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PULSE DURATION MEASUREMENT OF PICO-SECOND DUV PHOTO-CATHODE DRIVING LASER BY AUTOCORRELATION TECHNIQUE USING TWO-PHOTON ABSORPTION IN BULK MATERIAL*

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Abstract

Photocathode RF guns have been used for generating high brightness electron beams. Measurement of the pulse duration of photocathode driving laser in deep-ultraviolet (DUV) wavelength is quite important to estimate the electron beam properties generated from the RF gun. The autocorrelation technique has been commonly used for pulse duration measurement of laser pulses. Two-photon absorption has been utilized as the nonlinear process in the autocorrelation measurement of ultrashort pulse laser beams in DUV region. In this study, DUV autocorrelator utilizing the two-photon absorption in a sapphire plate as the nonlinear process was developed. The developed autocorrelator was used to measure the pulse duration of ps-DUV laser pulses which has been used for driving photocathode RF guns in the free electron laser facility at Institute of Advanced Energy, Kyoto University. As the result, the pulse duration of deep-UV laser pulse was measured as 5.8 ± 0.2 ps-FWHM.

INTRODUCTION

Recently, photocathode RF guns are widely used for generation of high brightness electron beams. At the Institute of Advanced Energy, Kyoto University, a 4.5-cell RF gun with a LaB_6 thermionic cathode used for driving mid-infrared free electron laser (MIR-FEL) has been operated with laser induced photoelectron emission [1]. And the MIR-FEL performance, especially for the peak power, has been significantly increased with the photocathode operation. In parallel, a compact THz coherent undulator radiation source using a 1.6-cell photocathode RF gun has been developed [2]. For driving those RF guns, a multi-bunch picosecond-deep-ultraviolet (ps-DUV) photocathode driving laser system has been developed [3]. The pulse duration of DUV photocathode driving laser is so important parameter, which determines the initial electron pulse duration at the cathode. Therefore, measurement of its pulse duration is so important to estimate the available electron beam parameter. In many electron accelerator facilities, steak cameras have been used for measuring the pulse structure of DUV laser pulses. However, the streak camera is so expensive and not easy to use. As an alternative method, some facilities using photocathode RF guns have been developed cross correlator which uses femtosecond near infrared (fs-NIR) laser as a probe to measure the cross correlation between the ps-DUV laser and the fs-NIR laser using difference frequency generation [4, 5]. The cross correlation method is only available in the facilities where the fs-NIR lasers are available.

In the ultrafast laser community, an autocorrelation technique utilizing a two-photon absorption (TPA) in a bulk material has been developed for measuring the pulse duration of ultrashort UV and DUV pulses [6, 7]. In this study, an autocorrelator using TPA in a sapphire crystal was developed and used for measuring the pulse duration of photocathode driving laser at the Institute of Advanced Energy, Kyoto University. The measurement principle, the developed autocorrelator, and measured results are reported in this paper.

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MEASUREMENT PRINCIPLE

In general, intensity autocorrelation technique is used for measuring the pulse duration of short pulse lasers. The basic setup of the intensity autocorrelator is shown in Fig. 1. At first, the laser beam is divided into two pulses by a beam splitter. Those two beams are focused by a focusing optics on a nonlinear material. The arrival time difference of the two pulses is controlled by an optical delay inserted in one side of the optical beam path. The nonlinear signal generated at the nonlinear crystal as the function of the arrival time difference is recorded to obtain the information of overlap of those two pulses. Finally, by analyzing the recorded result, the pulse duration of injected laser beam is determined. In the visible and infrared region, second harmonic generation crystals are normally used as the nonlinear crystal and then the intensity of second harmonic light is measured by photodetectors.

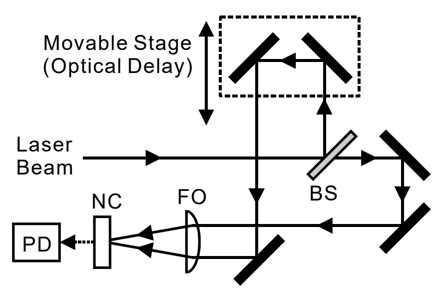

Figure 1: Schematic diagram of basic setup of the intensity autocorrelator used for laser pulse duration measurements. BS: Beam Splitter, FO: Focusing Optics, NC: Nonlinear Crystal, PD: Photodetector.

The laser pulses with the wavelength shorter than 300 nm were mainly used for photoelectron generation in photocathode RF guns. In our case, the laser wavelength is 266 nm and its second harmonic wavelength is 133 nm. The second harmonic wavelength (133 nm) is in the vac-

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uum UV region and absorption by the atmosphere is high. Therefore, it is not a good idea to use the second harmonic generation as the nonlinear phenomena for the laser beam with the wavelength of 266 nm. Therefore, TPA has been utilized as the nonlinear phenomena to measure the pulse duration of UV and DUV pulses [6, 7]. In this method, the laser beam is divided into an intense (pump) beam and a weak (probe) beam. The variation of transmittance of probe beam as the function of arrival time difference of those two pulses is recorded. In the case of TPA, the phase matching condition, which is normally required for second harmonic generation and sometimes limits the shortest pulse duration can be measured, does not need to be achieved or considered. The autocorrelation using TPA simply requires spatial overlap of pump and probe beams. Theoretical study of the TPA intensity and the measurable shortest pulse duration for various bulk materials has already been done so far [7]. Based on the theoretical study, we selected a sapphire crystal because of its high TPA intensity at DUV region and good availability.

EXPERIMENTAL SETUP

The schematic diagram of TPA autocorrelator developed for this study is shown in Fig. 2. A small fraction (around 10%) of the DUV laser beam injected to this device was reflected by a beam sampler (BS: BSF10-UV, Thorlabs) and injected to a reference detector (Ref. PD: DET25K/M, Thorlabs) to monitor the intensity of incident laser beam. The transmitted beam through the beam sampler was then injected to another beam sampler and divided into the intense transmitted (pump) and weak reflected (probe) beams. Those two beams were reflected by two mirrors and focused on a sapphire plate (SP) by a focusing lens (FL). The probe beam after passing through the sapphire plate was injected to a signal detector (Sig. PD: DET25K/M, Thorlabs). Focusing lenses were arranged in front of the two detectors to reduce the influence of the pointing instability. The laser intensity both on

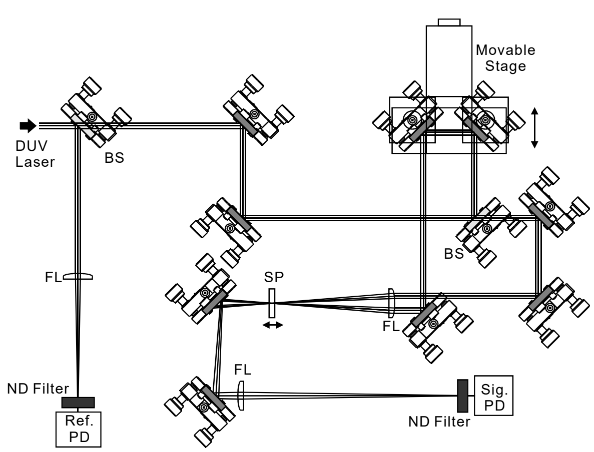

Figure 2: Schematic diagram of UV autocorrelator utilizing the two-photon absorption in a sapphire plate as the nonlinear process. BS: Beam Sampler, FL: Focusing Lens, SP: Sapphire Plate, ND: Neutral Density Filter, PD: Photodiode.

the reference and signal detectors are attenuated by ND filters to avoid saturation of those detectors. The laser intensity measured by the signal detector was divided by that measured by the reference detector to cancel out the variation of the intensity of the incident laser beam. The arrival time difference of the pump and probe pulses was varied by changing the condition of the optical delay line which was inserted in the optical path of the probe beam. The sapphire plate was placed on a linear translation stage for changing the focusing condition and the fluence of the laser beam on the sapphire plate.

RESULTS

In this study, the pulse duration of photocathode drive ps-DUV laser developed at the Institute of Advanced Energy, Kyoto University [3] was measured. The laser was developed for multi-bunch electron beam generation for oscillator FEL. The laser system was operated at the single pulse condition with the repetition rate of 2 Hz.

Before autocorrelation measurements, direct TPA of pump beam as the function of the longitudinal position of the sapphire plate was measured. The measured results for a 2-mm thick sapphire plate with the laser pulse energy of 2.5 and 18 μJ are shown in Figure 3.

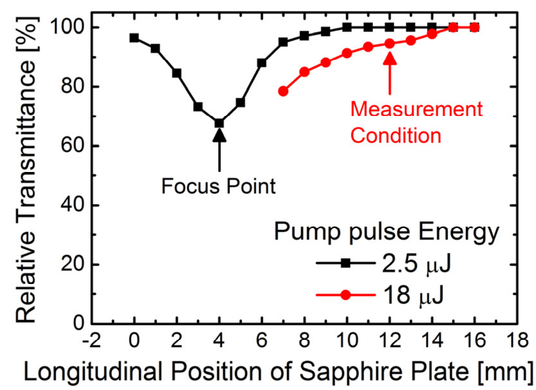

Figure 3: Variation of pump laser transmittance as the function of the longitudinal position of a sapphire plate (2 mm thick) with two different pulse energy conditions.

As one can obviously see in the figure, the relative transmittance of the pump beam strongly depended on the longitudinal position of the sapphire plate, i.e. fluence of the laser beam on the sapphire plate. The observed maximum transmittance change in the case of 2.5-μJ condition was 32% at the focus point of the DUV laser. In the case of 18-μJ condition, the ablation of the sapphire plate was observed at the focus point. The longitudinal position of the sapphire plate and the pulse energy of the pump beam in the autocorrelation measurement were adjusted to 12 mm and 18 μJ, respectively. In this condition, the sapphire plate is placed on the off focus condition to have larger laser beam size and to ease the difficulties of spatial overlap of pump and probe pulses.

For autocorrelation measurements, the probe beam position was adjusted to have the largest TPA of the probe

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beam at the zero delay condition of the pump and probe pulses. After the good overlap of the pump and probe pulses were achieved, TPA autocorrelation measurements were performed. The typical result for a 2-mm thick sapphire plate is shown in Fig. 4. The least square fitting of measured autocorrelation trace with the Gaussian function was performed and then the width of autocorrelation trace was determined as 9.9 ps-FWHM. The laser pulse duration was evaluated as 7.0 ps-FWHM with the assumption of the Gaussian laser pulse shape, i.e. the conversion factor of $1/\sqrt{2}$. Same measurements were performed for sapphire plates with the thickness of 1 and 0.5 mm. For each condition, measurements were performed 5 times to check the reproducibility. The measured pulse durations were summarized in Fig. 6 and Table 1. The data points represent the averaged value of 5-times measurement and the error bars represent the standard deviation of 5-times measurement.

The shortest measured result (5.8 ± 0.2 ps-FWHM) was obtained when the 1-mm thick sapphire plate was used. In the case of 0.5-mm sapphire plate, the measured pulse duration was longer than that with the 1-mm plate. And the reproducibility was poor. It was because of low signal to noise ratio and weak TPA in the sapphire plate. The result with the 2-mm thick sapphire plate was 1 ps longer than the 1-mm thick one. The previous theoretical study [6] reported that the measurable shortest pulse duration with a 200-μm sapphire plate at the wavelength of 266 nm was around 15 fs. Then the measurable shortest pulse duration for a 2-mm thick sapphire plate expected to be 150 fs. Our result was not consistent with the theoretical expectation. In the theoretical work, only a pulse elongation effect due to the dispersion inside in the sapphire was taken into account. For thicker sample and/or longer pulse duration, additional side effects may limit the performance of the TPA autocorrelator.

The obtained pulse duration (5.8 ± 0.2 ps-FWHM) was slightly shorter than the designed pulse duration (7.5-ps FWHM) of $Nd:YVO_4$ mode-locked oscillator which used in the laser system [3]. The pulse duration could be shortened by wavelength conversion from NIR to DUV using second and fourth harmonic generation crystals.

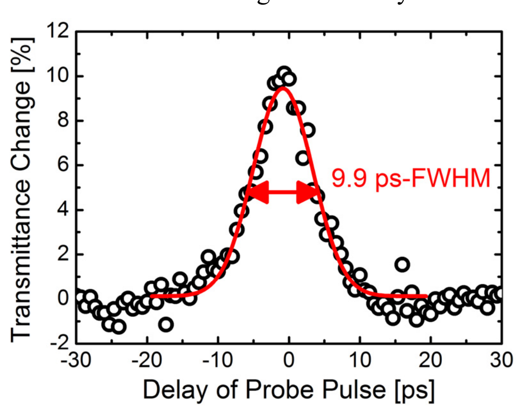

Figure 4: Typical measured results of autocorrelation measurement of DUV ps-laser at the Institute of Advanced Energy, Kyoto University.

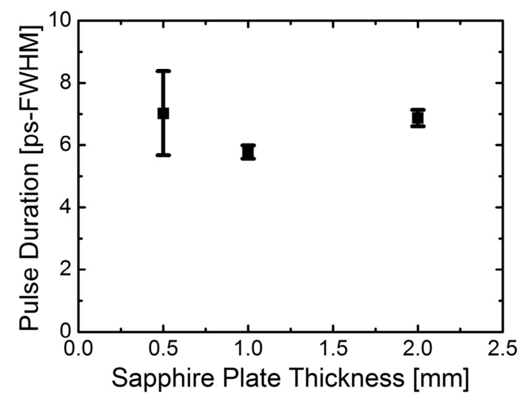

Figure 5: Measured pulse duration of ps-DUV laser with different thickness of the sapphire plates.

Table 1: Measured pulse duration of ps-DUV laser with different thickness of the sapphire plate

Thickness of Sapphire Plate	Measured Pulse Duration
0.5 mm	7.0 ± 1.3 ps
1.0 mm	5.8 ± 0.2 ps
2.0 mm	6.8 ± 0.3 ps

SUMMARY

In order to measure the pulse duration of DUV laser pulse used for driving photocathode RF guns at the Institute of Advanced Energy, Kyoto University, an autocorrelator utilizing the two-photon absorption has been developed. The DUV laser pulse duration was measured as 5.8 ± 0.2 ps-FWHM by using the sapphire plate with the thickness of 1 mm as the two-photon absorbing material at the wavelength of 266 nm. The measured pulse duration was slightly shorter than the specification of mode-locked $Nd:YVO_4$ oscillator (7.5 ps-FWHM). The wavelength conversion from NIR to DUV using second harmonic and fourth harmonic generation crystals may cause the pulse shortening.

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