HIGH POWER DEEP UV LASING ON THE UVSOR-II STORAGE RING FEL

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Abstract

Thanks to a recent upgrade of the UVSOR-II storage ring (lower beam emittance and higher peak current), an FEL gain has been enhanced much and we have succeeded in high power lasing in deep UV region. The highest extracted CW power so far is 0.25 W at wavelength of 215 nm and 1.1 W at 230 nm. Because of its variable wavelength even in deep UV region, high power and good coherence, the UVSOR-II FEL has come to be recognized as a useful tool by users inside and outside Institute for Molecular Science. Now UVSOR-II FEL has four users groups (solid state physics, surface physics, bio-moleculer science). Three different kinds of experiments have been successfully carried out in this year.

INTRODUCTION

On the UVSOR storage ring, a free electron laser has been developed as a new light source since early 1990s. In 1996, a helical optical klystron was installed and the performance of the FEL was improved much because of a smaller degradation of cavity mirrors and a higher FEL gain. Then the shortest wavelength (239 nm) of the storage ring FEL at that time was achieved [1].

Recently the storage ring was upgraded and the quality of the electron beam was much improved. With the increased FEL gain, a FEL lasing in shorter wavelength was expected, where more potential users exist. Here we report on an FEL experiment in the deep UV region at UVSOR-II aiming users application. The FEL should have enough power in addition to a good optical quality for application experiments. We also report recent upgrade of an rf accelerating cavity system, which plays an important role in the short wavelength lasing.

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UPGRADE OF RF CAVITY SYSTEM

In 2003, the UVSOR storage ring was reconstructed toward a lower emittance ring; we call it “UVSOR-II” after the reconstruction [2]. The chief aim of this upgrade is to provide users with brighter synchrotron radiation. We still continue the upgrade of the ring. We replaced rf accelerating cavity system in 2005 [3]. The aim is to improve lifetime of the electron beam with higher accelerating voltage. At the UVSOR, 90.1 MHz rf cavity had been operated with a 20 kW transmitter but the rf accelerating voltage (55 kV at maximum) was limited by low shunt impedance (1 MΩ) of the former cavity.

Table 1: Basic parameters of previous/present rf cavity

	Previous	Present
Frequency	90.1 MHz	90.1 MHz
Cavity voltage	55 kV	150 kV
Shunt impedance	1 MΩ	2.45 MΩ
Unloaded Q	8370	20300
Coupling	1.75	1.34
Structure	Re-entrant ×1	Re-entrant×1
Inner diameter	1000 mm	964 mm
Bore radius	50 mm	55 mm
Material	SUS + Cu	Cu (OFHC)
Tuner	Plunge×1	Plunger ×2

Hence the new rf cavity was designed to have higher shunt impedance. Table 1 shows basic parameters of previous/present rf cavity. The new cavity was installed in the spring of 2005 and the high cavity voltage of 150 kV was achieved. With the new cavity system, observed Touschek beam lifetime was increased by a factor of 3. This upgrade is also favourable to the FEL because higher accelerating voltage leads to shorter electron bunch and higher peak current.

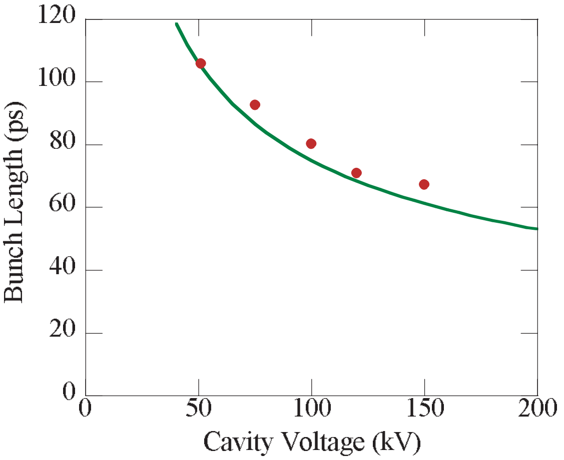

Figure 1: Natural bunch length in various rf voltage. The data points are measured values and the solid line is calculated bunch length.

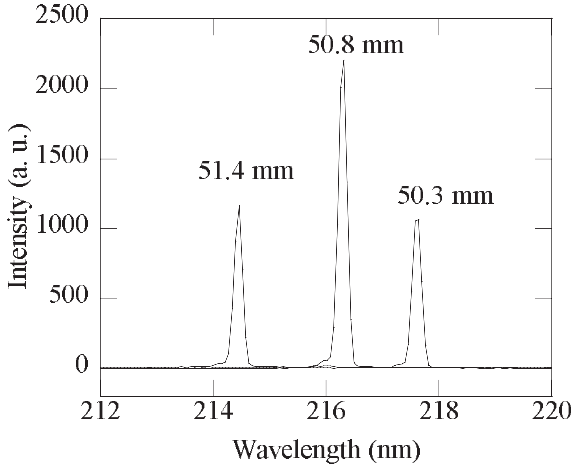

Figure 2: Typical FEL line spectra measured by changing gap width of the optical klystron. The resolution of the spectra is limited by that of the monochrometer used in the measurement.

Fig. 1 shows measured bunch length by using a streak camera after installing the new rf cavity. The bunch length at a cavity voltage of 150 kV is 67 psec; this value is 60 % of the previous one (110 psec). In this case FEL gain increased by a factor of 1.6 is expected. This leads the FEL lasing in the deep UV region where higher FEL gain is needed.

LASING AROUND 215 nm

We have planned an FEL lasing around 215 nm basically aiming to an user experiment. In the experiment, samples of bio-molecules are irradiated by a laser with the wavelength around 215 nm, where the absorption spectrum of the sample has a peak. The laser should have enough power in order to proceed the irradiation experiment quickly; otherwise the sample may be easily effected by bacteria.

In former UV lasing experiments at the UVSOR, multi-layers of HfO_2/SiO_2 had been employed for cavity mirrors. In a lasing experiment around 215 nm, the multi-layer can not be employed because the band gap energy of HfO_2 is about 5.6 eV (220 nm in a light wavelength) and a strong absorption is expected. Then we chose multi-layers of Al_2O_3/SiO_2; the band gap energy of Al_2O_3 is well above the laser photon energy requested. Since refraction index of Al_2O_3 is smaller than HfO_2, number of layers should be increased to attain reflectivity sufficiently high for lasing. On the other hand, transmission of a mirror becomes smaller and a less power is extracted through the mirror as increasing number of layers. Compromising reflectivity and transmission, we chose number of layer of 49 for downstream mirror and 37 for upstream mirror from which an FEL power is extracted. The expected round-trip reflectivity of the optical cavity is 99.3 % and the transmission of the upstream mirror is 0.5 %. Preparatory to the lasing experiment, we measured the round-trip reflectivity of the mirrors by ring-down method with a low electron beam current (~ 0.1 mA). The

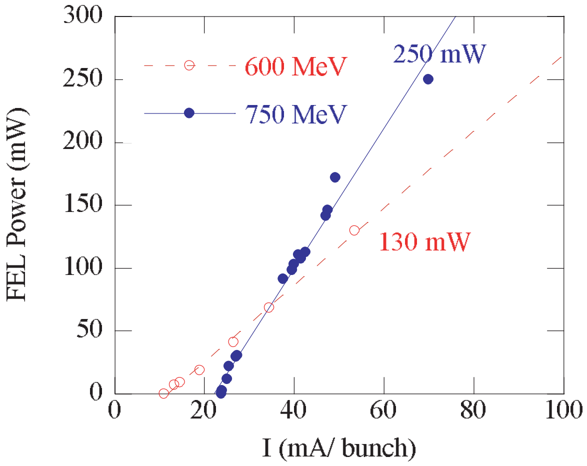

Figure 3: Measured extracted FEL power as a function of beam current at energy of 600 MeV and 750 MeV. The lines are guides to eyes.

measured value was around 97.8 %, which was much smaller than the expected one. We suppose that the low reflectivity came from a degradation of the mirrors due to synchrotron radiation during reflectivity measurement. The mirrors degradation, however, seemed to stop after the first irradiation by synchrotron radiation. Even after exposure to SR of more than 1000 mA h during the lasing experiment, we did not observe the essential change of the reflectivity.

The lasing experiment was started with an electron energy of 600 MeV, with which UVSOR FEL experiment had been made so far. The storage ring was operated in two bunch mode with equal bunch spacing. As seen in Fig. 2. lasing from 214 nm to 218 nm was successfully obtained changing a gap width of the helical optical klystron. In Fig. 3, extracted laser power is plotted as a function of a stored beam current in the storage ring. The threshold beam current for lasing was 11 mA/bunch. The calculated FEL gain at a beam current of 11 mA/bunch is about 2.3 %. This value is very consistent with the measured cavity loss of 2.2 %.

As a next step of the lasing experiment, we raised the electron energy from 600 MeV to 750 MeV, with which the storage ring is operated for SR use. According to the Renieri limit [4], the extracted FEL power is proportional to the total synchrotron radiation power per turn from electron beam. Since the total radiation power is proportional to the 4th power of the electron energy, higher extracted laser power is expected at 750 MeV. Storing a rather high beam current in the storage ring, we have obtained successful lasing at this electron energy for the first time on UVSOR-FEL. The measured threshold current for lasing is about 2 times higher than that in the case of 600 MeV. But a higher laser power is extracted as is expected. The extracted FEL power at 750 MeV is about 1.6 times of that at 600 MeV at a beam current of 70 mA/bunch, that is well above the threshold current. This relation is consistent with that of synchrotron radiation power; the total synchrotron radiation power

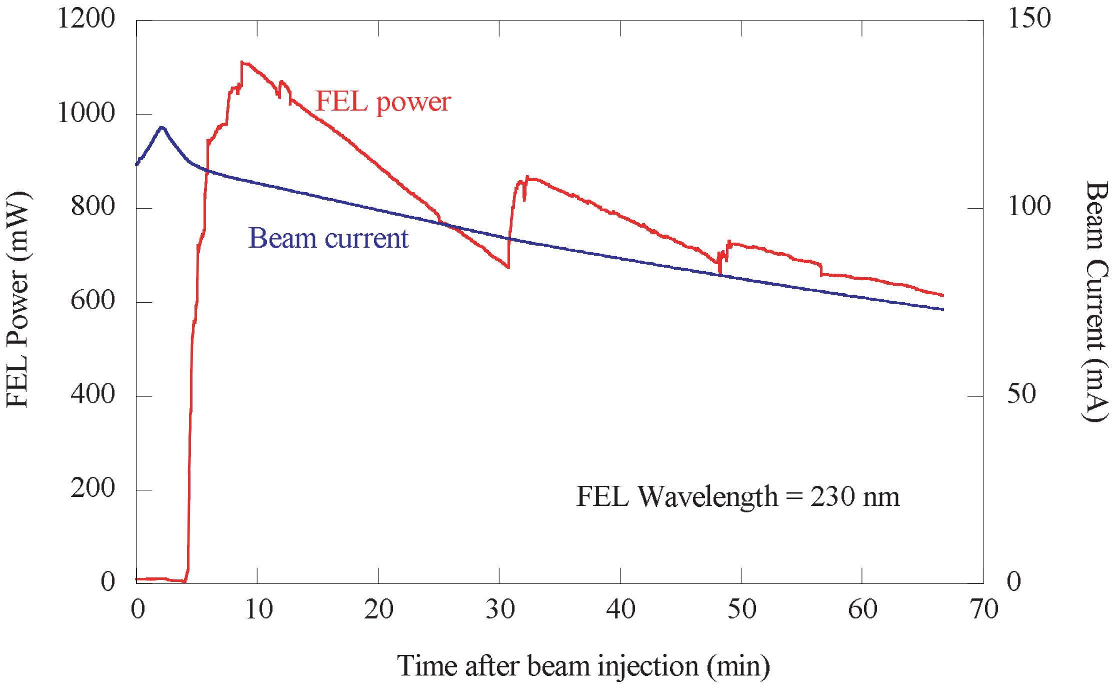

Figure 4: Extracted FEL power and beam current as a function of time. The FEL wavelength is around 230 nm. The maximum FEL power was 1.1 W.

from an electron at 750 MeV is about 2.4 times of that at 600 MeV. The higher electron energy has another advantage. The higher operating energy suppress Touschek effect, by which electron beam lifetime of UVSOR-II is limited. In the experiment at 750 MeV, we observed about three times longer lifetime, which resulted in longer lasing time for users experiment.

LASING AROUND 230 nm

Similar to the case of 215 nm-FEL, the lasing around 230 nm was planned oriented to users experiments. In the lasing experiment, multi-layers of Al_2O_3/SiO_2 were also employed for cavity mirrors. Measured round-trip reflectivity and transmission were 98.8 % and 0.8%, respectively. Therefore the optical characteristics of mirrors is advantageous for the FEL lasing as compared with mirror of 215 nm. The lasing experiment was carried out with an electron energy of 750 MeV. Fig 3 shows the extracted FEL power and the stored electron beam current as a function of time after the electron beam is stored. As is expected, higher extracted laser power was obtained and the observed maximum power reached 1.1 W at a beam current of 100 mA/bunch. During the experiment, drift of the laser power was observed especially at a high beam current as shown in the figure. The power could be recovered by adjusting the alignment with downstream mirror once again. Therefore the power drift can be explained by deformation of the cavity mirror due to heat-load from synchrotron radiation and from the FEL. The laser, however, became almost stable after about one hour exposure of synchrotron radiation.

The FEL around 230 nm was applied to two experiments on surface physics and photo-electron spectroscopy. The FEL extracted from the upstream mirror was transported to the experimental stations by using aluminium mirrors and was focused on samples by lenses. In the experiments, they started the measurement after the laser became stable. The FEL power around 0.5 ~ 0.2 W was actually applied. Although the experiments were made in limited machine time, the users succeeded in obtaining primary results.

CONCLUSION

We have succeeded in high power FEL lasing in deep UV around 215 nm and 230 nm. Users experiments of the FEL were carried out and primary results were obtained. The stability of the laser at the source position and also at the experimental station should be improved. Suppression of the thermal deformation of the cavity mirror and stability of the laser transport system are critical issues. We are going to lasing below 200 nm in near future. The shorter wavelength FEL is desired for the photo-electron spectroscopy experiment.

REFERENCES

[1] H. Hama et. al., Free Electron laser and its Applications in Asia, (1997) 17.
[2] M. Katoh et. al. Nucl. Instru. and Meth. A467 (2001) 68.
[3] A. Mochihasi et. al., UVSOR Activity Report 2004 (2005) 35. A. Mochihashi et. al., UVSOR Acitivity Report 2005 (2006) 37.
[4] A. Renieri, Nuovo Cimento, 53 (1979) 160.