STATUS OF UVSOR-II AND LIGHT SOURCE DEVELOPMENTS

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Abstract

UVSOR-II, a 750 MeV synchrotron light source of 53 m circumference, is now routinely operated with low emittance of 27 nm-rad and with four undulators, two variably polarized ones. The full energy injection was succeeded soon after upgrading the injector and the beam transport line. We have operated the machine routinely with full-energy injection in the user's run since July, 2007. We are going to start top-up injection hopefully in this year.

A resonator type free electron laser is successfully operational in very wide range, from visible to deep UV, with high average power exceeding 1 W. Recently, the wavelength has reached 200 nm. Intense coherent terahertz radiation was successfully produced by the laser-electron interaction. Coherent harmonic generation was also demonstrated by using the same laser system.

ACCELERATORS

The first beam of UVSOR was in 1983. Since then, this machine has been operated as one of the major synchrotron light sources in Japan [1]. Its relatively low electron energy is suitable to produce synchrotron radiation in longer wavelength region, from VUV to Terahertz. In 2003, after 20 year operation, the storage ring had a major upgrade [2], including a modification of the magnetic lattice [3]. After this upgrade, we have started to call the ring, UVSOR-II. The UVSOR-II has a small emittance of 27 nm-rad, which is smaller by a factor of 6 than before, and totally eight straight sections, which is twice larger. Six of the straight sections are available for insertion devices. Four of them are already occupied by undulators and two are reserved for future insertion devices. The main parameters of the ring are summarized in Table 1.

The ring is operated for about 40 weeks a year, 5 days a week and 12 hours a day. The beam injection is twice a day, at 9am and 3 pm. The filling beam current is 350 mA in multi-bunch mode and 100 mA in single bunch mode.

After the upgrade in 2003, the ring is routinely operated with the small emittance of 27 nm-rad. To suppress the strong Touschek effect due to the low emittance and to the low electron energy, a 3rd harmonic cavity is routinely used [4]. It is also effective to suppress the longitudinal coupled bunch instabilities. The main accelerating cavity, which was constructed more than 20 years ago, was replaced [5]. By this replacement, the RF accelerating voltage was greatly improved by a factor of 3. This was also effective to improve the lifetime.

To solve the lifetime problem eternally, we are preparing for the top-up operation. UVSOR-II had a 600 MeV booster synchrotron whose energy was slightly lower than the operating energy of the storage ring, 750 MeV. We have succeeded in accelerating electrons up to 750 MeV soon after upgrading the magnet power supply in 2006. In April 2007, the bending magnet power supply of the beam transport line has been replaced. This power supply is capable of transporting the full energy beam to the storage ring. After test operations from April 2007, we have, in the user's run, started operating the machine with full energy injection from July 2007. The repetition rate of the injection was reduced from 3 Hz at 600 MeV injection to 1 Hz at full energy injection to keep the peak electric power same as before. The injection rate of around 0.5 mA/s is lower than before, but still sufficient to fill the electrons within 15 minutes. We have performed the test of top-up injection. The beam current was successfully kept constant for around thirty minutes, as shown in Fig. 1. The radiation shield of the ring has been enhanced in FY2006 and FY2007, which assures protection of the radiation in the top-up injection.

A future plan, in which the ring would be further upgraded, is under consideration. By replacing the bending magnets which have been used for about 25 years with combined function ones, the emittance may be further reduced by a factor of two. In addition, by moving the injection point, a new straight section of four meter long would be available for an insertion device.

INSERTION DEVICES

UVSOR had three insertion devices until 2001, one superconducting wiggler and two undulators. During the upgrade project in 2003, the wiggler and one of the undulators were removed. Another undulator remained operational, which is a helical optical-klystron-type undulator used for providing VUV radiation to a beam line and also parasitically used for driving a resonator type free electron laser [6]. Two new in-vacuum type undulators were con-

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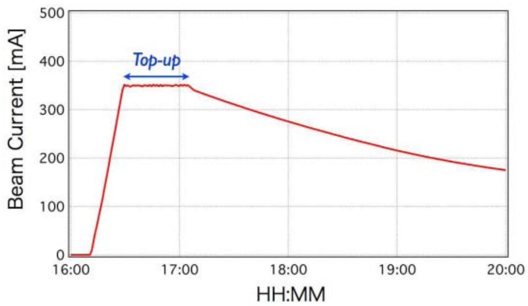

Figure 1: The test of the top-up operation in July 2007.

Table 1: Main Parameters of the Ring

UVSOR-II Storage Ring

Electron Energy	750 MeV
Circumference	53.2 m
Natural Emittance	27 nm-rad
Natural Energy Spread	4.2×10^{-4}
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
Straight Sections	4 m$\times$4, 1.5 m$\times$4
RF Voltage	100 kV
Betatron Tunes (horizontal, vertical)	(3.75, 3.20)
Momentum Compaction	0.028
Natural Bunch Length	108 ps
Filling Beam Current	350 mA (multi-bunch mode) 100 mA (single-bunch mode)

structed and were successfully commissioned [7], which provide VUV radiation.

In 2006, an APPLLE-II type undulator was constructed and installed, which provides VUV radiation of various polarization for users. [8] The closed orbit distortion and the betatron tune shift are compensated by the feed-forward system [9]. Change in the closed orbit is suppressed smaller than 10 μm during the change of the pole gap and during the change of polarization modes at 100 mm pole gap. We observe shortening of the beam life time at short gap smaller than 35 mm in vertical polarization mode. This shortening may be caused by the non-linear effect of the undulator on the electron dynamics. Some sophisticated correction scheme should be introduced.

At present, this relatively small ring has four undulators and has two short straight sections reserved for future undulators. The main parameters of the insertion devices are summarized in Table 2.

Table 2: Main Parameters of the Insertion Devices.

In-vacuum undulators	**U3**	**U6**
Number of Period	50	26
Period Length [mm]	38	36
Pole Length [m]	1.9	0.94
Pole Gap [mm]	15 $\sim$ 40	15 $\sim$ 40
Deflection Parameter	2.00 $\sim$ 0.24	1.78 $\sim$ 0.19

Helical undulator / Optical Klystron	**U5**
Number of Period	21 / 9+9 (Opt. Kly.)
Period Length [mm]	110
Pole Length [m]	2.35
Pole Gap [mm]	30 $\sim$ 150
Deflection Parameter	4.6 $\sim$ 0.07 (Helical) 8.5 $\sim$ 0.15 (Linear)

Apple-II variable polarization undulator U7	
Number of Period	40
Period Length [mm]	76
Pole Length [m]	3.04
Pole Gap [mm]	24 $\sim$ 200
Deflection Parameter	5.4 (max. horizontal) 3.6 (max. vertical) 3.0 (max. helical)

RECENT LIGHT SOURCE DEVELOPMENTS

Free Electron Laser

The free electron laser (FEL) at UVSOR-II has a long history and is still developing. After the upgrade of the magnetic lattice in 2003 and of the main RF cavity in 2005, the performance of the FEL was greatly improved [10]. Excellent properties were acquired by the upgrade such as the high power, the wide spectral range from 800 nm to around 200 nm, the natural synchronization with the SR and variable polarization. Several users experiments have been done or are in progress [11]. In FY2007, we have tried oscillating in wavelength below 200 nm, and succeeded oscillation at 199.4 nm, as shown in Fig. 2. [12] We will able to lase at around 190 nm in the not-so-distant future, which requires an introduction of a VUV diagnostic system and a development of cavity mirrors with more than 96 % round trip reflectivity. Some basic researches on the free electron laser dynamics has been successfully in progress, in collaboration with French team [13].

Terahertz Coherent Synchrotron Radiation

A laser bunch slicing system has been constructed at UVSOR-II. A Ti-sapphire laser was installed which could be synchronized with the RF acceleration of the ring. The repetition rate is 1 kHz and the pulse energy is 2.5 mJ. The laser beam was transported through the optical ports for the

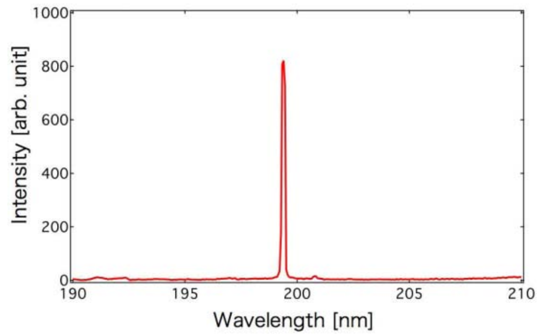

Figure 2: Demonstration of the FEL lasing below 200 nm. FEL lasing at 199.4 nm was measured.

FEL. The undulator for the FEL, which can be tuned to the laser wavelength, 800 nm, was used as the modulator.

We have started the bunch slicing experiment with observing coherent terahertz synchrotron radiation at the infrared beam line which is located at the second bending magnet downstream of the undulator. It was successfully demonstrated to control the spectra of the CSR by changing the laser pulse width or laser pulse shape [14]. In particular, for the first time, we have succeeded in producing monochromatic CSR in the bending magnet.

Coherent Harmonic Generation

The laser bunch slicing system has been used for coherent harmonic generation (CHG) experiment in collaboration with French Group. The CHG has possibility to produce the coherent radiation with short wavelength where cavity mirrors for the FEL are difficult to be available. The injected laser pulse interacts with the electron bunch in the undulator. As the bunch proceeding in the optical klystron type undulator, a density modulation of the laser wavelength is created. If the density modulation has higher order frequency component, coherent harmonics of the injected laser is generated. As injecting the 800 nm laser, the coherent third harmonic radiation of 266 nm was successfully observed at the optical monitor station downstream of the undulator [15]. It is interesting that the coherent harmonic radiation and the coherent terahertz radiation are generated simultaneously.

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