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Upgrade of beamline 3W1B at Beijing Synchrotron Radiation Facility *

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Abstract: To improve the performance of Beamline 3W1B at the Beijing Synchrotron Radiation Facility for the soft X-ray magnetic linear dichroism research at transition metals $L_{2,3}$ edges, a new monochromator was designed and built to replace the original one. After the assemblage, alignment and adjustment of the monochromator system, the first commissioning results were obtained. The photon energy range is from 50 to 1000 eV with spectral resolutions of 1600 at 250 eV and 1000 at 870 eV. The photon flux is of the order of 10^8–10^9 photons/s/200 mA/0.1%BW. In the electron's orbital plane the linear polarization degree of the light is higher than 99% at 704 eV. The beamline has satisfied the basic experimental requirements.

Key words: wiggler beamline, monochromator, varied-space plane grating, spectral resolution, linear polarization

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1 Introduction

Beamline 3W1B is a soft X-ray beamline at the Beijing Synchrotron Radiation Facility (BSRF) and has been used for nearly two decades to calibrate X-ray detectors and study magnetic material multilayers. The radiation source is a 1.5-m-long permanent magnet wiggler installed at the straight section of the storage ring of the Beijing Electron Positron Collider (BEPC). This wiggler has five periods and its maximum magnetic field is 1.5 T. Beamline 3W1B was constructed with an offset of 5.3 mrad from the wiggler axis.

During recent years, because the aging scanning mechanism of the beamline has become inaccurate and the electron beam current of the BEPC has been increased from 100 to 250 mA, the stability and the spectral resolution of this beamline have been greatly reduced. The plane mirror surface has been deformed measurably. The service efficiency of this beamline has become seriously restricted.

However, this wiggler beamline can provide synchrotron light with excellent linear polarization state [1] for the soft X-ray magnetic linear dichroism (SXMLD) research at $L_{2,3}$ edges of transition metals. Thus, we determined to improve the performance of the beamline. The upgrade chiefly involved the design and construction of a new monochromator with a more precise energy scanning mechanism, and the replacement of the entrance aperture and the plane mirror. The new monochromator is required to cover the photon energy range from 50 to 1000 eV with spectral resolutions of about 1000. At the same time, high linear polarization degree and high photon flux are also desirable. In this paper, the optical layout of Beamline 3W1B, the new monochromator, adjustment of the monochromator and the first commissioning results are briefly described.

2 The optical layout of beamline 3W1B

During the upgrade process, the optical layout of the beamline was not changed. As shown in Fig. 1, a water-cooled entrance aperture (AP1) is placed in the front of this beamline. Its horizontal width is fixed, limiting the horizontal angular acceptance to 0.64 mrad. After upgrade, its vertical width becomes accurately adjustable, defined by two independently moveable blades.

The first optical component behind the aperture is a spherical mirror (SM) with a water-cooled system. This spherical mirror horizontally focuses the radiation beam on the sample, and removes the X-ray with energy higher than 3000 eV reducing the thermal load on the optical system. After being deflected horizontally by the SM, the synchrotron beam comes into the monochromator. It is a variable included angle monochromator placed 19 m

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away from the center of the wiggler. This monochromator consists of a plan mirror (PM) and a varied-space plane grating (VSPG). The plane mirror deflects the light vertically onto the grating center, and the varied-space plane grating disperses the radiation into several beams according to the different wavelengths of the light, and focuses the monochromatic X-ray with expected energy to the exit slit. Between the monochromator and the exit slit there is an exit aperture (AP2) used for preventing stray light passing into the experiment station.

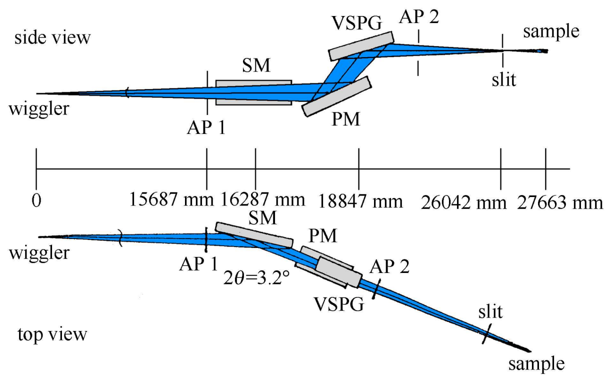

Fig. 1. Side view and top view of the beamline.

3 The new monochromator

The new monochromator was designed with a new plane mirror and the original varied-space plane grating. The surface-shape error of the new plane mirror is less than 3 μrad (rms). With regard to a varied-space plane grating, the relation between the groove spacing d and the groove position ω is given by the following formula

$$d(\omega)=d_0(1+b_2\omega+b_3\omega^2+b_4\omega^3+\cdots), \tag{1}$$

where d_0 is the groove spacing at the grating center; b_i (i=2, 3, 4$\cdots$) are the space variation parameters; and the ω direction is opposed to the direction of the incoming beam [2]. In our case, the grating parameters had been fixed before and could not be changed, d_0=1/1000 mm, b_2=1.7×10^{-4} mm^{-1}, b_3=b_4=0, and the effect of higher-order aberrations were neglected.

According to the focusing properties of the varied-space plane grating, which has been summarized by Masaaki I. et al. [3], and considering the invariable parameters of the grating, the optical arrangement of the new monochromator was adopted as shown in Fig. 2.

Here a 400-mm-long plane mirror is rotated around an out of plane axis. In this way, it not only deflects the incoming beam on the grating with accurate incident angles but also always makes the central ray of the beam up to the grating center. The rotation axis of the grating is at the center of the grating surface. Rotated to an appropriate angle, the grating can diffract the radiation beam and focus the monochromatic X-ray with desired photon energy to the exit slit.

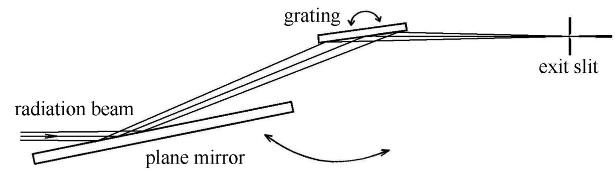

Fig. 2. The optical arrangement of the new monochromator.

The optical components and their rotating parts are placed in an ultra-high vacuum environment. The plane mirror is put into a water-cooled copper trough to reduce its thermal load. The external drive system rotates the plane mirror and the grating relying on the transmission mechanisms with the bellows seals insulating the vacuum.

4 Adjustment of the monochromator

As regards the variable included angle scanning structure monochromator, the parallelism between the rotation axes of the plane mirror and the grating has a great influence on the spectral resolution. YU Xiaojiang [4] et al. proposed a scheme to measure the unparallel degree of the two axes and re-align the two axes by using a paralleloscope. Based on their method, an unparallel degree of the two axes less than 10$''$ was obtained by using an autocollimator instead of a paralleloscope, which met the accuracy requirements.

The plane mirror and the grating were installed into the monochromator chamber by using an electronic theodolite and two precision optical levels. To calibrate the postural angles of the two optical components, a laser was used as a simulated light source. By detecting the reflection spot, we adjusted the yaw and roll angles of the plane mirror and the grating to make sure that the zero-order reflection spot and the first-order diffraction spot each always had a negligible horizontal deviation (less than 1 mm) on the screen 14 m downstream the grating. After the monochromator was installed into the beamline, the yaw and roll angles of the two optical components were slightly readjusted to direct the zero-order beam and the monochromatic beam onto the fluorescent screen set in a vacuum chamber at the experimental station.

5 Performance

To evaluate the spectral resolution and calibrate the energy of the beamline, we measured the photon absorption spectra of the Kr, Ar and Ne gases by using a gas ionization chamber. The gas ionization chamber consists of a bias electrode cylinder, two electron collectors and two shield electrodes. The bias electrode cylinder was biased by 40 V. The transmitted photon spectra were detected by a high resistance meter (6517A Keithley, USA) which was connected to one of the electron collectors. There was a thin Si_3N_4 (200 nm) vacuum-insulated window on the front end of the gas ionization chamber. The measurements were performed with the gas pressure less than 15 Pa and the exit slit width of 120 μm.

Figure 3 shows the measured absorption spectrum of the krypton $M_{4,5}$ edges. The FWHM of the isolated peak at 91.2 eV corresponding to the $3d_{5/2}\rightarrow 5p$ transition of krypton is 0.097 eV. The absorption spectra of the $L_{2,3}$ edges of argon measured before (a) and after the upgrade (b) are shown in Fig. 4. The FWHM of the first peak in Fig. 4(b), the $2p_{3/2}\rightarrow 4s$ transition of argon at 244.4 eV, is 0.191 eV, which is much smaller than the measured value of 0.8 eV before the upgrade as shown in Fig. 4(a). As shown in Fig. 5, the FWHM of the first peak corresponding to the $1s\rightarrow 3p$ transition of neon is 0.912 eV.

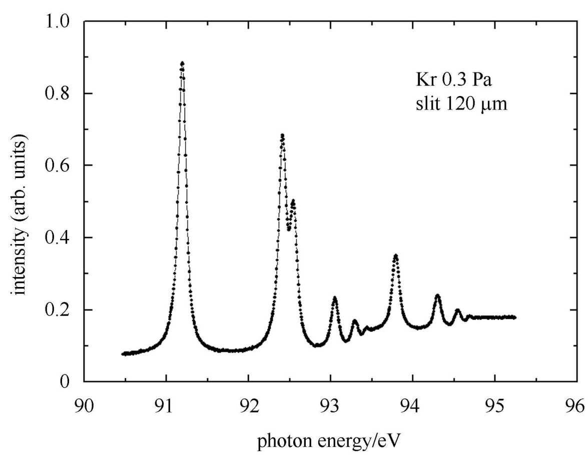

Fig. 3. The absorption spectrum of the krypton $M_{4,5}$ edges.

However, the line width of the measured spectrum is wider than the instrumental width of the monochromator, because it is a superposition of the natural line width of the resonance and the instrumental width. The natural line widths of the krypton $3d_{5/2}\rightarrow 5p$ transition, the argon $2p_{3/2}\rightarrow 4s$ transition and the neon $1s\rightarrow 3p$ transition were reported to be 0.083 eV [5], 0.121 eV [5] and 0.3 eV [6], respectively. Thus, we estimate the resolving power ($E/\Delta E$) of 1800 at 90 eV, 1600 at 250 eV and 1000 at 870 eV.

The measurements of photon flux at the experimental station were made using a silicon photodiode (AXUV-100G: IRD Inc., USA) with the exit slit width of 120 μm. The photon flux was estimated from the conversion of the measured photocurrent of the photodiode. In the photon energy range from 100 to 1000 eV, the photon flux is of the order of 10^8–10^9 photons/s/0.1%BW, which has been normalized to an electron beam current of 200 mA.

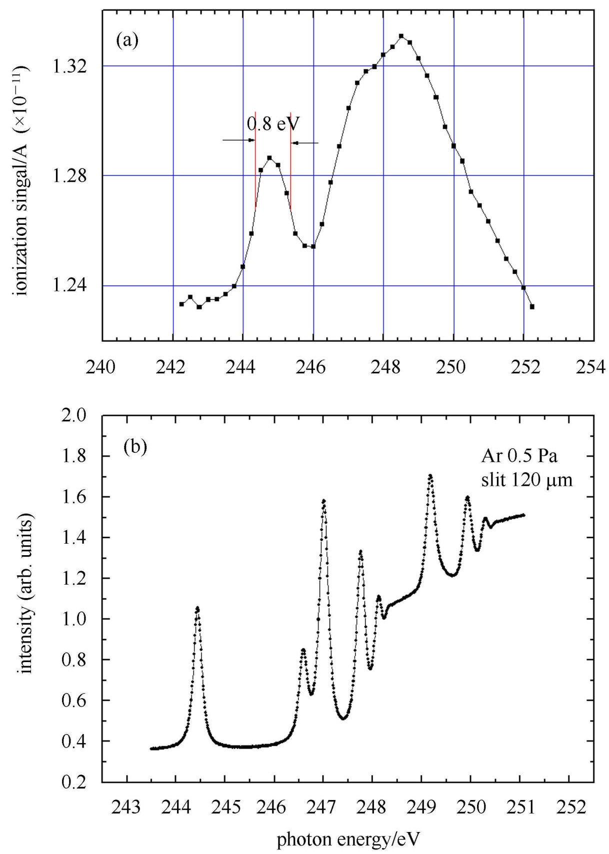

Fig. 4. The absorption spectra of the argon $L_{2,3}$ edges before (a) and after the upgrade (b).

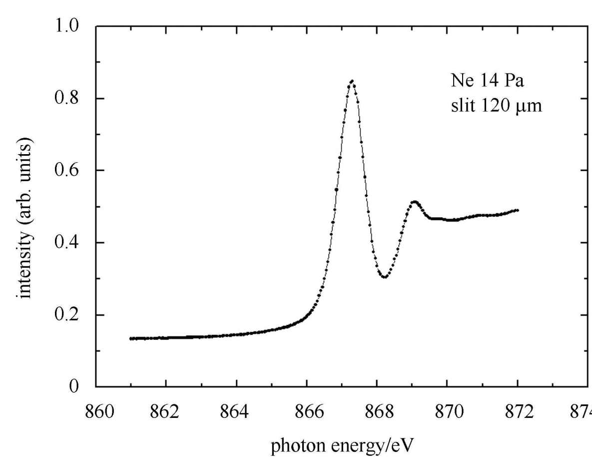

Fig. 5. The absorption spectrum of the neon K edge.

The linear polarization degree of the light at the experimental station was measured with an ultra-short-period W/B_4C multilayer (1.244 nm) as a polarization analyzer. The vertical width of the entrance aperture was set to 0.5 mm. By changing the vertical position of the entrance aperture, the linear polarization degrees of the light in different vertical observation angles (ψ) were measured. The calculated values and the experimental values are shown in Fig. 6. In the electron's orbital plane, corresponding to the vertical observation angle ψ=0, the linear polarization degree of the light is higher than 99% at 704 eV.

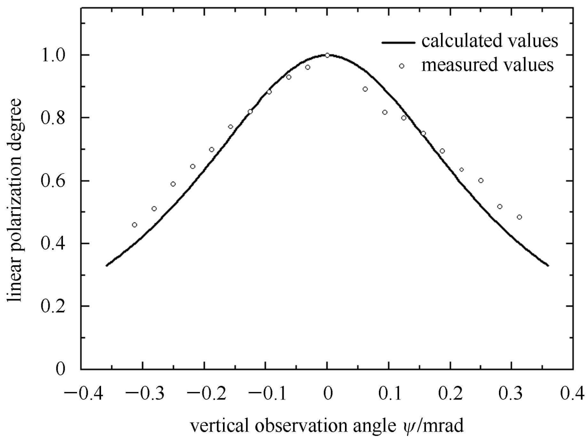

Fig. 6. The linear polarization degrees in different vertical observation angles.

6 Conclusion

The main modification in our beamline was the replacement of the monochromator. The new monochromator was built with a more precise energy scanning mechanism, and equipped with a water-cooled system for the plane mirror. A new plane mirror was used and the carbon contamination on the grating surface was cleaned.

After the upgrade, Beamline 3W1B covers the photon energy range from 50 to 1000 eV with a spectral resolving power of above 1000. The photon flux is about 10^8–10^9 photons/s/200 mA/0.1%BW. The linear polarization degree of the light in the electron's orbital plane is higher than 99% at 704 eV. The spectral resolution has increased greatly and the first commissioning results have satisfied the basic experimental requirements.

Currently, further optimizations of the monochromator are being performed to produce higher spectral resolution and photon flux, and an upgrade of the experiment station is also being carried out for the soft x-ray magnetic linear dichroism research in transition metals.

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