PRESENT STATUS OF PHOTO-CATHODE RF GUN SYSTEM AND ITS APPLICATIONS AT WASEDA UNIVERSITY*

R. Kuroda#, D. Ueyama, M. Kawaguchi, N. Kudo, T. Kuribayasi, T. Saito, K. Sakaue, S. Minamiguchi, R. Moriyama, Y. Hama, K. Hidume, H. Hirama, M. Washio,
Waseda University, Tokyo, Japan
S. Kashiwagi, Osaka University, Osaka, Japan,
J.Urakawa, H.Hayano, KEK, Ibaraki, Japan
X. J. Wang, BNL, New York, USA

Abstract

High quality electron beam generation using photo-cathode rf gun system and its application experiments have been developed at Waseda University since 2002 fiscal year. Our system is a table-top size within 2×2 m^2 including the rf gun system and can generate about 4 MeV low emittance electron beam. This is applied for soft X-ray generation using laser Compton scattering and pulse radiolysis experiments based on the pump-probe technique. In case of the soft X-ray generation, the laser Compton scattering experiment between about 4.2 MeV electron beam and Nd:YLF laser light (1047 nm) is performed at 20 degrees interaction angle, so that about 300 eV soft X-ray is generated. In case of the pulse radiolysis experiment, the electron beam is used for the pump beam. The probe light is generated as white light by concentrating Nd:YLF laser light (1047 nm) on the water cell. The measurement with about 30 ps (FWHM) time resolution of this system is demonstrated for the absorption of hydrated electrons.

INTRODUCTION

The relativistic high quality electron beam in both transverse and longitudinal phase space is required for various experiments in wide research field. In particular, high quality electron beam plays vital roles in ultra-short electron bunch production, coherent radiation, free electron laser (FEL) such as SASE, a pulsed X-ray generation and many other applications.

A low emittance electron beam is generated by BNL type 1.6 cells s-band photo cathode rf gun [1,2], which has advantages such as time structure of electron beam can be controlled by laser pulse width, 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 electron beam will be used for a pulsed soft X-ray source for a biological observation and a pulse radiolysis experiment for the observation of ultra-fast phenomena.

Short-pulsed 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. One of the most promising approaches to short-pulsed X-ray sources is the Laser Synchrotron Source (LSS), which is based on laser Compton scattering [3,4].

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 [5,6]. 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 using the relativistic electron beam for the pump beam and the white light for the probe beam.

In this conference, we will present the experimental results, status of this system and future applications.

*707 HRC: High Tech Research Project, MECSST
2002A-909 Special Project, Waseda University
#rkuroda@waseda.jp

HIGH QUALITY ELECTRON BEAM GENERATION SYSTEM

RF Gun System

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. Figure 1 shows the total beam line which is within 2×2 m^2 as a table-top size. The cathode surface of the rf gun cavity was polished using diamond powders. Present quantum efficiency of Cu cathode has been achieved about 5×10^{-5} without laser cleaning. High accelerating field is effective to reduce an emittance growth due to space charge effect for a 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.

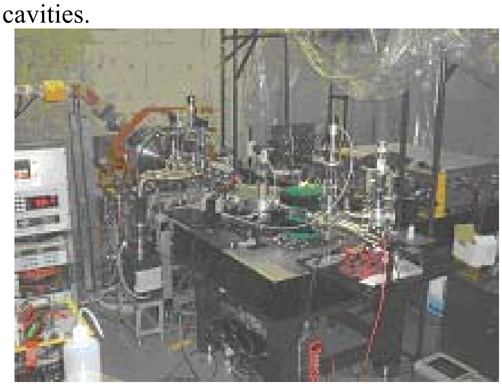

Figure 1: The view of the total beam line

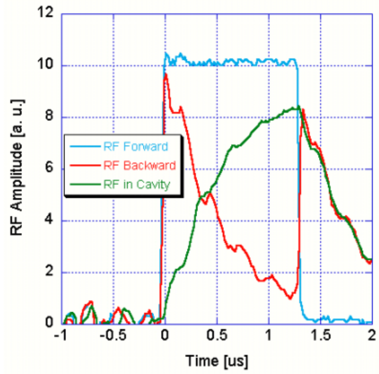

Figure 2: The typical rf signals of rf forward, backward and picked up from the rf gun cavity

Main parts of rf source 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. Figure 2 shows the typical rf signals at the peak rf power of 10 MW and the rf pulse width of 1.4 µs. These signals are rf forward, rf backward and rf picked up from rf gun cavity.

Laser System

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 irradiation of, 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 [8,9]. 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.

Additional Laser Amplification

Our all solid state Nd:YLF laser system (PULRISE-V) can provide about 1 mJ/pulse at fundamental wavelength. However, our requirement for the soft X-ray generation experiment and the pulse radiolysis experiment is larger than 10 mJ/pulse. Therefore, a flush lamp pumped 2-passed laser amplification using Nd:YLF crystal (60 mmφ × 90mm) has been installed. The maximum gain of the amplifier is about 10^2 at 900 V flushing voltage. The optimum laser energy can be arbitrary obtained by changing the flushing voltage. 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 picosecond pulsed white light for the pulse radiolysis experiment.

Electron Beam Status

High quality electron beam is produced by a photo-cathode rf gun system. The 4th harmonic laser (UV: 262 nm) which is irradiated to the photo-cathode of the rf gun is obtained from a Nd:YLF fundamental laser (IR: 1047 nm) by passing through two beta barium borate (BBO) crystals in the PULRISE-V laser system. The electron bunch charge and beam energy was measured as a function of rf phase. The typical results are shown in Fig. 3. The bunch charge of 1 nC is achieved at the beam energy of 4.3 ± 0.1 MeV. 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. Figure 4 shows the block diagram of the synchronization system.

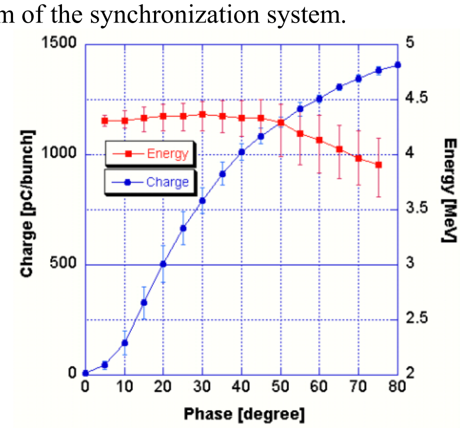

Figure 3: The charge and energy of the electron beam as a function of the rf phase.

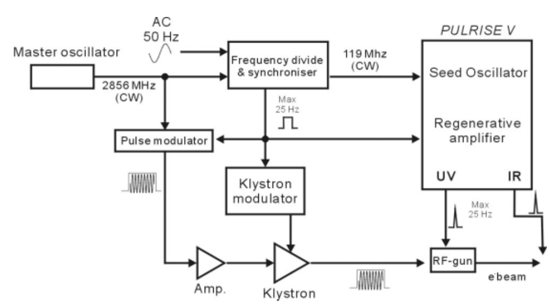

Figure 4: Block diagram of the synchronization system

The beam emittance and the bunch length measurements were carried out using slit scan method and two frequencies analysis technique, respectively [10]. Comparing between results of experiments and simulations, these were agreed well [11].

BEAM APPLICATIONS

Soft X-ray Generation

Short pulsed soft X-ray sources are required in various research fields, such as material, chemical, medical and biological science. 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*. In "water window" region, K-shell absorption edges of O (532 eV), C (284 eV) and N (400 eV), which are main components of living bodies [12]. The LSS 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. Short pulsed soft X-ray generation using laser Compton scattering between a 4.2 MeV electron beam and a 1047 nm laser has been successfully performed at Waseda University.

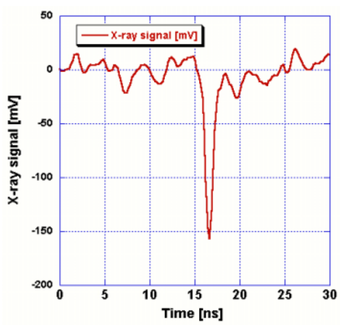

Figure 5: The typical X-ray signal

Figure 5 shows the typical X-ray signal detected by the Microchannel plate (MCP). The total number of the detected photons is obtained from the amplitude of the X-ray signal using its gain and the quantum detection efficiency. The amplitude of X-ray signal that is about 156 mV corresponds to the number of detected photons about 53. In this case, the total number of generated photons is analytically estimated about 4.7×10^3 /pulse This X-ray has maximum energy of about 300 eV that is between the K-shell absorption edges of N and C. It is expected that this soft X-ray will have any 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. 6, 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.

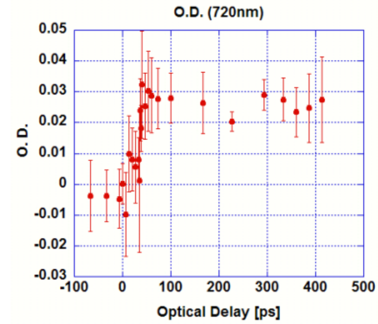

Figure 6: The time profile of the absorption of hydrated electrons

SUMMARY

The operation of rf gun system which is a table-top size within 2×2 m^2, the measurements of the electron beam characteristics and its application experiments have performed after 2002 fiscal year. Soft X-ray generation have been successfully performed using laser Compton scattering. To apply this to the soft X-ray microscopy for the biological observation, high intensity of soft X-ray is necessary adopting well-designed X-ray optical system. On the other hand, the measurement with about 30 ps (FWHM) time resolution of the picosecond pulse radiolysis system 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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