DEVELOPMENT OF LASER-COMPTON X-RAY SOURCE USING OPTICAL STORAGE CAVITY*

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Abstract

We have been developing a pulsed-laser storage technique in a super-cavity for a compact x-ray sources. The pulsed-laser super-cavity enables to make high peak power and small waist laser at the collision point with the electron beam. We already obtained a pulse-train x-rays through the laser-Compton scattering between a multi-bunch electron beam and an optical super-cavity. And also, we performed a X-ray imaging via laser-Compton X-ray. On these successful results, we decided to upgrade our system for increasing X-ray flux by 3-order of magnitudes for practical use. For an optical cavity, we designed 4-mirrors bow-tie cavity in order to increase the power. On the other hand, electron accelerator was also upgraded to increase the bunch number in the train. We use 3.6cells rf-gun and 12cell standing wave booster linac. As a result, 2-order increase of X-ray flux was achieved. Design of upgraded our laser-Compton X-ray source, the results of X-ray experiments and future prospective will be presented at the conference.

INTRODUCTION

An X-ray generation method based on laser-electron Compton scatterings (LCS) is one feasible technique for a high brightness X-ray source. It utilizes a process in which energetic electrons are scattered elastically by target laser photons, with an energy transfer from the electrons to the photons. The advantage of LCS is; in order to produce the same energy, typically only one hundredth $\sim$ thousandth of the electron energy is required thanks to its short undulation period[1] compared with synchrotron light sources. For instance, a 30 MeV electron beam with the laser wavelength of $\sim 1\ \mu$m can produce 15 keV X-rays. The advantage has propelled worldwide laboratories to develop compact LCS X-ray sources with a brightness equivalent to the second generation light sources.

We have been developing a compact X-ray source based on a pulsed-laser storage cavity operated with a burst amplifier[2] and a normal conducting linac. The pulse train LCS X-rays were already achieved using a multi-bunch electron beam and a pulsed laser optical cavity[3]. Also, we have already tried to take X-ray images by LCS X-rays[4]. Recently, we have upgraded our accelerator system and optical storage cavity in order to increase the photon flux. Moreover, we have already performed a LCS X-ray generation experiments with an upgraded system.

The paper is organized as follows: in the next section we describe our experimental apparatus; this is followed by a section showing the recent results of LCS experiments and discussion. In the last section, we summarize our results.

EXPERIMENTAL SETUP

Accelerator and Laser

The LCS X-ray generation experiment was performed at a LUCX accelerator facility located inside the housing of the KEK Accelerator Test Facility (ATF). Firstly, we show the upgraded accelerator setup in Fig.1 The LUCX accelerator is composed by 3.6cell photo-cathode rf electron gun and 12cell booster linac. Both accelerating cavities are standing wave tube with almost same filling time, thus we can almost completely compensate the beam loading energy difference in the multi-bunch beam by Δt method[5]. About 8MeV electron is produced by 3.6cell rf-gun and accelerated up to 23MeV by booster linac. Then, we have a LCS collision point at the center of 4-mirrors planar bow-tie type optical storage cavity. Fig.2 shows the drawing around the collision point. The laser cavity system

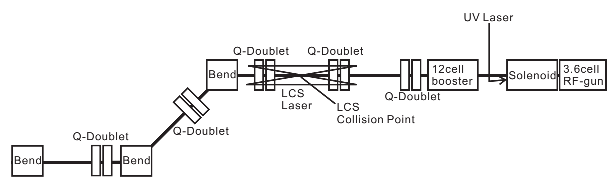

Figure 1: Schematic of LCS experimental setup at LUCX.

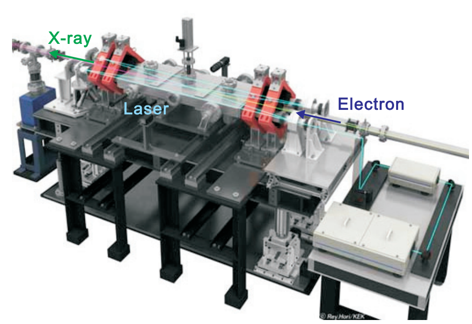

Figure 2: Drawing of the LCS collision point.

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is mounted in the electron forcusing magnet in order to achieve both long passage optical cavity and tight forcusing optics for electron beam. After the collision point, an electron beam is separated from the LCS X-ray by a dipole magnet and transported to the dump.

The parameters of electron and laser at the collision point in Tab.1. The electron beam and laser have same pulse spacing, thus the all bunches interact with laser pulses stored in the optical cavity. In the optical cavity, 9-pulses are stored due to the revolution frequency of optical cavity. This long passage cavity makes the laser spot larger on the cavity mirror, then we can enahance the stored power as much as possible. Moreover, the collision angle is shallower than before, and it increases the luminosity of LCS collision. However, both electron and laser size at collision point is even larger than before, because the rf processing is not completed for electron beam and the optical alignment is not enough for laser. They will be improved in near future.

Table 1: Electron beam and laser pulse parameters.

Quantity	Value
Electron beam	
Energy	23 MeV
Charge	0.9 nC/bunch
Number of bunches	150/train
Bunch spacing	2.8 ns
Beam size (rms)	85/95 μm (H/V)
Bunch length	15 ps (FWHM)
Repetition rate	1.56-12.5 Hz
Laser pulse	
Wavelength	1064 nm
Pulse energy	0.3 mJ
Cavity finesse	335
Pulse spacing	2.8 ns
Spot size (rms)	89/85 μm (H/V)
Pulse duration	7 ps (FWHM)
Colliding angle	7.5 deg

X-ray Detector

Around 9keV X-ray will be produced via LCS of 1064nm wavelength laser and 23MeV electrons collide at an angle of 7.5deg. As an X-ray detector, we used Micro-Channel Plate (MCP) and Sillicon-On-Insulator (SOI) pixel sensor[6]. MCP is the well-established detector for LCS X-ray detection[3]. In this experiment, we firstly used SOI sensor, which has active sensor and readout circuit on same wafer by using SOI technique. Such a configuration produces high resolution pixel sensor and large S/N detection. The imaging detector setup is shown in Fig.3. LCS X-ray is extracted to the air through the Be-window and collimated by the Pb collimator. The SOI sensor and MCP are located after the collimator, and the SOI sensor is mounted on the linear motor stage, thus we can switch SOI sensor and MCP.

Figure 3: X-ray detector setup.

RESULTS AND DISCUSSIONS

LCS X-ray generation experiment was performed at LUCX upgraded system as described above. After the evaluation of LCS X-ray detection and position adjustment by MCP detector, we tried to detect by SOI sensor. Fig.4 shows the result of LCS X-ray detection by SOI. ADC counts of each pixel corresponds the x-axis and y-axis is the number of entries. It is clear that the LCS X-ray enhance the peak around 50counts. The calculated S/N was more than 10, nevertheless, MCP detection was S/N$\sim$1. This is because SOI sensor has very small pixel (17μm) and BG makes electron shower due to high energy, which detected along the several pixels, while LCS X-ray detected by only one pixel. Thorefore, we can obviously separate the BG and Signal events.

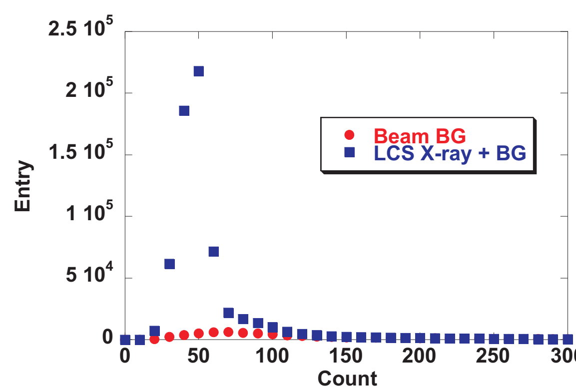

Figure 4: Plot of BG and LCS X-ray by SOI sensor.

The resulting X-ray flux and expected X-ray flux is shown in Tab.2. The expected flux was calculated by CAIN using electron-laser parameters in Tab.1. Measured flux

Table 2: Measured and Expected X-ray Flux.

Expected	
Energy	8-9keV(on SOI sensor)
Bandwidth	8% (FWHM)
Within SOI	7015 ph./train
Total Flux	8.2×10^6 ph./sec
Measured	
Within SOI	5460 ph./train
Total Flux	6.4×10^6 ph./sec

was almost consistent with the expected flux. The difference between them, we expected, due to the jitters of electron and lasers. Also, the flux exceeded more than 5×10^6 ph./sec.

The SOI sensor can also readout the X-ray image with high spatial resolution. We show a chillie pepper X-ray images by both MCP imager (Fig.5) and SOI sensor (Fig.6). It is obviously seen that the SOI sensor has much higher spatial resolution than MCP imager. Also, the number of pulses for each images were same, however the SOI image was clearer than that of MCP imager, because of the S/N. LCS X-ray detection by SOI sensor was successfully carried out and we found that it is quite useful for the LCS X-ray detection and imaging. However, on Fig.6, horizontal white lines can be observed like a noise due to the readout sector of SOI pixels. This should be improved in the future.

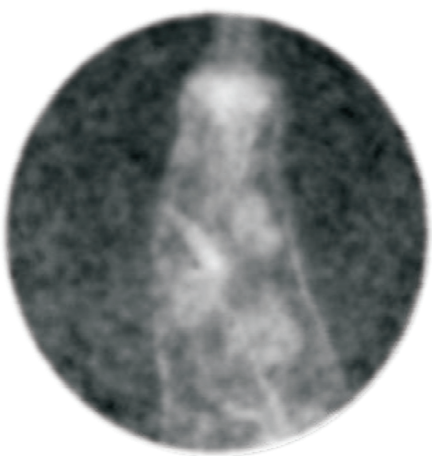

Figure 5: Chillie pepper X-ray image by MCP and phosphor screen.

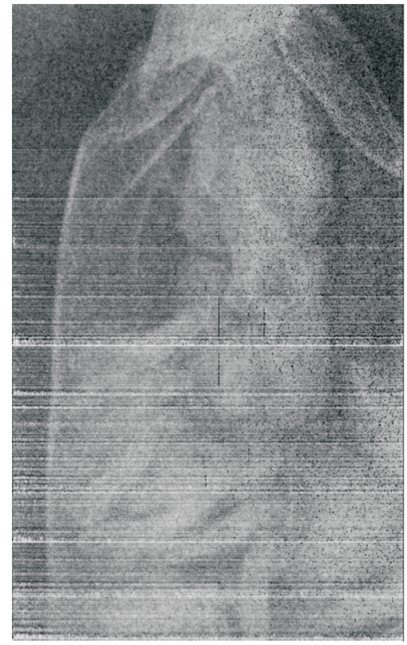

Figure 6: Chillie pepper X-ray image by SOI pixel sensor.

SUMMARY

In conclusion, we have upgraded our LUCX LCS X-ray system both accelerator and laser. The resulting X-ray flux was 6.4×10^6 ph./sec in total bandwidth. This value is almost 2-order larger than before upgrading. SOI pixel sensor was firstly used for LCS experiment. SOI sensor successfully provides larger S/N and high spatial resolution X-ray image.

In near future, we will continue the rf processing for newly installed 3.6cell and 12cell booster linac cavity in order to achieve 1000bunch train and a lower emittance beam. Also, the optical storage cavity have to be tuned for the design specification and increase finesse i.e. enhancement factor of the cavity. These minor improvement provides more than 1-order increase of flux, therefore the flux will exceed 10^8 ph./sec.

REFERENCES

[1] K. -J. Kim et al., Nucl. Instrum. Meth., A341, 351-354, (1994).

[2] K. Sakaue et al., Nucl. Instrum. Meth., A637 S107-S111 (2011).

[3] K. Sakaue et al., Rev. Sci. Instrum., 80(12) 123304 1-7 (2009).

[4] K. Sakaue et al., AIP Conf. Proc., 1466 272-277 (2012).

[5] S. Liu et al., Nucl. Instrum. Meth., A584, 1-8 (2008).

[6] Y. Arai et al., Nucl. Instrum. Meth., A636(2011)S31-S36.

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