SATURATION PHENOMENA OF VUV CHG AT UVSOR-II*

T.Tanikawa#, The Graduate University for Advanced Studies [SOKENDAI], Okazaki, 444-8585, Japan
M.Adachi, M.Katoh, J.Yamazaki, H.Zen,
UVSOR Facility, Institute for Molecular Science, Okazaki, 444-8585, Japan
M.Hosaka, Y.Taira, N.Yamamoto, Nagoya University, Nagoya, 464-8603, Japan

Abstract

An undulator gap dependence and seed laser power dependence on coherent harmonic generation (CHG) in VUV were measured at UVSOR-II. In the experiment of the laser power dependence, we have observed a saturation of coherent harmonics' intensity. A system of high-harmonic generation (HHG) in gas to generate a seed light for shorter wavelength CHG is under development.

INTRODUCTION

The laser seeding technique, injecting seed light of full coherence into an electron bunch in an undulator, is used in a single-pass seeded free-electron laser (FEL)[1] to improve temporal coherence of self-amplified spontaneous emission (SASE)-FEL, for a coherent harmonic generation (CHG) [2,3,4] and for high-gain harmonic generation (HGHG) [5].

At UVSOR-II, a 750 MeV synchrotron light source, a resonator-type FEL has been studied for many years [6,7,8]. In recent years, by utilizing a part of the FEL system, studies on CSR in the terahertz range and CHG in the deep ultra-violet (DUV) range have been performed by using a femto-second laser system. In past studies, DUV coherent harmonics (CHs) with circular polarization have been successfully generated [9,10]. In this paper, the generation of CH in vacuum-ultra violet (VUV) and some systematic measurements of VUV CHG, particularly in the saturation regime, are described.

SPECTRUM MEASUREMENT SYSTEM FOR VUV CHG

Configuration

Figure 1 illustrates the experimental setup of the spectrum measurement. The seed light is created using a femto-second Ti: Sapphire laser generated by a mode-locked oscillator (Mira, COHERENT), which is synchronized with the RF acceleration of the storage ring, and a regenerative amplifier (Legend, COHERENT). The seed light is injected with 1 kHz repetition rate via a sapphire window. A wave plate and polarizer for changing laser power, a lens pair for expanding the laser beam and a focusing lens (f = 5000 mm) made of BK7 are settled upstream of the sapphire window and the laser is focused most strongly in a modulator part of an optical klystron (OK).

The coherent harmonics generated by the interaction between the laser pulse and the electron beam are introduced to a light diagnostics section or to a VUV spectrum measurement system.

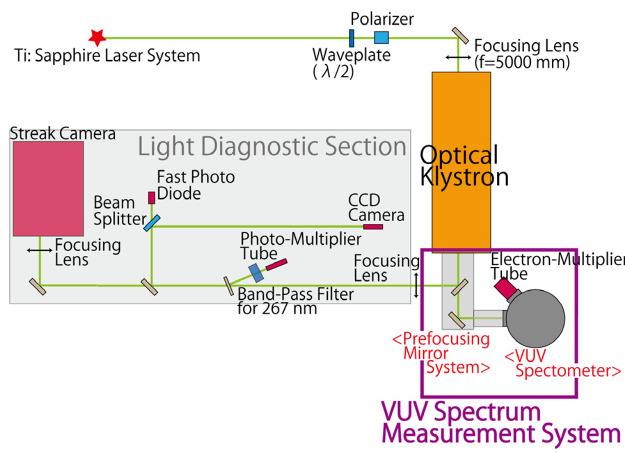

Figure 1: Schematic drawing of the experimental setup used in spectrum measurement of CHG.

Parameters

Table 1 shows the parameters of the electron beam, the OK and Ti: Sapphire laser in this experiment.

Table 1: Experimental Parameters

< Electron Beam >	
Beam Energy	600 MeV
Beam Current	~ 30 mA
Bunch Length	161 ps
Natural Emittance	17.5 nm-rad
Natural Energy Spread	3.4 × 10-4
Revolution Frequency	5.64 MHz
Operation Mode	Single Bunch
<Optical Klystron>	
Period Length	110 mm
Number of Periods	9 + 9
K value	6.18
N_d	45

*This research was partially supported by JSPS research fellow DC, Grant-in-Aid for Scientific Research (B20360041) of JSPS and Quantum Beam Technology Program of JSPS/MEXT.
#tanikawa@ims.ac.jp

<Ti: Sapphire Laser>	
Wavelength	800 nm
Pulse Energy	～2.0 mJ
Pulse Duration	130 fs ～ 1.3 ps
Repetition Rate	1 kHz

In the parameter of the OK, the N_d means the wave number of the radiation overtaken the electron beam in a buncher of the OK.

Methods

Spacial and temporal alignments between the electron beam and the Ti: Sapphire laser acting as the seed light were performed in the light diagnostic section. The spacial alignment was performed so that the electron beam and the seed light overlapped in the whole modulator part of the OK by using a CCD camera. The rough temporal alignment was performed by using a pin-photo diode and the precise temporal alignment was performed by using a sub-picoseconds streak camera (C5680, Hamamatsu Photonics).

The spectrum measurements of CHs were performed by using VUV spectrum measurement system. The system is constructed of an aluminium coated pre-focusing mirror, a spectrometer (VMK-200-UHV, Vacuum & Optical Instruments) with a platinum coated concave replica grating of 2400 grooves/mm and an electron multiplier tube (R5150MOD, Hamamatsu Photonics) as a detector.

EXPERIMENTAL RESULT

Spectra of Coherent Harmonics

As the result of spectrum measurements of spontaneous emissions (SEs) and CHs, CH was observed up to the 9th harmonic (89 nm in wavelength). Figure 2 shows the 5th harmonic of CH and SE and Fig. 3 shows the 7th harmonic of them. The data show that the bandwidth of CHs was narrower than that of SEs.

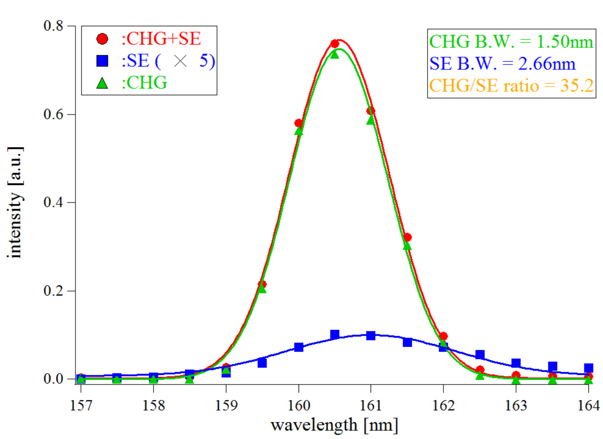

Figure 2: 5th harmonic spectra of coherent harmonic and spontaneous emission. Dots are measurement data and solid lines are Gaussian fitting.

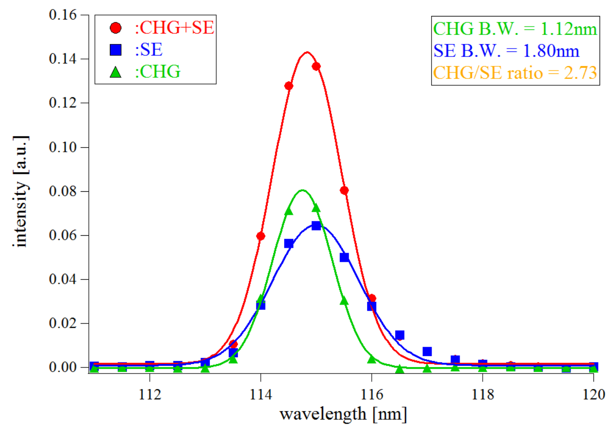

Figure 3: 7th harmonic spectra of coherent harmonic and spontaneous emission. Dots and solid lines are same as in Fig. 2.

Undulator Gap Dependences of Coherent Harmonics Wavelength and Intensity

Figure 4 shows the dependence of the 5th harmonic intensity and wavelength of the CH and SE on the undulator gap (magnetic field).

The peak wavelength of SE shows linear dependence on the gap of OK. On the other hand, in the case of CH, the peak wavelength of the CH is fixed at the harmonic wavelength of the seed light. In addition, the peak intensity shows the same tendency with that of the SE intensity at the peak wavelength of CH. This can be explained as follows. The spectrum of CH is analytically described as

$$\frac{dI_{CH}}{d\lambda} = \frac{dI_{\mathrm{SE}}}{d\lambda} N(N-1)\,|\,F(\lambda)\,|^2 \quad , \qquad (1)$$

where I_{CH} is the intensity of CH, N is the number of electron interacting with the seed laser, $F(\lambda)$ is the form factor of the electron pulse and I_{SE} is the intensity of SE [11]. In this case, the peak wavelength is determined by the spectral dependence of form factor $F(\lambda)$, because the form factor has a narrow peak around the harmonic wavelength of the seed light. Therefore the dependence on the OK gap is dominated by the $dI_{\mathrm{SE}}/d\lambda$ term in Eq. 1, since the form factor doesn't have much dependence on the OK gap.

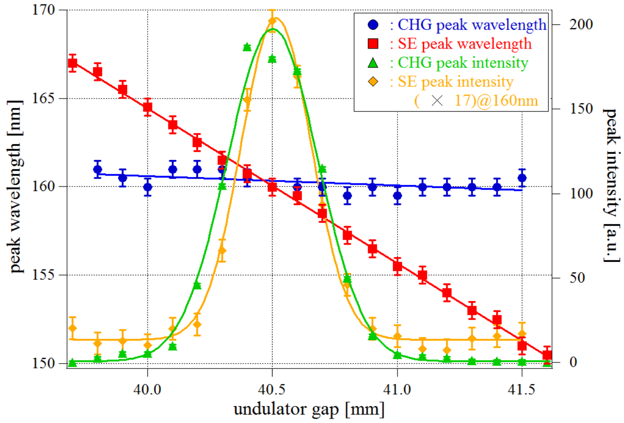

Figure 4: Dependence of 5th CH and SE wavelength and intensity on gap of optical klystron. Dots are measurement and solid lines are fitting line (linear and Gaussian).

Peak Power of Seed Light Dependences of Coherent Harmonics Intensities

The dependence of CH intensity on the peak power of seed light has been measured. As a result, saturation of CH has been observed as shown in Fig. 5. In this figure, peak intensities of the 3rd, 5th and 7th CH are plotted as a function of the peak power of the seed light. As the peak power of seed light increases, CHs intensities also increase but tend to saturate and show a peak around 1~2 GW. For higher seed light power, the 2nd and 3rd peaks on the 5th harmonic appeared. This may be explained as the result of over-bunching and re-bunching. These results will be compared with simulations in a future paper.

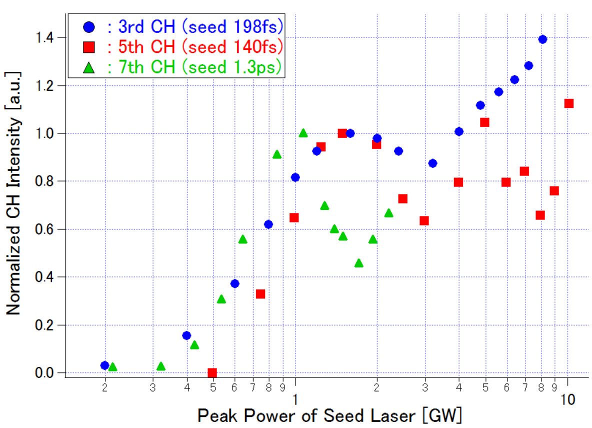

Figure 5: Dependence of CH intensity on peak power of seed laser.

TO GENERATE SHORTER WAVELENGTH CH

To generate a shorter wavelength CH at UVSOR-II and also to establish the seed light technology in single pass FEL, a seed light source based on high-harmonic generation (HHG) in a gas is under development. Now the HHG system as shown in Fig. 6 and 7 has been constructed. The target wavelength is 160 nm (5th harmonic). The HHG experiment will start soon and a HHG-seeded CHG experiment will be demonstrated then.

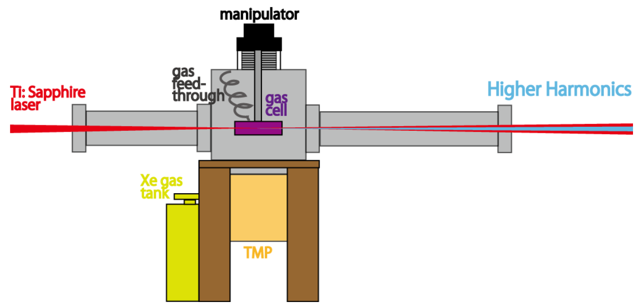

Figure 6: Schematic drawing of HHG in gas system.

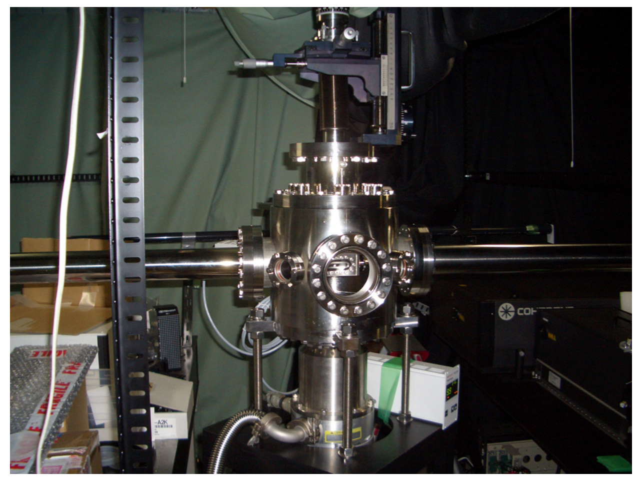

Figure 7: Photo of HHG in gas system.

SUMMARY AND FUTURE PLAN

VUV CH has been observed up to the 9th harmonic. The bandwidths of CHs are narrower than that of SE. These results should be compared with simulations including the chirping of the seed laser and the saturation. The peak wavelength of CH is fixed at harmonics of the same wavelength as the seed light under varying the pole gap of OK. The dependence of the peak intensity of CH on the gap is determined by that of SE. The dependence of CH intensity on the peak power of seed light has been measured and saturation phenomena have been observed. A HHG system has been constructed for shorter wavelength CHG.

REFERENCES

[1] G.Lambert, et.al, Nature Physics, VOL.4, 296-300, 2008.
[2] S.Werin, et.al, Nuclear Instruments and Methods in Physics Reserch A 290, 589-596, 1990.
[3] R.Prazeres, et.al, Nuclear Instruments and Methods in Physics Reserch A 304, 72-76, 1991
[4] C.Spezzani, et.al, Nuclear Instruments and Methods in Physics Reserch A 596, 451-458, 2008.
[5] L.-H.Yu, et.al, Science, VOL.289, 932-934, 2000.

[6] M.Hosaka, et.al, UVSOR Activity Report 2007, 2008.
[7] M.Hosaka, et.al, Nuclear Instruments and Methods in Physics Research A 507, 289-293, 2003.
[8] H.Zen, et.al, Proceedings of FEL 09, Liverpool, England, 2009.
[9] M.Labat, et.al, The European Physical Jounal D, VOL44, Number1, 187-200, 2007.
[10] M.Labat, et.al, Proceedings of FEL 08, Gyeongju, Korea, 2008.
[11] O.Grimm, Proceedings of PAC 07, New Mexico, USA, 2007.