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Diffractive–refractive optics: X-ray splitter

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The possibility of splitting a thin (*e.g.* undulator) X-ray beam based on diffraction–refraction effects is discussed. The beam is diffracted from a crystal whose diffracting surface has the shape of a roof with the ridge lying in the plane of diffraction. The crystal is cut asymmetrically. One half of the beam impinges on the left-hand part of the roof and the other half impinges on the right-hand side of the roof. Owing to refraction the left part of the beam is deviated to the left whereas the right part is deviated to the right. The device proposed consists of two channel-cut crystals with roof-like diffraction surfaces; the crystals are set in a dispersive position. The separation of the beams after splitting is calculated at a distance of 10 m from the crystals for various asymmetry and inclination angles. It is shown that such a splitting may be utilized for long beamlines. Advantages and disadvantages of this method are discussed.

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1. Introduction

In order to increase the versatility of a synchrotron radiation source it is sometimes useful to split the beam from one source (bending magnet, wiggler, undulator) into two or more beams. In the case of bending magnets or wigglers, this is not a problem: the beam is broad enough to insert a crystal which will deviate part of the beam in the vertical direction. In this way, one wiggler source can be used for two beamlines, as seen for example at ELETTRA (XRD1 and SAXS). For narrow beams such as undulator beams this approach is also possible but is difficult because of the narrow beam.

There are various kinds of X-ray splitters. Splitting of a Laue diffracted beam for interferometers was shown, for example, by Bonse & Materlik (1976) and Hart *et al.* (1980). Some X-ray splitters are based on mirrors or multilayers (*e.g.* Haga *et al.*, 1998; Wang *et al.*, 2003), diffraction gratings (*e.g.* Goray, 2008) or diamond crystals (*e.g.* Freund *et al.*, 1995; Lider *et al.*, 2001). Only diamond crystals are used for splitting undulator X-ray beams; here the diamond crystal deviates a certain wavelength by diffraction to one beamline, and the rest of the beam passes through the low-absorbing diamond crystal and may be used for other beamlines. This approach is used, for example, at the ESRF.

In this paper another possible solution of undulator (and not only undulator) beam splitting is proposed and discussed theoretically; it is based on diffractive–refractive optics (Hrdý & Hrdá, 2008) using silicon crystals.

2. Proposal

As was shown by Hrdý (2001), the X-ray beam diffracted from a crystal with inclination angle β and asymmetry angle α (positive or negative) is sagittally deviated by angle δ (Fig. 1), where

$$\delta = K' \tan\beta. \quad (1)$$

Here

$$K' = K(2 + b + 1/b)/(4\cos\alpha), \quad (2)$$

$$b = \sin(\theta - \alpha)/\sin(\theta + \alpha), \quad (3)$$

and for silicon

$$K = (1.256 \times 10^{-3})\ [\mathrm{nm}^{-2}]\ d_{h,k,l}\ [\mathrm{nm}]\ \lambda\ [\mathrm{nm}]. \quad (4)$$

The angle θ is the Bragg angle and λ is the wavelength.

Let us suppose that an X-ray beam is diffracted from a channel-cut crystal as shown in Fig. 2(*a*) such that the centre of the beam hits the edge (ridge) of the first roof-like surface of the crystal. This divides the beam into two parts, which are slightly sagittally deviated by an angle δ in opposite directions [in fact we have observed and measured

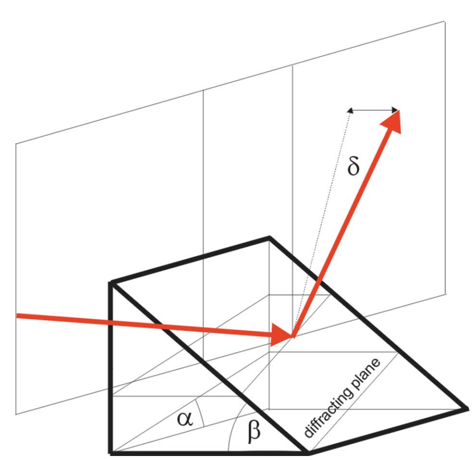

Figure 1
Diffraction on a crystal with angle of asymmetry α and inclination angle β. The diffracted beam is deviated from the plane of diffraction in the sagittal direction by angle δ.

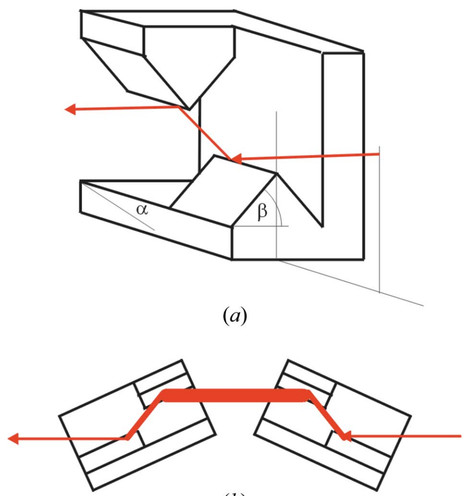

Figure 2
(*a*) Channel-cut crystal monochromator with roof-like diffracting surfaces. α is the angle of asymmetry, *i.e.* the deviation of diffracting crystallographic planes from the 'ridge' of the roof; β is the inclination angle. (*b*) Dispersive arrangement of the two channel-cut crystals shown in (*a*).

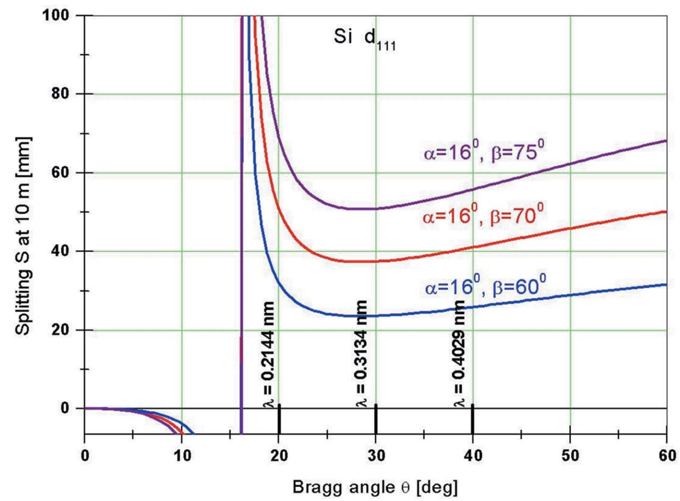

Figure 3
Dependence of the splitting S of the beams at a distance of 10 m from the crystals on θ. The calculation is performed for an angle of asymmetry α = 16° and three values of the inclination angle β.

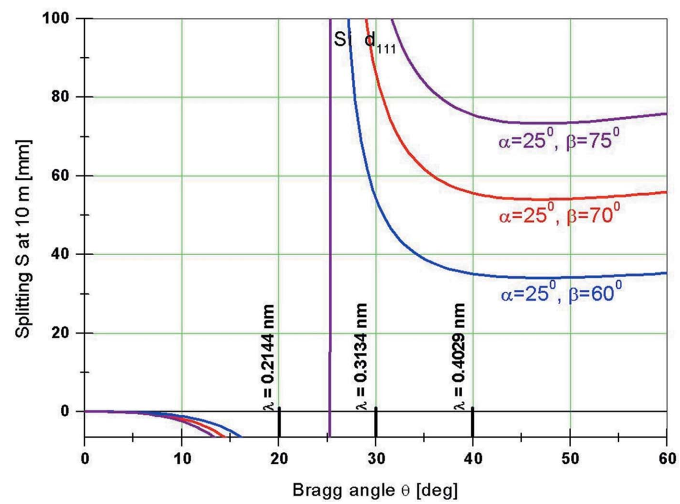

Figure 4
Dependence of the splitting S of the beams at a distance of 10 m from the crystals on θ. The calculation is performed for an angle of asymmetry α = 25° and three values of the inclination angle β.

such a splitting (Hrdý *et al.*, 1998; Artemiev *et al.*, 2000; Korytár *et al.*, 2001)]. After diffraction from the second roof-like surface this deviation is multiplied by 2. For reasons explained by Hrdý & Siddons (1999) it is desirable to use two such channel-cut crystals set in a dispersion position as shown in Fig. 2(*b*). This cancels the vertical and horizontal spread of the beam. The beam leaving the second crystal has practically the same cross section as the beam impinging on the first crystal. The sagittal deviation of the beam after diffraction from the second crystal is 4δ and thus angular separation of both parts of the beam is

$$\Delta = 8\delta. \tag{5}$$

The separation S of both beams at a distance l from both crystals is

$$S = l\Delta. \tag{6}$$

Fig. 3 shows the calculation of S at a distance l = 10 m from the silicon crystals diffracting on (111) crystallographic planes. The asymmetry angle is α = 16° and the calculation is performed for three values of β: 60°, 70° and 75°. All three curves show a relatively small variation of S with θ around 25–30° but in this region the splitting S is minimal. When the Bragg angle θ is approaching α (grazing incidence) the splitting S grows rapidly and is very sensitive to changes of θ. The splitting S grows with β but crystals with $\beta > 75°$ are most likely difficult to produce.

Fig. 4 shows what happens when α is increased to 25°. This restricts the use of this kind of splitter to the soft X-ray region but at the same time it increases the splitting S.

3. Discussion and conclusion

From Figs. 3 and 4 it is obvious that splitting of the undulator beam by the above-described method is possible but requires a long beamline (several tens of metres). The main drawback is that the wavelengths of both branches cannot be tuned independently. (However, one can imagine re-designing and splitting the channel-cut monochromator so that one half moves independently of the other; then one half of the monochromator deals with one half of the beam and the other half of the monochromator deals with the other half of the beam.) This kind of splitter could be, for example, used for applications where there is a need to change the phase, polarization or optical path of each of the beams and then recombine the beams at the sample position.

Another disadvantage is that Δ depends on λ even if this effect may be reduced in certain wavelength regions. Each beam generated is asymmetric in terms of how the intensity is distributed within it. This may be considered as a third disadvantage. An advantage, however, is that the refraction of higher harmonics is small and thus they are not deviated. This means that between two spots separated by S and corresponding to fundamental harmonics there must be another spot corresponding to higher harmonics. The fundamental and higher harmonics are thus easily separable. By a horizontal shift of the monochromator perpendicular to the impinging beam it is possible to redirect a part of the diffracted beam from one branch to another branch. In this way it is possible to switch the beam over from the left to the right branch and *vice versa*. In other words the whole beam may be deviated to the left or to the right (the higher harmonics go practically straight on). The diffraction on the inclined surface decreases the impinging radiation power density and thus reduces the effect of thermal load.

This method requires a crystal with a very good quality edge. By mechano-chemical polishing we are able to produce a sharp edge whose radius is negligible in comparison with the horizontal dimension of the undulator beam, *i.e.* 1–2 mm.

To maximize S it is desirable to choose α according to the wavelength region of the undulator. Obviously this method is more suitable for the soft X-ray region. For hard X-rays it may be advantageous to use a stack of X-ray prisms (compound refractive prisms) which would work in a similar manner as the above-proposed device. The main difference is that prisms transmit polychromatic radiation which is angularly dispersed. This provides an opportunity to choose different wavelengths in both branches and the deviation for certain wavelengths may be adjusted by adding or removing a certain number of prisms. This will be discussed elsewhere.

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