IMPROVEMENT OF SOFT X-RAY GENERATION SYSTEM BASED ON LASER COMPTON SCATTERING *

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Abstract

A compact X-ray source is required in various fields such as biological science and material development. At Waseda University, a table-top size soft X-ray source based on laser Compton scattering has been developed. Using 1047 nm laser beam (Nd:YLF) and 4.6 MeV electron beam generated from a photo-cathode RF-gun, we had already succeeded in generating laser Compton X-rays [1]. The energies are within the "water window" region (250-500 eV) [2] which can be applied to biological studies. For good signal to noise (S/N) ratio and more photons, we remodeled our collision chamber and laser amplifier system. With these modifications, the X-ray photons detected by a micro channel plate (MCP) have increased tenfold to reach 312 /pulse. All the generated photons was estimated to be 3.28×10^4. Moreover, we succeeded in generating soft X-rays stably for more than 10 hours. Good S/N ratio stable X-rays have made it possible to observe the beam-laser interaction precisely.

INTRODUCTION

Laser Compton Scattering

Laser Compton scattering is the inverse energy transfer process of general Compton scattering between a relativistic electrons and low energy photons such as laser light. Laser light, which collides with high energy electrons, get energy and are scattered as X-rays. Figure 1 shows the scattering in electron-rest frame and laboratory frame.

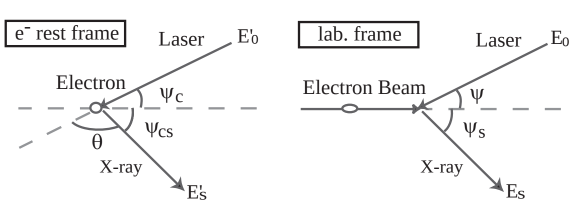

Figure 1: Coordinates of laser Compton scattering.

Let the photon energy and electron beam energy in laboratory frame be E_0 and γmc^2, respectively. The energy of scattered photons E_s is given as

$$E_s = \frac{mc^2\gamma^2 E_0(1+\beta\cos\psi)(1+\beta\cos\psi_{cs})}{mc^2+\gamma E_0(1+\beta\cos\psi)(1+\cos\psi_{cs})} \qquad (1)$$

where $\cos\psi_{cs} = (\cos\psi_s - \beta)/(1-\beta\cos\psi_s)$. Equation (1) shows the energy of scattered X-ray varies along with energy of photon, energy of electron, and collision angle. This energy tunability is very useful for biological observation because the wavelength dependence of the absorption coefficient varies in each element.

Water Window

The energies of generated X-rays are within the water window (250-500 eV) [2] where the X-ray absorption coefficient of water is much less than that of constituent elements of cells. For this reason, applications to biological studies are expected such as a bio-microscope with which we can observe living cells without dehydration.

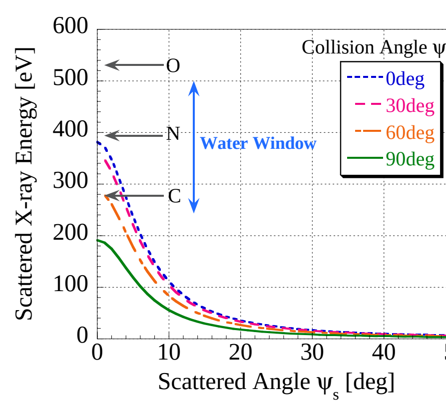

Figure 2: Calculated energy distribution of scattered X-rays with different collision angle where E_0 =4.6 MeV and water window region.

X-RAY GENERATION SYSTEM

Our X-ray generation system shown in Fig. 3 is table-top size (2.5×2 m^2) including all the beam line and a picosecond Nd:YLF laser system (Pulrise V: Sumitomo Heavy Industry Co.). 1047 nm IR laser passes through flash lamp amplifier system and delay line which controls the timing

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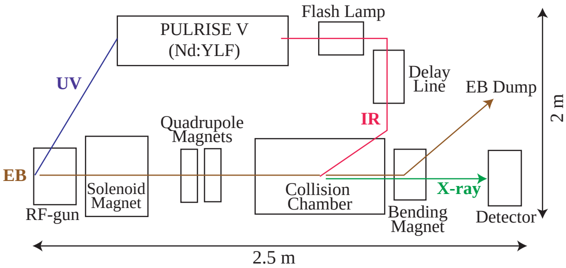

Figure 3: X-ray generation system at Waseda University.

of the collision. On the other hand, the 4th harmonic of Nd:YLF, 262 nm UV laser, is injected to the Cu cathode of the RF-gun after the profile optimization. The electron beam and the IR laser are synchronized easily because both IR and UV laser are from the same system. For the X-ray signal detection, a MCP is used.

Table 1 is the experimental parameters at the collision point. The electron beam size has measured precisely by after-mentioned experiments.

Table 1: Experimental parameters at collision point.

Electron Beam		Laser Beam	
Beam energy	4.6 MeV	Wavelength	1047 nm
Bunch charge	350 pC	Pulse energy	36 mJ
Beam size	251 μm	Beam size	42 μm
Beam size	56 μm	Beam size	42 μm
Bunch length	10 ps (FWHM)	Pulse duration	10 ps (FWHM)
Repetition rate	5 Hz	Repetition rate	5 Hz

EXPERIMENTAL RESULTS

For good S/N ratio and more photons, we remodeled our collision chamber and the flash lamp amplifier system. As a result, both S/N ratio and photon number have improved remarkably. Moreover, by using good S/N ratio generated X-rays, it has become possible to observe precisely the interaction between the electron beam and the laser.

Remodeling of Collision Chamber

We remodeled our collision chamber as shown in Fig. 4.

- The collision part and bending part have been united to dump the electron beam before it diffuses. The bremsstrahlung X-ray should be reduced and we can expect higher luminosity X-ray because strong convergence has become possible. Also, shorter distance from to the detector increases the detected photons.
- Beam pipes inside the chamber have been removed to reduce backgrounds.
- We installed position tunable IR mirror in the chamber before the collision point. We can choose collision angle from 15 to 20 degree, *i.e*, X-ray energy.

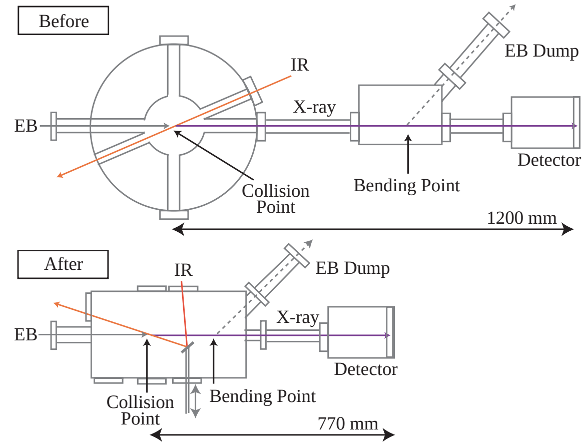

Figure 4: Old chamber and remodeled one.

3-pass Flash Lamp Amplifier System

For more photons, we adopted 3-pass amplifier system which the laser passes through the flash lamp 3 times. The laser power has amplified to 40 mJ, but we use up to 36 mJ considering the damage threshold of optical components [3].

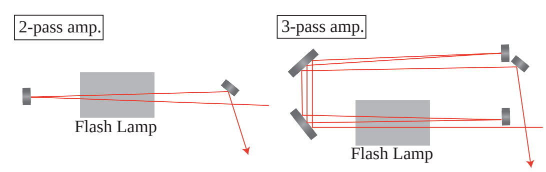

Figure 5: Flash lamp amplifier system.

Soft X-ray Generation

With the modifications, good S/N ratio picosecond pulse soft X-ray was obtained. The maximum energy and the energy spread were calculated to be 370 eV and 0.7% at the detection point, respectively.

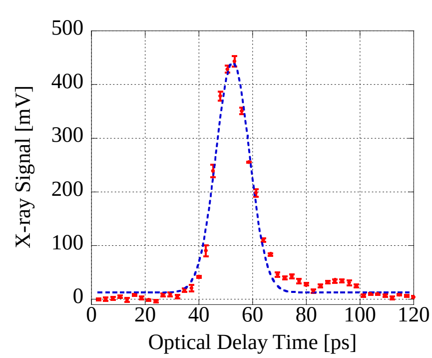

Figure 6: X-ray intensity with cross correlation between the electron beam and the laser beam.

Figure 6 shows the x-ray signal as a function of the timing of the laser pulse by moving the optical delay line. The best fit of the figure was obtained with σ=6.2 ps *i.e.*, 14.6

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ps in FWHM. Considering the bunch length (10 ps) and the laser pulse duration (10 ps), the figure shows a clear cross correlation between the electron beam and the laser pulse. The generation results before [4] and after the modification are arranged in Table 2.

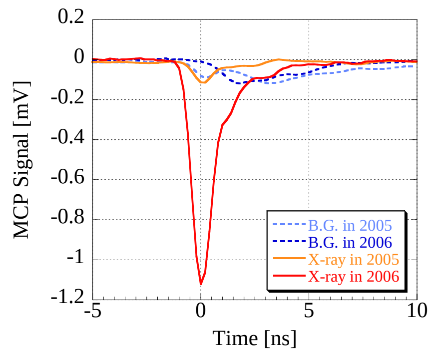

Figure 7: X-ray signal detected by MCP.

Table 2: Generated soft X-rays.

	Before	After
S/N ratio	1.4	123
Maximum X-ray energy [eV]	370	370-377 tunable
Detected photons	30	312
Generated photons	6.87×10^3	3.28×10^4

Characteristics of Electron-Laser Interaction

- Electron beam size measurement

  By scanning the laser position at the collision point and measuring the X-ray signal, the electron beam size was measured precisely. After deconvolution, horizontal and vertical beam sizes were obtained as 250 μm and 56 μm respectively. The resulting X-ray signals shown below also reveal detailed profile of the electron beam at the collision point.

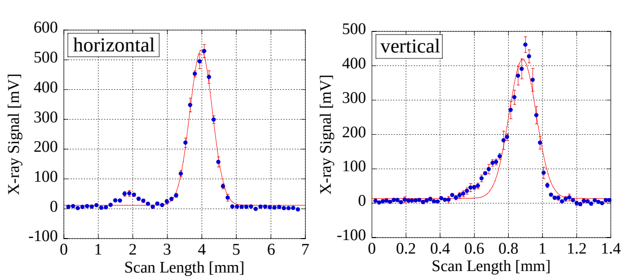

Figure 8: Laser position scan horizontal and vertical.

- Collision angle dependence

  By moving the position tunable mirror, the dependence of photon number on collision angle was observed. This result is consistent with the theory of laser Compton scattering.

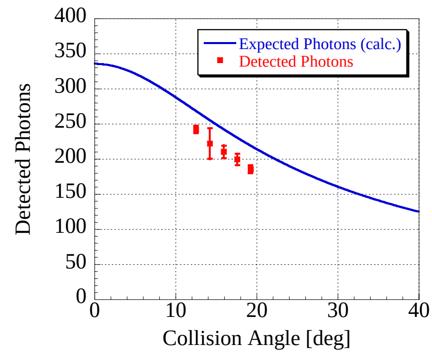

Figure 9: Collision angle dependence.

Stability Test

Stable X-ray generation is important for future practical use. Figure 10 shows the result of stability test. We succeeded in generating soft X-rays for more than 10 hours although the generated photons gradually decreased. We need to stabilize both the timing system and the laser system including the flash lamp amplifier.

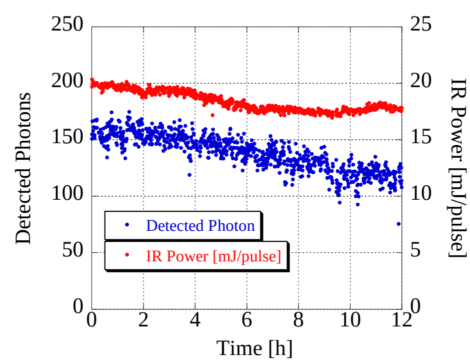

Figure 10: Soft X-ray generation stability test.

SUMMARY AND FUTURE PLANS

At Waseda University, we have succeeded in generating soft X-rays in the water window region with photo-cathode RF-gun and picosecond laser system. With remodeled generation system, good S/N ratio picosecond pulse soft X-ray was obtained. The total generated photons was 3.28×10^4. The multi-bunch electron beam system will be available after installing Cs_2Te cathode in 2007. Now we are ready to measure two dimensional distribution of the X-rays with charge-coupled device and a photo resist [5].

REFERENCES

[1] S. Kashiwagi et al., J. Appl. Phys., 98, 123302 (2005)

[2] B. L. Henke et al., Atomic Data and Nuclear Data Table 27 (1982)

[3] R. Moriyama et al., Proc. of EPAC'06, MOPCH056 (2006)

[4] R. Kuroda et al., Proc. of EPAC'04, p2684 (2004)

[5] T. Saito et al., Proc. of PAC'05, p1260 (2005)

1-4244-0917-9/07/$25.00