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不同材料滤片对 13～43 nm 高次谐波的抑制

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摘要：国家同步辐射实验室光谱辐射标准和计量光束线(U27)的 SGM 分支是专门为光学元件性能测试和探测器定标而建造的。为了能够精确测量光学元件在极紫外和软 X 射线波段的性能，必须充分抑制高次谐波提高光谱纯度。对于已经建成的光束线，要改变光学设计和现有结构来抑制高次谐波是困难的，最简单且有效的方法是用不同材料的滤片来抑制不同波段的高次谐波。为了研究高次谐波的抑制效果，可将 840 l/mm 透射光栅放在 U27 光束线 SGM 分支的出射狭缝后面色散出射光，用探测器做角度扫描记录下信号强度曲线，然后分析得到高次谐波的含量和分布。本文分别研究了不同厚度的 Al(200、400 和 600 nm)、Si_3N_4/Mo/Si，Si_3N_4/Mo/Si/Mo/Si 多层膜滤片(100/50/200 nm，100/50/150/150/250 nm)和 Al/Mg/Al 滤片对 13～43 nm 光谱高次谐波的抑制效果。研究结果显示，400 nm 厚的 Al 滤片适合于 17～33 nm 光谱高次谐波的抑制，在保证探测器信号强度的条件下，高次谐波信号强度占探测器信号强度的比例<2%，经探测器量子效率修正后，高次谐波比例<0.6%。Si_3N_4/Mo/Si/Mo/Si 多层膜滤片可以有效地抑制 13～19 nm 的高次谐波，Al/Mg/Al 滤片对 30～43 nm 的高次谐波有很好的抑制作用。这一结果为光学元件的透射率、反射率和探测器精确定标奠定了基础。

关 键 词：同步辐射；高次谐波抑制；滤片
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Suppression of higher-order harmonics by different material filters in 13～43 nm

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Abstract: The Spherical Grating Monochromator(SGM) branch of Spectral Radiation Standard and Metrology (U27) beamline is specially built for measurement of the properties of optical elements and detectors. In order to accurately measure the performance of optical elements, higher-order harmonics must be suppressed efficiently. For the existing beamline where the design cannot readily be altered, the simplest method is to use transmission filters to suppress higher-order harmonics. With a 840 l/

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mm transmission grating used behind the exit of SGM in U27 beamline, the exit beam can be dispersed and the contributions of the different orders can be analyzed. Results of higher-order suppression by 200 nm, 400 nm, 600 nm thickness Al filters, 100/50/200 nm, 100/50/150/150/250 nm thickness Si_3N_4/Mo/Si, Si_3N_4/Mo/Si/Mo/Si multilayers and Al/Mg/Al filter in the region of 13～43 nm show that when the thickness of Al filter is 400 nm, and the wavelength is between 17 nm and 33 nm, the contributions of higher orders to the detector signal intensity are less than 2%, and the detector intensity is strong enough when the beam on. After being corrected by quantum efficiency of the detector, higher order contributions are less than 0.6%. Si_3N_4/Mo/Si/Mo/Si filter can be efficiently used to suppress higher-order harmonics in the region of 13～19 nm, and Al/Mg/Al filter can be used to suppress higher-order harmonics in the region of 30～43 nm efficiently. These are important for the accurate calibration of absolute reflectivities of multilayer and detector etc.

Key words: synchrotron radiation; higher-order harmonic suppression; filter

1 Introduction

With the fast development of space science, Extreme Ultraviolet (EUV) lithography and micro-fabrication rapidly, there is a huge demand on pure EUV and soft X ray spectra (XUV). Synchrotron radiation (SR) has been proved to be an invaluable research tool especially in the region of XUV. However, the presence of higher order harmonics in the monochromated synchrotron beams is a universal problem. Several approaches have been used to suppress higher order harmonics, such as differentially pumped rare gas absorption filtering developed by Suits et al[1], eight pairs of total-reflection mirrors developed by Waki et al[2]. For existing beamlines where the design cannot be readily altered, the use of transmission filters is the simplest way to suppress higher order harmonics.

Transmission filters, which consist of a thin layer of metal or other materials, are commonly used in the extreme ultraviolet and soft X ray wavelength regions to transmit a desired bandpass and to attenuate out-of-band radiation[3]. These filters can also be used to reduce higher-order harmonics. Quinn[4] studied higher order suppression in diffraction grating monochromator using thin films. Seely[5] researched on measurement of extreme-ultraviolet attenuation edges of magnesium, tin, and indium filters.

In order to determine the contribution of higher-order harmonics with a small enough uncertainty, a 840 l/mm transmission grating (TG) (made in house) is utilized behind the exit of spherical grating monochromator (SGM) in U27 beamline, so that the exit monochromated beams can be dispersed and the contribution of higher order harmonics can be quantitatively analysed. This method allows the fraction of higher order harmonics to be determined at every desirable wavelength[6-7]. Quantitatives results of higher-order harmonics suppression by different thickness Al filters, Si_3N_4/Mo/Si, Si_3N_4/Mo/Si/Mo/Si multilayers and Al/Mg/Al filter in the region of 13～43 nm are presented in this article.

2 Experiment of approach

U27 is dedicated to synchrotron metrology in NSRL. SGM is one branch of U27 dedicated to the property measurement of optical elements and the calibration of detectors. It consists of front toroidal mirror (TM_1), entrance slit (S_1), spherical grating monochromator (SGM), exit slit (S_2) and back toroidal mirror[8] (TM_2), as shown in Fig. 1.

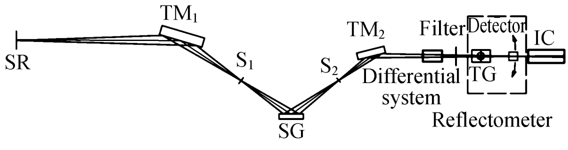


Fig. 1 Schematic diagram of SGM branch optical system

The filter is in front of the reflectometer, and the detector and TG are inside the reflectometer. The detector can rotate about TG.

TG is utilized to disperse the mono exit beam. In front of the detector there is a horizontal aperture of 0.5 mm in width. The detector can rotate and record the zero, first, second, and higher order signal intensities, as shown in Fig. 2. The mono SR irradiates perpendicularly

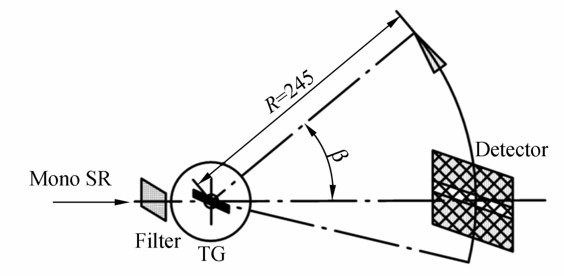


Fig. 2 Geometric structure of filter, TG and detector

on TG. The detector rotates along the arrow. β is a diffraction angle. The grating formula is as follows:

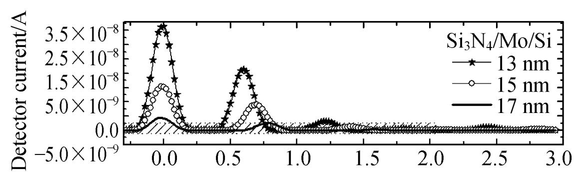
$$d \sin \beta = m\lambda$$

where d is the grating period, m is the diffraction order, and λ is the wavelength. If λ_0 is the base wavelength, $\lambda = \lambda_0 / n$ is higher order harmonics at the base wavelength. $n = 2, 3, 4...$ $d = l/840 = 1.2\ \mu m$, λ_0 is in the region of 13～43 nm.

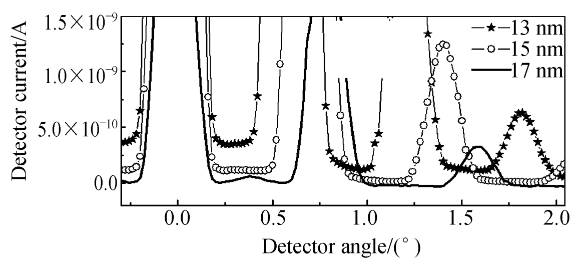
The diffraction angle at base wavelength β_0 and higher order harmonics β can be calculated using the formula above. The higher order harmonics diffraction peaks can be established by comparing the calculated diffraction angles. The intensity contribution of higher order harmonics can be quantitatively determined by curve area integral. The contribution of the higher order harmonics in 13～43 nm can be determined after the detector signal is corrected by the quantum efficiency.

3 Experimented results

The VUV in the region of 13～33 nm is widely used for measurement of optical element properties. The purity of spectrum is the key role to an accurate measurement. The efficiencies of higher order harmonics suppression vary with different thickness Al, Si_3N_4/Mo/Si filters, and filters of different materials cover different spectral regions because of their absorption edges.



(a)



(b)

Fig. 3 Intensity curves of detector with Si_3N_4/Mo/Si filter at wavelength of 13, 15, 17 nm

Si_3N_4/Mo/Si and Si_3N_4/Mo/Si/Mo/Si filters are researched in the wavelength region of 13～19 nm for higher-order harmonics suppression. Fig. 3 shows the detector recorded diffraction intensity curves of TG while the exit beam of SGM is transmitting through Si_3N_4/Mo/Si filter at wavelength of 13, 15, 17 nm. Fig. 3(b) is the amplified shadow area of (a) on the top. The first diffraction angle is enhanced with the basic wavelength increasing. Fig. 4 shows the intensity with filter Si_3N_4/Mo/Si/Mo/Si. It can be seen by comparing Fig. 3 and Fig. 4 that higher order diffraction peak still can be seen at an angle of 0.38° at a wavelength of 17 nm with

Si_3N_4/Mo/Si filter. Tab. 1 shows the percentage of higher orders to the first orders with a wavelength in the range of 13～19 nm and Si_3N_4/Mo/Si, Si_3N_4/Mo/Si/Mo/Si filers.

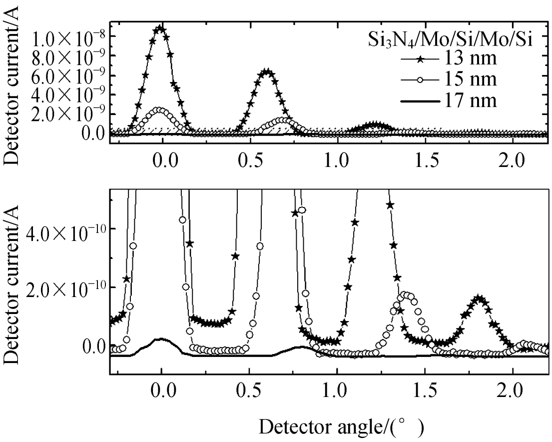


Fig. 4 Intensity curves of detector with Si_3N_4/Mo/Si/Mo/Si filter at wavelength of 13, 15, 17 nm.

Tab. 1 Percentage of higher order over first order after QE modification

λ (nm)	Si_3N_4/Mo/Si intensity higher order (%)	QE modified (%)	Si_3N_4/Mo/Si/Mo/S intensity higher order (%)	QE modified (%)
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	1.47	0.53	0	0
17	2.27	1.02	0	0
18	6.60	2.00	0	0
19	14.5	4.1	0	0

Al filter is suitable for wavelength of 17～34 nm. For comparison, the experiment was done without filter or with 200, 400, 600 nm thickness Al filters. Fig. 5 shows intensity curves without filter, Fig. 6, Fig. 7 and Fig. 8 show intensity curves with 200, 400, 600 nm thick Al filter respectively. As the filter thickness increases, the percentage of higher-order decreases.

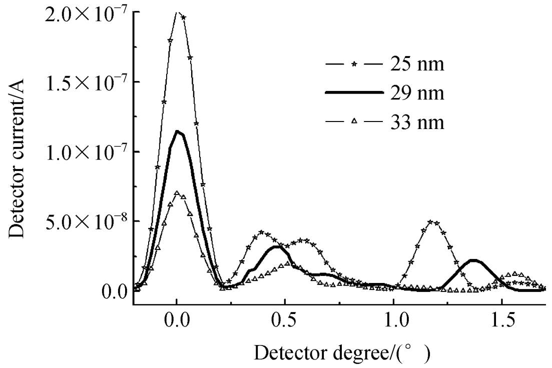


Fig. 5 Intensity curves of detector scanning at wavelengths of 25, 29 and 33 nm without filter

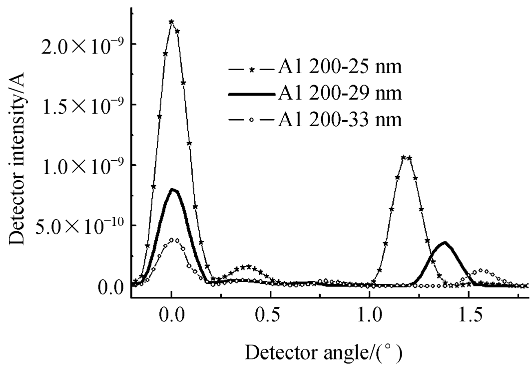
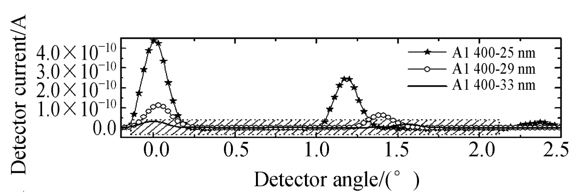
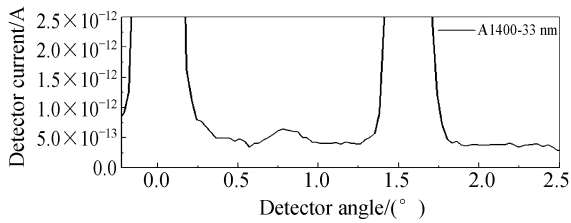


Fig. 6 Intensity curves of detector scanning at wavelengths of 25, 29 and 33 nm and with 200 nm Al filter.



(a) Wavelength of 25, 29, 33 nm



(b) Amplified shadow area of (a) at wavelength of 33 nm

Fig. 7 Intensity curve of detector scanning with 400 nm Al filter

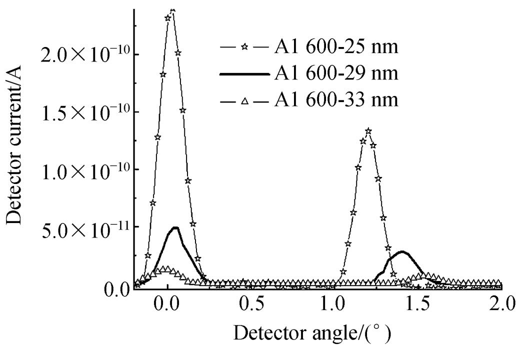


Fig. 8 Intensity curves of detector scanning at wavelengths of 25, 29 and 33 nm with 600 nm Al filter

Tab. 2 gives the percentages of higher-order over first order at basic wavelength, without filter or with different thickness Al filters. According to the data shown in Tab. 2, it is preferred to choose 400 nm thick Al filter to suppress higher orders in the region of 17～33 nm. The purity of spectra is better than 99% when the detector intensity is strong enough.

Tab. 2 Percentage of higher-order over first order at basic wavelength without and with 200, 400, 600 nm thickness Al filters after QE modification

λ nm	No filter	Al 200 nm	Al 400 nm	Al 600 nm
17	22.6%	6.3%	0	0
19	26.5%	0.9%	0	0
21	24.8%	1.8%	0	0
23	46.9%	3.0%	0	0
25	67.8%	5.7%	0	0
27	71.6%	7.0%	0	0
29	72.1%	6.7%	0	0
31	73.6%	15.4%	0	0
33	72.2%	26.6%	0.6%	0.6%

Al/Mg/Al filter is chosen to reduce the higher-order harmonics in the region of 30～43 nm depending on the energy of the absorption edge. Since Mg is an active metal, so Al is covered on its both sides to prevent oxidation. The Al/Mg/Al filter was purchased from Luxel Corporation (USA) and its layers thickness are 15, 150, 15 nm respectively. Fig. 9 shows TG diffraction intensity curves with Al/Mg/Al filter at a wavelength in the region of 30～50 nm. Fig. 10 shows higher-order harmonics with Al/Mg/Al filter used to suppress high-order harmonics. When the wavelength is shorter than 44 nm, the higher-order intensity is less than 19%.

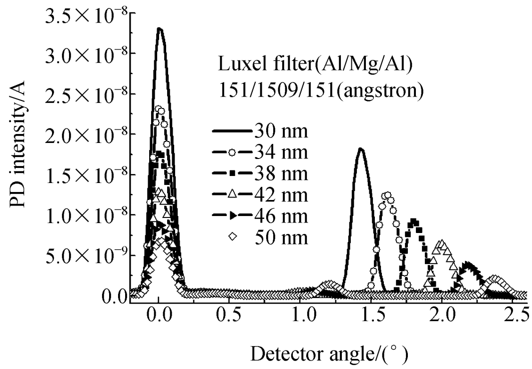


Fig. 9 TG diffraction intensity curves with Al/Mg/Al filter at a wavelength in the range of 30～50 nm

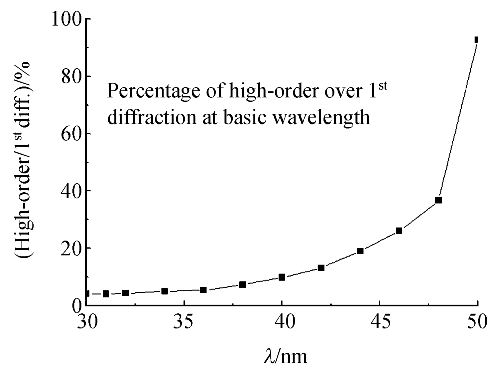


Fig. 10 Higher-order content with Al/Mg/Al filter

4 Conclusion

Si_3N_4/Mo/Si/Mo/Si filter can be chosen to suppress the higher-orders in the region of 13～19 nm and the purity of spectra is better than 99%. When the wavelength is between 17～33 nm, 400 nm Al filter can be chosen to suppress higher-orders and the purity of spectra is better than 99% too. Al/Mg/Al transmission filter is used to reduce higher-order in the spectral region of 30～44 nm and the contribution of higher-orders to the detector signal is kept to less than 19%.

5 Acknowledgement

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