Hard X-ray Interaction with Material
(Development of computation code OEHL)

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Third generation SR sources can produce a tremendous amount of high power X-rays, e.g. of the order of 10 kwatts. The deposition of such X-ray energy brings heat load problems in every parts of beamline components. The design of beamline requires many complex calculations for the cooling system. Most of these calculations involve X-ray material interaction. In this study the re-emitted spectra and re-emitted power of a hard X-ray traversing solid material formulated analytically. Based on the formula, the re-emitted power can be calculated[1-6]. Here the re-emitted X-ray means the X-ray scattered out of the material due to the Compton scattering, the Rayleigh scattering and the X-ray of fluorescence due to the inner-shell vacancy radiative decay. The developed calcualtion code is called OEHL (Optical Element Heat Load) analysis program. In this report we briefly describe the contents without formulas and an example of application to a SPring-8 MPW. (As for the formulas, see references [3-6].) The source X-rays could be any synchrotron radiation beam, white or monochromatic filtered and apertured by an arbitrary set of materials or windows.

The detailed scattering processes are described as following. (1) The source X-rays are absorbed by the material under consideration through photoionization, the Compton scattering and the Rayleigh scattering. The secondary particles, such as scattered X-rays, photoelectrons are produced. Meanwhile, the inner-shell vacancies are also created by the X-ray material interaction. (2) Some of the secondary X-rays (scattered X-rays, fluorescence X-rays) can be transmitted or back scattered out of the material. (3) The photoelectrons produced by the X-ray material interaction may also escape from the material, but the possibility is so small that it can be neglected. Here, we are only interested in the re-emitted X-rays out of the material and the heat power absorbed by the material. Figure 1 shows a geometry of the specimen considered and the coordinates system used. Figure 2 shows a schematic figure of typical beamline setup to be used in the SPring-8 beamlines.

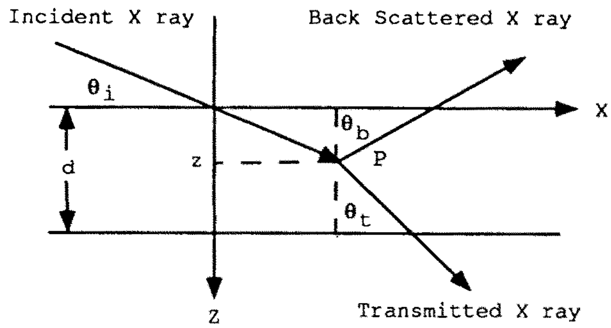

Fig. 1 The layout of a specimen.

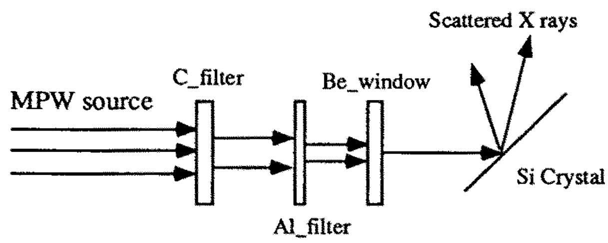

Fig. 2 An example of optical elements arrangements of the SPring-8 MPW beam line.

The X-rays generated from an insertion device MPW will pass through a graphite, Al filter and Be window and inject on a Si crystal monochromator in an evacuated chamber. The reason we use the graphite filter as the first optical element is that graphite can stand for a huge heat power. The Al filter is used to absorbed medium energy X-rays which are not interesting to the beam users. The Be window is used to separat the UHV chamber from the user's experimental chamber. The following typical SPring-8 MPW parameters are chosen for the calculations: electron beam energy in the storage ring E=8 GeV, beam current I=100 mA, K parameter 16, period λ=18 cm, total length L=3.96 m and resulting the critical energy Ω_c=40.5 keV, the total output power P=14.54 kW. The huge power is concentrated in a very small angle. The divergence on the vertical direction is much smaller than that on the horizontal direction due to the large K value. In the calculations we assume that the electron beam divergence is zero because the electron beam divergence is smaller than the divergence of radiated X-ray; the electron beam divergence does not strongly influence the radiation divergence in this case.

Figure 3 shows the X-ray spectra of the MPW photon flux after the graphite filter and that after the Al filter. The flux after the Be window is almost the same as the flux after the Al filter. The X-ray transmitted out of the Be window will be injected on a Si crystal with a given incidence angle. Caluculated results of the heat distributions by using OEHL analysis code on each filter or window are listed in Table I. Most of the heat power is loaded to the first filter element, graphite and second, Al. For the graphite filter, the soft X-ray is almost completely absorbed, while about 10 % of the absorbed power is re-emitted out of the filter due to the Compton and the Rayleigh scatterings. For the Be window, the Rayleigh and the Compton scatterings are significant and about 80 % of the absorbed power is re-emitted out of the Be window. The Be window does not subject to large heat power. Figure 4 shows the heat power and the re-emitted power due to the Compton and the Rayleigh scatterings from Si crystal for various incident angle to the Si surface. At small incident angle, the X-rays are easily scattered out of the material so that the heat power increases with the incident angle. At the same time, the penetrated power will increase as the incident angle increases. Due to the two competition mechanism, the final heat power will first increase and then decreases slightly as shown in Fig. 4. It is noted that the re-emitted X-rays become the heat source for the secondary Si crystal.

These kinds of calculations by using OEHL analysis code can be applicable to many kinds of and combinations of solid materials.

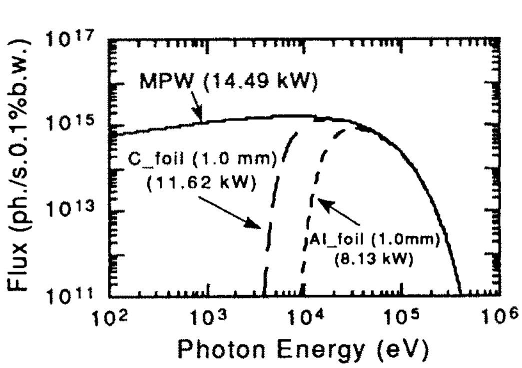

Fig. 3 X-ray specra of a MPW, after the graphite filter and after the Al filter, respectively.

Table I Absorbed power and re-emitted power for C-Al-Be filters (W).

Filter	AP	Pbc	Ptc	Pbr	Ptr	HP
C (1.00mm)	2873	164	214	8	75	2411
Al (1.00mm)	3487	114	159	9	130	3075
Be (0.25mm)	60	20	28	0	3	9

AP: Absorbed power, HP: Heat power, Pbc: Compton back scattered power, Ptc: Compton transmitted power, Pbr: Rayleigh backscattered power, Ptr: Rayleigh transmitted power.

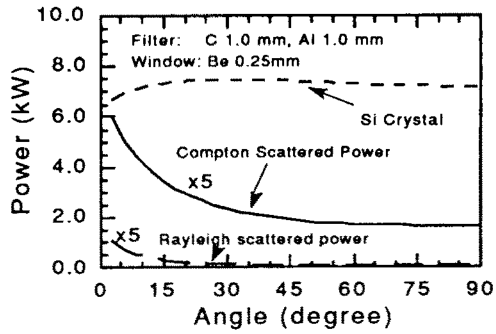

Fig. 4 Heat power as a function of incidence angle for the first Si crystal and back scattered power in the SPring-8 MPW beam line.

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