BEAM TEST OF THERMIONIC CATHODE X-BAND RF-GUN AND LINAC FOR MONOCHROMATIC HARD X-RAY SOURCE

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Abstract

Compton scattering hard X-ray source for 10-40 keV are under construction using the X-band (11.424 GHz) electron linear accelerator and Nd:YAG laser at Nuclear Professional School, University of Tokyo. Main advantage of this system is to produce tunable monochromatic hard (10-40 keV) X-rays with the intensities of 10^8-10^9 photons/s (at several stages) and the table-top size. The X-ray yield by the electron beam and Q-switch Nd:YAG laser of 2.5 J/10 ns is 10^7 photons/RF-pulse (10^8 photons/sec in 10 pps). X-band beam line for the demonstration is under commissioning. At the beam generation experiment by thermionic cathode 3.5 cell X-band RF-gun, 2.0 MeV electron beam with average current 0.2 μA is observed. We also design to adopt a technique of laser pulse circulation to increase the X-ray yield up to 10^8 photons/pulse (10^9 photons/s). The laser pulse circulation experiment is performed with low energy (20 mJ/pulse)and enhancement of X-ray yield will be estimated about 10 times.

INTRODUCTION

Hard X-rays of 10-40 keV are now very useful in medical science, biology and material science. For example, monochromatic X-ray imaging, CT. In addition, Dual energy X-ray CT[1, 2], Micro-angiography[4] and Subtraction imaging with contrast agent[3] and Dual energy X-ray are realized that require two monochromatic hard X-ray.

Intense hard X-rays are generated by a third generation light source. However, most SR sources are too large to be applied and used widely for public usage of the monochromatic hard X-ray. Therefore, we are developing a compact monochromatic hard X-ray (10-40 keV) source based on laser-electron collisions with the X-band (11.424 GHz) linac system[5, 6, 7]. One to ten percent narrow band X-rays are generated by collimating scattered photons that are related to the energy and scattering angle.

A multi-bunch electron beam generated by a thermionic-cathode RF gun is collimated and compressed temporally by an alpha-magnet and accelerated by X-band accelerating structures. The electron beam is bent by the achromatic bends and focused at the collision point(CP). About a 10 ns hard X-ray is generated via Compton scattering upon laser-electron collision. After the collision, the electron beam is bent and decelerated by an X-band decelerating structure. The decelerated electron beam with an energy lower than 1 MeV is injected to a beam dump. In addition, this system can generate dual energy monochromatic hard X-ray using two Nd:YAG laser by turn.

The laser system for collision is composed of a Q-switch Nd:YAG laser and a laser pulse circulating system to increase X-ray yield.

To demonstrate that the proposed X-ray source can be realized and will be useful in medicine, an X-band linac beam line for the proof-of-principle experiment shown in Fig. 2 is under construction. The X-ray yield by the electron beam and Q-switch Nd:YAG laser of 2.5 J/10 ns is 10^7 photons/RF-pulse (10^8 photons/sec in 10 pps). X-band beam line for the demonstration is under commissioning. We also design to adopt a technique of laser pulse circulation to increase the X-ray yield up to 10^8 photons/pulse (10^9 photons/s)[8].

In this paper, result of electron beam generation experiment by X-band thermionic cathode RF-gun and current status of the X-band linac beamline.

X-BAND BEAMLINE FOR PROOF-OF-PRINCIPLE EXPERIMENT

Compact hard X-ray source based on the X-band linac that we propose is shown in Fig. 1. Multi-bunch beam generated by thermionic-cathode RF-gun is accelerated by X-band accelerating structures. The beam is bent and focused at the collision point. About 10 ns hard X-ray is generated

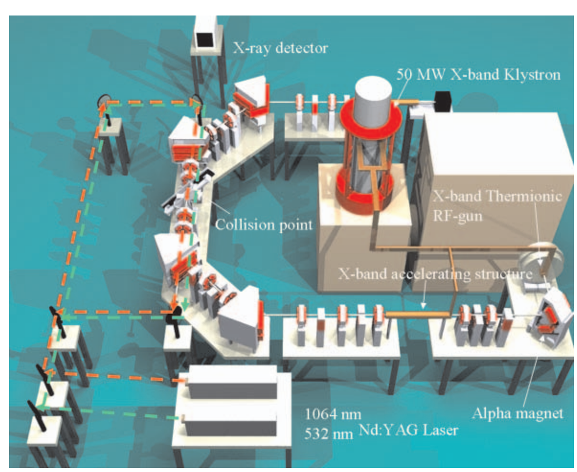

Figure 1: Schematic illustration of Compact Hard X-ray source based on thermionic-cathode X-band RF-gun, X-band accelerating structure and Q-switch Nd:YAG laser.

Table 1: Beam parameters at the collision point.

Beam energy	35 MeV
Charge/bunch	20 pC
bunches/RFpulse	10^4
Beam size(rms)(x,y)	100, 100 μm
Beam emittance(x,y)	10, 10 πmm·mrad

Table 2: Properties of the generated X-ray with electron beam energy 35 MeV, charge 20 pC/bunch.

laser wavelength (nm)	1064	532
pulse energy of laser (J/pulse)	2.5	1.4
Xray yield (photons/pulse)	9.9×10^6	4.4×10^6
Maximum X-ray energy(keV)	21.9	43.8

via Compton scattering on laser-electron collision.

X-band linac is applied to the compact hard X-ray source. RF-wavelength of the X-band is 1/4 of S-band (2.856 GHz). However, the maximum filed gradient as ~ 40 MV/m enable remarkable compactness.

An X-band accelerating structure with 0.7 m long is used for the X-ray source. The technologies for X-band accelerating structure developed for future linear colliders[9] at KEK and SLAC are fully adapted for this development. At first, the RDS type accelerating structure has been adopted, which is already under manufacturing.

We adopt PPM type X-band Klystron (E3768A) designed for linear colliders[9]. Klystron Modulator is under design to fit this X-ray source. RF power is above 50MW in 1 μs.

Beam parameters at the collision point (CP) are shown in Table 1.

To concentrate on R&D of the accelerator, we choose a commercial and reliable laser for laser-electron collision.

To realize such a compact system, we adopt two Q-switch Nd:YAG laser with the intensity 2.5 J/pulse(1.4J/pulse for second harmonics), the repetition rate 10 pps, the pulse length 10 ns(FWHM) and wavelength of 1064 nm(fundamental). single electron bunch is 20pC. but macron bunch (RF pulse) is 1μsec long and has about 10^4 bunches. In this situation, laser pulse circulation system(LPCS) will play the important role in this system for increasing the X-ray yield.

The X-ray yield per bunch is calculated with cross section of Compton scattering and Luminosity. Detail of the calculation is shown in another paper[5]. Property of the X-ray is summarized in Table 2

BEAM GENERATION BY THERMIONIC CATHODE X-BAND RF-GUN

Test of RF generation and RF aging of the X-band klystron is under way. Peak power of RF is estimated to 10 MW per RF output port of the klystron. Total output power is 20 MW and pulse length 600 ns, repetition rate 5 pps.

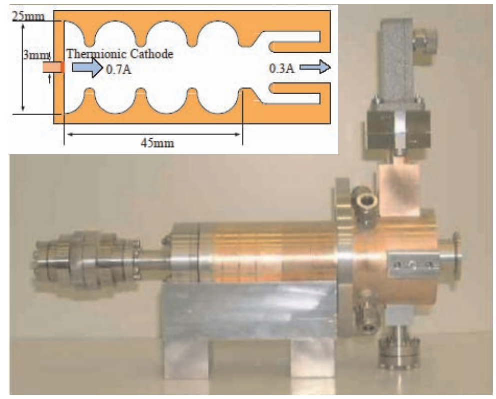

Figure 2: Photograph and schematic illustration(cut view) of the X-band RF-gun.

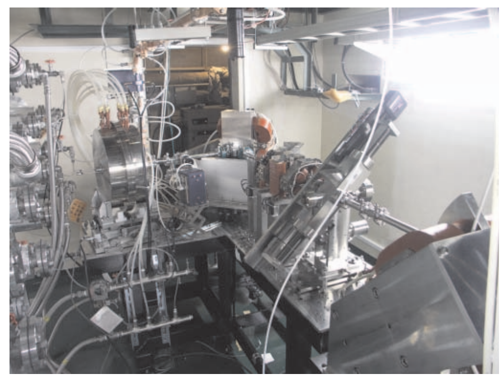

Figure 3: Photograph of the beamline for X-band RF-bun experiment.

After RF parameters ware reached to required by the experiment, we started RF-aging and beam generation experiment of the X-band thermionic cathode RF-gun.

Fig.2 shows the Drawing of the RF-gun.

Fig.3 is a photograph of the beam line for the RF-gun experiment. The beam line has the RF-gun, Two piece of beam current monitor(Current Transformer), an alpha magnet to compress beam bunch and collimate beam energy, and beam diagnostic section.

Next of the RF-gun experiment, Klystron aging is continued to reach the RF parameter up to 50 MW, 1 μs, 5 pps. Then, X-band accelerating structure is installed and acceleration test and X-ray generation will be performed at this autumn.

CURRENT STATUS OF THE X-BAND LINAC BEAMLINE

The construction of X-band beamline is almost complete. almost of component is placed on the beamline. Fig.6 and Fig.7 show the beamline including the X-band RF-gun, alpha-magnet, achromatic arc and collision point.

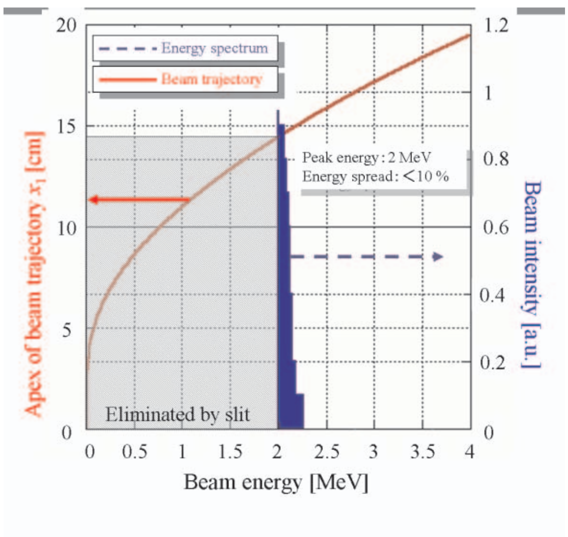

Figure 4: Energy spectrum of the electron beam measured by the alpha magnet (right-hand axis). The left-hand axis shows the apex of the beam trajectory in the alpha magnet.

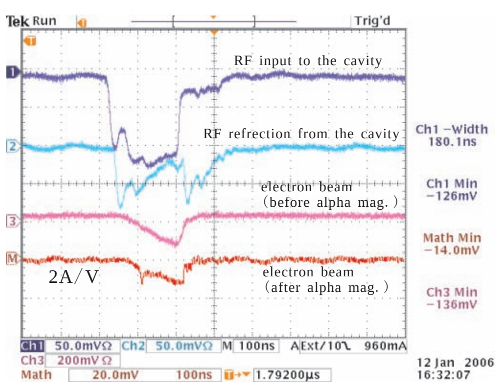

Figure 5: RF waveform propagating forward and reflected (upper two lines) from the gun cavity. The bottom two lines show the beam currents observed at the entrance and the exit of the alpha magnet, by a current transformer.

CONCLUSION

We are developing the compact X-ray source by laser-electron collision based on the X-band linac for medicine. To realize a remarkably compact system, we adopt the X-band system and commercial Q-switch laser. 2.0 MeV electron beam with average current 0.2 μA is observed in the beam generation experiment using the thermionic-cathode X-band RF-gun. Most of beamline components are placed on the beamline. Then, beam accleration and X-ray generation experiment will be performed in this year.

ACKNOWLEDGEMENTS

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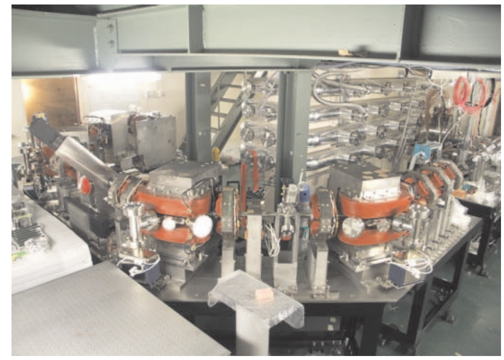

Figure 6: Photograph of the X-band linac beamline including the X-band RF-gun and alpha-magnet.

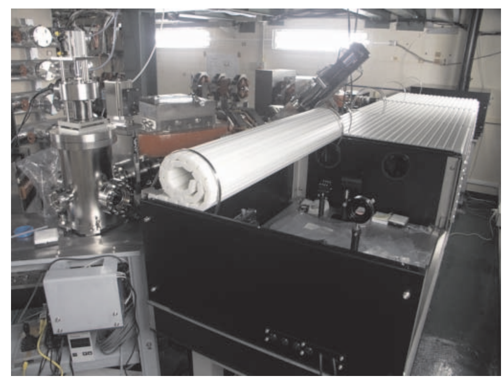

Figure 7: Photograph of the X-band linac beamline including the collision point and laser optics with laser pulse circulation system (LPCS).

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