchrotron beams. In our system, this crystal can be removed and replaced by another crystal with a new piezoelectric actuator arrangement. This adaptive system could be applied to focussing optics without heat-load problems, for example in a bending magnet beam line using a mirror as the first optical element.

6. ACKNOWLEDGEMENTS

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