Ion Trapping Phenomenon in UVSOR Electron Storage Ring

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We observed the dependence of vertical tune on the vacuum condition in the UVSOR ring. We changed the vacuum conditions by turning off distributed ion pumps (DIPs) and sputtering ion pumps (IPs), and measured the vertical tune with the RF-KO method. In a series of experiments, we performed the measurement under a multibunch condition in which a series of 12 bunches followed by 4 empty buckets are stored in the ring. Figures 1(a) and 1(b) show that the tunes changed when the averaged vacuum pressure was changed. We also observed the dependence of the vertical tune on beam current under the multibunch condition without changing the vacuum conditions but different two vacuum conditions: at a low vacuum pressure (Exp. 1) and at a high vacuum pressure (Exp. 2). Figure 2(a) shows the change in average pressure in the ring during each experiment. As seen in Fig. 2(b), under the multibunch conditions the dependence of vertical tune on beam current tends to become larger with increasing the vacuum pressure. Weak dependence in single-bunch condition and that of horizontal tune in the multibunch condition implies the change in the vertical tune is caused by ion-trapping phenomenon.

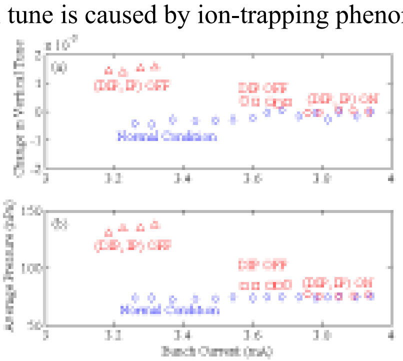

Fig. 1 (a) Change in the vertical tune when vacuum pumps were intentionally turned off. (b)Change in average pressure when the pumps were turned off.

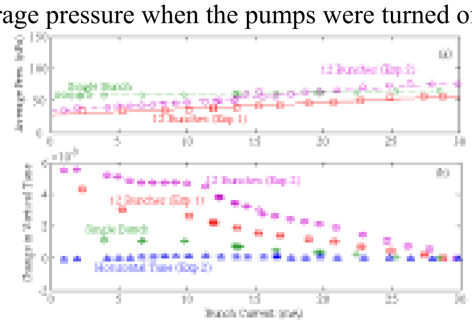

Fig. 2 (a) Averaged vacuum pressure for Exp. 1, Exp. 2 and single-bunch condition. (b) Dependence of tune on beam current in vacuum condition in Fig. 2(a).

According to the ion-trapping theory [1], vertical tune decreases as beam current decreases, however, experiments say that the vertical tune increases with the beam current decreases. This contradiction suggests that the neutralization factor of trapped ions increases as beam current decreases; namely, the number of trapped ions increases as beam current decreases. We have estimated theoretically the dependence of neutralization factor on beam current by evaluating capture rate [2] of ions by both an analytic method based on the classical theory of ion trapping [1,3] and tracking method. In the calculation we assume CO^+ as a main ion species because CO is a main residual gas component in the UVSOR ring. To reconstruct the experimental results, we considered not only the change in partial pressure of CO during the experiments but also effects from C^+ and O^+ which come from multiple ionization of CO^+. Figures 3(a) and 3(b) show the tracking and analytic calculations for Exp. 1 and 2 with experimental results. The tracking calculations considering all ions agree with the experiments qualitatively, however, they overestimate the change in vertical tune at a bunch current of less than ~15 mA. One of the causes of the overestimation is estimation of multiple ionization cross section of CO, that is difficult to estimate properly. The analytic calculations also tend to overestimate the change in vertical tune; this is because stability condition can be only considered in the analytic calculation.

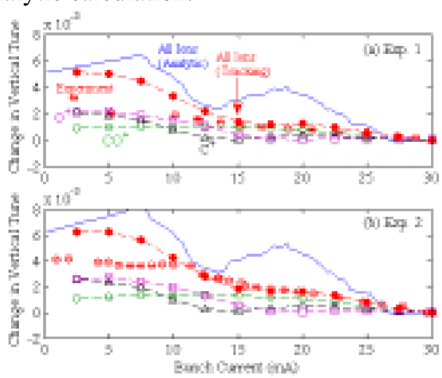

Fig. 3 (a) Experimental results, tracking and analytic calculations of change in vertical tune for Exp. 1 and (b) Exp. 2.

[1] R.D. Kohaupt, DESY Interner Bericht No. H1-71/2 (1971) (unpublished).
[2] A. Mochihashi *et al.*, Jpn. J. Appl. Phys. **44** (2005) 430.
[3] Y. Baconnier and G. Brianti, CERN Internal Rep. No. CERN /SPS/80-2(DI) (1980) (unpublished).

Upgrade of RF Cavity in UVSOR-II Electron Storage Ring

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As we have referred in previous activity report [1] we have built new main RF cavity of the UVSOR-II electron storage ring. The new cavity can generate RF voltage of 150 kV [1] without exchanging high-power RF transmitter that has maximum output of 20 kW. The cavity has been installed in a short straight section in the UVSOR-II at shutdown period in the spring 2005, and soon has been achieved designed RF voltage of 150kV in high-power commissioning.

Figure 1 shows a layout of the UVSOR-II before/after the improvement of the main RF cavity. Due to the upgrade, the RF section has been moved from a long straight section (S7 section) to a short straight section (S2 section). Previous RF cavity has been already dismounted from the ring; the site will be able to be made good use of other devices such as undulators in the future.

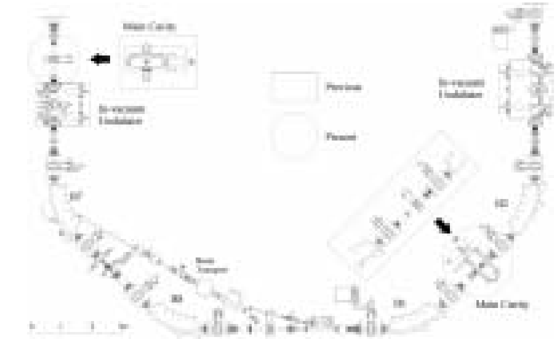

Fig. 1 Layout of the UVSOR-II before and after the upgrade of the main RF cavity.

Figure 2 and Table 1 show a drawing and basic specification of the new main RF cavity. For comparison, the same parameters for the previous cavity are shown in the table. Basic design of the new cavity is unchanged compared to the previous one, however, the shunt impedance and unloaded quality factor become about 4 and 2.5 times larger. The previous cavity was made from clad steel plates (SUS+Cu), whereas the new cavity is made from OFHC; that makes temperature control to be easier. To keep tuning condition stable, SUS materials are partly used as mechanical supports in out-of-vacuum surfaces. The new cavity has 2 movable plunger-type tuners; one is used for auto-tuning and the other is usually fixed and can be used for detuning higher-order-mode. These tuners have enough tuning width for operation of the cavity (full width of 400 kHz for each tuner). Input coupler for previous cavity was air-cooled, but new coupler has water-cooling channel to cool especially ceramic window part.

Figure 3 shows a photograph of new RF cavity just after installation to the UVSOR-II. After installation and evacuation, high-power commissioning was started. The commissioning went smoothly, and designed RF voltage of 150 kV was achieved easily.

Now not only high-power aging but also beam test has been proceeding to improve stability of RF field and vacuum condition in the cavity. After the commissioning the cavity will be operated in users run from May 2005.

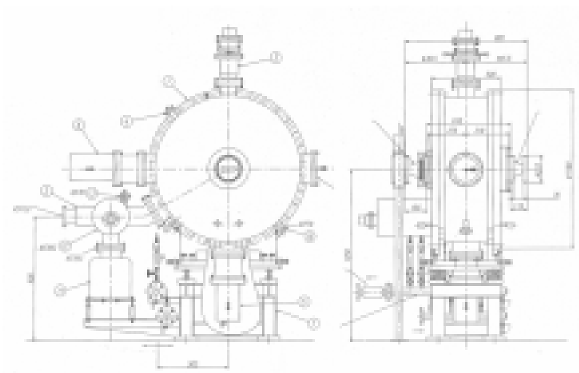

Fig. 2 Drawing of the new main RF cavity.

Table 1 Parameters for the previous and present cavities.

	Previous	Present
Frequency	90.1 MHz	90.1 MHz
Cavity voltage	55 kV	150 kV
Shunt impedance	0.5 MΩ	2.45 MΩ
Unloaded Q	8000	20300
Coupling	1.75	1.34
Material	SUS + Cu	Cu (OFHC)
Cells	Re-entrant×1	Re-entrant×1
Coupler	Air-cooled	Water-cooled
Tuner	Plunger×1	Plunger×2
Inner diameter	1000mm	1175mm
Bore radius	50mm	55mm

Fig. 3 Photograph of new cavity covered with jacket heaters. A view from outside the storage ring.

[1] A. Mochihashi *et al.*, UVSOR Activity Report 2003 (2004) 35.

BL5U(FEL)

High Power FEL Lasing in the Deep UV Region

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An out-coupled power of a storage ring free electron laser (FEL) is a critical issue for its application experiments. Recently we planned to apply the UVSOR-FEL to an irradiation experiment on biosohere [1]. In the experiment, a switchable circular polarized laser in the deep UV region (200 ~ 300 nm) is necessary. We already succeeded in lasing in the wavelength region in 1997; however the out-coupled power was too small for further application experiment. At that time, we had to employ high reflectivity mirrors for an optical cavity and the transmission which is proportional to the out-coupled power was small. While since the upgrade of the storage ring (UVSOR-II), the FEL gain has been increased by more than factor 2 because of smaller beam size and we can employ high transmission mirrors that allow high out-coupled power.

The lasing experiment was made is in the wavelength region around 255 nm. Multi-layers of HfO_2/SiO_2 were chosen as cavity mirrors because they have the highest efficiency (= transmission/cavity loss) at the wavelength. Numbers of layers of the mirrors were chosen to be 19 and 15 for front and backward cavity mirrors, respectively. We employed small number of layers for the backward mirror because higher transmission was needed for the mirror from which the laser power was extracted. The calculated round trip reflectivity is 99.3% and the transmission of the backward mirror is 0.4%.

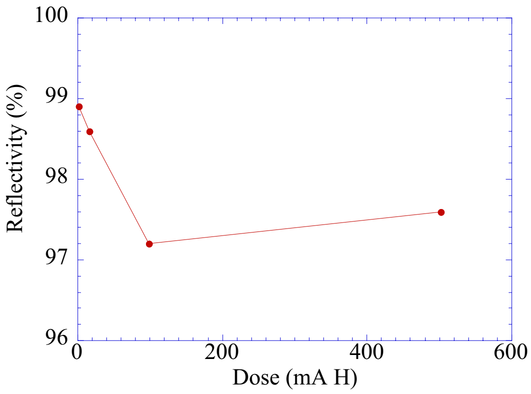

Fig. 1 Roundtrip reflectivity of the cavity mirrors as a function of irradiation dose.

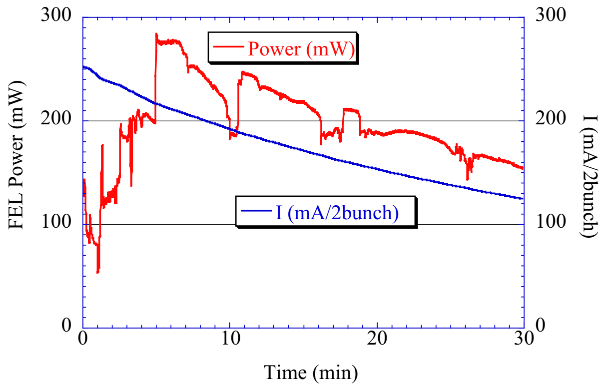

Fig. 2 Out-coupled FEL power and the beam current.

During the lasing experiment, we measured round trip reflectivity as the front mirror was irradiated by synchrotron radiation from the helical optical klystron type undulator. Fig. 1 shows measured round trip reflectivity as a function of irradiation dose. As the dose increases, the reflectivity decreases quickly but the degradation seems to be saturated at a dose more than 100 mA hours. The averaged value of the reflectivity after the irradiation was 97.4%. With the reflectivity, the calculated threshold beam current was 25 mA/bunch and was almost consistent with the measured threshold current of 34 mA/bunch. With such a high threshold current, it is important to store high beam current in the storage ring. By optimization of the injector system, we have been able to store a beam current of more than 100 mA/bunch. Then we could succeed in the lasing with the mirrors and we proceeded to the application experiment. In the application experiment, we irradiated a biosohere with a circularly polarized FEL and analyze a chirality of the product. During the experiment, power irradiated on the sample was recorded and an example is shown in Fig. 2. As seen in the figure, the maximum extracted power was 0.28 W but it decreased as the beam current decreased. The average power was about 0.2 W and was found to be enough to dissociate the sample.

[1] H. Nishino *et. al.*, in this issue.

BL6B

Obsevation of Intense Far-Infrared Synchrotron Radiation at UVSOR-II

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We have observed intense far-infrared synchrotron radiation at the beam line BL6B [1] of UVSOR-II storage ring [2] operated in single bunch modes. The wave length region of the far-infrared radiations which are detected by using an InSb bolometer is between 0.2 mm and 3.0 mm. The duration and the period of the bursts are about 200 µsec and 10 - 15 msec, respectively. Each burst consists of several quasi-periodic micro-bursts whose periods are about 30 µsec. The peak intensity of the bursts is about 10000 times larger than the intensity of synchrotron radiations in the same wavelength region observed in normal multi-bunch modes. We expect that the bursts of the far-infrared radiation are “coherent synchrotron radiations”.

Experiments and Results

We measured the bursts of far-infrared synchrotron radiation at the BL6B beam line constructed for using the synchrotron radiation of infrared region [1]. The electron beam energy was 600 MeV in our measurements.

We used an InSb hot electron bolometer (Infrared Laboratories, Inc) to detect the far-infrared radiations. The detector was sensitive to the wavelength region between 0.2 mm and 3 mm. The response of the detector was several microseconds.

Fig. 1 shows the average intensities of the far-infrared radiations in the single bunch mode (dots) and the multi-bunch mode (gray line) with the average beam currents. The far-infrared radiations passing thorough a chopper (100 Hz) were detected by the InSb bolometer. The output signals from the bolometer were inputted in a lock-in amplifier. In the multi-bunch mode, the intensity of the far-infrared radiations is proportional to the beam current. In the single bunch mode in lower beam current, the average intensity is also proportional to the beam current and is the same as it in the multi-bunch mode. However, when the beam current is over 140 mA, the intensity of the far-infrared radiations is suddenly increased. There are also increases of the intensity at around 80 mA.

Fig. 2 shows the time structure of the far-infrared radiations at the beam current of 178 mA measured by using an oscilloscope. The radiations are generated as periodic bursts at this beam current. The period of the bursts is about 10 – 15 msec.

The time structure of a typical burst at 201 mA is shown in Fig. 3. The pulse width of the burst is about 200 msec in which there were several micro-bursts of the width of about 30 msec. The peak intensities of the bursts are about 10000 times larger than the intensity of the ordinary synchrotron radiations of the same wave length at the same average beam current.

Summary

We observed bursts of far-infrared synchrotron radiation in the wave length region between 0.2 mm and 3.0 mm at BL6B of UVSOR-II. The bursts were generated when the beam current exceeded a certain threshold current. We expect that the bursts are coherent synchrotron radiations caused by density modulations of electrons in a beam bunch.

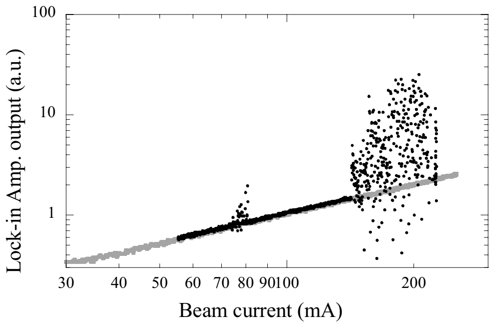

Fig. 1 Average intensity of THz-radiaion.

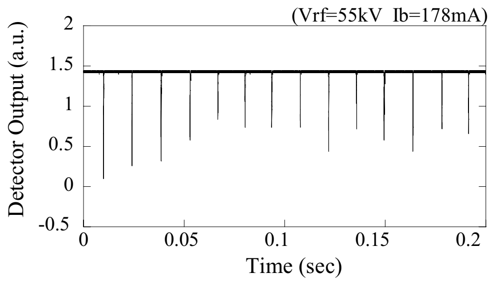

Fig. 2 Time structure of THz-bursts.

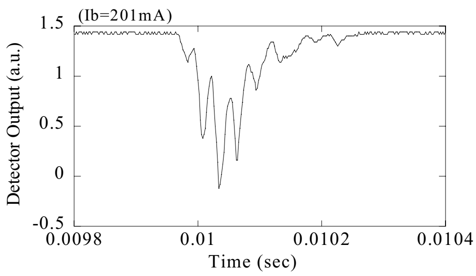

Fig. 3 Time structure of a burst.

[1] S. Kimura *et al.*, AIP Conf. Proc. 705.

[2] M. Katoh, Journal of Japanese Society for Synchrotron Radiation Research, **17**(1) (2004) 10.