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Optical Design for a Seya-Namioka Beamline at SRC

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The separate-focus function mirrors are used as a premirror system for Seya-Namioka beamline at Synchrotron Radiation Center in Stoughton, Wisconsin. The quality of each focus is verified by using a ray tracing program SHADOW. In this beamline, all optical elements are cylindrical except the spherical grating. An attempt to find out a good combination of exit and refocus mirrors was also made.

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I. INTRODUCTION

The unique and varied properties of synchrotron radiation and the recent development of new storage ring light sources have opened up a large expansion in research techniques and experimental possibilities in many disciplines, that include physics, chemistry, biology, microelectronics, and metallurgy [1-5]. The research developed from these groups includes techniques such as angle-resolved photoemission spectroscopy, time-resolved fluorescence spectroscopy, absorption spectroscopy, x-ray lithography, x-ray microscopy and medical radiography. Of course each technique requires certain specific properties of the radiation to be enhanced while other characteristics can be masked or ignored. In order to achieve the experimental source requirements from "raw" synchrotron light, a proliferation of monochromator devices have been designed and built to meet many of the needs from researchers. Currently, progress in monochromator design or beamline design is directed toward improving the characteristics of the existing design as well as implementing new ideas. At the same time strides have been made in optical technology due to the increasing demands for better imaging and transmitting characteristics of optical elements.

In the vacuum ultraviolet (VIJV) photon energy range, the Seya-Namioka monochromator [6-9] is a usual consideration for this range due to its simplicity in the scanning mechanism, easily operated for two fixed entrance and exit slits, and a reasonable good resolving power of about 5000 (If the finite slit width, figure slope error, and grating width are taken into consideration, the value of resolving power will be reduced further). So the Seya-Namioka beamline is a common beamline operated in every synchrotron radiation facility around the world for VUV spectra. However, we know the Seya-Namioka beanline in different facilities may have different kinds of arrangements for the premirror system and postmirror system in order to fit different experimental techniques. The one in the Synchrotron Radiation Research Center (SRRC), Taiwan, R.O.C. uses grazing incidence plane and toroidal mirrors as a premirror system to have a separate-focus function, and a nearly stigmatic image at final focus position, high throughput, high polarization enhancement are obtained [10]. The other one in the National Synchrotron Light Source (NSLS), Brookhaven [II] has a normal incidence configuration of premirror system in order to cut off high order contamination in the VUV spectra. In Japan, the Seya-Namioka beamline in Photon Factory (KEK) [12] uses a foregrating arrangement to reject the high order spectra and to obtain a resolving power above ten thousand. Thus it is clear to see that the purposes of premirror system and some time with the combination of postmirror system are to have a stigmatic beam, high flux, large polarization enhancement, and low contamination in the spectra.

In this paper, we will apply the idea of separate-focus by using only two cylindrical mirrors to form the premirror system in the Seya-Namioka beamline. The parameters of these optical elements as well as their geometrical arrangement are proposed. A ray tracing program SHADOW was used to verify the quality of each focus. Finally, an attempt was made to give a. fairly good combination of exit and refocusing mirrors to fulfill the users' requirements that the beam at the sample position should be 100 cm beyond the center of refocusing mirror, i.e., large working space.

II. THE DESIGN

From the experiences of the optical system designer and the suggestions from general users, we may now draw up the desirable features for a high performance photon beamline at VUV range.

(1) Utilize the optical elements which can be manufactured precisely and easily. For instance, it is achievable to have half an arc second slope accuracy for plane, cylinder, and sphere elements.

(2) Simplicity in the driving/scanning mechanism.

(3) Using one grating between the entrance and exit slit. The resolving power is determined by the optical performance between the slits.
(4) The fewer the reflecting elements, the better is for the transmission. Since each reflecting element will cut down the incoming flux from 20% to 50% depending on the figure quality of the element, the wavelength, the angle of incidence, and the coating material.
(5) With adequate deflecting photon beam by the mirror systems, more room and working space can be left for accommodation of adjacent beamline and experimental station.

We have also learned that the idea of separate focusing by two optical elements have been applied to many photon beamlines in the world [13-16]. However, for the VUV spectra range, the Seya-Namioka beamline, no two cylindrical elements for separate focusing function has ever been used for the prefocusing purpose in the Synchrotron Radiation Center (SRC), Wisconsin, and even rare in the world.

With the understanding as stated above, we will use the simplest two cylindrical elements to decouple the focusing properties ahead of the spherical grating, and use a cylindrical mirror as exit mirror to focus the image at the exit slit to the position of the tangential focus of the spherical grating. The image at this position will be focused to the sample position by a refocusing toroidal or ellipsoidal mirror.

II-l. The prefocusing section

Fig. 1 shows the schematic layout of the new Seya-Namioka beamline. At the left figure there two optical elements, the one closest to the light source is the horizontal focusing mirror (HFM), which accepts 25 mrad of the horizontal fan of radiation. With the SRC operating at 0.8 GeV and 100 mA average electron current, this HFM accepts only 6.9 Watt. So we do not need to care much about the cooling problem, not only its power dissipation is low, but also it is not a resolution determining element. Another vertical focusing mirror (VFM) is close to the spherical grating. Since both are cylindrical mirrors. This means that they each focus in only one direction and that their optical functions are decoupled. We would expect that the image of focus will be rectangular.

Now recalling the well-known equations for imaging with a cylindrical mirror at nonnormal incidence:

$$\frac{1}{p}+\frac{1}{q}=\frac{2}{R\cos\phi} \tag{1}$$

if the generators of the cylindrical surface lie in a plane parallel to the plane of incidence, and

$$\frac{1}{p}+\frac{1}{q}=\frac{2\cos\phi}{R} \tag{2}$$

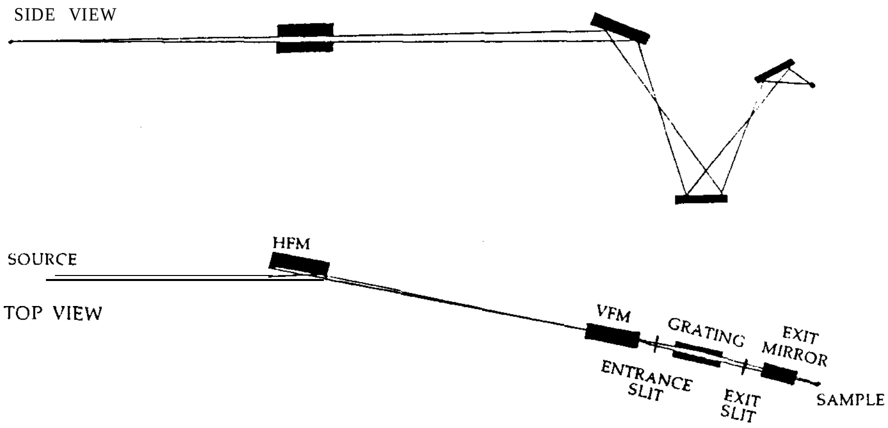

FIG. 1. Geometrical layout of the new Seya-Namioka beamline

if the generators lie in the plane perpendicular to the plane of incidence. Here p is the source distance, q the image distance, R the radius of curvature of the cylindrical surface, and ϕ is the angle of incidence for the principal ray. It is evident from these equations that as the angle of incidence increases the image point calculated from Eq. (1) *moves* steadily closer, while that from Eq. (2) moves monotonically away. We use the orientation appropriate to Eq. (1) for mirror HFM, and that appropriate to Eq. (2) for mirror VFM. These choices are based on the idea developed by Gerhardt [17,18]. VFM vertically images the source at the plane of the entrance slit of the monochromator with a magnification $M = q/p =$ 0.1, and an aperture ratio f/20. HFM horizontally images the source 40.65 cm ahead of the entrance slit with a magnification of 1, and an aperture ratio f/40.

A ray tracing program, written and coded by Professor Franco Cerrina of the University of Wisconsin at Madison [19-23], was used to simulate this optical system. Table I. lists the geometrical parameters necessary for this ray tracing work. Figs. 2a, 2b, 2c are the image patterns of synchrotron radiation source at 10 eV, the horizontal focus point, and the vertical focus point at the entrance slit, respectively. The rectangular image at the entrance slit illustrates the perfect focusing of the VFM and HFM.

II-2. The monochromator section

The monochromator is a 1m Seya-Xamioka specially built by Physical Science Lab (PSL) in Stoughton, Wisconsin. Optically, it is rotated from the conventional orientation so that the entrance arm rises at 54.75° from the horizontal and the grating rulings are horizontal. Mechanically, it is all-metal sealed, acid-cleaned stainless-stell, bakeable to 250°C, pumped with 200 l/s noble ion pump with a Titanium sublimation pump, and has a

TABLE I Geometrical parameters of Seya-Namioka beamline.

Source to HFM	2.350 m
HFM to VFM	2.290 m
VFM to entrance slit	0.464 m
Entrance slit to grating	0.818 m
Grating to exit slit	0.818 m
Exit slit to exit mirror	0.203 m
Exit mirror to sample position	0.203 m
HFM incident angle	80.0”
VFM incident angle	62.625’
Grating Z.O. incident angle	35.125”

base pressure less than 1 x 10^{-9} torr. The entrance and exit slits are flexural hinge mounted blades actuated by a micrometer. The slit width varies linearly with micrometer setting. To prevent the slits from damaged, internal stops prevent the slits from closing completely. The standard spherical grating is 1200 l/mm, coated with Gold, and 8.33 A/mm for the linear dispersion.

With the monochromator set for $\lambda \simeq$ 300 A, the position of the astigmatic image formed by HFM lies on the line which is tangent to the Rowland circle at the center of curvature of the grating. Hence, at this wavelength the focusing grating reimages (one to one) the astigmatic HFM image at the point where the above tangent line intersects the exiting ray. This point lies about 40 cm beyond the exit slit, and is a natural location for experimental samples on which user wishes to concentrate light. The astigmatic image of VFM is reimaged by the grating on the exit slit plane. Finally, a cylindrical exit mirror will focus the image on the exit slit plane to the same focus point as spherical grating does in its tangential focusing. By virture of this kind of separate focus, a nearly stigmatic image can be obtained.

The monochromator and beamline design described enhances the polarization of the VUV radiation emitted by Aladdin, SRC. When the initial polarization of the synchrotron light is considered along with the enhancement of the reflections, the polarization of the exit light beam should be about 99 per cent. This value is calculated from the theoretical emission intensity and reflection enhancements. Since this enhancement is not highly sensitive on wavelength over the VUV region, and since the polarization of Aladdin radiation increases with photon energy, we expect that the polarization will not fall below 99% over the useful range of the monochromator.

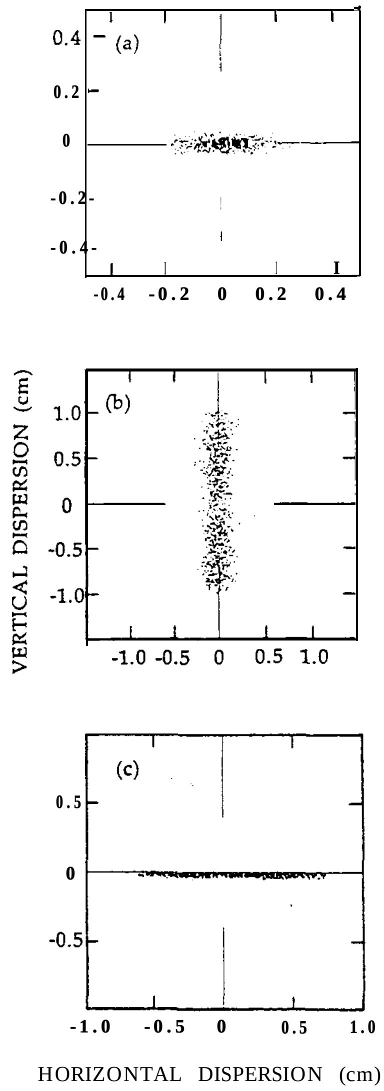

FIG. 2. Image patterns of the Seya-Namioka beamline at (a) source (b) horizontal focus and (c) vertical focus (entrance slit) positions. The mirrors in this ray tracing have the ideal cylindrical figure.

11-3. The refocusing section

Normally, the position for the final stigmatic focus image is 22 cm from the exit flange, it makes a small working space for the experimental station. In order to serve the requirements from the users for a large working space: especially for their research topics on **gas** phase spectroscopy and angle-resolved photoemission. A toroidal or ellipsoidal mirror was considered to let the stigmatic image beyond the exit mirror focus further.

Based on the above considerations, an attempt was made to find a good geometrical arrangement for the exit mirror and refocusing mirror. Fig. 3 shows the geometrical layout of the exit mirror and refocusing mirror. An optimization rotation angle a is important, which will affect the aspherical mirror size and the final throughput. Through the ray tracing, length for the exit and refocusing mirror as change of a are shown in Fig. 4. We can see, as the rotation angle a increasing, the length of exit cylindrical mirror will increase and the size of refocusing mirror decrease rapidly. From the optical technology point of view, a better choice seems to be a combination of small aspherical refocusing mirror (either toroidal or ellipsoidal) and a large cylindrical exit mirror. This is in the situation of large rotation angle.

In regard to the throughput, Fig. 5 shows the combined reflectivity calculated by generalized Fresnel equations [24] for coating material Platinum and Gold as a function of

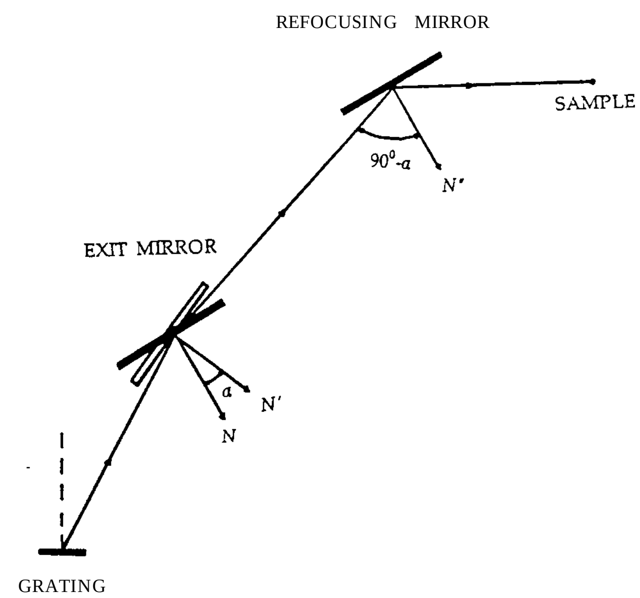

FIG. 3. Side view of the geometrical layout of the exit mirror and refocusing mirror in the Seya-Namioka beamline a is the rotation angle.

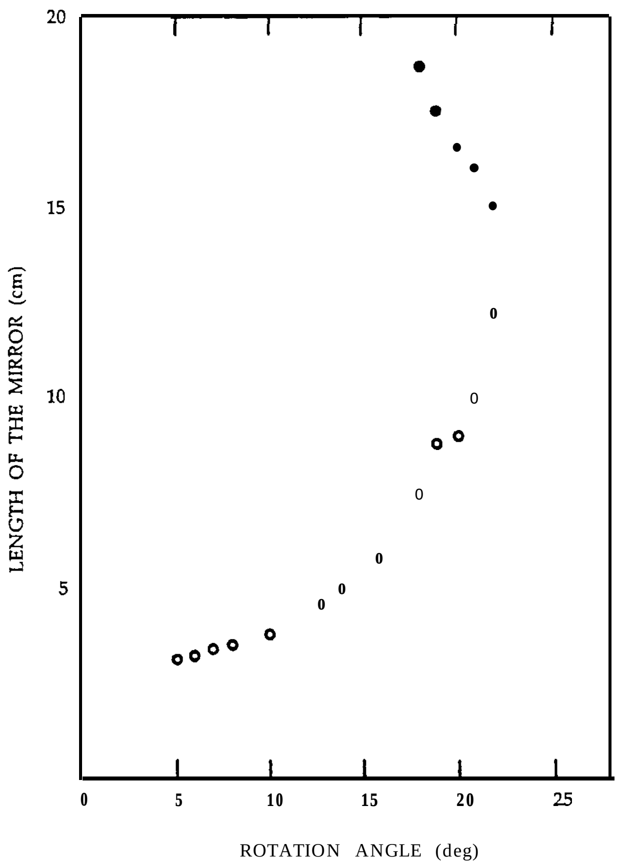

FIG. 4. The length of exit and refocusing mirror at several rotation angles (○ for exit mirror, • for refocusing mirror).

rotation angle in two different photon energies. It is clear that Platinum is a good material choice for the high throughput purpose, and the total reflectivity increasing above (and below) 13 ” .

The beam size at final focus (beyond the refocusing aspherical mirror) for both ellipsoidal and toroidal mirror are listed in Table II. The horizontal beam sizes do not change obviously as a function of rotation angle. However, the vertical beam sizes change dramatically, this is attributed to the astigmatic coma aberration at grazing incidence. So we can have a smaller beam size and high throughput at the sample position by choosing the rotation angle above 13 ” .

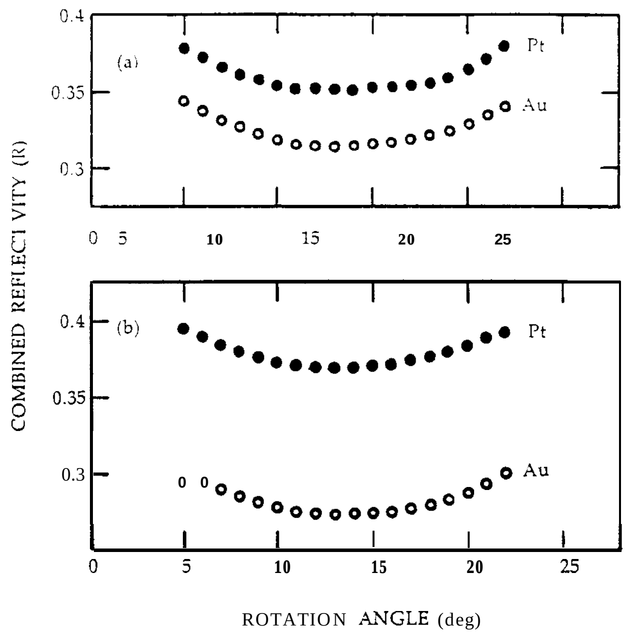

FIG. 5. The combined reflectivities of exit and refocusing mirrors for coating materials Pt and Au at photon energy (a) 10 eV (b) 20 eV.

TABLE II. The final image sizes for both ellipsoidal and toroidal refocusing mirrors. a is rotation angle.

a	beam size [H×V, cm²]	
[deg]	ellipsoidal	toroidal
5	0.44 x 0.125	0.4 x 0.56
6	0.4 x 0.048	0.36 x 0.4
7	0.4 x 0.048	0.36 x 0.28
8	0.4 x 0.048	0.36 x 0.2
10	0.4 x 0.048	0.38 x 0.088
13	0.38 x 0.04	0.34 x 0.04
16	0.38 x 0.04	0.34 x 0.04
19	0.38 x 0.036	0.36 x 0.036
22	0.38 x 0.033	0.36 x 0.036

III. SUMMARY

In this work, we apply the separative focusing properties to the prefocusing mirrors of Seya-Namioka beamline in SRC. All mirrors in this beamline are cylindrical. To consider the large working space for the users, an attempt was made to find a good combination of exit mirror and refocusing mirror, based on: (1) small aspherical refocusing mirror; (2) small focus beam at sample position; (3) high throughput ; (4) the exit beam parallel to the floor.

We hope that this geometric arrangement may improve the performance of the Seya-Namioka beamline at SRC.

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