SPECTRAL MEASUMENT OF VUV CHG AT UVSOR-II*

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Abstract

A vacuum ultra-violet (VUV) light diagnostic system has been constructed for coherent harmonic generation (CHG) experiment at UVSOR-II. Undulator K value dependence of the CHG spectra and peak laser power dependence of CHG intensity were measured.

INTRODUCTION

At UVSOR-II, a 750 MeV synchrotron light source, a resonator-type free electron laser (FEL) has been studied for many years [1,2,3]. By utilizing a part of the FEL system, studies on CHG in deep ultra-violet (DUV) range have been performed by using a femto-second laser system in these years. In the past studies, DUV coherent harmonics (CHs) with circular polarization have been successfully generated [4,5].

VUV SPECTROMETER AND PREFOCUSING MIRROR SYSTEM

At the UVSOR-II, the FEL and CHs light are extracted through a quartz window downstream of the FEL cavity. A spectrometer for visible and DUV light (C5094, Hamamatsu Photonics) has been employed to measure the spectrum of CHs and FEL. The spectrometer doesn't have sensitivity to the VUV light. In addition, the window and air intensively absorbs the VUV light. In order to measure CHs in VUV range, a new VUV spectral measurement system has been constructed.

Figure 1 and 2 illustrates configuration of the new VUV spectrum measurement system, which is directly connected to the FEL cavity. The VUV spectrometer (VMK-200-UHV, Vacuum & Optical Instruments) equips a concave replica grating (2400 grooves/mm, Pt coated, 4.5 of F number), whose has a sensitivity in a wavelength range of 50 ~ 300 nm. The spectrometer is Seya-Namioka configuration of 64 degree of input-output angle and is compatible with an ultra-high vacuum environment. An electron multiplier tube (R5150MOD, Hamamatsu Photonics) is used as the photo detector, which has sensitivity below 200 nm.

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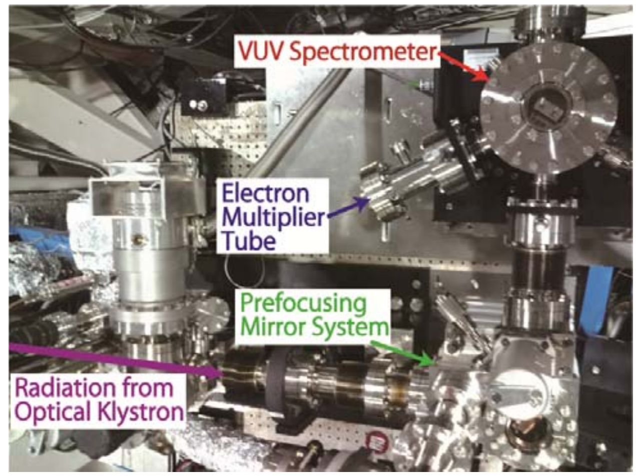

Figure 1: VUV spectral measurement system downstream of the FEL cavity.

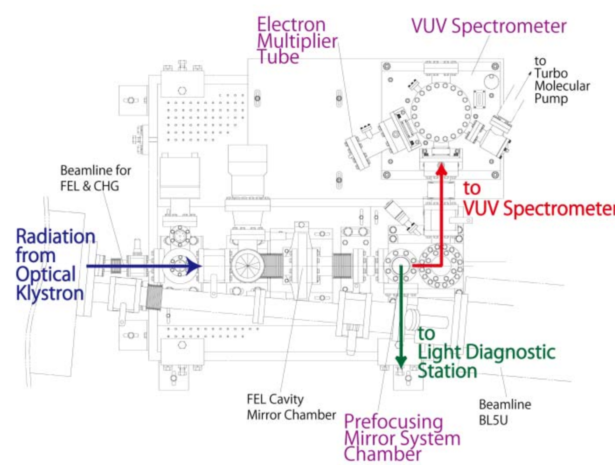

Figure 2: Layout of VUV spectrometer and prefocusing mirror system.

SPECTRAL MEASUREMENT OF VUV CHG

Experimental Setup

Figure 3 illustrates the experimental setup of the spectral measurement. Femto-second Ti: Sapphire laser pulses are generated by a mode-locked oscillator (Mira, COHERENT) synchronized with the RF acceleration of the ring and a regenerative amplifier (Legend, COHERENT). They are injected with 1 kHz repetition rate from the upstream side of the FEL cavity via a sapphire window with an antireflection coat. A focusing lens (f = 5000 mm) made of BK7 is settled upstream of the sapphire window and the laser is focused in the entrance of modulator part of OK.

The CHs generated by the interaction between the laser pulse and the electron beam are introduced to the light diagnostics section or to the VUV spectral measurement system.

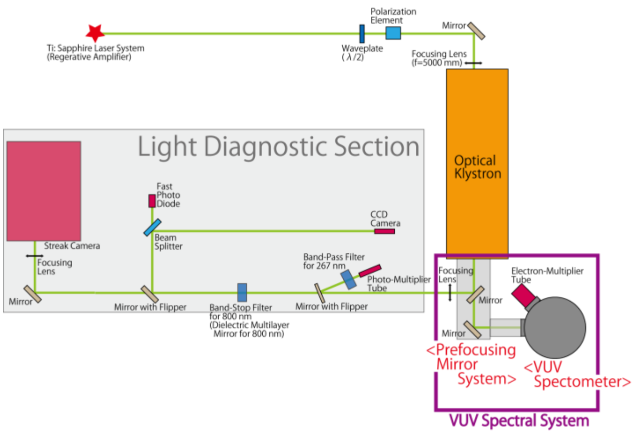

Figure 3: Schematic drawing of the experimental setup in spectral measurement experiment of CHG.

Table 1: Experimental Parameters

< Electron Beam >	
Beam Energy	600 MeV
Beam Current	~ 20 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	6.32
Nd	45
<Ti: Sapphire Laser>	
Wavelength	800 nm
Bandwidth	12 nm
Pulse Energy	~ 2.0 mJ
Pulse Duration	130 ~ 1215 fs
Repetition Rate	1 kHz

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

Experimental Results

The CHs up to 9th order (89 nm) could be observed. Figure 4 shows the spectra of 5^{th} harmonic of the spontaneous emission (SE) and CH. The data clearly shows the bandwidth of CH (1.17 nm FWHM) was much narrower than that of SE (7 nm FWHM). The bandwidth of SE can be roughly estimated as

$$\frac{d\lambda_{SE}}{\lambda_{SE}} \approx \frac{1}{h\,N_u}, \qquad (1)$$

where λ_{SE} is the wavelength of SE, h is the order of harmonics, N_u is the number of period of OK. In this case, N_u is 9. While, the bandwidth of CH is

$$\frac{d\lambda_{CH}}{\lambda_{CH}} \approx \frac{1}{h\,N_{seed}}, \qquad (2)$$

where λ_{CH} is the wavelength of CH, N_{seed} is the number of waves in the seed laser [6]. In this case, the N_{seed} is about 68 because the pulse duration of seed laser is 181 fs. Hence, this result, which shows the spectral narrowing, has a good agreement between the experimental and above estimation results.

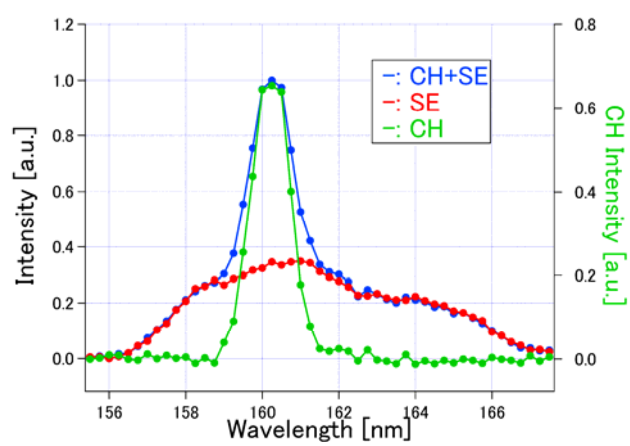

Figure 4: Spectra of incoherent emission (SE; red line) and coherent emission (CH; green line) at the 5th harmonic.

The dependence of 5^{th} harmonic intensity and wavelength of the CH and SE on K value, the deflection parameter of OK, are shown in Fig. 5. The peak wavelength of SE approximately shows linear dependence on the K value of OK. On the other hand, in the CH case, the peak wavelength of the CH is fixed at 160 nm. In addition, the peak intensity shows same tendency with that of SE intensity at 160 nm. This can be explained as follows. The spectrum of CH is analytically described as

$$\frac{dI_{CH}}{d\lambda} = \frac{dI_{SE}}{d\lambda} N(N-1)\,|\,F(\lambda)\,|^2 \quad , \qquad (3)$$

where I_{CH} is the intensity of CH, N is numbers of electron interacting with the seed laser, $F(\lambda)$ is a form factor of the electron pulse and I_{SE} is the intensity of SE [7]. 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 harmonics of seed laser. Therefore the dependence on the K value is dominated by $dI_{SE}/d\lambda$ term in Eq. 3, since the form factor doesn't have much dependence on the K value.

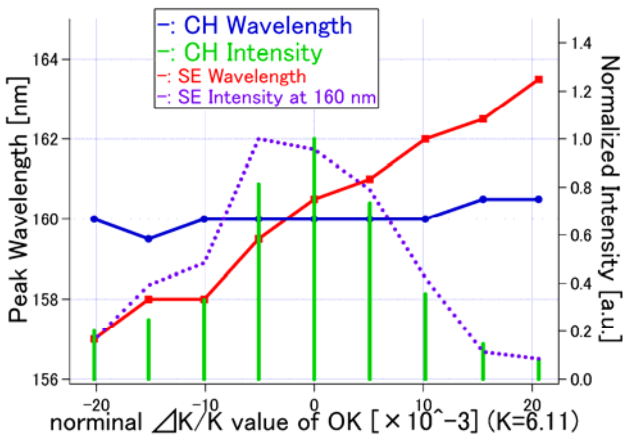

Figure 5: Dependence of CH and SE wavelength and intensity on K value. CH and SE intensity is normalized by peak intensity at ΔK/K=0.

The dependence of CH intensity on the peak power of seed laser has been measured. As the result, saturation phenomena of CH have been observed as shown in Fig. 6. In this figure, peak intensities of 3rd and 5th CH are plotted as a function of peak power of the seed laser in GW range. As the laser power increase, the CH intensity increases but tends to saturate and shows a peak around 1~2 GW. For higher laser power, the 2nd and 3rd peaks appear. This may be explained as the result of over-bunching and re-bunching. These results will be compared with simulation.

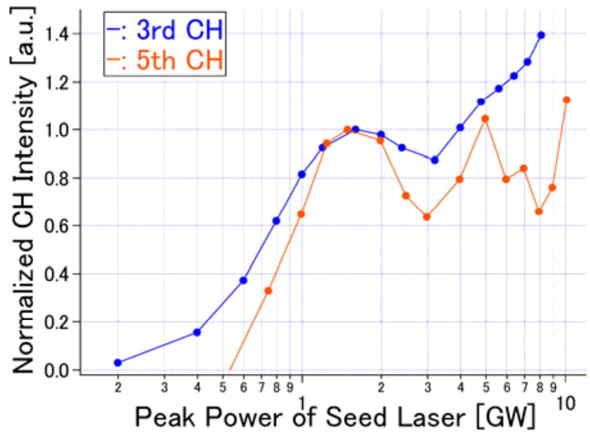

Figure 6: Dependence of CH intensity on peak power of seed laser.

SUMMARY AND FUTURE PLAN

We have constructed the VUV spectral measurement system and have successfully observed spectra of VUV CH. Moreover, the dependence of the wavelength and intensity on K value and dependence of CH intensity on the seed laser power have been measured. Saturation phenomena have been observed.

We plan to utilize high harmonic generation (HHG) in a gas for the short wavelength seed light. Now the HHG system is under development.

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