DEVELOPMENT OF PULSED SOFT X-RAY SOURCE AT WASEDA UNIVERSITY

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Abstract

We have been developing pulsed soft X-ray source using inverse Compton scattering between an electron beam and a pulsed IR laser light at Waseda University. The electron beam is accelerated by a laser driven photo-cathode rf gun system up to 5 MeV. The IR laser light for the Compton scattering and UV laser light for irradiation of the photo-cathode in the rf gun are generated from an all solid state Nd:YLF laser system. We will generate soft X-rays with various energies by changing collision angles.

1. INTRODUCTION

The low emittance and short pulse electron beam generation system using the laser driven photo cathode rf gun have been developed at Waseda University. It will be applied for a compact soft X-ray source using Laser Synchrotron Source (LSS). LSS is based on inverse Compton scattering between the high quality electron beam and the stabilized laser light[1]. The high quality electron beam is generated using 1.6 cells s-band photo cathode rf gun system. It has many advantages such as time structure of electron beam can be controlled by characteristics of laser light, a bunching system is not necessary, and high accelerating field in the cavities of rf gun can be suppress emittance growth due to space charge effect.

The LSS has many good features such as tunability of the wavelength, the yield, the spectrum and the scattered angle of X-rays, respectively. Those characteristics of scattered X-rays can be controlled by varying the collision angle between the electron beam and the laser light. We are planning to apply the LSS for X-ray microscopy to get the images of hydrated biological specimens without blurring caused by radiation damage and thermal diffusion. In this year, we will carry out our first experiments on the soft X-ray generation by 20 degrees, 60 degrees and 90 degrees Compton scatterings at Waseda University. In this paper, we will report the results on numerical simulation and the experimental setup for the system.

2 RF GUN SYSTEM

Rf-gun system is composed of the BNL type 1.6 cell S-band rf cavities with Mg cathode, a set of solenoid magnets for emittance compensation, a stabilized laser and rf power source[2,3]. Using Mg cathode, which had developed at Brookhaven National Laboratory, we are able to get higher quantum efficiency than Cu cathode. Higher accelerating field is effective to reduce an emittance growth due to space charge effect for high current beam. However, we will suffer the increase of dark current due to field emission in the high gradient operation. Therefore, in order to reduce the dark current, a diamond turning method has been applied for a fine manufacturing of the rf-gun cavities.

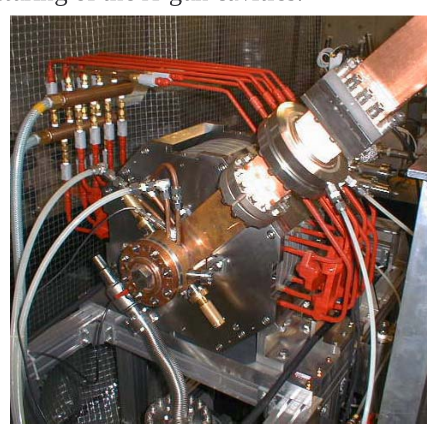

Fig.1 Rf gun system

The electron beam is emitted from the photo cathode using irradiation of UV laser light (262 nm, 4th harmonics of Nd:YLF fundamental light), therefore the characteristics of electron beam can be controlled by the laser injection timing, a beam profile of laser light in transverse and longitudinal direction.

Main parts of rf source for the rf-gun consists of 10 MW S-band klystron (Tomson: TV2019B6) and a small pulse modulator (Nissin Electric Co., Ltd.). The pulse modulator has good stability and flatness of the output pulse. The amplitude jitter of klystron voltage was about 0.38 % (p-p) for 20000 pulses and the pulse flatness was 0.25 % (within >1.5 μs pulse flat-top).

On the other hand, we have started the simulation work using MAGIC code and PARMELA for the BNL type s-band rf-gun to find good operation parameters, such as setting of solenoid magnet system, laser injection phase and so on. From these simulations, we found that transverse emittance growth due to the electric field in radial direction could not be neglected in the case of high gradient acceleration. More careful analysis taking account of slice emittance to clarify the relation between the transverse emittance growth and the strength of accelerating field is necessary.

3. LASER SYSTEM

All solid state picosecond Nd:YLF laser system (PULRISE-V), which was developed by SHI (Sumitomo Heavy Industries, ltd.), is used for the irradiation of cathode of rf-gun system and X-ray generation and pulse radiolysis experiment.

The laser system has an active timing and intensity stabilization systems against a temperature change and timing jitter from a reference rf signal. Fluctuation of air and vibrations of mirrors on the laser optical path affects the laser intensity and spatial profile on the cathode, so that the laser system is put inside the irradiation room for achieving short optical path length from the main body of the laser to the cathode of rf gun. Such the location, an electromagnetic noise and radiation may influence the laser system to increase timing and amplitude jitters. Therefore, the timing and amplitude fluctuation between a seed laser and the reference rf signal had been investigated using time domain demodulation technique. As the result of the measurement, the timing fluctuation between the seed laser and reference signal was less than 1 ps with timing stabilization system, therefore the electromagnetic noise and radiation had given no effect to timing stability. So that we can achieve the small timing jitter between the laser light and electron beam down to sub-picosecond time region. It is sufficiently small timing fluctuation for the X-ray generation and the pulse radiolysis experiment under the picosecond time resolution. On the other hand, the laser intensity was fluctuated through certain damage onto a pumping laser diode. By putting electromagnetic and radiation shielding around the laser body, it is possible to operate the laser system under the good intensity and pointing stabilities.

4. SOFT X-RAY GENERATION

Soft X-rays having different energy spectrum are very useful for biological observation, because wavelength dependence of absorption coefficients is different in each element in the biomolecules. We can observe only a certain element by taking the difference of two images, which are observed using two different wavelength of the soft X-ray. K-shell absorption edges of Oxygen, Carbon and Nitrogen, which mainly constitute of a living body, are 2.322 nm, 4.368nm and 3.099 nm, respectively. Those absorption edges are included in the range of “water window”. Since the absorption coefficient of water is much smaller than protein’s absorption coefficient in this range of “water window”, a dehydration of the specimens is not necessary.

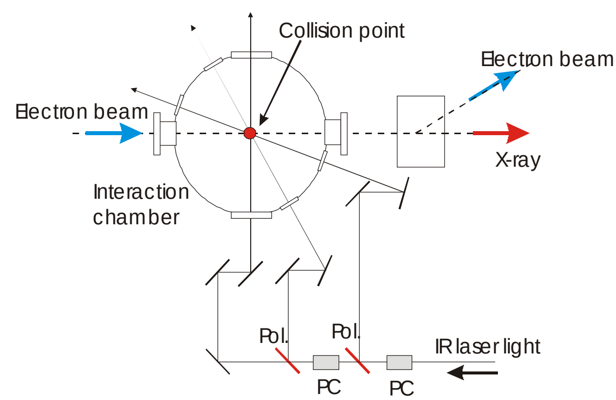

Fig. 2 Optical switching system for inverse Compton scattering

The interaction chamber for the laser Compton scattering experiment is designed to change the crossing angle between laser light and electron beam. Three crossing angles, for example 20, 60 and 90 degrees, can be selected to generate X-rays having different energy spectrum[4]. Laser optical path at each injection angle to the interaction chamber is selected using a combination pockels cells and polarizer as shown in Fig. 2.

The 4 mJ, 10 ps (FWHM) pulsed Nd:YLF (IR:1047nm) laser beam is introduced through the window and focused at the center of the chamber. After interaction, laser beam go through from the opposite window. A dipole magnet separates the electron beam and the scattered soft X-ray after the interaction point. The timing jitter between the Nd:YLF laser and electron bunches is negligible in comparison with the electron pulse width, since source of UV for the photo cathode illumination of the rf-gun and IR for the Compton scattering is the same laser light.

Electron beam

Beam energy	5.0 MeV
Bunch charge	3 nC
Bunch length (FWHM)	10 ps
Beam size at focal point (μx/μy)	100/100 μm

Nd:YLF laser

Wave length	1.047 μm
Energy/pulse	4 mJ
Pulse length (FWHM)	10 ps
Beam size at focal point (μx/μy)	30/30 μm

Table 1. Electron beam and Nd:YLF laser parameters

Crossing angle (°)	Maximum scattered photon energy [eV] ([nm])	Number of Photons/pulse (within 3 deg. of scattered angle)
0	453 (2.74)	3.8×10^5 (1.4×10^5)
20	440 (2.82)	1.2×10^5 (4.3×10^4)
60	340 (3.65)	3.7×10^4 (1.3×10^4)
90	227 (5.46)	2.1×10^4 (7.4×10^3)

Table 2. Total number of photon at different crossing angle

5. SUMMARY

In the near futurer, we will start the operation of rf-gun system and measure the characteristics of electron beam precisely. Experiment of soft X-ray generation will be performed using inverse Compton scattering between high quality electron beam and stabilized laser light at different crossing angle. To apply the LSS to X-ray microscopy, high intensity of soft X-ray is necessary and X-ray optical system. To get as high luminosity as possible at the LSS, good focusing and bunching of electron beam and upgrade of laser is required.

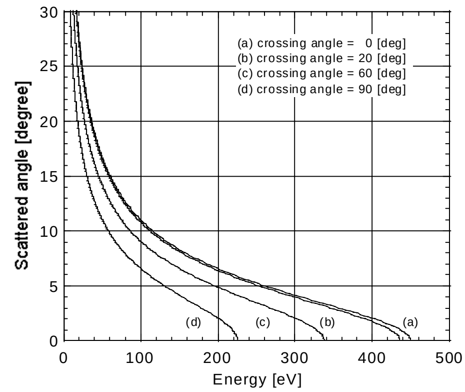

Fig. 3 Angular distribution of generated X-rays at different crossing angle

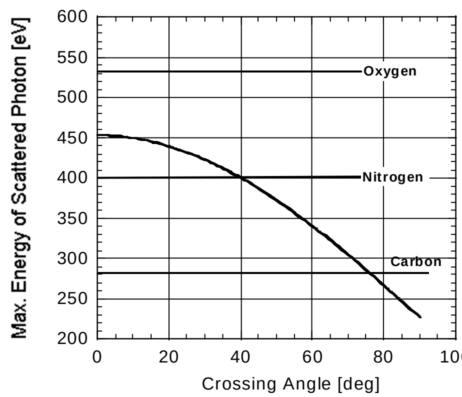

Fig. 4 Maximum scattered photon energy at differentcrossing angle

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