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Holographically recorded ion-etched varied line spacing grating for a monochromator at the Photon Factory BL19B

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Abstract

Holographically recorded, ion etched ruled gratings can be obtained for the varied line spacing plane grating (VPG) monochromator at the Photon Factory BL19B. A new holographic recording method makes it possible to manufacture VPGs with large varied line coefficients for reducing the aberration terms in the optical path function. The efficiency at higher photon energies and the quantity of stray light are improved in comparison with mechanically ruled gratings. The calculation shows that the much lower efficiency at higher photon energies is not intrinsic for saw-tooth type gratings. It seems to be caused instead by carbon contamination, radiation damage, deformation at manufacturing and so on.

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Keywords: Monochromator; Varied line spacing; Holographically recorded

1. Introduction

There is a short distance between the gratings and the exit slit (1000 mm) of the varied line spacing plane grating (VPG) monochromator at the Photon Factory (PF) BL19B. The gratings must have large varied line coefficients for reducing the aberration terms in the optical path function. It is difficult to determine the holographic exposure parameters for manufacturing such gratings, by means of conventional holographic recording methods, especially with a large groove density of 2400 lines/mm. Thus, the gratings for the BL19B type monochromator are manufactured by a mechanical ruling method. Although successful results for the BL19B type monochromator have to some extent been obtained [1], the disadvantages at higher photon energies of mechanically ruled gratings remain. The quantity of stray light and efficiency in this region are usually improved by using ion etched ruled gratings. As for the efficiency in the higher photon energy region, a small blaze angle is preferred, which was unavailable for 2400 lines/mm gratings (At present good mechanical ruling gratings for lower groove density of 600/1000 lines/mm with small blaze angles are provided by Hitachi Ltd. as mentioned in Ref. [2].)

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Recently, Jobin-Yvon Ltd. has developed a new holographic recording method [3] that enables one to make large varied line coefficients. The new method consists of one or two additional gratings for constructing non-spherical waves. It has more parameters than other methods, using parallel waves, spherical or non-spherical waves constructed by concave mirrors.

In this paper, we estimate the relative quantity of stray light and the relative efficiency of a holographically recorded, ion etched VPG to that of a mechanically ruled VPG. Both gratings have a central groove density of 2400 lines/mm. The former is abbreviated as H2400 and the latter as M2400. The H2400 and M2400 have square wave and saw-tooth groove profiles, respectively.

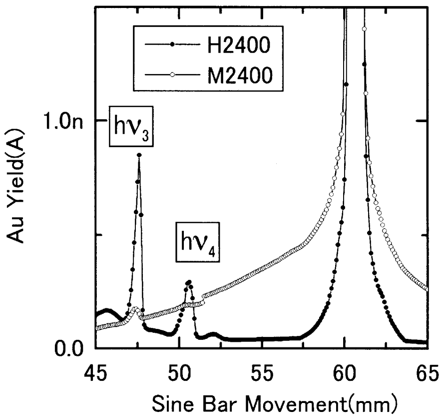

Fig. 1. Total electron yield spectra of gold including the zero-order reflection of the gratings with a K-value of 1.37 and with deviation angles of 174.40°. The 3rd and 4th order undulator radiation are indicated by hv_3 and hv_4, respectively.

2. Grating parameters

The groove density can be expressed by

$$D(w) = D_0 + D_1 w + D_2 w^2 + D_3 w^3 \quad (1)$$

where the coefficients D_0, D_1, D_2, D_3 of the H2400 are specified (measured) to be 2400(2400 $\pm$ 1)/mm, 5.4330(5.441 $\pm$ 0.011)/mm^2, 8.0957 $\times 10^{-3}$ ((7.6 $\pm$ 0.6) $\times 10^{-3}$)/mm^3 and 1.0775 $\times 10^{-5}$ (not measured)/mm^4, respectively [1,4]. These coefficients have not been measured for the M2400. As for the groove profiles, the specified (measured) groove depth is 5.2 (5.0) nm and the groove to width ratio is 0.68 (0.62) for the H2400. The blaze angle of the M2400 is 2.5 $\pm$ 0.3°. The material used for both gratings is CVD SiC. The reflective surfaces of the H2400 and the M2400 are coated with Pt and Au, respectively.

3. Results

Fig. 1 shows the total electron yield spectra of gold, including the zero-order reflection, for undulator radiation at the PF BL19B. The magnetic pole period was 72 mm. The intensities are normalized by the stored current of the PF storage ring, which was 300 mA. The spectra were obtained with a K-value of 1.37 corresponding to a magnetic pole gap of 45 mm. The deviation angles were fixed to 174.40° being optimized for a photon energy of 1250 eV, which is the 3rd order of the fundamental energy at an undulator gap of 45 mm. The exit slit width is fixed to 4.5 μm. It is clear that the quantity of stray light originating from the zero-order reflection of the H2400 grating is lower than that of the M2400 grating. Moreover, the 3rd and 4th order undulator radiation are clearly observed in the H2400 spectrum. Wide range spectra are shown in Fig. 2 with a K-value of 2.73. The other parameters are the same as the spectra in Fig. 1. At photon energies higher than approximately 400 eV, the H2400 has higher efficiency than the M2400.

Resolutions for the H2400 are checked by the absorption spectra of the gaseous nitrogen 1 s core level as shown in Fig. 3. The gas cell is approximately 100 mm long. The pressures of gas is set to 0.1 torr. The resolution of the M2400 has already been checked by the absorption spectra of the nitrogen 1 s core level and reached approximately 5000 [1]. For the H2400 the spectra with an exit slit of 4.5 μm width are shown in Fig. 3(a) and with an exit slit of 8.5 μm width in Fig. 3(b). The latter resolution is estimated to be approximately 5000 by comparing the spectrum with the spectra obtained by convoluting Gaussian function [5], which is almost equal in extent to the M2400 with an exit slit of 10 μm.

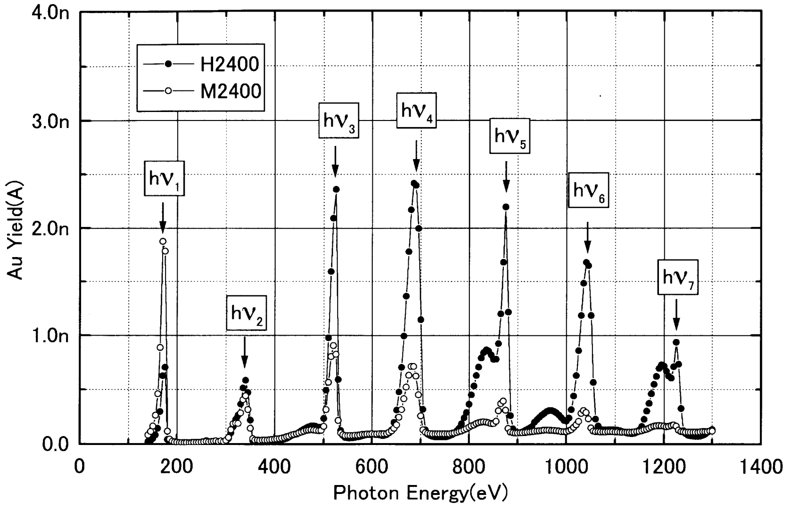

Fig. 2. Wide range total electron yield spectra with a K-value of 2.73. The nth order radiation is indicated by $h\nu_n$ ($n = 1,2,\ldots,7$).

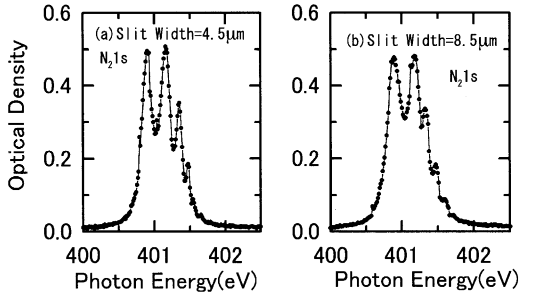

Fig. 3. 1 s photoabsorption spectrum of nitrogen gas with an exit slit width of (a) 4.5 μm and (b) 8.5 μm.

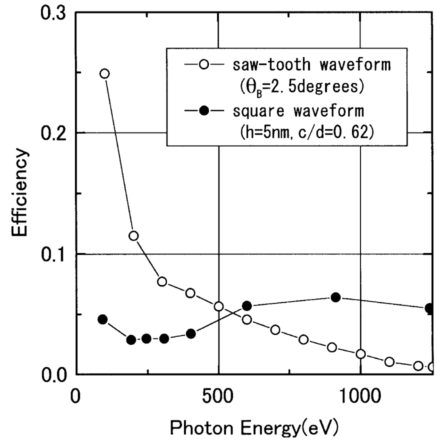

Fig. 4. Calculated efficiencies of grating with saw-tooth and square wave groove profiles by the scalar theory.

4. Discussion

The efficiency calculation for both types of gratings was performed by the scalar theory [4,6] including the groove shadow effect and the reflectivity effect of the coating materials. The results as shown in Fig. 4 indicate the saw-tooth type has lower efficiency than the square wave type in the photon energy region above 600 eV. This is qualitatively consistent with the experimental results. The efficiency ratio of the M2400 to the H2400, however, is much lower than the calculated results. This seems to be caused by extrinsic factors, such as carbon contamination, radiation damage, deformation at manufacturing and so on. In fact, the M2400 grating has been used for three years. Radiation exposure of the M2400 is longer than the H2400. For a fair comparison of the H2400 and the M2400, freshly manufactured gratings should be used or the estimation should be performed after exposing for the same period.

The resolution is usually estimated by deconvolution of the absorption spectra of standard gases.

In our case, however, the scanning movement of the monochromator is not smooth enough to be able to estimate a resolution of more than 5000 at a photon energy of 400 eV. It can only be concluded that the resolution of both types of gratings may reach approximately or slightly more than 5000.

5. Conclusion

The holographically recorded, ion etched grating improves the efficiency in the higher photon energy region and reduces the quantity of stray light for the monochromator at the PF BL19B. The VPGs for the monochromator at the PF BL19B can be considered to be focusing elements for diffracted radiation with a magnification of $\sim 1/60$. The results suggest that holographically recorded, ion etched ruled VPGs with small manufacturing errors may be available for making micro-beams in the higher photon energy region.

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References

[1] 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.

[2] Y. Saitoh, H. Kimura, Y. Suzuki, T. Nakatani, T. Matsushita, T. Muro, T. Miyahara, M. Fujisawa, K. Soda, S. Ueda, H. Harada, M. Kotsugi, A. Sekiyama, S. Suga, Rev. Sci. Instrum. 71 (2000).

[3] B. Deville, F. Bonnemason, J. Flamand, V. Millet, A. Thevenon, V. Gattino, B. Touzet, Proc. SPIE 3450 (1998) 24.

[4] Jobin-Yvon Ltd, Test Report of Varied Line Spacing Diffraction Grating, 1998.

[5] C.T. Chen, F. Sette, Rev. Sci. Instrum. 60 (1989) 1616.

[6] A.P. Lukirskii, E.P. Savinov, Opt. Spectrosc. 14 (1963) 147.