ELSEVIER
Nuclear Instruments and Methods in Physics Research A 467–468 (2001) 313–316
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

# Quasi-periodic grating for a monochromator at the Photon Factory BL19B

M. Fujisawa[a,*], K. Harada[a], A. Fukushima[a], S. Shin[a], Y. Kamiya[a], T. Tanaka[b], T. Kita[b]

[a] *Synchrotron Radiation Laboratory, Institute for Solid State Physics, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8581, Japan*

[b] *Hitachi Ltd., Instrument Division, 882 Ichige, Hitachnaka-shi, Ibaraki-ken 312, Japan*

**Abstract**

A quasi-periodic grating, ruled to eliminate second order diffraction, is installed in the monochromator at the Photon Factory BL19B. Higher order diffraction in the spectra of undulator radiation is observed at the non-integer multiples of a fundamental wavelength with the use of the quasi-periodic grating. The quantity of second order diffraction, estimated by photoelectron spectra of gold, is almost zero except at some photon energies. © 2001 Elsevier Science B.V. All rights reserved.

*PACS:* 42.79.D

*Keywords:* Monochromator; Quasi-periodic grating

## 1. Introduction

As far as one uses usual periodically ruled diffraction gratings with saw-tooth groove profiles to monochromatize synchrotron radiation, higher order diffraction inevitably gets mixed with the first order diffraction. For a monochromator that covers wide photon energy range from UV to soft X-ray, the deviation angles of the gratings and the mirrors must be large to obtain sufficient reflectivity at higher photon energies. At lower photon energy region, it is difficult to eliminate the higher order diffraction by small reflectivity with small incident angles of higher photon energies.

Recently, second order radiation was successfully eliminated in the visible light region using a quasi-periodic ruling grating [1]. In this paper, we investigate the features of a quasi-periodic grating in the varied line spacing plane grating (VPG) monochromator at the Photon Factory (PF) BL19B [2]. Specifically speaking, we estimate the ratio of second order radiation to the first order radiation and diffraction efficiency and compare them with those of a normal periodic grating. Both gratings have a central blaze density of 800 lines/mm. The quasi-periodic and normal periodic grating is abbreviated as Q800 and as N800, respectively.

*Corresponding author. Synchrotron Radiation Laboratory, Institute for Solid State Physics, University of Tokyo, 3-2-1 Midoricho, Tanashi-shi, 188 Tokyo, Japan. Fax: +81-471-34-6041.

*E-mail address:* fujisawa@issp.u-tokyo.ac.jp (M. Fujisawa).


PII: S 0 1 6 8 - 9 0 0 2 ( 0 1 ) 0 0 3 1 5 - 1

## 2. Grating parameters

Varied line coefficients are determined by using the following parameters, central groove density of 800 lines/mm, optimized photon wavelength of 8 nm, incident angles of 88.660°, distance between a light source and a grating of 22.3 m and distance between a grating and an exit slit of 1 m. Actual distance between a source and a grating is 19.5 m. An optimized deviation angle for each photon wavelength is decided by setting the defocus terms of the optical path function equal to zero [2]. Both type of gratings are manufactured by a mechanical ruling method and have saw-tooth groove profiles with a specified blaze angle of 1.5–2.0° for the Q800 and 2.5 ± 0.5° for the N800. The material used for both grating is CVD SiC with a reflective surface coated with Au.

A structure factor ($S$) for a quasi-periodic grating is expressed by

$$S = \frac{\sin\delta}{\delta} \text{ where } \delta = \pi\frac{(\tau+1)}{(\tau^2+1)}(-m+n\tau). \quad (1)$$

For the Q800, $\tau$ and $\delta$ [1,3,4] are decided by setting $S = 0$ at $m = n = 2$ in order to eliminate second order diffraction. Thus, $\delta$ can be expressed by

$$\delta = \frac{\pi}{2}\frac{(-m+n\sqrt{3})}{(-1+\sqrt{3})}.$$

Higher order diffractions appear at non-integer order of

$$m' = \frac{m\sqrt{3}+n}{\sqrt{3}+1}(m, n = \text{integer}). \quad (2)$$

Diffraction intensities are obtained from square of the structure factor when form factors are neglected.

## 3. Results and discussions

Black and white circles in Fig. 1 show the total electron yield spectra of gold for the undulator radiation at the PF BL19B with the N800 and the Q800 grating, respectively. The magnetic pole period was 65 mm. The intensities are normalized to the stored current of the PF storage ring, whi ch was 300 mA. The spectra were obtained with a $K$-value of 1.54 corresponding to a magnetic pole gap of 65 mm. The exit slit was fixed to 8.5 μm. The fundamental peak is located at a photon energy of 260 eV in both spectra. For N800, a peak of second order diffraction is observed at 130 eV, indicated by an arrow with the symbol **A** in the figure. On the contrary, for the Q800, no peaks at that position are observed there. Higher order diffraction is, however, observed at non-integer multiples of the fundamental wavelength, indicated by the arrows with the symbols **B** or **C** in Fig. 1.

Bars in Fig. 1 indicate locations and intensities of higher order diffraction of the Q800. The locations are obtained from an equation $h\nu_1/m'$, where $m'$ is a non-integer number calculated by Eq. (2). The intensities are calculated by squares of the structure factors in Eq. (1) and are normalized as the height of the bar that indicates first order intensity coincides with the height of the fundamental peak of the spectrum of the Q800. The numbers in the rectangles inserts stand for $m'(m, n)$. The calculated locations agree with the peaks in the spectra. The calculated intensities are, however, larger than the measured results. That seems to be due to the form factor. Higher order diffraction efficiency of the Q800 largely depends on the form factor.

Intensity ratio of the second order radiation to the primary radiation was estimated from photoelectron intensities of gold 5d valence bands at photon energies of 51 and 100 eV and gold 4f core levels at higher photon energies. Typical gold 4f core level photoelectron spectra are shown in Fig. 2. The first order excitation photon energy was set to be 260 eV. The undulator parameters were the same as the spectra in Fig. 1. The spectra obtained by the excitation of first order diffraction are shown in the Fig. 2a and c with the N800 and the Q800, respectively. The intensity of the Q800 is approximately half that of the N800. The spectra obtained by the excitation of second order diffraction are shown in Fig. 2b and c with the N800 and the Q800, respectively. The intensity of the Q800 is approximately one sixth of the N800. The same estimation for the other photon energies were performed and are summarized in Fig. 3 with the ratio of the intensities with second

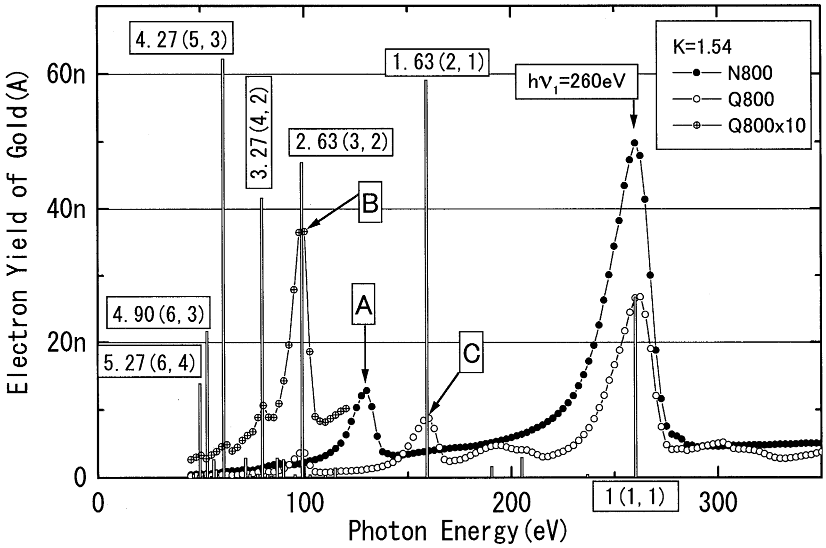


Fig. 1. Total electron yield spectra of gold with a $K$-value of 1.54. Bars indicate locations and intensities of higher order diffraction of the Q800 calculated by the structure factor. Numbers in rectangles stand for $m'(m, n)$. A peak indicated by an arrow with symbol **A** shows second order peak of the fundamental wavelength with N800. Peaks indicated by arrows with symbols **B** and **C** show non-integer multiples of the fundamental wavelength with Q800.

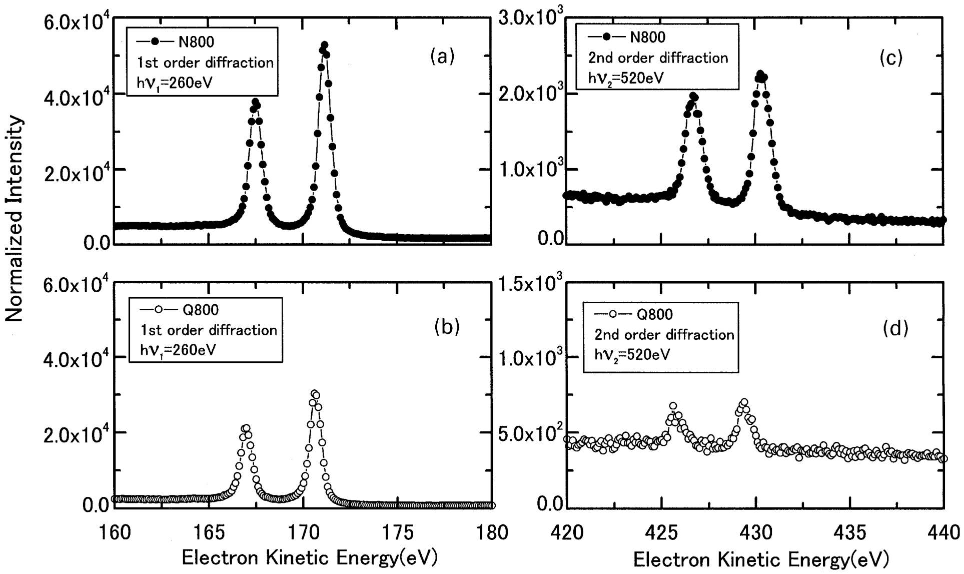


Fig. 2. Photoelectron spectra of gold 4f core level. Excitation photon energies are obtained by first order diffraction with (a) the N800 and (b) the Q800, and second order diffraction with (c) the N800 and (d) the Q800.

order diffraction to that with first order diffraction. The photon energy dependence of the photoelectron emission efficiencies was calibrated by the photoionization cross-sections [5]. For the N800 the amount of second order radiation is 5–16% in the lower energy region than 310 eV, while for the Q800 it is almost zero except at photon energies of 215 and 260 eV. According to Eq. (1),

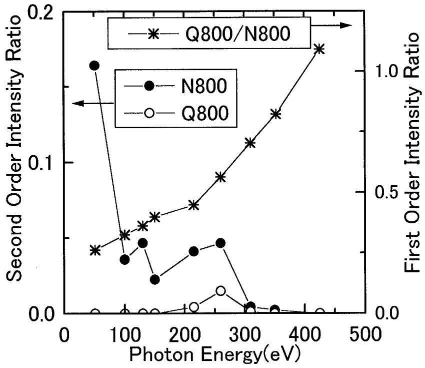


Fig. 3. Ratios of second order diffraction to 1st order diffraction estimated by the photoelectron spectra. Asterisks show the ratio of first order diffraction of the Q800 to that of the N800 obtained by the total electron yield spectra.

however, second order diffraction intensities must be zero. The actual groove shape of the Q800 does not have perfect saw-tooth waveform and has flat region between a short interval and a following long interval. It seems to be considered that the imperfectly quasi-periodic feature of the Q800 shifts the condition to eliminate the second order diffraction at photon energies of 215 and 260 eV.

Fig. 3 also shows the intensity ratio of Q800/N800 obtained by the total electron yield spectra. The intensity ratio varies from 0.26 to 1.09 in the photon energy region from 51 to 425 eV. At photon energy of 100 eV, the calculated diffraction efficiencies for the normal periodic gratings by the scalar theory [6] are almost the same with blaze angles from 1.5 to 2.5°. Thus, the ratio of 0.32 at photon energy of 100 eV is considered to be the efficiency ratio of the Q800 to N800, if they would have the same blaze angles from 1.5 to 2.5°.

Resolution was checked by measuring absorption spectra of argon 2p core level. The N800 and the Q800 have the almost the same resolution above 3000 at a photon energy of 240 eV with an exit slit of 4.5 μm.

## 4. Conclusion

With the use of a quasi-periodic grating, the second order diffraction for the VPG monochromator at the PF BL19B are almost eliminated except at photon energies of 215 and 260 eV. The first order diffraction also decreases approximately by 70%. The quasi-periodic grating is useful for the experiments, with the use of undulator radiation, that require the high purity of monochromatic radiation even if the intensities decrease.

## Acknowledgements

The authors thank Dr. M. Koike at the Japan Atomic Energy Research Institute for valuable comments on the efficiency calculation.

## References

[1] K. Harada et al., Harada's Master Thesis, 1998, unpublished.
[2] M. Fujisawa, A. Harasawa, A. Agui, M. Watanabe, A. Kakizaki, S. Shin, T. Ishii, T. Kita, T. Harada, Y. Saitoh, S. Suga, Rev. Sci. Instrum. 67 (1996) 345.
[3] D. Levine, P.J. Steinhardt, Phys. Rev. B 34 (1986) 596.
[4] C. Janot, in: J.M. Perez-Mato, F.J. Zuniga, G. Madariaga (Eds.), Method of Structure Analysis of Modulated Structure and Quasicrystals, World Scientific, Singapore, 1991, p. 20.
[5] J.J. Yeh, I. Lindau, At. Data Nucl. Tables 32 (1985) 1.
[6] A.P. Lukirskii, E.P. Savinov, Opt. Spectrosc. 14 (1963) 147.