MEASUREMENT OF ULTRA-SHORT ELECTRON BUNCH DURATION BY COHERENT RADIATION ANALYSIS IN LASER PLASMA CATODE

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Abstract

We have performed measurement of electron bunch duration from laser plasma acceleration.

Spectrum analysis of the transition radiation from the electron bunch was selected for measurements, using an IR (infrared) bolometer with different filters first. The bunch is estimated to be 30fs in PIC simulation, but measured duration was 2ps by the result of bunch elongation at 340mm downstream from the plasma edge due to broadness of energy spectrum.

And then measurement by In-Sb polychromator aiming shot-by-shot measurement is also done. But the signal of transition radiation cannot be detected by X-ray background signal even if shielding by Pb. So we have done optimisation of X-ray shielding and position of detector.

INTRODUCTION

In the field of radiation chemistry better time resolution comes to be needed. Above all, pump and probe method in pulse radiolysis has fine time resolution (ps in linac system). Since a laser plasma cathode is one of the most promising approach that can generate ultra-short electron bunches (30ps in PIC simulation cf. linac 240fs) [1,2,3], a laser plasma cathode has the great advantage of femtosecond time-resolved applications. There are some experiments for pulse radiolysis using laser plasma cathodes [4,5], but they are not accompanied with experimental measurement of electron bunch duration.

Since the time-resolution of the fastest streak camera that is used widely for a conventional linear accelerator is only 200 fs, we have to use other methods for the bunch duration measurement. We use the spectrum measurement of coherent transition radiation (CTR) with an IR (infrared) bolometer and polychromator. It is because this method has possibility to single-shot measurement of the electron bunch duration by polychromator. But, more intensity and stability of TR is necessary for measurement by polychromator.

We applied external magnetic field (0.2T) on the gas jet and obtained a stable beam, with spot size 5mm(FWHM) and emittance 0.06πmm-mrad, and charge 1.0nC[6]. This will improve the signal of CTR intensity and make shot-by-shot measurement .possible.

COHERENT RADIATION

When a charged particle crosses the boundary between the two media with different permittivity, transition radiation is emitted from the boundary. Under the condition that one electron passes from a medium to vacuum, intensity of transition radiation can be written as,

$$I_e = \frac{\alpha\beta^2 \sin^2\theta}{\pi^2\lambda(1-\beta^2\cos^2\theta)} \qquad (1)$$

where α is fine structure constant, β the particle velocity expressed in units of c, λ the wavelength of transition radiation, and θ the angle of emission with respect to the direction of the electron velocity.

Radiation from an electron bunch can be expressed by superposition of radiation from each electron in the electron bunch. Total intensity of radiation from an electron bunch is obtained by,

$$I_{total} = NI_e + N(N-1)f(\lambda)I_e \qquad (2)$$

where N is the number of electrons in the electron bunch, and f(λ) the bunch form factor. When the wavelength of radiation is longer than the bunch length, radiation becomes coherent; the bunch form factor becomes unity and total intensity of radiation is proportional to the square of N. When the wavelength is shorter than the bunch length, however, radiation becomes incoherent; the bunch form factor becomes zero and total intensity of radiation is proportional to N. Since N is usually on the order of 10^7~10^{10} in a laser plasma cathode and a conventional linear accelerator, intensity of transition radiation is extremely enhanced if radiation is coherent.

On the assumption that the distribution of electrons in the electron bunch is symmetric to some reference angle, and that each electron is independent each other, the bunch form factor can be written as,

$$f(\lambda) = \left| \int_{-\infty}^{\infty} \exp(\frac{i2\pi z}{\lambda}) S(z) dz \right|^2 \qquad (3)$$

where z is the direction of electron velocity, S(z) the normalized electron distribution function in the electron bunch. As shown in equation (3), the bunch form factor is given by Fourier transform of the electron distribution function. Hence, the distribution function can be derived from inverse Fourier transformation of the bunch form factor, and the bunch duration can be also estimated.

BUNCH ELONGATION

If the energy (velocity) of each electron differs in the bunch, electron bunch can streches according to their energy spectrum.Fig.1 shows calculated elongation of the bunch duration, according to their energy. In Maxwell distribution of maximum energy 5MeV, bunch duration will be 2ps (FWHM).

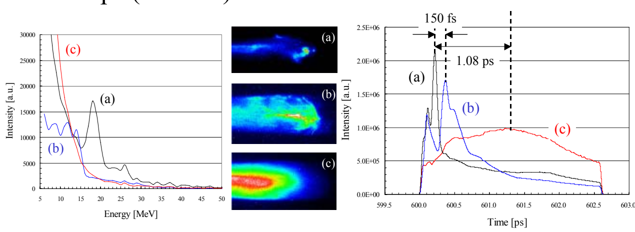
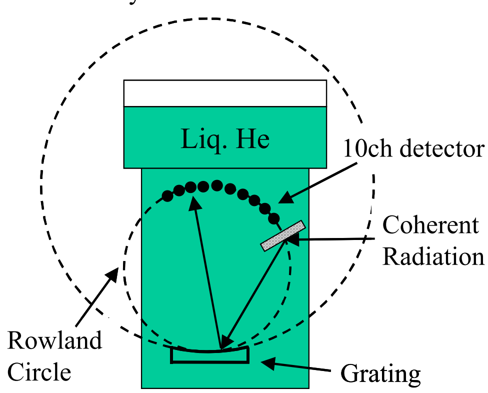


Figure 1: Bunch elongation depending.on energy.

SINGLE SHOT MEASUREMENT

Polychromator has 10 channels to measure intensity of the radiation and can get spectrum shot by shot. Fig. 2 shows the schematic image of the polychromator. Since the bunch duration at Ti-foil varies shot by shot as already described, a single-shot measurement is required for more detailed evaluation of the bunch duration. In the measurement using the polychromator, however, CTR is separated according to its wavelength by the grating and delivered into each detector. Therefore, strong intensity of CTR is necessary.



Figur 2: 10ch InSb polychromator.

EXPERIMENTAL SETUP

The experimental setup is shown in Fig.3. The Ti:Sapphire laser system based on the chirped pulse amplification (CPA) technique generates an ultra-short intense laser pulse with the energy up to 600 mJ and the pulse duration of 38 fs at full width half maximum (FWHM). The central wavelength is 790 nm. The laser pulse is focused by f/3.5 off-axis parabolic mirror (OAP) into a helium gas jet. The focal spot size is 6 μm at $1/e^2$ in intensity and therefore the laser intensity is estimated to be 3.5×10^{19} W/cm^2. 0.2T external magnet field is applied on the gas jet into progressive direction. The properties of the electron beam emitted from the gas jet, such as the spatial distribution, the energy spectrum, and the charge, are evaluated with a fluorescent screen (DRZ), an electron spectrometer and an integrated current transformer (ICT), respectively.

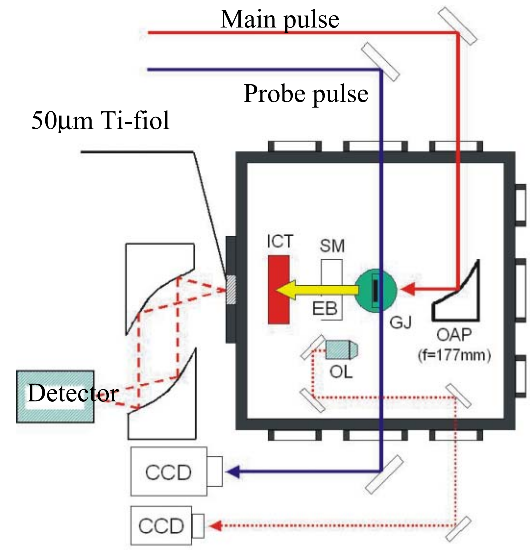


Figure 3: experimental setup.

Titanium foil with thickness of 50 μm is placed 340 mm downstream from the gas jet. Transition radiation is emitted from Ti-foil when the electron beam hits, and delivered into the IR bolometer with OAP. In the optical path from Ti-foil to the bolometer .

RESULTS AND DISCUSSION

First, CTR emitted from Ti-foil is measured by IR bolometer. The IR bolometer is equipped with three kinds of inner filters. They are low-pass filters, which cut radiation with wavelength shorter than 10 μm, 100 μm, and 280 μm. We obtain the average spectrum of CTR by combination of these inner and outer filters.

Fig. 4 shows spectrogram of measured CTR versus wavelength and calculated bunch for factor at bunch duration1,2,3 ps(FWHM). From this fitting, electron bunch duration is estimated to be 2ps in FWHM. But, signal intensity was not improved as expected.

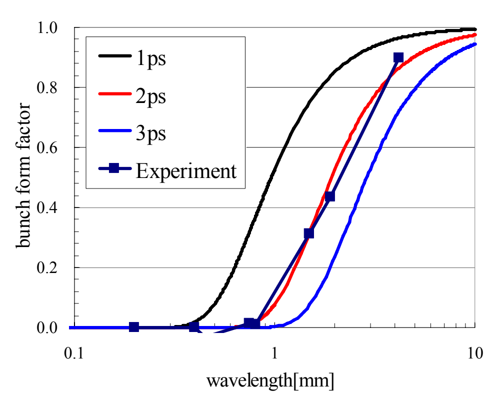


Figure 4: spectrum of CTR measured by bolometer.

Then we tried measurement by polychromator. But the signal of transition radiation is unknown by an X-ray background signal even if shielding by Pb, and meaningful result cannot be obtained. So, the intensity of

CTR is not increased though the charge of the beam became ten times higher than previous experiments. For measurement using polychromator, high S/N ratio has to be achieved. To intensify CTR, bring Ti-foil close to the gas jet, and to decrease the X-ray background, we have done optimisation of shielding by Pb.

We have performed Shielding optimisation, using NAI scintillator as detector. As a result, signal of X-ray background was rather small at the side of experimental chamber compare to distant point in a progress axis of electron beam (about a quarter in signal intensity). Considering transmittance loss, the best detector position will be the near side of chamber.

PULSE RADIOLYSIS

As further experiments, we are going to perform experimental proof of pulse radiolysis measurement, with electron bunch from laser plasma cathode as excitation pulse. Use water as a sample in 10mm quartz cell, and measure absorption by hydrated electrons generated in the water. But here, electron (<5MeV) can be easily scattered in the water. So electron used for excitation is estimated to be too small for pump and probe method. Therefore, Kinetic methods with He-Ne laser (central wavelength: 633nm) as probe light will be chosen for this experiment. As mentioned before, since measurement experiment with known electron bunch duration has not been handled, this will contribute to realize precise evaluation of pulse radiolysis method with laser plasma cathode.

Fig.5 shows experimental setup for the pulse radiolysis measurement with laser plasma cathode.

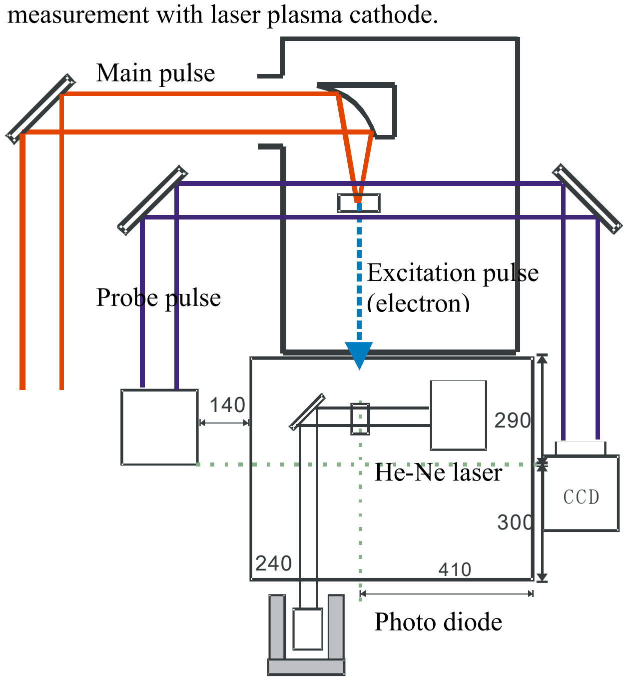


Figure 5: experimental setup for the pulse radiolysis measurement with laser plasma cathode

Incident probe light will be vertical to pump pulse. This is because low energy electrons will be scattered and excitation mainly occur in the surface of cell.

Finally we are aiming at pump and probe, experiment with laser plasma cathode. In this system, there are no theoretical jitters between probe pulse and excitation electron beam, and duration of both laser pulse and electron beam can be fs order. Therefore, The realization of fs time resolution system is anticipated. But, as mentioned before, duration of electron bunch is stretched by broad energy spread of the beam to be 2ps. So, for realization of fs pump and probe pulse radiolysis system, it is necessary to make the energy spectrum of the beam mono-energetic and evaluate the timing jitter between probe laser and electron beam experimentally.

CONCLUSION

We have performed the measurement of the electron bunch duration from a laser plasma cathode by the spectrum measurement of coherent transition radiation using bolometer. The bunch duration at Ti-foil is 2ps in average due to elongation of the electron bunch.

But the measurement in polychromator was failed because of the insufficiency of S/N ratio in CTR. We have performed optimisation of shielding and present a way to improve CTR signal.

As problems to solve and further experiments, we will handle single shot measurement with optimised X-ray shielding and shortened distance between gasjet and Ti-foil. And experimental proof of Kinetic pulse radiolysis measurement with known electron bunch duration will be held in this July.

REFERENCES

[1] T. Ohkubo, Doctor Thesis, University of Tokyo, 2006
[2] T. Ohkubo, *et al*, Phys. Rev. ST-AB 10, 031301,2007
[3] A. Maekawa, *et al*, Nucl. Instr. and Meth. A, 2007
[4] Ned Saleh.et al , REVIEW OF SCIENTIFIC INSTRUMENTS 71 6 ANL.2000
[5] Beata Brozek-Pluska et al, Radiation Physics and Chemistry 72 2005
[6] T. Hosokai, *et al*, Phys. Rev. Lett. 97, 075004,2006