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DEVELOPMENT OF YB-BASED LASER SYSTEM FOR CRAB CROSSING LASER-COMPTON SCATTERING*

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Abstract

We are going to demonstrate the principle of crab crossing in laser-Compton scattering which creates head-on collision in a pseudo manner to enhance the intensity of laser-Compton X-ray. When the electron beam is tilted by half of the collision angle, the scattered X-rays becomes the largest. Calculation shows that more than threefold luminosity will be achieved in our system and could be larger luminosity depending on the beam parameters. The intensity of scattered light can be efficiently enhanced by using a collision laser with high intensity, high quality and ultra-short pulse duration. Thus, we have introduced a regenerative amplifier using ceramics thin-disk as a collision laser and developed a dedicated laser system. In this conference, we will report on our laser system and results of crab crossing laser-Compton scattering.

INTRODUCTION

Laser-Compton scattering (LCS) is a phenomenon in which the energy of an electron is transferred to a laser photon and a high energy photon beam can be generated. The experiment using the 6GeV electron storage ring and ruby laser in 1965 is the beginning of the LCS experiment [1], and since then, the development of the LCS technology is progressing with that of the electron accelerator and the laser technology.

In the present circumstances, an X-ray tube is used for X-ray imaging and non-destructive inspection, but the wide energy width causes a reduction in resolution and contrast of X-ray images. There are large synchrotron radiation facilities (ex: SPring-8) as an X-ray source with high brightness and high stability, but the facility is huge and not suitable for industrial applications. On the other hand, laser-Compton X-ray is quasi-monochromatic, high brightness, excellent in directivity and short pulse characteristics. In LCS X-ray source, since the energy of the electron beam is lower by about two orders, the accelerator facility can be miniaturized. LCS is expected for industrial application as a compact X-ray source, but for that purpose it is necessary to enhance intensity of X-ray. In this paper, we report on laser system development for increasing the scattered X-ray and collision experiment.

LCS AND CRAB CROSSING

Laser-Compton Scattering

Figure 1 shows the collisional scattering (LCS) of the electron beam (Lorentz factor γ) and the laser (energy of laser photon$_0$).

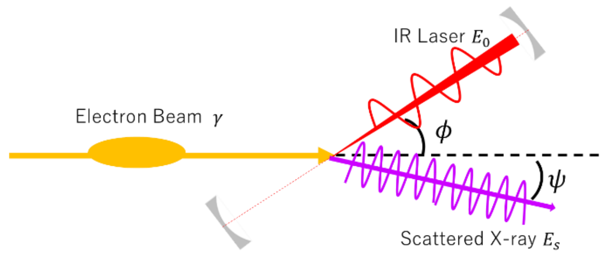

Figure 1: Schematic of LCS.

The maximum X-ray energy (E_s^{max}) would be obtained along the electron beam axis $\psi = 0$ and written as

$$E_s^{max} \simeq 2\gamma^2 E_0 (1 + \beta \cos\phi) \quad (1)$$

Here, β is v/c, where c and v the velocities of light and electrons, respectively. The energy of the scattered light is variable by adjusting the beam energy and the collision angle of the laser. Further, the polarization of the scattered X-ray follows the polarization characteristics of the collision laser and exhibits high polarization. In the case of collisions between pulses, the scattered X-ray also becomes pulses and exhibits short pulse characteristics. The number of scattered photons is given by the product of cross section and luminosity, as follows.

$$N = \sigma \times L \quad (2)$$

Since the total cross section is unchangeable once the laser wavelength and beam energy is decided, it is necessary to increase the luminosity as much as possible to obtain the high brightness X-ray. Luminosity can be expressed as seen in Eq. (3). N_e is the number of electrons in a bunch and N_l is the number of photons in a laser pulse. Assuming that the electron beam and the laser are Gaussian, $\sigma_H, \sigma_V, \sigma_L$ represents the sizes of the horizontal, vertical, and longitudinal respectively. The subscripts e is for the electron beam and l is for the laser. Table 1 shows the expected experimental parameters assumed for the system.

Table 1: Parameters of Electron Beam and Laser Pulse

	Electron Beam	Laser Pulse
Energy	4.2 MeV	1.2 eV(1030nm)
Intensity	40 pC	10 mJ
Transverse Size	100 µm	50 µm
Duration	3 ps(rms)	1 ps(FWHM)

The relationships between the collision angle and the luminosity are shown in Figure 2.

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$$L = \frac{N_e N_l (1+\beta \cos\phi)}{2\pi\sqrt{\sigma_{Ve}^2+\sigma_{Vl}^2}\sqrt{\sigma_{He}^2(\beta+\cos\phi)^2+\sigma_{Hl}^2(1+\beta\cos\phi)^2+\sin^2\phi(\sigma_{Le}^2+\beta^2\sigma_{Ll}^2)}} \quad (3)$$

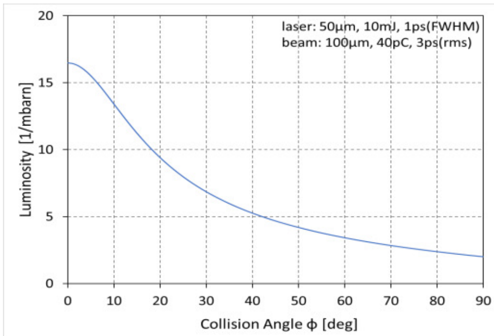

Figure 2: Luminosity dependence on collision angle.

We can see that the luminosity is maximized when collision angle is zero, i.e. head-on collision and monotonically decrease as collision angle increase. However, state-of-the-art LCS X-ray sources utilizes an optical enhancement cavity and the laser pulse would be repeatedly collided with the electron beam to increase the collision numbers [2]. In such cases, the interference between the optical cavity mirror and the electron beam must be avoided. Therefore, typical LCS X-ray sources have a certain colliding angle which causes a reduction in luminosity [3]. In this study, we introduce crab crossing to LCS to solve this problem.

Crab Crossing LCS

Crab crossing is a method of realizing a pseudo head-on collision and preventing a decrease in luminosity, originally developed in an electron-positron collider. In the system, both electron bunch and positron bunch were tilted. In this study, only the electron beam is tilted using a rf-deflector. Figure 3 shows the schematic illustration of crab crossing LCS. In LCS, when the electron beam is tilted by the half of the laser collision angle ($\theta = \phi/2$), the maximum luminosity can be obtained [4].

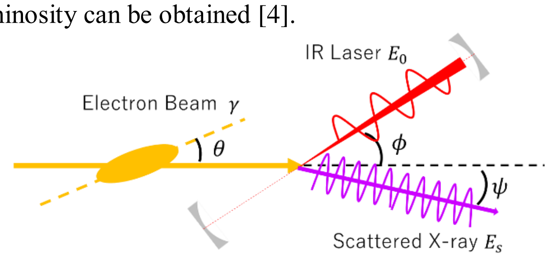

Figure 3: Schematic of crab crossing LCS.

The crab ratio is defined as the luminosity ratio between crab crossing ($\theta = \phi/2$) and normal collision. Figure 4 shows the relationship between the collision angle and the crab ratio in our system.

We are planning to conduct the proof of principle experiment at 45 deg and expected crab ratio is 3.01. By comparing the blue and purple lines, we can say that the luminosity is compensated by crab crossing. Here, we have to consider what the required parameter for the collision laser is. The laser pulse duration is to be significant effect to the crab ratio. The relationship between the pulse duration of the collision laser and the crab ratio is shown in Fig. 5

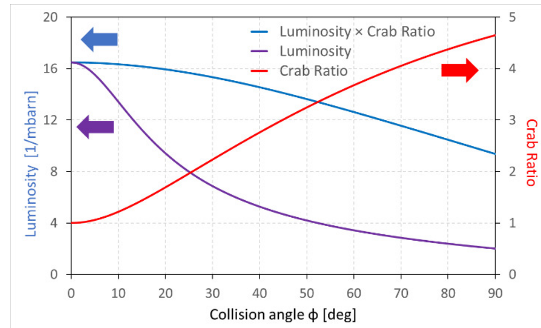

Figure 4: Crab ratio as a function of collision angle.

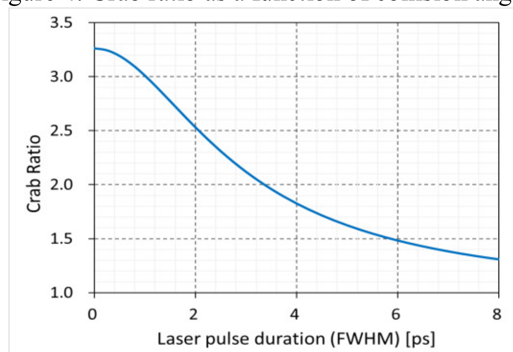

Figure 5: Laser pulse duration and crab ratio.

The shorter the pulse duration of the collision laser, the more it can benefit from crab crossing. Therefore, we have developed a laser system with high intensity and ultrashort pulse using Yb fiber oscillator and Yb:YAG thin-disk regenerative amplifier for crab crossing LCS.

COLLISION LASER SYSTEM

We have developed a dedicated laser system for crab crossing LCS. In this laser system, the pulse energy of 10 mJ, and pulse duration of 1 ps (FWHM) is targeted using the Chirped Pulse Amplification (CPA) method, which is shown in Fig. 6.

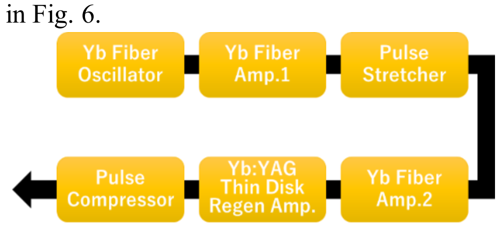

Figure 6: Schematic of collision laser system.

An ANDi laser with Yb fiber is used as an oscillator to generate femtosecond laser pulse. After a preamplifier by Yb fiber, the pulse duration is stretched to over 100 picoseconds using chirped fiber Bragg grating (CFBG). The output from CFBG is amplified again by Yb fiber and amplified by an Yb:YAG thin-disk regenerative amplifier as the main amplification. Thin-disk is a ceramic disk-like gain medium and have better heat dissipation than rod type. The thickness of thin-disk is 100 μm and can be cooled uniformly with a heat sink behind. Thus, the thermal lens effect can be suppressed, and high quality, high efficiency

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laser can be generated. The schematic of regenerative amplifier is shown in Fig. 7.

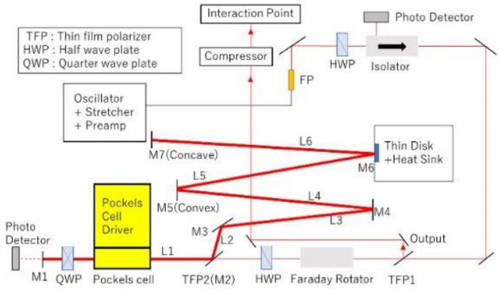

Figure 7: Schematic of thin-disk regenerative amplifier.

The pulsed pump LD with high power is used to pump the disk of Dausinger + Giesen GmbH. The module is manufactured by Dausinger. We confirmed the regenerative amplification of the pulse by the build-up waveform with a photodiode and an oscilloscope. Figure 8 shows the build-up waveform. A pulse energy of 15 mJ is obtained at a repetition frequency of 100 Hz and 96 round trips.

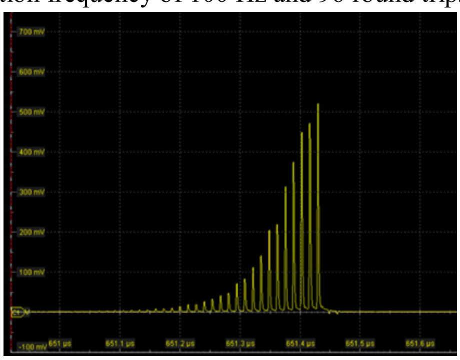

Figure 8: Pulse build-up regenerative amplifier.

Then, the regenerative amplified laser is pulse-compressed with diffraction grating pairs and is then collided with the electron beam. Table 2 shows the parameters of the electron beam and the collision laser in the collision experiment. Note that the output energy is reduced because the Pockels Cell (PC) is damaged.

Table 2: Parameters of Electron Beam and Laser Pulse in the Collision Experiment

	Electron Beam	Laser Pulse
Energy	4.7 MeV	1.2 eV(1030nm)
Intensity	40 pC	4 mJ
Transverse Size	280 μm	26.8 μm
Duration	3 ps(rms)	1.77 ps(FWHM)

LCS EXPERIMENT

Experimental Setup

We performed LCS with the developed laser system. The beamline in the collision experiment is shown in Fig. 9. Electron beam with energy of 4.7 MeV is generated by the 1.6 cell photocathode rf-gun at a resonance frequency of 2856 MHz. The electron beam and laser are interacted at an angle of 45 deg and the generated X-ray is measured by MCP.

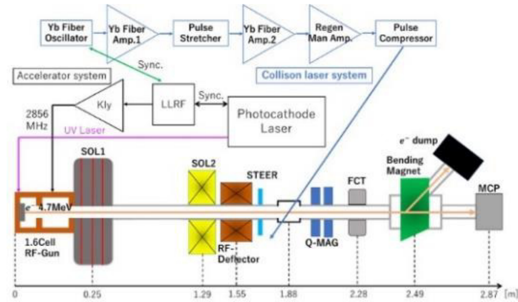

Figure 9: Experiment setup in LCS.

LCS Result and Discussion

The resulting X-ray signal is 350 mV. The change in X-ray signal during timing scan is shown in Fig. 10. Note that the X-ray signal is normalized by FCT.

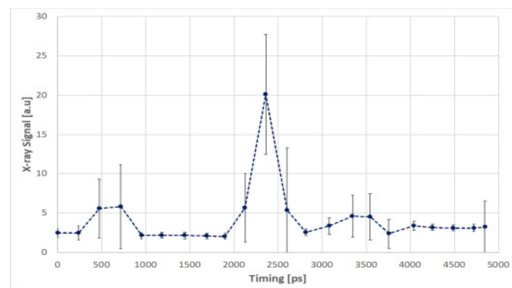

Figure 10: X-ray signal as a function of timing.

Due to instability of the laser intensity, the X-ray signal fluctuated greatly. It will be necessary in the future to make the laser intensity highly stable and to improve the timing synchronization accuracy.

Crab Crossing LCS Result and Discussion

we have performed crab crossing LCS. The electron beam is tilted by 22.5 deg. Although we succeeded in observing the X-ray signal,which was 270 mV and couldn't enhance the X-ray. We couldn't prove the principle of crab crossing LCS.

CONCLUSION

We have developed a high-intensity, high-quality, ultra-short pulse laser system to demonstrate the principle of crab crossing LCS. Due to PC damage, the target pulse energy is not obtained. We succeeded in observing 300-400mV X-rays in LCS, but there was no difference between crab crossing and normal crossing. In near future, we will construct a ring cavity regenerative amplifier and complete the laser with the targeted parameters. After that, we plan to demonstrate the principle of crab crossing LCS.

REFERENCES

[1] C. Bemporad *et al.*, Phys*ical* Re*view* 138, B1546-B1549 (1965).

[2] K. Sakaue *et al.*, in *Proc.* IPAC'15, paper TUPJE011, pp. 1635-1637 (2015).

[3] T. Akagi *et al.*, Phys*ical Review* Accel*erators and* Beam*s*, vol. 19, p. 114701 (2016).

[4] A. Variola *et al.*, Phys*.* Re*v.* ST Accel*.* Beam*s*, vol. 14, p. 031001 (2011).