PRESENT STATUS OF PHOTO-CATHODE RF GUN SYSTEM AND ITS APPLICATIONS

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Abstract

High quality electron beam generation using photo-cathode rf gun system and its applications have been developed at Waseda University. This system can generate up to 4.6 MeV low emittance electron beam with bunch length of about 10 ps (FWHM). It is applied for soft X-ray generation using laser Compton scattering and pulse radiolysis experiments based on the pump-probe technique. In the former, Compton scattering experiments between about 4.6 MeV electron beam and 1047 nm laser beam is performed at 20 degrees interaction angle, so that about 370 eV soft X-ray is generated. In the latter, the electron beam is used for the pump beam and the probe beam is generated as white light by concentrating laser beam on the water cell, so that the measurement with about 30 ps (FWHM) time resolution of the pulse radiolysis system is demonstrated for the absorption of hydrated electrons. In this conference, we will present the experimental results, status of this system and future applications.

INTRODUCTION

The relativistic high quality electron beam with short-bunch and low-emittance is required for various experiments in wide research fields. Especially, they play a critical role in the short-pulse X-ray generation using laser Compton scattering, the pulse radiolysis investigation based on the pomp-probe technique [1], and coherent light source such as X-ray SASE-FEL [2].

A low-emittance and short-bunch electron beam can be generated by the laser driven photo-cathode rf gun system [3, 4], which is based on BNL type of 1.6 cells S-band cavity and it has good advantages that time structure of electron beam can be controlled by laser pulse width, a bunching system is not necessary so that the total system can be compact, and high gradient electric fields in the rf cavities can be suppress emittance growth due to space charge effect.

At Waseda University, the high quality electron beam with energy of about 5 MeV generated from our rf gun system have been investigated to apply to a short-pulse soft X-ray source for the biological observation [5] and a pulse radiolysis investigation for ultra-fast physical and chemical phenomena [6]. The electron beam diagnostics such as the emittance and bunch length measurement is very important for these applications [7-8]. In particular, the transverse emittace is most sensitive value because it is changed by the laser injection phase to the input rf and laser injection method to irradiate to the photo-cathode. The comparison among the three deferent laser injection methods have been carried out by measure the vertical emittance using the double slit scan technique.

One of the most promising approaches to short-pulse X-ray sources is the Laser Synchrotron Source (LSS), which is based on laser Compton scattering [9, 10]. The short-pulse soft X-ray source using laser Compton scattering have been developed at Waseda University. Especially, soft X-ray with the energy in "water window" region, which is 250 eV – 500 eV (2.5 nm – 5 nm), can be extensively applied to biological studies, because the absorption coefficients of proteins in this region are larger than that of water. Dehydration of biological specimens can be avoided in both studies *in vivo* and *in vitro*. K-shell absorption edges of O (532 eV), C (284 eV) and N (400 eV), which are main elements of living bodies, exist in "water window" region [11]. The monochrome X-ray with energy between these edges can be employed for the intrinsic contrast imaging in hydrated samples. The compounds containing these elements in the sample can be highlighted. The laser Compton scattering possesses so many features including its wide energy tunability and its compactness of instruments X-ray with narrow energy bandwidth and good directivity can be selected by cutting out with the scattered angle.

Pulse radiolysis system based on the pump-probe technique is one of the most powerful experimental methods to investigate early events in radiation physics and chemistry [12, 13]. The pulse radiolysis system for the absorption spectroscopy will be used for the experiment not only on excited singlet states but also on excited triplet states and on ionic states. At Waseda University, the stroboscopic picosecond pulse radiolysis experiment using rf gun system was performed at Waseda Universityb for the absorption of hydrated electrons to measure its time resolution using the electron beam for the pump beam and the white light for the probe beam.

HIGH QUALITY ELECTRON BEAM GENERATION SYSTEM

RF Gun System with Nd:YLF Laser

The rf gun system is composed of the BNL type 1.6 cell S-band rf cavity with Cu cathode, a set of solenoid magnets for emittance compensation [7], a stabilized laser and rf power source. The total system is very compact

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within 2 × 2 m^2 as a table-top size. Main parts of rf source consists of 10 MW S-band klystron (Tomson: TV2019B6) and a pulse modulator (Nissin Electric Co., Ltd.). This pulse modulator can give good stability and flatness of the output RF pulse.

All solid state picosecond Nd:YLF laser system (PULRISE-V), which was developed by SHI (Sumitomo Heavy Industries, ltd.), is used not only for the rf gun drive, but also for X-ray generation and pulse radiolysis experiments. 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 affect the laser intensity and pointing stability on the photo-cathode. The laser system is put inside the accelerator room to achieve short optical path length to the photo-cathode. The timing and amplitude fluctuation due to an electro-magnetic noise and radiation had been investigated using time domain demodulation technique between a seed laser and the reference rf signal [14, 15]. As a previous result, the timing jitter was measured less than 0.5 ps and the affects of the electromagnetic noise and radiation was negligible for the laser stability. It is sufficiently small timing fluctuation for the soft X-ray generation and the picosecond pulse radiolysis experiment. As a additional laser amplification for the beam applications, a flush lamp pumped laser amplification using Nd:YLF crystal (65 mmφ × 90mm) has been installed. High power laser beam was obtained by amplifying the residual fundamental laser beam (IR: 1047 nm) to collide with the electron beam for the laser Compton scattering and to generate the white light of picosecond pulse for the pulse radiolysis experiment.

Electron Beam Status

High quality electron beam is produced by a photocathode rf gun system. The 4th harmonic laser (UV: 262 nm) which is irradiated onto the photo-cathode in the rf gun cavity. The electron bunch charge and beam energy was measured as a function of rf phase. The typical results are shown in fig. 1 (left). The bunch charge of 1 nC is achieved at the beam energy of 4.6 ± 0.1 MeV with bunch length of about 10 ps (FWHM). UV laser to drive the rf gun and IR laser for the applications were generated from a same seed oscillator, so that it was easily to make synchronization between them.

LOW EMITTANCE BEAM GENERATION

Transverse emittance is most important value of the electron beam for its applications. In case of the rf gun, the transverse emittance is not only varied by changing the rf phase and the solenoid magnetic field, but also depends on the laser injection method to the photo-cathode. The emittance comparison experiments have been performed among three deferent methods, the slanting injection (normal injection), the slanting injection with profile shaping and the perpendicular injection. As the emittance measurement method, the double slit scan technique has been developed at Waseda University [8]. This technique can give the phase space distribution without Gaussian assumption and reduce the space charge effect better comparing with Q-scan technique. The emittance measurements on each injection method were carried out at rf phase of 10, 20, 30 degree under the same bunch charge of 100 pC, 200 pC, 300 pC, respectively, by controlling the laser energy.

As a result in fig. 1 (right), the perpendicular injection and slanting injection with profile shaping can generate the low emittance beam. In case of the perpendicular injection, bunch charge under the same laser energy was one third of the slanting injection due to the effect of the relation between the laser linear polarizing angle and the incident angle to the photo-cathode. Consequently, the slanting injection with profile shaping is the optimum method for the laser injection.

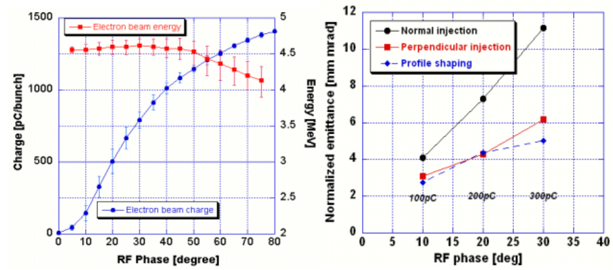

Figure 1: The charge and energy of the electron beam (left) and minimum normalized emittance of each injection method (right) as a function of rf phase.

BEAM APPLICATIONS

Soft X-Ray Generation

Short-pulse X-ray source is required in various research fields, such as material and medical science. To meet these demands, R&D on the next-generation light source has been initiated at several laboratories in the world.

In this experiment, short-pulse soft X-ray generation based on laser Compton scattering between a 4.6 MeV electron beam and a 1047 nm laser beam at 160 deg of the laser propagation angle ϕ toward the electron beam has been successfully performed. A spatial overlap between the electron beam and the laser beam is confirmed by observing both beam images on the identical phosphor screen located at the collision point using a CCD camera. Cherenkov light is emitted by electron beam passing through a 5 mm-thickness glass plate and reflected by an Al mirror with a small pinhole at the collision point, so that the Cherenkov light can be guided toward the same direction of the laser beam to make time and spatial coincidence between them. The laser beam passes through the pinhole and both the laser beam and the Cherenkov light are guided to a streak camera. The generated X-ray is separated from the electron beam using the analyzer magnet and guided to an X-ray detector. The detector is a circular Microchannel plate (MCP) (F4655-10: HAMAMATSU PHOTONICS K. K.) with high speeded response that has about a gain of 5 × 10^6 and the quantum detection efficiency of the MCP is about 10 % at 370 eV X-ray [16]. The distance between

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the collision point and the detection point is about 840 mm and the effective diameter is about 15mm. The X-ray scattered within about 8.9 mrad was detected.

Figure 2 (Left) shows the typical X-ray signals detected by the Microchannel plate (MCP) by changing the timing between the electron beam and the laser beam. The total number of the detected photons is obtained from the amplitude of the maximum X-ray signal using its gain and the quantum detection efficiency. The amplitude of X-ray signal that is about 380 mV corresponds to the number of detected photons about 1.9×10^2 /pulse. In this case, the total number of generated photons is analytically estimated to be approximately 1.9×10^4 /pulse This X-ray has maximum energy of about 370 eV with 0.2 % energy bandwidth that is between the K-shell absorption edges of N and C. It is expected that this soft X-ray will have many application to the biological observation.

Pulse Radiolysis System

The pulse radiolysis system for the absorption spectroscopy will be used for the experiment not only on excited singlet states but also on excited triplet states and on ionic states. The stroboscopic picosecond pulse radiolysis experiment was performed based on the pump-probe technique. The electron beam for the pump beam is generated from the rf gun. The white light for the probe beam is converted by concentrating Nd:YLF laser light (1047 nm) on the water cell. In fig. 2 (right), the measurement with about 30 ps (FWHM) time resolution of this system was demonstrated for the absorption of hydrated electrons.

In near future, pulse radiolysis experiments using this system will give us very important knowledge on the primary reactions of molecules, atoms and other material complexes. Through the various experiments, it will be found that datum on relaxation mechanism of electrons and excited states, dissociation mechanism of molecules to radicals and other states, and so on.

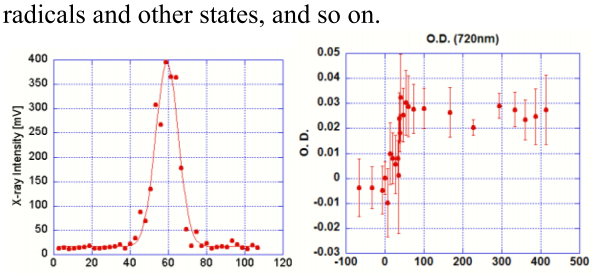

Figure 2: the typical soft X-ray signals (left) and time profile of absorption of hydrated electrons on pulse radiolysis experiment (right).

SUMMARY

The operation of our rf gun system with Nd:YLF laser which is a table-top size within 2×2 m^2, the measurements of the electron beam characteristics and its application experiments have been performed. To investigate the laser injection method to irradiate to photo-cathode, the vertical emittance of the electron beam was measured using the double slit scan technique by changing the laser injection methods, normal injection, profile shaping and perpendicular injection. It is clearly found that the slanting injection with the laser profile shaping is the vest method among three injection methods.

Soft X-ray generation in "water window" region based on the laser Compton scattering has been successfully carried out using our rf gun system in a table-top size within 2×2 m^2. This X-ray has maximum energy of about 370 eV and the total number of generated photons is analytically 1.9×10^4 photons/pulse. Out of total generated X-ray, the useful soft X-ray that has energy between the K-shell absorption edges of N and C is analytically about 4.0×10^3 photons/pulse within about 50 mrad scattered angle that correspond to about 5.2 % energy bandwidth and we can select such useful soft X-ray by cutting out within the scattered angle. It is expected that this X-ray will have many application to many wide research fields such as biological observation. As next step, soft X-ray optics with zone plates and an X-ray CCD camera was proposed for the soft X-ray microscopy to apply to the biological observation.

On the picosecond pulse radiolysis experiment using our rf gun system, the measurement with about 30 ps (FWHM) time resolution is demonstrated for the absorption of hydrated electrons. Various pulse radiolysis experiments to investigate early events in radiation physics and chemistry will be started from this year.

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