X-BAND LINAC BEAM-LINE FOR MEDICAL COMPTON SCATTERING 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 YAG laser at Nuclear Engineering Research laboratory, University of Tokyo. This work is a part of the national project on the development of advanced compact medical accelerators in Japan. National Institute for Radiological Science is the host institute and U. Tokyo and KEK are working for the X-ray source. Main advantage 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. In addition, dual energy monochromatic X-ray source can be realized that generate two monochromatic hard X-ray by turin with high (up to 10 pps) repetition rate by one X-ray source.

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 circulation to increase the X-ray yield up to 10^8 photons/pulse (10^9 photons/s).

INTRODUCTION

Hard X-rays of 10-40 keV are now very useful in medical science, biology and material science. for exaple, Dynamic IVGAC[1, 2] and monochromaticd X-ray imaging, CT. In addition, Dual energy X-ray CT[3] and Substruction imaging with contrast agent 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[4]. One to ten percent narrow band X-rays are generated by collimating scattered photons that are related to the energy and scattering angle.

The final target of this study is an integrated system for medicine. as shown in Fig.1. This system is equipped with an X-band RF-source and a moving arm including an X-band linac, Q-switch laser system and X-ray detector.

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

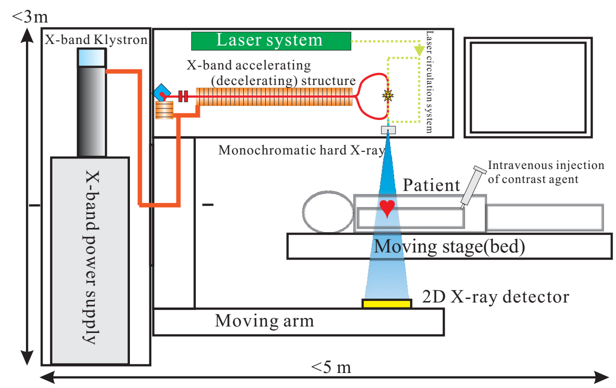

Figure 1: Final target of this study.

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 monochrmatic 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 circulation to increase the X-ray yield up to 10^8 photons/pulse (10^9 photons/s).

In this paper, we present the design and numerical analysis of the X-ray source system to demonstrate hard X-ray generation and its applications.

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. 2. 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 via Compton scattering on laser-electron collision.

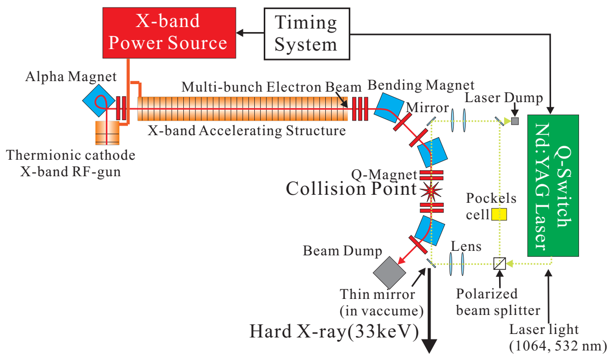

Figure 2: Schematic illustration of Compact Hard X-ray source based on thermionic-cathode X-band RF-gun, X-band accelerating structure and Q-switch Nd:YAG laser.

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 1: Beam parameters at the collision point

X-band linac

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 $\sim$ 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[7] 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[7]. Klystron Modulator is under design to fit this X-ray source. RF power is above 50MW in 1 μs.

The beam optics of the X-band linac beam line designed using SAD[8] code is shown in Fig.3. Beam parameters at the collision point (CP) are shown in Table 1.

Laser system

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).

In second step, to switch the X-ray energy immediately, we add the laser system. Each laser system for fundamental and second harmonics are shot by turn. Then we can generate dual energy monochromatic X-ray by turn with repetition rate of 12.5 Hz as shown in Fig.4. Advantage

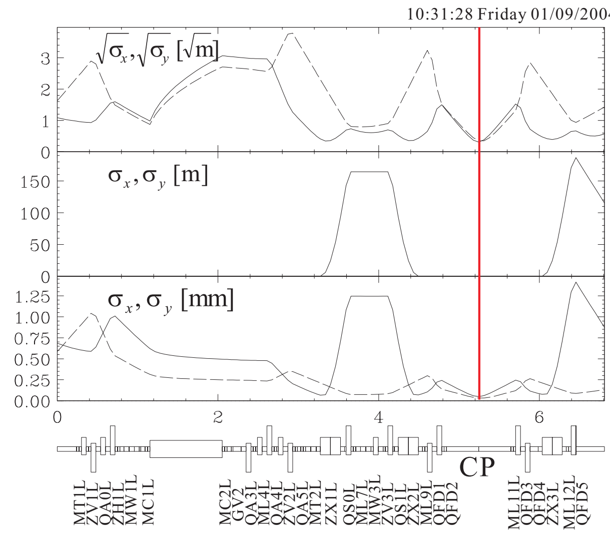

Figure 3: Beam optics for X-band linac.

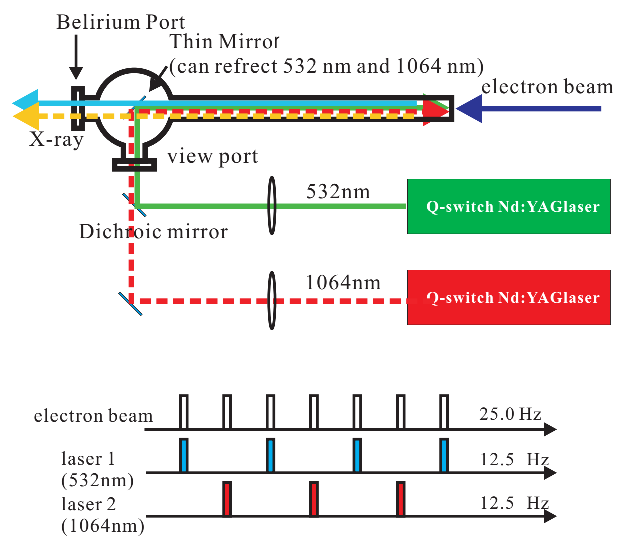

Figure 4: Concept of dual energy X-ray generation system.

of the this dual energy X-ray source is the switing of X-ray energy with high repetition rate that is very useful for dynamic sustructon imaging and dual energy X-ray CT.

To increase X-ray yield, we have to design the technique of circulation of laser pulse, which enhance the luminosity by 10 times. Detail of the laser pulse circulation system will be report in another paper.

X-ray yield and properties

The X-ray yield per bunch is calculated with cross section of Compton scattering and Luminosity. Enegy distributions and energy due to scattering angle of the X-ray for each wavelength of laser light with electron beam energy 35MeV are shown in Fig.5. Property of the X-ray is summalized in Table 2

Figure 6 shows the mean energy and rms energy spread of the available X-ray for each laser wavelength when scat-

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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

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

tered photon are collimated with each collimated angle.

TEST OF X-BAND RF SOURCE AND X-BAND THERMIONIC CATHODE 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.

After RF parameters ware reached to required by the RF-gun experiment, we started RF-aging of the X-band thermionic cathode RF-gun. Detail of the exprtiment will be shown in another presentaion.

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

APPLICATION

Many application of monochromatic hard X-ray is proposed and performed with 3rd generation SR source. Main purpose of this study is demonstration of these applicaton in proposed X-ray source.

After the X-ray generation experiment, we start the experiment for application, for example, Dual energy X-ray CT. Detail of the applicaton experiment is reported in another presentation.

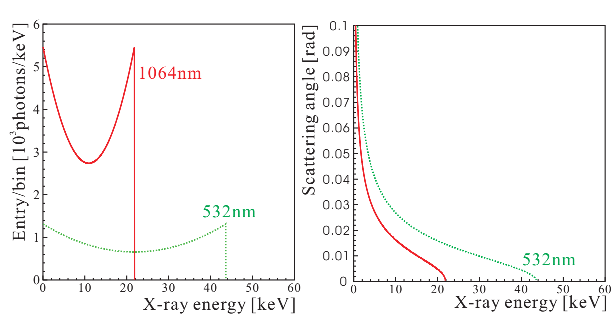

Figure 5: Energy spectrum of X-ray for laser wavelength of 1064 and 532 nm with electron beam energy 35 MeV.

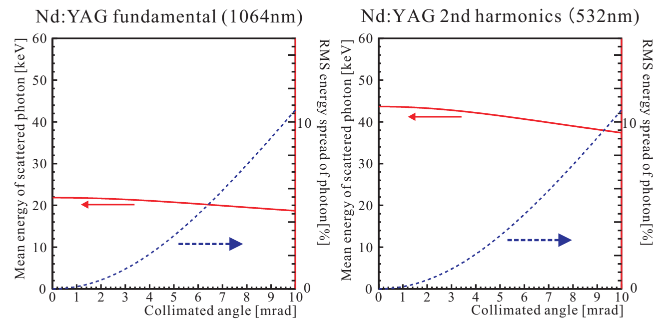

Figure 6: Energy spred in rms and mean energy of available X-ray with each collimated angle.

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. 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). We also design to adopt a technique of laser circulation to increase the X-ray yield up to 10^8 photons/pulse (10^9 photons/s).

Final target of this study is the integrated system for medicine shown in Fig. 5. This system has X-band RF-source and moving arm including X-band linac, Q-switch laser system and X-ray detector. We can perform dynamic IVCAG so as to CAG and can get clear dynamic image of coronary artery with less distress for patients.

ACKNOWLEDGEMENTS

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