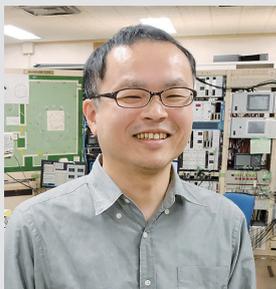


# Exploring a New Application of Synchrotron Radiation with Novel Light Source Technologies

## UVSOR Synchrotron Facility Division of Advanced Accelerator Research



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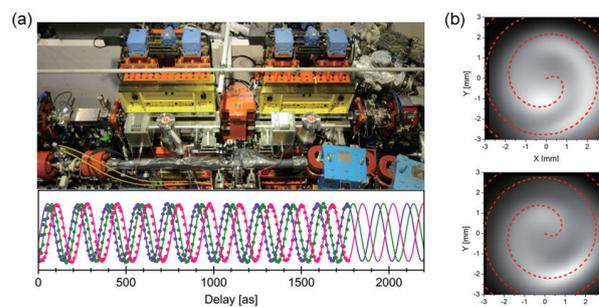
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UVSOR synchrotron at IMS is a compact low-energy synchrotron radiation facility which has been operating for more than 40 years. The light source performance is still in the word top level and continuous studies on the development of novel light source technologies have been conducted since the 1980s. From a viewpoint of exploring a new application of synchrotron radiation, UVSOR has advantages on the light source performance and the agility to immediately implement new concepts.

The waveform of electromagnetic radiation from an ultra-relativistic electron reflects the motion of the electron. This implies that, by controlling the electron motion in the magnetic field, one can control the properties of the radiation waveform in the nanometer or Angstrom scale. Our group has succeeded in generating the optical vortex beam which has helical phase plane and coherent double-pulse using insertion devices installed in the UVSOR synchrotron (Figure 1). The use of mutual coherence between the double-pulsed components enables time-domain interferometry experiments for controlling and monitoring the quantum state of matter using

synchrotron radiation. Such an approach can be applied to the development of new spectroscopic and imaging methods using synchrotron radiation. We aim to develop novel measurement methods and their applications based on manipulating the motion of high-energy electrons in a synchrotron ring.



**Figure 1.** (a) Tandem-undulator system in the UVSOR-III synchrotron. Attosecond interference in photoexcitation of helium atoms is attached in the bottom panel. (b) Generation of optical vortex beam by synchrotron radiation.

### Selected Publications

- T. Fuji, T. Kaneyasu, M. Fujimoto, Y. Okano, E. Salehi, M. Hosaka, Y. Takashima, A. Mano, Y. Hikosaka, S.-I. Wada and M. Katoh, “Spectral Phase Interferometry for Direct Electric-Field Reconstruction of Synchrotron Radiation,” *Optica* **10**, 302 (2023).
- T. Kaneyasu, Y. Hikosaka, M. Fujimoto, H. Iwayama and M. Katoh, “Electron Wave Packet Interference in Atomic Inner-Shell Excitation,” *Phys. Rev. Lett.* **126**, 113202 (2021).
- Y. Hikosaka, T. Kaneyasu, M. Fujimoto, H. Iwayama and M. Katoh, “Coherent Control in the Extreme Ultraviolet and Attosecond

Regime by Synchrotron Radiation,” *Nat. Commun.* **10**, 4988 (2019).

- T. Kaneyasu, Y. Hikosaka, M. Fujimoto, T. Konomi, M. Katoh, H. Iwayama and E. Shigemasa, “Limitations in Photoionization of Helium by an Extreme Ultraviolet Optical Vortex,” *Phys. Rev. A* **95**, 023413 (2017).
- T. Kaneyasu, Y. Takabayashi, Y. Iwasaki and S. Koda, “Beam Lifetime Study Based on Momentum Acceptance Restriction by Movable Beam Scraper,” *Nucl. Instrum. Methods Phys. Res., Sect. A* **694**, 107 (2012).

## 1. Attosecond Interferometry Experiments Using Synchrotron Radiation

Attosecond interferometry experiments have been conducted using the light source development beamline BL1U in UVSOR-III synchrotron (Figure 2).<sup>1)</sup> In recent years, we have studied the interference phenomena between the photoelectron wave packets. The sequential interaction of an atom with a pair of coherent light pulses results in the production of a pair of photoelectron wave packets which interfere with each other during the propagation in a free space. The control and observation of photoelectron wave packet interference has been achieved so far by employing coherent pulse pairs generated by laser sources. In contrast, we have recently demonstrated that the phase coherent double pulses generated by a synchrotron light source can be utilized for the purpose of controlling the interference of photoelectron wave packets produced in the extreme ultraviolet wavelength range.<sup>2)</sup>

Figure 3 presents the time-domain photoelectron interferogram associated with the photoionization of 5p electron in xenon atom. This interferogram is composed of photoelectron spectra acquired at various phase shifter delays. During the measurement, the central wavelength of linearly polarized radiation was set to approximately 40 nm and the kinetic energy of the photoelectron was determined using a hemispherical electron energy analyzer. The interferogram exhibits periodic modulation with a period of approximately 140 as, which corresponds to the photon frequency. The clear modulation of this interferogram indicates that the photoelectron wave packet interference can be precisely controlled by varying the time delay, which was calibrated by the frequency-domain interferometry.<sup>3)</sup> Furthermore, the interferogram exhibits intensity modulation with a period of 3 fs. This effect can be attributed to the evolution of the spin-orbit wave packet produced in the  $\text{Xe}^+$  ion, suggesting that the tandem undulator could be used to explore ultrafast quantum state dynamics with attosecond resolution.

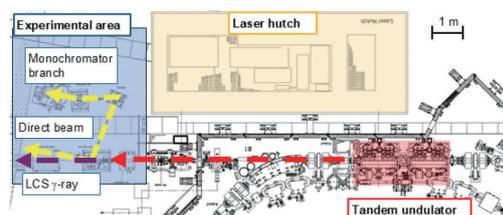


Figure 2. Layout of the light source development beamline BL1U.

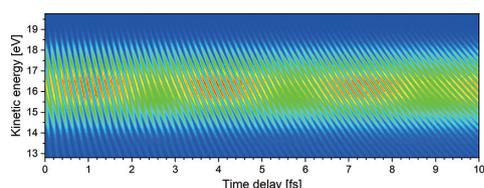


Figure 3. Time-domain photoelectron interferogram obtained for xenon 5p ionization.

## 2. Development of Atomic Fluorescence Polarimeter

Polarization represents one of the most significant characteristics of synchrotron radiation. The horizontally linear polarization of the radiation emitted from a bending magnet has been widely employed in various measurements for a long time. In addition, the rapid advancement of insertion devices in the 1990s has enabled arbitrary control of the polarization state of undulator radiation. However, the polarization state of the light changes according to the reflective properties of the beamline optics. Consequently, in order to ensure accurate measurements based on the polarization properties of synchrotron radiation, it is crucial to evaluate the polarization state of the light at the sample position.

To date, the synchrotron community has devoted considerable effort to the development of polarimeters for wavelengths shorter than those of vacuum ultraviolet (VUV) radiation. Simpler approach to measure the polarization of short wavelength light is to take advantage of the interaction of light with atoms and molecules in the gas phase. The use of a fluorescence polarimeter based on the conversion of VUV light into visible fluorescence light via atomic resonance allows the complete determination of the polarization state with a simple apparatus. In this study, the degree of linear polarization and the angle of inclination of the polarization axis of VUV light have been measured with a fluorescence polarimeter utilizing helium and neon atoms (Figure 4).<sup>4)</sup> This study demonstrates that a fluorescence polarimeter can be used in conjunction with a variety of atoms and molecules and thus extends the range of wavelengths to which this method can be applied.

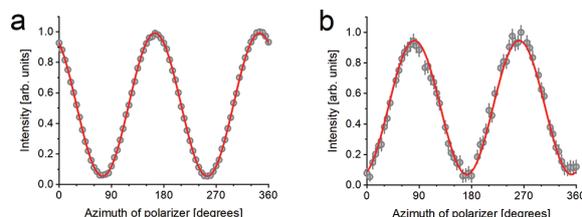


Figure 4. The fluorescence yield measured as a function of the polarizer angle for (a) helium and (b) neon atoms. The degree of linear polarization and angle of the polarization axis can be derived from the periodic modulation of the fluorescence yield.

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- 1) T. Kaneyasu, Y. Hikosaka, S. Wada, H. Ota, H. Iwayama, K. Shimizu, M. Fujimoto and M. Katoh, *J. Phys.: Conf. Ser.* **3010**, 012086 (2025).
- 2) T. Kaneyasu, Y. Hikosaka, S. Wada, M. Fujimoto, H. Ota, H. Iwayama and M. Katoh, *Sci. Rep.* **13**, 6142 (2023).
- 3) Y. Hikosaka, T. Kaneyasu, S. Wada, H. Kohguchi, H. Ota, E. Nakamura, H. Iwayama, M. Fujimoto, M. Hosaka and M. Katoh, *Sci. Rep.* **13**, 10292 (2023).
- 4) T. Kaneyasu, H. Takeda, K. Hosaka and J. Adachi, *J. Electron Spectrosc. Relat. Phenom.* **279**, 147488 (2024).

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