DEVELOPMENT OF HIGH BRIGHTNESS SOFT X-RAY SOURCE BASED ON INVERSE COMPTON SCATTERING*

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INTRODUCTION

At Waseda University, a table top electron source based on laser photo-cathode RF-gun has been developing for beam physics and many applications. We can choose the parameters of electron beam easily by changing laser power and RF phase as usage. These characteristics enable us to study beam physics by beam analysis. Also, we generate a soft x-ray source based on inverse Compton scattering and experiment pulse radiolysis [3]. Especially, the soft x-ray is expected to realize a bio microscope. We have already generated soft x-ray. [2] As the next step, we need a higher intense x-ray and system optimization.

Inverse Compton scattering

Inverse Compton scattering is the inverse process in energy transportation of Compton scattering, that is the energy of electron beam transports to the low energy laser photon. It is nothing but Compton scattering in electron rest frame.In the case of inverse Compton scattering, the energy of scattered photon is determined by energy of electron, laser wavelength, collision angle and scattered angle.

Fig. 1 shows the energy of X-ray which energy of electron is about 4.6 MeV, and laser wavelength is 1047 nm. In case of choosing the 20 deg as collision angle, maximum energy of X-ray is 370 eV. And by sorting minute scattering angle, we can get quasi-mono-energetic x-ray which energy width is less than 0.1 %.

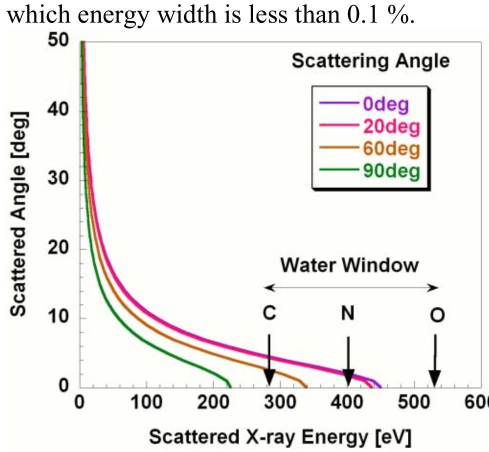

Figure1. Angular distribution of generated X-ray at different scattered angle.(The electron beam energy is 4.6MeV.)

*Work supported by Grant-in-Aid for Scientific Research (B)(2) 16340079 from MESSC, Japan

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Soft x-ray in 'water window region'

The energy of soft x-ray which we can generate is within the 'water window region' [4]. The x-ray in this region is absorbed by constituent elements of the living body such as carbon, oxygen, and nitrogen, but not by water. For this reason, we can take x-ray images using soft x-ray in 'water window region' without any interruption of water. The images will show us a contrast of absorption rate of carbon and nitrogen, i.e. the density distribution of constituent elements. Moreover, we will be able to observe inside the living cells because there's no need to dehydrate or slice cell samples.

SOFT X-RAY GENERATION

Experimental Setup of X-ray generation

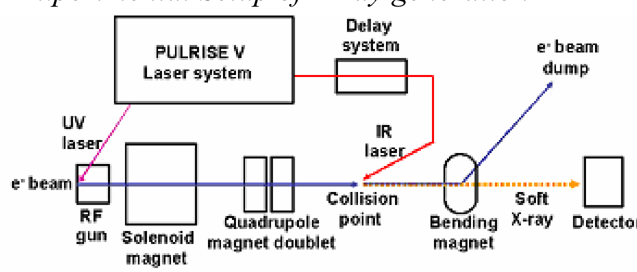

Figure2. X-ray generation system.

The system of soft x-ray production is shown in Fig. 2.Fundmental wave (Nd:YLF, 1047nm) is passed through a flash lamp base amplifier, and used for the collision laser. On the other hand 4th harmonics (262nm) is injected to the photo-cathode whose profile is optimized in order to generate high quality electron beam. The soft X-ray is generated by the collision of IR laser with electron beam at an angle of 20 degrees. Both IR laser and UV laser are originally from the same laser system, thus IR laser and electron beam synchronize precisely. Table 1 shows the parameters of electron beam and IR laser at the collision point.

Moreover, MCP (Micro Channel Plate) is used for the detection of the soft X-ray, and the soft X-ray CCD is for the profile measurement.

Table 1 parameters at the collision point.

IR laser parameters		Electron beam parameters	
Wavelength	1047 nm	Beam energy	4.6 MeV
Pulse energy	10 mJ/pulse	Bunch charge	600 pC
Beam size σx	80 μm	Beam size σx	280 μm
Beam size σy	80 μm	Beam size σy	250 μm
Pulse width	10 ps (FWHM)	Bunch length	10 ps (FWHM)
Repetition rate	5 Hz	Repetition rate	5 Hz

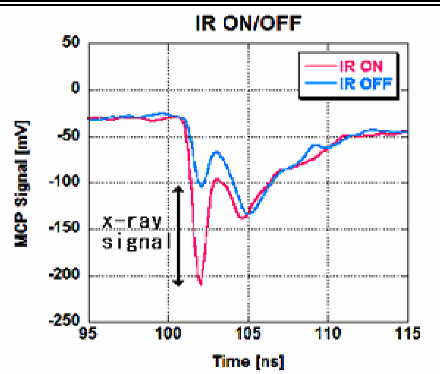

Figure 3 X-ray signal (MCP)

The signal of the soft X-ray detected by MCP is shown in Fig. 3. The photon number of soft X-ray calculated by this signal is 1.9×10^2, [5] and the total photon number is 1.6×10^4[6].

We have succeeded in generating of the soft X-ray as described in the previous paragraph. However, according to the profile measurement of soft x-ray by CCD, it is necessary to increase the photon number by a factor of 10^2. In the case of MCP detection, one of the big problems is the unignorable background. It is caused by bremsstrahlung radiation of electron beam halo, and it makes difficult to detect soft x-rays.

By the result of soft x-ray CCD measurement, we found that it is difficult to detect X-ray profile in this setting because IR laser background was detected more than the count of soft x-ray we had expected. Therefore, the IR laser background must be reduced and stabilized.

GENERATE HIGH BRIGHTNESS SOFT X-RAY AND REDUCE BACKGROUND

Remodel of collision chamber

We designed and made a new chamber to generate high brightness soft X-ray and reduce the background. Old and new chambers are described below. (Fig. 4)

Improvement 1

: Integration of collision chamber and isolation chamber of electron beam.

It is expected to reduce the background because the bremsstrahlung x-ray decreases. This helps electron beam to be focused efficiently. Then, the beam size at the collision point is expected to be smaller, and total generated photon number will be increase. Moreover, the distance between the collision point and the measurement point became shorter. This contraption increases photon number at the detector.

Improvement 2

: Removal of the guiding tube of IR laser in the chamber.

It is the hollow chamber, and removed the guide tube of IR laser Reduce the CCD background caused by diffuse reflection of IR laser in the chamber.

Improvement 3

: Setting a mirror inside the chamber which lead IR laser to collision point.

This system makes collision angel more sharpen than before. (15 deg) and it is expected to grow the luminosity. Furthermore, we can choose the energy of soft x-ray by changing the position and the angle of the mirror.

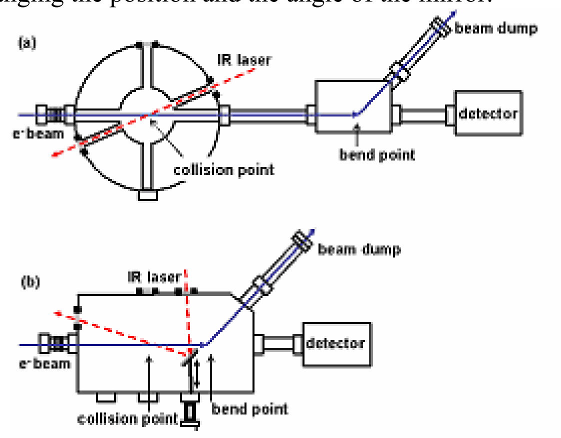

Figure 4 Chamber set up.
(a) Previous chamber. (b) Remodelled chamber.

Remodel of bremsstrahlung back ground

Fig 5 shows the background measured by MCP with remodelled chamber. The soft x-ray signal will be appeared on peak (1). Therefore, we can say that we succeeded in reducing the background about 6 times less than the original. Peak (2) is the signal made at end dumping, after electron beam is isolated from x-ray. For this reason, peak (2) can be ignored in case of using MCP. Additionally, the beam size at the collision point became smaller because we can focus electron beam without worrying about the background. We succeeded in increasing the density of electron beam.

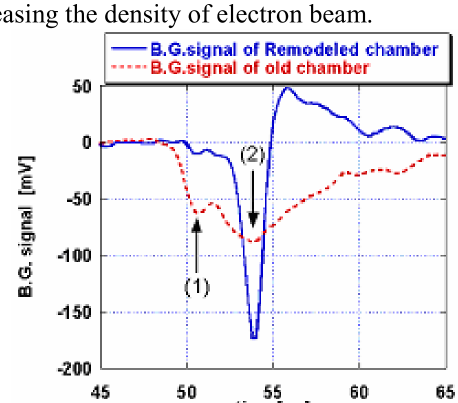

Figure 5 Background signal (MCP).
RF phase 40 deg, electron charge 190 pC.

Fig 5 shows the background measured by MCP with remodelled chamber. The soft x-ray signal will be appeared on peak (1). Therefore, we can say that we succeeded in reducing the background about 6 times less than the original. Peak (2) is the signal made at end dumping, after electron beam is isolated from x-ray. For this reason, peak (2) can be ignored in case of using MCP. Additionally, the beam size at the collision point became smaller because we can focus electron beam without worrying about the background. We succeeded in increasing the density of electron beam.

Reduction of IR laser back ground

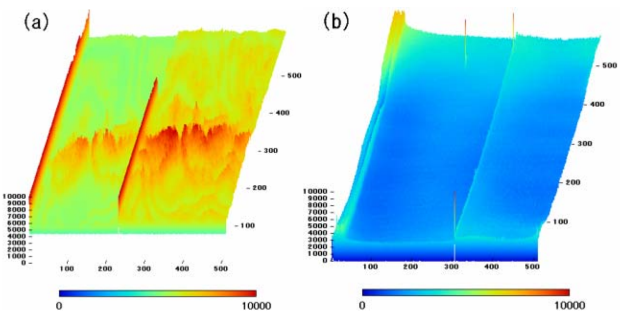

Figure 6 IR laser back ground (CCD).
(a) Previous chamber. (b) Remodelled chamber.

Fig. 6 shows IR laser background measured by soft x-ray CCD with the new chamber. The exposure time is 10s (5 Hz). All the backgrounds except IR laser background are deducted. From fig. 6 we can see that CCD count number and intensity distribution are both reduced. Fluctuation by shot which is an important factor to measure soft x-ray reduced too, less than the count of the x-ray.

MULTI-PASS AMPLIFIER SYSTEM

To achieve further high brightness, we designed multi-pass amplifier (Fig. 7). In this system, IR laser pass through The flash lamp (Nd;YLF) any number of times by using pockels cell. It will be for fourfold increase of IR laser power (present power is 10mJ/pulse).

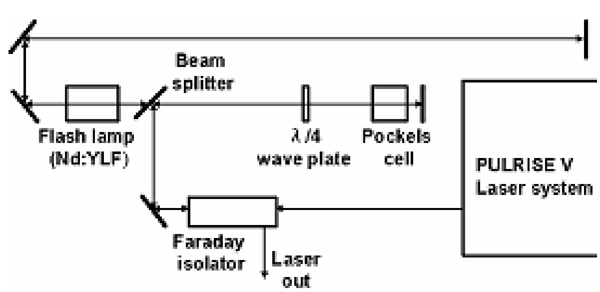

Figure 7 Multi- pass amplifier system

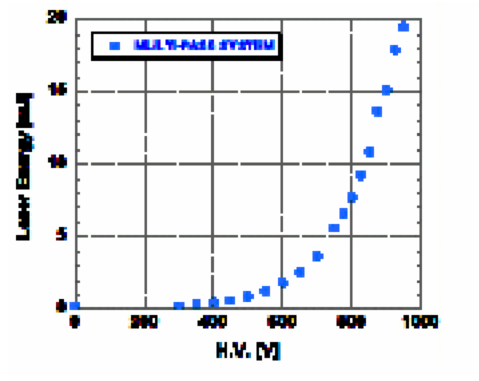

Figure 8 Laser energy amplified by flash lamp

To realize this project, we made multi pass AMP optics system without a pockels cell as an exploratory experiment. This system reduced the attenuation rate of IR laser power, and succeeded in 20 mJ/pulse amplification. We will install a pockels cell in this system.

CONCLUSIONS

We have been generating the soft x-ray using inverse Compton scattering. However, it is necessary to increase the photon number by a factor of 10^2 in order to measure the profile of soft X-ray by CCD. Therefore, we designed and made a new chamber to generate high brightness soft X-ray and reduce background. And then we succeeded in reducing the bremsstrahlung background for t MCP about 6 times less than the original. Moreover, we succeeded in reducing the IR background for CCD.

About IR laser amplifier, the laser power achieved to 40 mJ/ pulse by using multi pass amplifier system.

Now we aim to generate more high brightness soft X-ray with the new system we introduced in this paper.

ACKNOWLEDGEMENTS

Authors would like to express great thanks to all the member of KEK-ATF group for their cooperation on the operation, and to Dr. X. J. Wang at BNL for many helpful advices about construction of the RF-gun system.

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