PRELIMINARY EXPERIMENT OF THE THOMSON SCATTERING X-RAY SOURCE AT TSINGHUA UNIVERSITY

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Abstract

A preliminary experiment of the Thomson scattering x-ray source is being planned and constructed to generate short-pulsed, tunable x-rays in the range of ~4.5 kev by Thomson scattering of laser photons from a relativistic electron beam. Laser photons of λ = 1064 nm are Thomson backscattered by a 16MeV electron beam. The laser is derived from a 1.5J, 6ns Nd:YAG laser. The parameters of electron beam and laser have been measured. The simulated and experiment results are described in this paper.

INTRODUCTION

The development of compact, tunable, ultra-short pulsed, monochromatic X-ray source is useful in a number of fields including medical imaging, solid state physics, material science, chemical, biological and industrial applications. Some mechanisms, such as X-ray free electron lasers [1], electron bunch slicing in synchrotrons [2], and relativistic electron laser Thomson scattering [3,4,5], can produce the X-ray. The X-ray source based on Thomson scattering between the relativistic electrons and short pulse laser have some advantages, such as good directional radiation, high brightness, wavelength tenability and a short pulse in pico-second and femto-second regions. With the development of table-top-terawatt (T3) laser system, it is shown that Thomson scattering is one of the most promising approaches to ultra-short pulsed x-ray. A number of experimental studies of Thomson scattering have been performed recently. Researches on Thomson scattering x-ray source are being carried out in Tsinghua University [6,7].

In this paper, the preliminary experiment of Thomson scattering x-ray source in Tsinghua University with a 16Mev backward traveling wave linac and a 1.5 J, 6ns laser is described and the result of the experiment is also presented.

EXPERIMENT SET-UP

Preliminary experiments of Thomson scattering are made by the use of the 16MeV Backward Traveling Wave electron linac and the Nd:YAG laser system. The schematic diagram of the experiment is shown in Fig 1. The electron beam is generated by a triode electron gun, bunched and accelerated by the Backward Traveling Wave linac which is powered by a 2856MHz klystron with up to 4.5MW at the repetition rate of 5Hz. The macro-pulse duration is about 160 ns, which is comprised of a train of micro-pulses 10psec in duration separated by 350ps. At the exit of the linac, a 50 μm thick Ti window is used to separate the linac from the interaction chamber to maintain ultra-high vacuum in the linac. The electron beam is focused at the interaction regions using four quadrupole magnets and two steering magnets. A bending magnet is placed at the exit of the electron beam, which is used to analyze the electron energy and separate from the generated x-ray. The beam is damped at the faraday cup shielded with lead block to measure the beam current and reduce the X-ray background caused by the electron bombardment the wall.

The laser system consists of a flash lamp-pumped, active Q-switched Nd:YAG oscillator, two single passed 12mm diameter Nd:Glass rod amplifier which is mounted in water-cooled jacket and illuminated on the side surface using two Xe flash lamps with an 100J/pulse of input energy. The laser system can produce 6 ns (FWHM) output pulse of λ=1064nm with an energy about 1.5J at a repetition rate of 5Hz. A lens with a 1.5m focal length is placed immediately before the vacuum window into the chamber, which focuses the laser to a RMS beam size of 220μm at the interaction region. A mirror in the vacuum is used for reflecting the laser to the interaction point. Head on scattering geometry (~177deg) is adopted to get the maximum x-ray yield. After the interaction region, the laser is reflected to the laser dump, this is necessary, because if the laser beam is dump directly, the breakdown on the damaged optic generates visible and UV light, which results in spurious signals on the X-ray detector.

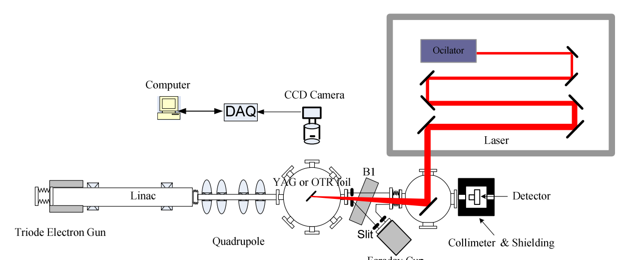

Fig. 1: Schematic diagram of the preliminary experiment .

A 100mm thick YAG screen doped 0.3% Ce and a CCD camera are used to monitor the electron beam and laser beam profile at the interaction point. Quadrupole scan method is used to measure the beam's emittance. The effects of beam emittance, energy spread, interaction position and time mismatch of both beams are simulated by the code CAIN [8]. The parameters of the laser system and linac and estimates of x-ray based on simulation are summarized in table 1.

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Table 1: Parameters of the Thomson scattering preliminary experiment

Electron beam	
Beam energy	16Mev
Macro-pulse current	100mA
Radius at focus	0.8mm(rms)
Emittance	14π mm mrad
Macro-pulse length	160 ns
Laser pulse	
Wavelength	1064 nm
Energy	1.5J/pulse
Pulse duration	6 ns (FWHM)
Focal spot size	220 mm(rms)
Repetition rate	5Hz
X-ray pulse	
Collision angle	177 deg
Max. photon energy	4.6 kev
Pulse duration	6 ns (FWHM)
Number of photons (in 4.8mrad scattered angle)	480 /pulse
Total number of generated photons	$1.2\text{x}10^4$ /pulse

A large number of bremsstrahlung hard X-ray is generated while the electron beam goes through the Ti window. Most of it transmits in the same direction of electron beam and the Thomson scattering X-ray photons, and it can't be distinguished with the Thomson scattering x-ray in space. The selection of the proper x-ray detector is crucial in the preliminary experiment. It should be sensitive to the scattered 4.6Kev photons of interest, but should be insensitive to the hard X-ray generated by the electron beam. Initially a 1mm thickness CSI scintillator coupled to the photomultiplier tube (PMT) was used, but it was too sensitive to the background hard X-ray. A MCP proves to be a good choice for it is not so sensitive to the hard x-ray and its fast response speed. With the strict relation of the time between with the laser beam, we can subtract most of the hard X-ray background. The distance between the collision and detection point is about 1.5m, and the diameter of the sensitive area of detector is 14.5mm. Only the x-ray scattered within 4.8mrad from the direction of electron beam propagation will be detected under these conditions.

EXPERIMENT RESULT

A typical oscilloscope trace from the experiment is shown in figure 2. A photodiode is placed immediately after the laser oscillator, and serves as timing fiducial. In order to subtract the background x-ray signal from Ti window and beam line, two set of X-ray signals are taken with laser pulses and without them as the background. The signal is averaged over 500-1000 shots to reduce a signal fluctuation. The X-ray signal in figure 2 is detected 90 ns before the laser signal. The delay between the two signals is the sum of the time for the laser to propagate from the oscillator to the interaction point, the time for the x-ray to propagate from the interaction point to the detector, and the difference in cables length which is 40m for photodiode signal and 17m for X-ray signal.

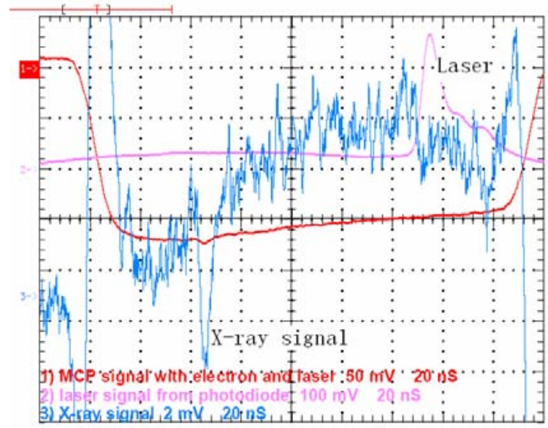

Fig. 2: Oscilloscope trace showing the laser pulse, the signal obtained from MCP, and the detected X-ray signal.

In order to demonstrate that the X-ray signal is due only to the interaction of the laser pulse with the electron beam, several null tests are performed. No x-ray signal is observed when the electron or the laser beam fired individually. No x-ray signal is detected while change the focus point of electron beam with the steering magnets. If the laser is fired before and after the electron beam, no x-ray signal pulse is detected. The relative timing between the laser and the MCP signal is a important factor in discriminating between the desired Thomson scattering X-ray and background x-ray signals.

The full width of half maximum (FWHM) of the X-ray is about 6 ns, which is agree with the estimated value from the parameters of linac and laser. The total number of photons scattered in the 4.8 mrad is obtained from the x-ray signal intensity on the MCP using its gain and quantum efficiency of detection. The gain of the detector is about $2\text{x}10^5$ with 1400 volt dc, and the quantum detection efficiency of MCP is about 5% for about 4 kev x-ray. The intensity of the X-ray signal, about 6mV in figure 3, corresponds to about 20 detected photons. In this case, the total number in 4.8mrad is analytically estimated to be about 410. This number, which is about 15% smaller than the simulated value, is acceptable because of the jitter of the beam's focus point, the mismatch of the interaction point, the measurement errors of the beam and laser's parameters, and so on. The total number of generated photons is calculated to be about 10^4/pulse.

SUMMARY

A preliminary experiment of Thomson scattering X-ray source has been performed in Tsinghua University which generates Thomson scattering X-ray photons from the interaction of a 1.5J, 6ns laser pulse with a 16Mev, 100mA electron beam. The measured X-ray characteristics are about 10^4 per pulse with 6 ns pulse duration, which is in good agreement with the simulation result. In order to minus the influence of the hard X-ray generated from the bremsstrahlung radiation, a new experiment is underway to reflect the scattered X-ray photons with X-ray mirror. Work is also continuing on new experiment to generate sub-ps X-ray pulse with a photocathode RF gun and fs TW laser system.

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