Thermal and Structural Analyses for Beryllium and Diamond Windows

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Since X-ray windows located at the downstream end of the front-end are directly irradiated by the synchrotron radiation, they are under the tough thermal condition. On SPring-8 beamlines, we plan to use beryllium windows in combination with x-y slits and filters. Further the availability of diamond windows has been also studied in consideration of the future increase in radiation power. We describe the thermal and structural analyses on the window in a pilot beamline where a planer undulator (λu:32 mm, N:140, l:4.5 m) will be located. The finite element analysis using the ANSYS code was made under the condition that K value was set to the maximum value of 2.3 giving the fundamental photon energy of 5.2 keV.

The spatial distribution of the absorbed power in the window is given as

$$F(x, y) = \frac{\sqrt{2}\,P}{\pi\sqrt{\pi}\,\sigma_x V} \exp\left(-\frac{x^2}{2\sigma_x^2}\right)\sqrt{1-\frac{y^2}{V^2}},$$

where P is the total absorbed power in the window and σ_x and V represent the horizontal and vertical spreads of the absorbed power, respectively. The window diameter was 10 mm and the thickness of beryllium was 250 μm, while the thickness of diamond was varied from 50 to 250 μm. The window platform with 2 cooling channels was made of Cu. The window was located at 33 m from the source.

The maximum temperature and equivalent stress of the window as a function of the filter thickness are shown in fig.1 under the condition with the x-y slit having the aperture of 2.3mm×0.9mm. In this case, the thicknesses of beryllium and diamond windows were 250 μm and 125 μm, respectively, so that the material thicknesses may be equivalent. Assuming that the allowable maximum temperature and stress for beryllium are 400 °C and 280 MPa (0.2% of yield strength), we estimated the minimum thickness of the filter in fig.1 to be 340 μm. The transmitted photon flux was 5.9×10^{14} photons/s/0.1% bw. For diamond, the allowable temperature should not exceed the oxidation temperature of 600 °C [1] , and 1/3 of tensile stress (1.3 GPa) was assumed for the allowable stress. Maximum temperature and stress are both below these limits for the same amount of photon flux as applied above.

Fig.2 depicts the variations of maximum temperature and equivalent stress with increasing thickness of the diamond window with an x-y slit and without a filter. The temperature decreases owing to the improvement of the heat transfer on the window as the window thickness increases, while the stiffness rise in it brings increase in the stress. However the maximum temperature and equivalent stress are below these limits. At the window thickness of 50 μm, the transmitted flux becomes maximum value of 9.4×10^{14} photons/s/0.1%bw.

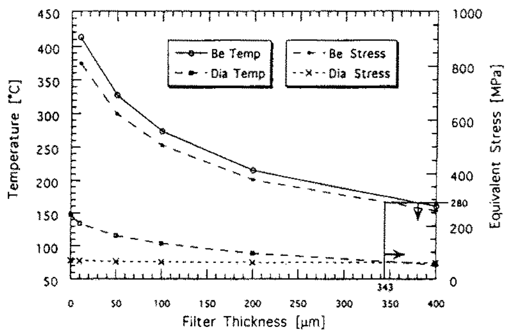

Fig.1 Maximum temperature and equivalent stress of the beryllium window and the diamond window as a function of the thickness of a graphite filter (with the x-y slit)

These analyses show that the beryllium window can be used in the beamline by placing the graphite filter and the x-y slit, however the transmission of 5.2 keV photon becomes 30%. For the diamond window, its excellent thermal and structural properties[2] allow it to be used even without a graphite filter and the photon transmission reaches 47 %. To maximize X-ray transmission, the diamond window should be thin as about 50 μm, therefore the airtight against the atmospheric pressure and the degradation by the irradiation must be further investigated and the establishment of making process of synthetic diamonds to fulfill theses requirements is indispensable.

References

[1]A.M.Khounsary et al., Nucl.Instr.Meth. A319 (1992)

[2] N.B.Novikov et al., Naukova Dumka (1987)

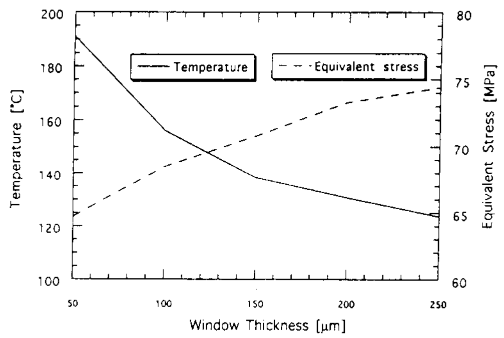

Fig.2 Maximum temperature and equivalent stress of the diamond window as a function of the window thickness (with the x-y slit, without the filter)