RECENT EXPERIMENTS AND PROSPECT ON THE NIJI-IV VUV/IR FEL

H. Ogawa#, K. Yamada, N. Sei, M. Yasumoto, K. Yagi-Watanabe
Research Institute of Instrumentation, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

Abstract

The NIJI-IV free electron laser (FEL) is being developed as a compact light source with very good optical quality and ultra-wideband tunability from the VUV to the IR. To obtain lasing at shorter wavelengths in the VUV region, continuous efforts to improve the cavity-mirror performance have been made, so that the original loss of mirrors was recently decreased around 195nm. A new optical cavity system, composed of two sets of a heavy granite base and a stable mirror manipulator, was installed to stabilize the lasing and also to extend the tuning range. As for the IR FEL, modification of the beam transport system to make space for installation of the optical cavity was completed.

INTORODUCTION

Storage ring FELs (SRFELs) are unique source and have advantages such as good spectral resolution, high repetition rate, and natural synchronisation with synchrotron radiation from insertion devices or bending magnets. These features of SRFELs are suitable for pump-probe experiments and observing a continuous change of a phenomenon without giving sample damage. Indeed, the use of SRFELs for the real-time surface observation has been investigated in combination with a photoemission electron microscopy (PEEM) at DUKE [1,2] and AIST [3,4]. Many efforts to shorten the wavelength in SRFELs have been made [5-7] for such applications. At AIST, an FEL research has been performed using the compact storage ring NIJI-IV and the FEL lasing down to 198nm was achieved [7]. The NIJI-IV is a racetrack-type storage ring whose circumference is 29.6m. The ring has two straight sections of 7.25 m and 4.1 m in length and a 6.3-m optical klystron ETLOK-II [8] is equipped in the longer straight section for the UV/VUV FEL experiments as shown in Fig.1. In 2004, a 3.6-m optical klystron ETLOK-III [9] was installed into the other straight section and the construction for lasing in the IR region is going on [10]. The optical klystron parameters are summarized in Table 1. Here we report recent progress in the NIJI-IV FEL.

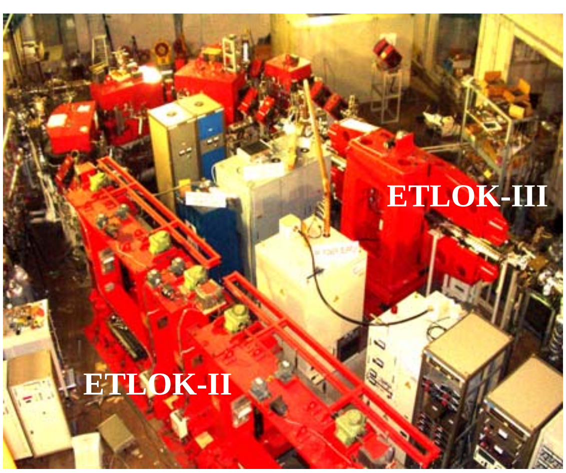

Figure 1: NIJI-IV FEL system.

Table 1: Parameters of optical klystron ETLOK-II and III

	ETLOK-II	ETLOK-III
Total length [m]	6.288	3.55
Magnetic period		
Undulator section [mm]	72	200
Dispersive section[mm]	216	720
Number of period N_u	42×2	7×2
Deflection factor K	<2.29	<10.04
Wavelength [μm]	0.198-0.595	(0.4-12)

DEVELOPMENT OF THE VUV/IR FEL

VUV FEL Mirror

To shorten the FEL wavelength, we have been upgrading the NIJI-IV FEL system. The replacement of NIJI-IV vacuum chambers as well as installation of thin sextupole magnets has been performed in order to increase FEL gain. As for the laser cavity, Al_2O_3/SiO_2 dielectric multilayer mirrors were adopted for the wavelength below 220 nm. In a previous study, we tried FEL oscillations below 195 nm with two kinds of Al_2O_3/SiO_2 mirrors but failed to obtain the oscillation. The original losses of the cavity composed of two mirrors around 195nm were small as 1.9%-2.6%, while the losses after irradiated by the undulator radiation from ETLOK-II were rapidly increased through degradation of dielectric multilayer mirrors as shown in Fig.2, so that the oscillation could not be realized [10]. To improve the mirror performance, the Al_2O_3/SiO_2 mirrors were manufactured again by tuning the dielectric coating condition. As a result, the original loss of the cavity was presently obtained to be down to 1.2%, which was sufficient to realize the lasing around 195nm. After measuring an evolution of degradation of the mirrors, we are planning to perform the FEL oscillation experiments below 195nm.

#ogawa.h@aist.go.jp

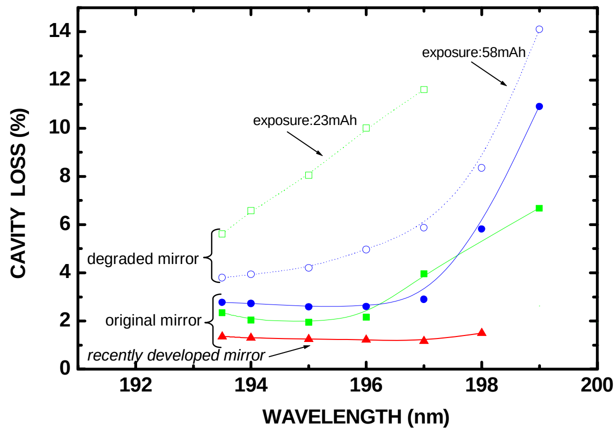

Figure 2: Wavelength dependence of the cavity loss of Al_2O_3/SiO_2 multilayer mirrors. The losses of mirrors manufactured in the previous work are shown by squares and circles, while the loss in the present work is represented by triangles.

Optical cavity system

It was observed that the intensity of the NIJI-IV FEL was modulated with a few to 10 ms period near the best cavity tuning condition and the lasing mode was not fixed at a stable CW mode [11]. Although its origin has never been identified, it is probably caused by a mechanical vibration of the mirror vacuum chamber, because the base of our mirror holders had a slender structure whose weight was only 20-30 kg. Therefore new optical cavity system has been made for the stabilization of the FEL oscillation, which is needed for FEL application research such as a photoemission electron microscopy. Figure 3 shows a photograph of the new system which was installed into an upstream side of ETLOK-II in this year. We chose heavy granite stone, whose weight was about 2 ton, as the base of the cavity, so that the vibration of the base in an optical axis was dumped below 0.1 mm, which was measured with a vibration sensor under frequency of 200 Hz. The mirror chamber is remotely manipulated by five-axis stage with gimbal optical mount and three linear stages (Newport SL20AN, M-MTM100PP.1, M-ILS50PP and M-MVN80 with precision motorized actuators LTA-HL). The cavity length and mirrors can be adjustable with resolutions of 0.1 mm and 0.8 mrad, respectively. In addition, a novel feature is that the chamber has two in-vacuum mirrors that are interchangeable with reproducible adjustment. This will enable us to extend FEL tuning range restricted by a narrow reflection bandwidth of dielectric multilayer mirrors. We will measure the stability of the FEL oscillation with the optical cavity system after commissioning of new beam transport system as described in the following subsection.

Figure 3: New optical cavity system.

Beam transport system

In order to extend lasing range toward a long-wavelength region, we have been developing the NIJI-IV FEL in the infrared (IR) region using ETLOK-III. The FEL gain in the visible and near-IR regions was evaluated to be over 2% from observed spectra of a spontaneous emission from the ETLOK-III [10]. The realization of FEL lasing can be expected in the visible and near-IR regions since high-reflection mirrors of 99.8% or more are available. We are preparing to make an optical cavity system for the IR FEL and its mirror diameter would be 50mm, which is larger than that for the UV/VUV FEL of 30mm, by considering diffraction loss.

However, there was no space to install the upstream cavity system for the IR FEL because a beam transport line was too close to the storage ring. Therefore we decided to modify the transport system to make a space for the cavity. The detail of design for new beam transport system was written in [10]. We have constructed the new transport system, as shown in Fig.4, which is 2.48m away from the former one and the beam commissioning has been started. The beam was transported from LINAC to

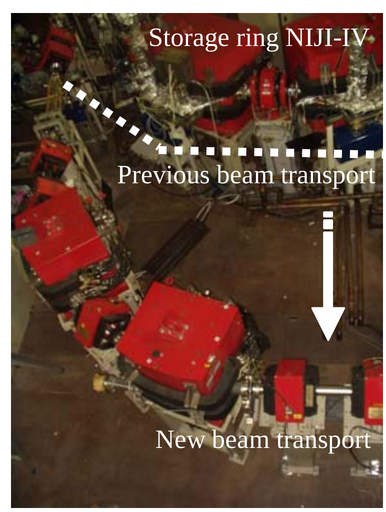

Figure 4: Photograph of a part of new beam transport system. The place where previous beam transport located is indicated by dashed line.

an entrance of the storage ring and focused into a septum chamber of NIJI-IV. The final tuning of beam parameter is now in progress.

DUV FEL APPLICATION

Recently, performance of the NIJI-IV FEL was improved at the deep UV (DUV) around 200 nm by both optimizing the transmittance of the output coupler and increasing stored electron-beam energy [3]. Thus we can make real-time observation of chemical reactions on a transition metal surface using a photoelectron emission microscopy (PEEM). The metal surface was irradiated by an FEL or spontaneous emission from ETLOK-II at a wavelength of 202 nm, and the catalytic CO-oxidation ($2CO + O_2 \rightarrow 2CO_2$) on a Pd(111) single crystal surface has been investigated by introducing CO and O_2 gases at a pressure of ~10^{-5} Pa [4]. Figure 5 shows the setup for FEL-PEEM measurement. The PEEM system (STAIB Instrumente, type 350) is only applicable at pressures below ~10^{-5} Pa, since a micro channel plate (MCP) image intensifier equipped in the system requires a vacuum of better than ~10^{-5} Pa during operation. A differential pumping is necessary for observation of chemical reaction under higher pressure. Therefore we prepared a turbo molecular pump (Varian Turbo-V70LP) that is being added to a differential pumping port close to MCP. We are planning to observe chemical reactions on the transition metal surfaces at higher pressure of ~10^{-3} Pa.

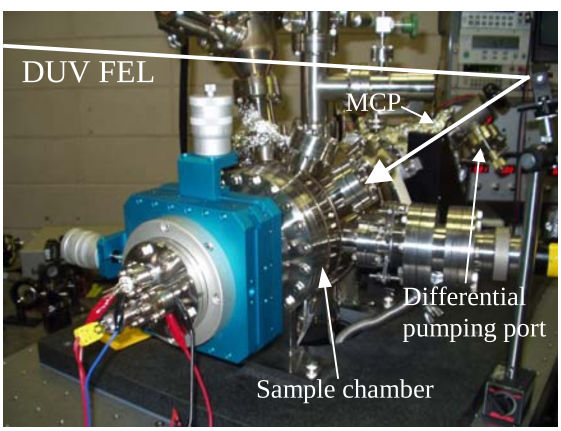

Figure 5: Photograph of the FEL-PEEM system.

SUMMARY

An FEL with wide wavelength range from the VUV to IR has been studied based on compact storage ring NIJI-IV. To shorten the lasing wavelength, Al_2O_3/SiO_2 multilayer mirrors optimized at 195nm were improved and the cavity loss of the original mirrors was successfully reduced by 30%, compared with that of previous ones. The preparation for the lasing in the IR region is also proceeding. The beam transport system in NIJI-IV has been modified to make space for the optical cavity of the IR FEL. Furthermore, in order to stabilize the FEL oscillations in the UV/VUV regions, new optical cavity system holding two in-vacuum interchangeable mirrors has been installed, which was composed of heavy granite base and five-axis manipulators. This will enable us to carry out reproducible FEL application experiments, such as real-time observation of surface chemical reactions.

ACKNOWLEDGEMENTS

This study was financially supported by the Budget for Nuclear Research of the Ministry of Education, Culture, Sports, Science and Technology, based on the screening and counseling by the Atomic Energy Commission of Japan.

REFERENCES

[1] W.-C. Yang et al., J. Appl. Phys. 94 (2003) 5720.
[2] W.-C. Yang et al., Phys. Rev. Lett. 90 (2003) 136102.
[3] K. Yamada et al., Proceedings of the 26th Free Electron Laser Conference, August 2004, Trieste, p.311.
[4] H. Ogawa et al., Proceedings of the 27th International Free Electron Laser Conference, August 2005, Stanford, p.467.
[5] F. Curbis et al., Proceedings of the 27th International Free Electron Laser Conference, August 2005, Stanford, p.473.
[6] V.N. Litvinenko et al., Nucl. Instr. and Meth. A470 (2001) 66.
[7] K. Yamada et al., Nucl. Instr. and Meth. A528 (2004) 268.
[8] T. Yamazaki et al., Nucl. Instr. and Meth. A331 (1993) 27.
[9] N. Sei et al., Jpn. J. Appl. Phys. 41 (2002) 1595.
[10] N. Sei et al., Proceedings of the 27th International Free Electron Laser Conference, August 2005, p.469.
[11] K. Yamada et al., Nucl. Instr. and Meth. A475 (2001) 205.