Upgrade of Saga-university beamline in SAGA-LS

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Abstract. Saga-university beamline has been upgraded by installing a new planar-type undulator for advanced researches on nano-surfaces and interfaces in the soft X-ray region. The magnetic field of the undulator along the electron beam trajectory was measured at the magnetic gap width between 30 and 150 mm. After the installation of the undulator in a 2.7-m straight section of the Saga-LS storage ring, the performance of the beamline with varied line spacing plane grating monochromator was examined by measurements of peak energy, photon flux, and energy resolution. The beamline is opened for the experimental use in the energy region between 32 and 800 eV using fundamental and the higher harmonics.

1. Introduction

The Saga-university beamline BL13 at the SAGA-LS is a soft X-rays beamline for researches on nano-surface and interface of advanced materials. One of the two branches (VLS station) in the beamline is designed to use for undulator radiation. The varied line spacing plane grating monochromator (VLS-PGM) with an arm length of 4 m is composed of the grazing incidence mount with three spherical mirrors and two varied line spacing plane gratings. A high-resolution photoemission system with a gated-detector and a mode-locked Ti:sapphire laser with the regenerative amplifier is installed at the beamline [1]. Using these systems, we can perform the time-resolved high-resolution photoemission study for various photo-excited phenomena and surface dynamics, in addition to the conventional high-resolution angle-resolved photoemission study. However, the performance of the photoemission measurement with undulator radiation was restricted because of the old undulator that was moved from UVSOR facility. After the installation of a new planar-type undulator, the VLS station has been precisely adjusted, achieving the designed performance.

2. Undulator

The new undulator was designed to replace the old one that had been installed in a 2.7-m straight section (LS4) of the SAGA-LS [2] without replacing the vacuum chamber of LS4. The basic parameters of the undulator are listed in Table 1. The total length of the new undulator is 2122.5 mm. The permanent magnets are Nd-Fe-B (NEOMAX-44CH) with TiN coating. Although the length of the...
straight section and the size of the vacuum chamber of LS4 are not changed, the periodic length is increased from 85 to 86 mm, with less length of end-pole magnets. The mechanical precession and the alignment of the magnetic poles have been improved.

Figure 1 shows the measured vertical magnetic field along the beam axis at the gap width of 40 mm. The horizontal magnetic field was less than 2 mT. The vertical field distribution are fitted by \( B_y(z) = B_{y0} \sin(2\pi z/\lambda_u + \phi) \), where \( B_{y0}, \lambda_u \) and \( \phi \) are fitting parameters. The peak magnetic field at the magnetic gap width of 40 mm has been obtained as 0.3975 T within the precession less than 0.5 % at each pole. The magnetic fields at gap width between 30 and 150 mm were also measured in detail. The end-pole magnets of a half period are installed at both ends of the 24 periods magnets. The steering magnets that are installed at both ends of the undulator have been also replaced to ones with smaller turns in order to control the steering field more precisely.

Table 1. Parameters of the planar undulator.

| Periodic length [mm] | Number of periods | Magnet size [mm] | \( B_r \) [T] | Magnet gap [mm] | Deflection parameter K |
|----------------------|-------------------|-----------------|--------------|----------------|------------------------|
| 86                   | 24                | 21.5×20×80×     | 1.34         | 35-150         | 3.86-0.05              |

Figure 1. Measured magnetic field at the gap width of 40 mm and the difference of the vertical field from \( B_y(z) = B_{y0} \sin(2\pi z/\lambda_u + \phi) \), where \( B_{y0}, \lambda_u \) and \( \phi \) have been determined by a least mean squares fitting.

3. Performance

Figure 2(a) shows the relation between the fundamental peak energy and magnetic gap. The measured peak energy of the new and old planar undulators are shown by solid and open circles, respectively. Thin solid line on the peak energy of the new undulator shows the calculated peak energy using the measured magnetic field at the magnet gap between 30 and 150 mm. The measured magnetic field at each gap width is also shown in the figure 2(a) by solid triangles using the right axis. As shown in figure 2(a), the fundamental peak energy between 35 and 193 eV is obtained by new undulator at the magnetic gap of 40-90 mm, while the old undulator was operated at the minimum gap width of 43 mm due to the limitation of the clearance between the vacuum duct and magnet holder. The fundamental
peak energy at the gap width of 35 mm is calculated to be 26 eV, but the VLS station is practically used in the photon energy range above 32 eV due to the present grating and mirror configuration.

The photon flux at the sample position has been evaluated by a total electron yield of Au. Figure 2(b) shows the photon flux at the gap width of 57.2 mm. The horizontal and vertical acceptance angles are 2 and 0.2 mrad, respectively. The width of the entrance (S1) and exit (S2) slits of the VLS-PGM is 20 µm. The photon flux at three combinations of mirrors and gratings with different deflection angles, M21-G1(174°), M22-G1(170°) and M23-G2(167°), are shown by solid lines. As shown in figure 2(b), the higher harmonics are clearly observed up to 9-th order at 830 eV. The photon flux on the old undulator at the gap width of 50 mm which gives the same peak energy on the new undulator at 57.2 mm are shown by thin dashed lines. While the overall distribution of the measured photon flux is very similar for both undulators, it is found that the photon flux at the higher harmonics is increased by a factor of about 1.5.

![Figure 2](image)

Figure 2. (a) Relation among fundamental peak energy, magnetic field and magnetic gap. (b) The comparison of the photon flux from new and old planar undulators.

Figure 3(a) shows the peak flux at the gap width between 40 and 100 mm. The photon flux with the undulator gap of 65.0 mm are also shown. The entrance and exit slit widths are 20 µm. The photon flux of 1×10^{11} photons/s/100mA is obtained at 125 eV. The third and fifth order light of the undulator radiation is clearly observed at about 375 and 625 eV, respectively. The dip at around 290 eV is due to carbon contaminations on mirrors. As shown in figure 3(a), the photon flux of 1×10^{11} and 5×10^{9} photons/s/100mA is obtained with the slit widths of 20 µm at about 130 eV and 250-600 eV, respectively. It has been confirmed that the available photon energy range is between 32 and 800 eV.

The energy resolution of SR excited photoemission measurements at the VLS Station of BL13 has been estimated by the sharpness of the Fermi edge of Au reference. Figure 3(b) shows the photoemission spectrum of Au at 10 K excited by the undulator radiation with the photon energy of 60 eV. The widths of the both slits are 30 µm. The acquisition time is about 30 minutes. Au film has been evaporated by using resistively-heated W basket in the ultra-high-vacuum. From the spectral shape analysis, it is found that the overall energy resolution is about 8.0 meV with the electron pass energy of 2 eV. Since the energy resolution of the photoelectron energy analyzer at the present setup of the photoelectron spectrometer is 4.5 meV determined from a separate measurement using the HeI resonance line as an excitation source, the energy resolution of the monochromator is estimated to be 6.6 meV, showing the resolving power of 9090.
The core-level photoemission measurements with the undulator radiation and the gated-detector under the optical excitation by the Ti:sapphire regenerative amplifier are used to trace dynamical phenomena in the sub-micro to micro second region such as surface photo-voltage on semiconductor surface. These measurements have no restrictions from the bunch-filling mode of the storage ring. In addition, the time- and angle-resolved two-photoemission study with femto-second pulses from a higher-harmonics generator of the regenerative amplifier can be conducted at the beamline. The methodology which combines the angle-resolved one-photon and two-photon emission measurement will be used as a powerful tool to study the occupied and unoccupied band structure and momentum-resolved electron dynamics on various materials.

![Figure 3](image_url)

**Figure 3.** (a) The trace of the peak flux at the gap width of 40-100 mm and the photon flux at the undulator gap of 65.0 mm. (b) The valence band photoemission spectrum just around the Fermi level of Au at 10 K excited by the undulator radiation with the photon energy of 60 eV.

4. **Summary**

The planar undulator consisted of 24 periods of an 86 mm length has been installed in a 2.7-m straight section of the Saga-LS, in order to provide brilliant soft x-rays at the Saga-university beamline BL13. The available photon energy range becomes between 32 and 800 eV after the present upgrade. The photon flux of $1 \times 10^{11}$ photons/s/100 mA was obtained at around 130 eV. The total energy resolution of 8.0 meV was confirmed by the photoelectron spectrum of Au. The present results indicate the high performance of the beamline BL13 for photoelectron spectroscopy in the soft x-ray region.

**Acknowledgments**

The authors express their sincere thanks to machine group members of the SAGA-LS for their efforts in the commissioning work and also to Dr. H. Kitamura of RIKEN for his help in the measurement of magnetic field.

**References**

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