

Light Source Developments by Using Relativistic Electron Beams

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UVSOR is a synchrotron light source providing low energy synchrotron light ranging from terahertz waves to the soft X-rays. Although it was constructed about 40 years ago, its performance is still in the world top level particularly among the low energy synchrotron light sources. This is the result of our continuous efforts on improving the machine. Our research group has been developing and introducing new accelerator technologies toward producing brighter synchrotron light with high stability, such as low emittance electron beam optics, novel insertion devices or state-of-the-art beam injection scheme. After two major upgrade projects, we now call our machine UVSOR-III. We have been developing novel light source technologies, such as free electron laser, coherent synchrotron radiation, structured light beams and laser Compton gamma-rays. We have been investigating beam physics which

would be the basis of the future developments of the facility.

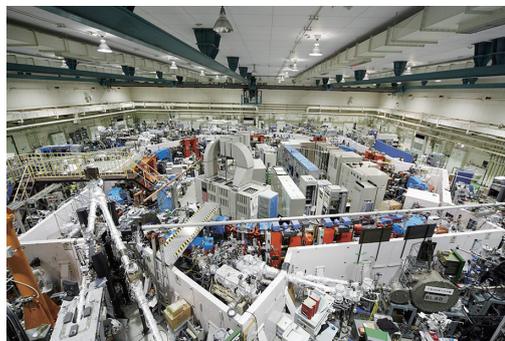


Figure 1. UVSOR-III Electron Storage Ring and Synchrotron Radiation Beamlines.

Selected Publications

- S. Bielawski, C. Evain, T. Hara, M. Hosaka, M. Katoh, S. Kimura, A. Mochihashi, M. Shimada, C. Szwaj, T. Takahashi and Y. Takashima, “Tunable Narrowband Terahertz Emission from Mastered Laser–Electron Beam Interaction,” *Nat. Phys.* **4**, 390–393 (2008).
- M. Shimada, M. Katoh, M. Adachi, T. Tanikawa, S. Kimura, M. Hosaka, N. Yamamoto, Y. Takashima and T. Takahashi, “Transverse-Longitudinal Coupling Effect in Laser Bunch Slicing,” *Phys. Rev. Lett.* **103**, 144802 (2009).
- M. Katoh, M. Fujimoto, H. Kawaguchi, K. Tsuchiya, K. Ohmi, T. Kaneyasu, Y. Taira, M. Hosaka, A. Mochihashi and Y. Takashima, “Angular Momentum of Twisted Radiation from an Electron in Spiral Motion,” *Phys. Rev. Lett.* **118**, 094801 (2017).
- 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, H. Iwayama and M. Katoh, “Electron Wave Packet Interference in Atomic Inner-Shell Excitation,” *Phys. Rev. Lett.* **126**, 1132202 (2021).
- T. Fuji, T. Kaneyasu, M. Fujimoto, Y. Okano, E. Salehi, M. Hosaka, Y. Takashima, A. Mano, Y. Hikosaka, S. Wada and M. Katoh, “Spectral Phase Interferometry for Direct Electric-Field Reconstruction of Synchrotron Radiation,” *Optica* **10**(2), 302–302 (2023).

1. Light Source Technology Developments

We have been developing light source technologies at the UVSOR-III electron storage ring using a dedicated experimental station BL1U, which was constructed under the support of Quantum Beam Technology Program of JST/MEXT aiming to develop novel light sources and explore their applications. The BL1U is equipped with two undulators which constitute an optical klystron (Figure 2), a laser system which is synchronized with the accelerator beam and a dedicated beamline consisting of mirrors and a monochromator whose arrangement can be flexibly changed according to the types of the experiments (Figure 3).

In collaboration with Hiroshima Univ. and Nagoya Univ., we have succeeded in producing spatially structured synchrotron radiation such as vortex beam and vector beam. We are now exploring their applications.

We have been exploring the possibility utilizing the temporal structures of undulator radiation, in collaboration with Saga Light Source, Toyama Univ. and Hiroshima Univ. We have succeeded in the coherent controls of atoms and in observing ultrafast change of an electronic state of an atom by using radiation from two undulators arranged in tandem. We have demonstrated a state-of-the-art technology to observe ultrafast properties of synchrotron radiation, in collaboration with Toyota Technological Institute.



Figure 2. Twin Polarization-variable Undulators/Optical Klystron at UVSOR-III.

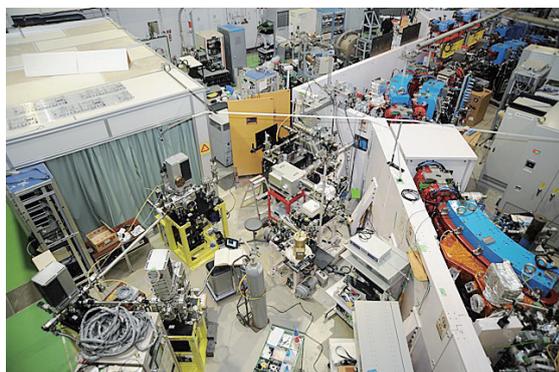


Figure 3. UVSOR BL1U experimental station for source development studies.

In these years, we are interested in the quantum nature of synchrotron radiation photons. We have established a technique to store only one electron in the synchrotron. We are working on experimental studies on photon emission from a single electron. Some of the results have been published as bachelor thesis and master thesis in Hiroshima Univ.

We have developed a laser Compton scattering gamma-ray source at BL1U, which is capable of producing ultrashort, monochromatic and energy-tunable gamma-rays. They are now opened for public use.

We have been continuing experimental studies on the origin of the homochirality of biomolecules using intense circularly polarized undulator radiation at BL1U, in collaboration with Yokohama National Univ., Hiroshima Univ. and NIFS. This year, we have started a new project on exploring novel experimental techniques based on chiral undulator radiation, including optical vortex and other chiral structured light.

2. Accelerator Technology Developments

We carried out several upgrades on the UVSOR electron synchrotron since 2000. We designed a special beam optics intended to higher brightness. We developed necessary accelerator components, reconstructed the accelerator and commissioned it. We have commissioned six undulators successfully, three of which are variable polarization type and others in-vacuum type. Moreover, we have been continuously introducing new accelerator technologies such as the top-up operation in which the electron beam intensity is kept quasi-constant at a high beam current, 300mA, and the novel beam injection scheme with a pulsed sextupole magnet. As the result of all these efforts, now, the machine is one the brightest synchrotron light sources among the low energy machines below 1GeV in the world.

Currently, the storage ring is stably operated, however, the requirements from the users for the higher brightness is getting stronger, because new light sources and upgrade plans are being realized all over the world. We had sought a possibility to reduce the emittance with the present magnet configuration. So far, we have found a few beam optics which would give lower emittance around 10 nm. However, they are not compatible with the operation of the narrow gap undulators. Then, we started a design study on a new light source facility. Currently we are focusing on designing a synchrotron with the electron energy of 1 GeV and the circumference of around 70 m. In parallel, we are designing a magnetic lattice which has same beam energy and circumference as the present machine but would give significantly lower emittance.

We are collaborating with Nagoya University, Hiroshima University and KEK Photon Factory to develop new accelerator technologies for the future plans of these facilities. Accelerator magnets based on permanent magnets are being developed, which would contribute to the power consumption saving. New pulsed multipole magnet is also being developed to realize a novel beam injection scheme.