STATUS OF PHOTO-INJECTOR SYSTEM AND ITS APPLICATION EXPERIMENT AT WASEDA UNIVERSITY*

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Abstract

A research project named "High-Tech Research Center Project" which is supported by the Ministry of Education, Culture, Sports, Science and Technology have been conducted at Waseda University. In this project, a photo-injector system which is a laser driven photo-cathode rf-gun system has been used for production of low emittance and short bunched electron beam. Main parts of rf source for the rf-gun consists of 10 MW s-band klystron and a small pulse modulator. The pulse modulator has good stability and flatness of the output pulse. The measured dark current in our system is reduced very much even in high acceleration gradient. Accelerated electron beam energy and emittance are also measured and the good characteristics are demonstrated.

Development of pulsed X-ray generation by the inverse Compton scattering between short bunched electron beams and pulsed laser lights, and the pulse radiolysis system for the studies on radiation physics and chemistry have been planned. These two major application experimental setups have been installed and preliminary experiments have been started from January 2002. The status of the photo-injector system and the preliminary result of its application experiments will be presented in this conference.

1 INTRODUCTION

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.

At Waseda University, 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 characteristics of laser light, 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 the pulsed X-ray generation experiment for a biological investigation and the pulse radiolysis experiment for the observation of ultra-fast phenomena. In 2002 fiscal year, the short pulse soft X-ray generation will be performed for applying the X-ray microscopy.

One of the most promising approaches to short pulsed X-ray sources is the Laser Synchrotron Source (LSS). It is based on inverse Compton scattering between pulsed laser beams and picosecond electron bunches [3,4]. The LSS has many good features such as tenability of the wavelength, the yield, the spectrum and the scattered angle of X-rays, respectively. Those characteristics of scattered X-rays can be controlled by varying the collision angle between electron beam and laser light, by changing energy of electron beam or wavelength of laser light. We are planning to apply the LSS for X-ray microscopy to get the image of hydrated biological specimens without blurring caused by radiation damage and thermal diffusion. In this paper we will introduce present status of photo-injector system at Waseda University.

2 PHOTO-INJECTOR SYSTEM

2.1 Rf-gun system

Rf-gun system is composed of the BNL type 1.6 cell s-band rf cavities with Mg cathode [5,6], a set of solenoid magnets for emittance compensation [7], a stabilized laser and rf power source. A Mg cathode, which had developed at Brookhaven National Laboratory, has been used for our system. The cathode surface was polished using diamond powders. As the preliminary result, higher quantum efficiency than Cu cathode has been achieved about 10^{-4} 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. Typical dark current data is shown in Fig. 1 as the function of electric field at present. The dark current is reduced very much in our system.

The electron beam is emitted from the photo cathode by irradiation of UV laser light (262 nm, 4^{th} harmonics of Nd:YLF fundamental light), hence the characteristics of electron beam can be controlled by the laser injection timing against to rf phase, and beam profiles of laser light in transverse and longitudinal directions.

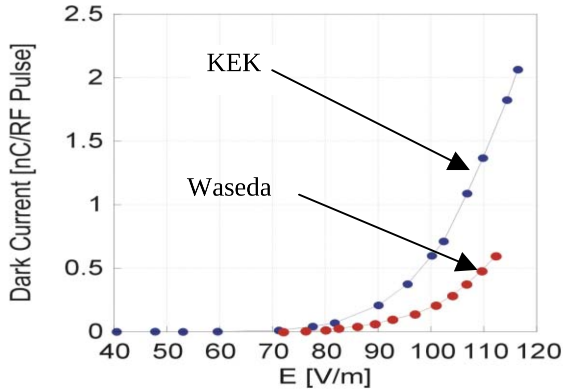

Fig. 1 Dark current measured under the beam test with the high gradient acceleration fields

Main parts of rf source for the rf-gun 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. The amplitude jitter of klystron voltage was about 0.38 % (p-p) for 20000 pulses and the pulse flatness was 0.25 % (within >1.5 μs pulse flat-top).

On the other hand, we are continuing the simulation work using MAGIC code and PARMELA for the BNL type s-band rf-gun to find good operation parameters, which are setting of solenoid magnet system, laser injection phase and so on. From these simulations, we found that transverse emittance growth due to the electric field in radial direction could not be neglected even in the case of high gradient acceleration [8].

2.2 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 cathode in rf-gun system, 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 affects the laser intensity and pointing stability on the cathode, so that the laser system is put inside the accelerator room to achieve short optical path length from the main body of the laser to the cathode of rf-gun. Such the location, an electro-magnetic noise and radiation may influence the laser system to increase timing and amplitude jitters. Therefore, the timing and amplitude fluctuation between a seed laser and the reference rf signal had been investigated using time domain demodulation technique [9]. As the result of the measurement, the timing fluctuation between the seed laser and reference signal was less than 0.5 ps with timing stabilization system, therefore the electromagnetic noise and radiation had given no effect to timing stability. We can achieve the small timing jitter between the laser light and electron beam at sub-picosecond time region. It is sufficiently small timing fluctuation for the X-ray generation and the pulse radiolysis experiment under the picosecond time resolution. On the other hand, the laser intensity was fluctuated through certain damage to a pumping laser diode. By putting electro-magnetic and radiation shielding around the laser body, it has been demonstrated that the laser system has been operated with the good intensity and pointing stabilities even in the accelerator room.

3 BEAM TESTS AND APPLICATION

3.1 Beam characteristics

Preliminary beam test has been demonstrated, and the bunch charge and beam energy are measured. The typical results are shown in Fig. 2. Bunch charge of 1nC is achieved at the beam energy of 3.8MeV.

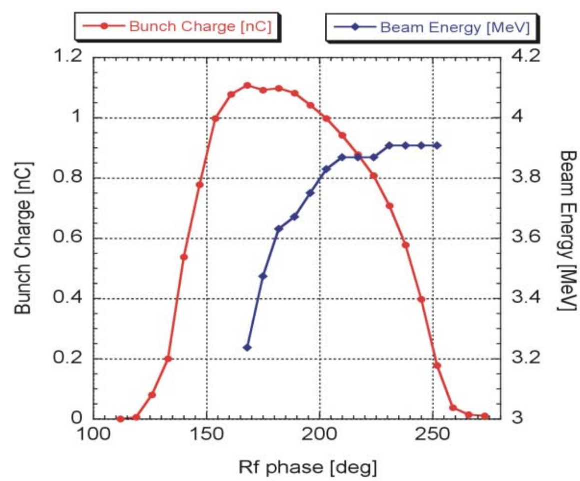

Fig. 2 Bunch charge and beam energy dependences by changing Rf phase

Beam emittance measurement is also carried out using "slit scan method". Beam profile measurements are also demonstrated using beam profile monitor at the same conditions. Comparison between experimental and simulation shows that the phase-space profiles of beams at the different solenoid magnet current were agreed well. Typical result of emittance growth by changing the bunch charge is shown in Fig. 3

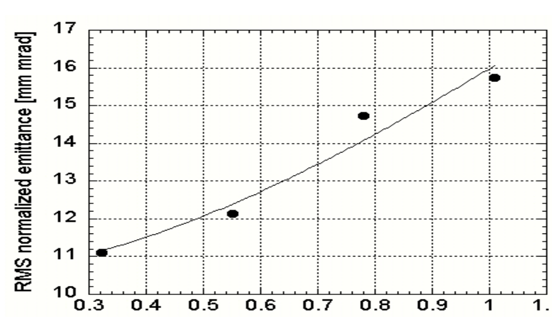

Fig. 3 Beam emittance measured by slit scan method as the function of bunch charge

3.2 Soft X-ray generation

Soft X-rays having different energy spectrum are very useful for biological observation, because wavelength dependence of absorption coefficients is different in each element in the bio-molecules. We can observe only a certain element by taking the difference of two images, which are observed using two different wavelength of the soft X-ray. K-shell absorption edges of Oxygen, Carbon and Nitrogen, which mainly constitute of a living body, are 2.322 nm, 4.368nm and 3.099 nm, respectively [10]. Those absorption edges are included in the range of "water window". Since the absorption coefficient of water is much smaller than protein's coefficient in this range of "water window", a dehydration of the specimens is not necessary. Inverse Compton scattering with different collision angles will generate soft X-rays, which have different energy spectrum. The total number of produced X-ray photons by inverse Compton scattering is given by the product of the cross section of Compton scattering (σ) and Luminosity (L), which is determined by the scattering geometry of electron beam and laser. In the case of head-on collision (zero crossing angle), the number of produced X-ray photons is maximized.

The "Compton chamber" has been installed and collision timing and position settings of electron and laser beams are undergoing.

3.3 Pulse radiolysis experiment

Pulse radiolysis technique is one of most powerful experimental method to investigate early events in radiation physics and chemistry. We will develop two different experimental setups using emission spectroscopy and absorption spectroscopy.

The emission spectroscopy system will be used for the experiments on excited singlet states of various kind of materials. For the first step of these experiments we will perform a conventional technique using a photo-detector such as PIN-photodiode in combination with monochromator and oscilloscope with time resolution up to 1ns. In this system, time resolution is determined by the cut-off frequencies of PIN-photodiode and oscilloscope. In near future, streak camera system, instead of PIN-photodiode and oscilloscope system, will be introduced. In such a case, time resolution will be up to 10ps.

The absorption spectroscopy system will be used for the experiment not only on excited singlet states but also on excited triplet states and on ionic states. Stroboscopic pulse radiolysis experiments will be performed using laser light as the probe light, which is divided from excitation laser light for RF-Gun cathode. Using this experimental setup, the measurement with 10 ps time resolution will be demonstrated for the absorption of hydrated electrons.

These pulse radiolysis experiments will give us very important knowledge on the primary reactions of molecules, atoms and other material complexes. Through the experiments, we will have datum on relaxation mechanism of electrons and excited states, dissociation mechanism of molecules to radicals and other states, etc.

Before stating the pulse radiolysis experiment, we have measured the beam spot profiles on the sample surface, located in the atmosphere. Beam spots size were expanded more than 3mm, but this is still acceptable for pulse radiolyisis experiments.

4 SUMMARY

We have started the operation of rf-gun system and measurements of the beam characteristics after this January. Characteristics of the electron beam with Mg cathode were measured at the first step of experiments. The higher quantum efficiency around 10^{-4} has been achieved.

Experiments of soft X-ray generation have started by using inverse Compton scattering between high quality electron beam and stabilized laser light at different crossing angle. To apply the X-ray microscopy, high intensity of soft X-ray is necessary adopting well-designed X-ray optical system. The preliminary test system of pulse radiolysis is installed, and measurement of beam spot size on the sample. After this summer, so-called stroboscopic system will be demonstrated.

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