RECENT PROGRESS OF THE UVSOR-FEL

M. Hosaka, S. Koda, M. Katoh, J. Yamazaki , K. Hayashi, K. Takashima
UVSOR Facility, Institute for Molecular Science, 38 Nishigo-Naka, Myodaiji, Okazaki 444–8585, Japan
H. Hama
Laboratory of Nuclear Science, Tohoku University, 1-2-1 Mikamine, Taihaku-ku, Sendai 982-0826, Japan

Abstract

At the UVSOR, performance of storage ring free electron laser (SRFEL) has been improved aiming users applications. Recently an experiment using SRFEL combined with synchrotron radiation (SR) was begun. As the first experiment, the double-resonant excitation of Xe has been investigated by using SR and SRFEL as pump and probe lights, respectively. Relevance of making use of SRFEL for the pump/probe experiment is demonstrated.

1 INTRODUCTION

On the UVSOR storage ring, free electron laser experiment has been performed with a helical optical klystron and lasing from the visible (590 nm) to the UV (240 nm) region has been already achieved. Since then we have been continuously improving performance of the UVSOR-FEL aiming to users applications. Main parameters and characteristics of the UVSOR-FEL are summarized in Table 1.

Table 1 Main parameters and characteristics of the UVSOR-FEL

Storage Ring	
Energy	600 MeV
Circumference	53.2 m
RF Frequency	90.1048 MeV
Harmonic Number	16
Maximum Beam Current for FEL	~100 mA/bunch
Helical optical klystron	
Number of periods	9+9
Period length	110 mm
Length of dispersive section	302.5 mm
K-value	0.07 ~ 4.6
Optical cavity	
Cavity Length	13.3 m
Mirrors	Ta_2O_5/SiO_2 or $Hf0_2/SiO_2$
FEL performance	
Wavelength	240 ~ 590 nm
CW output power	1.2 W (570 nm)
Spectral width	~ 10^{-4}
Tunable range	> 10 nm

SRFELs likely have a potentiality for scientific application as a unique light source because of, in addition to variable wavelength, good coherence and temporal feature, the natural synchronization with SR. Therefore combined use of those photons is easily applied to two-color experiments. Since most of SRFELs are installed in a synchrotron radiation facilities where various kind of SR beam lines are equipped, the utilization of SRFEL can be performed in many fields of applications.

The first two-color experiment using SRFEL was performed at the Super-ACO in 1995. The surface photo voltage effect induced by the UV-FEL photons (at 350 nm) on semiconductors surface and interfaces was measured by using SR as probe photons [1]. A lot was learned from the Super-ACO experiment, and then recently on the UVSOR storage ring a two-color experiment was begun. As the first experiment, we have tried to demonstrate the relevance of SRFEL for a pump/probe experiment in the gas phase molecular science that is the double-resonant excitation of Xe. In this paper, latest improvements of the UVSOR-FEL to satisfy requirements for users applications are described and the present status of the experiment is reported.

2 IMPROVEMENTS OF THE UVSOR-FEL

2.1 Temporal stability

Good temporal stability of SRFEL is significant for users applications, especially for pump/probe two-color experiments where jittering or drift of the synchronism between the FEL pulse and the SR pulse spoils a quality of the experimental data. The temporal feature of SRFEL is mostly governed by stability of the optical cavity when the longitudinal instability of the electron bunch is well suppressed. Even a very small detuning in the synchronism leads to time jittering and power fluctuation, and it is well known that a relatively large detuning causes a macropulse lasing with a repetition rate of ms range.

To perform user experiments, a longitudinal feedback system has been developed at the UVSOR. Instead of direct observation of the temporal deviation between the optical pulse and the electron bunch, signals from a pick-up electrode (the electron bunch) and from a fast photodiode (the FEL) are filtered and converted into rf signals at a certain harmonics of the FEL round-trip frequency. Then the time deviation is detected as a phase deference in the frequency domain [2]. Choosing a 24-th harmonics of the round-trip frequency, a time resolution less than 10 ps was obtained. Although the sampling rate is limited to be ~ 1 kHz due to a response time of a master oscillator, the micropulse jitter is reduced to less than 30 ps and the stable CW lasing is maintained for an adequate time.

2.2 Q-switching operation

The CW output power of SRFEL is limited by the "bunch heating" due to the interaction with the FEL optical pulse. However, using Q-switching technique, much larger peak power (~ 100 times) can be obtained (Fig.1 (a)), because lasing is started from a completely damped state of the energy spread of electron bunch. On the UVSOR, Q-switching is performed by repetitive jump of the RF-cavity frequency. Fig. 1(b) shows the extracted average power as a function of the repetition rate of Q-switching. As seen in the figure, a low repetition rate, the extracted power increases linearly with increasing a repetition rate, but at a repetition rate above 60 Hz it decreases because the electron bunch cooling-down due to the synchrotron damping (damping time = 20 msec UVSOR) is not sufficient. The relevance of Q-switching will be shown below.

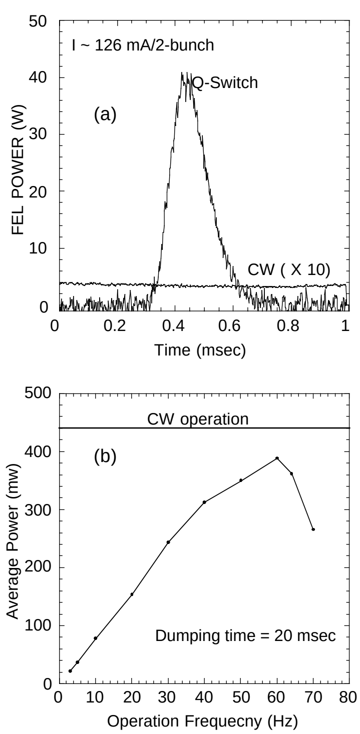

Fig. 1 (a) Measured extracted power of the FEL in the Q-switching operation compared with in the CW operation. (b) Average extracted power in the Q-switching operation as a function of the repetition rate.

3 PUMP/PROBE EXPERIMENT

As the first experiment, we have investigated the double-resonant excitation of Xe using SR as pump and SRFEL as probe. It consists, in a first step, of exciting ground state Xe atoms to the $5p^5 5d$ excited state with a SR pulse (the pump pulse) using 10.4 eV photons. In the second step, the excited atoms are ionized by a FEL pulse of the wavelength of 570.1 nm. Because the life time of the excited $5p^5 5d$ state is short (600 ps), the synchronization of the SR and laser is essential in the experiment.

The pump/probe experiment was carried out at a beamline BL3A1 of the UVSOR using SR from a planar undulator whose fundamental harmonics was adjusted to 10.4 eV. Since the beam line has no monochromator, an LiF filter is installed to suppress higher harmonics radiation from the undulator. The FEL light around 570 nm is extracted through the backward mirror and transported to an experimental station of the BL3A1 through a series of multilayer mirrors. The flight path of FEL, which is adjusted to synchronize timing between the FEL and the SR, is about 30 m. A focusing mirror (f = 10 m) was placed in the center of the flight path to keep the laser size small throughout the transport. About 69 % of the extracted power can be transferred to the experimental station. The fine adjustment of the timing is made using a movable optical delay of 50 cm at the experimental station. The FEL and SR photon from collinear opposite directions cross in the interaction region where an effusive jet of Xe gas crosses and the produced ions of Xe were detected by means of a conventional channeltron.

In the early stage of the experiment, we found that events rate of backgrounds which probably comes from interactions of SR photons with the detector structure was very high (~ 10^5 counts/sec) and it seemed to be very difficult to detects the pump/probe events. Then we employed the Q-switching technique to the experiment. As mentioned earlier, much larger peak power is provided with Q-switching FEL but the duration of lasing is relatively short (~ 0.2 msec). Therefore if events detected is gated with the duration, improvement of S/N by a factor 100 is expected. The spectrum obtained with the Q-switching technique is shown in Fig. 2(a). In the measurement the wavelength of the FEL was swept by changing the gap length of the helical optical klystron. Using the Q-switching technique, we could detect the true events and could adjust spatial and temporal overlap among the FEL, the SR and the gas jet and reduced the background. Consequently we could measure a spectrum using a CW FEL(Fig. 2 (b)). During the measurement the feedback system mentioned above was employed to stabilize the lasing. Due to the bandwidth of CW FEL narrower than Q-switching FEL, much improved spectrum could be obtained and asymmetric line shape described by the Fano formula could be clearly observed.

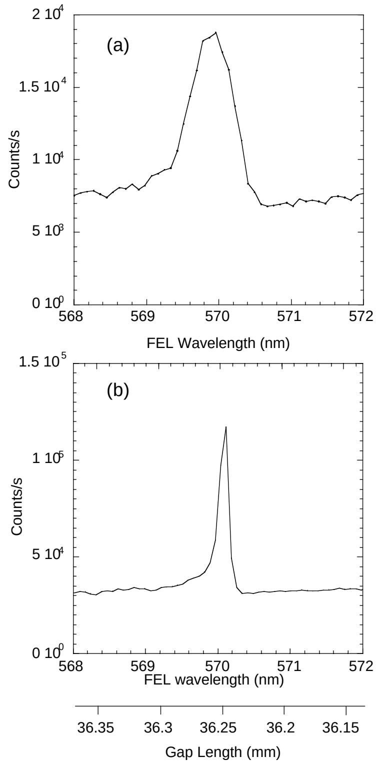

Fig. 2 Two-photon ionization signal of Xe, as a function of the wavelength of FEL, measured using the Q-switching FEL(a) and the CW FEL (b).

4 CONCLUSION

SRFELs have advantages as a unique tool for scientific application with good coherence and temporal feature. On the UVSOR storage ring, the required improvements of the SRFEL to be used for scientific applications has been made; a feedback system maintains the stable CW FEL lasing and Q-switching technique that enables to extract high peak power. With the improvement, double-resonant excitation experiment on atomic Xe coupling SRFEL and SR has performed. Although the experiment is still in progress, the obtained two-photon ionization spectrum shows the relevance of SRFEL for pump/probe experiments.

REFERENCES

[1] M. E. Couprie, R. Bakker, D. Garzella, L. Nahn, M. Marsi, F. Merola, T. Hara, M. Billardon, Nucl. Instr. and Meth A 375 (1996) 630.

[2] S. Koda, M. Hosaka, J. Yamazaki, M. Katoh and H. Hama, Nucl. Instr. and Meth. A (2001) in press.