DIRECT DIAGNOSTIC TECHNIQUE FOR A HIGH INTENSITY LASER BASED ON LASER COMPTON SCATTERING*

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Abstract

In laser produced plasma (LPP) EUV source, high intensity pulse CO_2 laser is essential for plasma generation. To achieve high conversion efficiency and stable EUV power, we would like to measure laser profile in collision point and make feedback system. There is no way to directly measure a high intensity laser profile at the focus point. Therefore, we have been developing laser profiler based on laser Compton scattering. Laser profile can be measured by scanning focused electron beam while measuring Compton scattering signal. We use compact electron accelerator based on Cs-Te photocathode RF gun at Waseda university. Electron beam is focused by solenoid lens. We simulated beam size using GPT, obtained beam size of 10 μm rms. We measured beam size by Gafchromic film HD-810. We have succeeded in observing minimum beam size of about 20 μm rms. In this conference, we will report result of simulation, beam size measurements, and the present progress.

INTORODUCTION

Extreme ultraviolet lithography (EUVL) is the next generation lithography for integrated circuit fabrication at 22nm half pitch mode [1]. In EUVL, several 100W EUV light is based on Sn plasma produced by CO_2 laser. CO_2 laser is required more than 100 kHz repetition rate, 200 mJ, 100 μm spot size and 10 ns pulse duration. To achieve high conversion efficiency and stable EUV power, we would like to measure laser profile in collision point and make feedback system. However, there is no way to directly measure such high power laser profile.

We have been developing laser profiler based on laser Compton scattering (LCS). Laser profile can be measured by scanning focused electron beam while measuring Compton scattering signal. If both laser and electron beam have a gaussian distribution, the observed profile of Compton signal as a function of electron position is a gaussian distribution. Observed rms width can be written down as;

$$\sigma = \sqrt{\sigma_{\text{laser}}^2 + \sigma_{\text{electron}}^2} \tag{1}$$

where σ_{laser} is the laser beam size, σ_{electron} is the electron beam size. If the electron beam size is much smaller than that of laser, the observed profile would be equivalent to the laser profile. To scan electron beam from various direction and reconstruct image used CT technique, we can obtain 2D laser profile.

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Focused electron beam is a key issue of this method. The more electron beam is focused, the higher resolution laser profile we can obtain. To achieve small beam spot, we use low emittance electron accelerator and special design solenoid lens. In this paper, we discuss GPT simulation and results of beam size measurement by Gafchromic film.

ACCELERATOR SYSTEMS

A photocathode rf gun is one of the most high quality electron source. Because of high gradient electric field on the cathode, it can generate small emittance beam. At Waseda university, we have been performed the high quality electron beam generation and applied research experiments, such as laser Compton soft-Xray generation [2] and pulse radiolysis [3].

The cavity structure is based on the design of the BNL Type IV, which have 1.6 cell structure. The rf frequency is 2856 MHz. The cavity is able to produce low emittance beam with 5 MeV beam energy. We use Cs-Te photocathode which have a high quantum efficiency and achieve 1 nC / bunch. The seed laser is Nd:YLF mode lock oscillator with 119 MHz frequency. We use LN intensity modulator to pick pulse train, it chooses the number of pulses from 1 pulse to 100 pulses. The pulse trains are amplified by Yb fiber amplifier and LD pumped amplifier 4 pass system. After two amplifications, IR pulses are converted to UV pulses by two nonlinear doubling crystals.

The experiment set up is shown in Fig. 1. There are beam diagnostic instruments. A current transfer measure beam charge and pulse train stability. Alumina fluorescent plate (Demarquest Co.) beam profile monitor is located behind solenoid magnets. 45 degree bending magnet is used for energy measurement. Our accelerator system is characterized it's small structure, the total length is less than 3 m.

For this experiment, we designed new solenoid lens. The

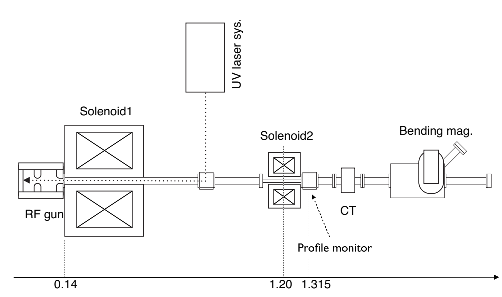

Figure 1: Schematic design of Waseda beam line.

lens shape and magnetic field was studied POISSON simulation code. The magnetic field calculated by POISSON and measured is shown in Fig. 2. Position is axis of beam traveling direction. To focus 5 MeV electron beam, we designed to achieve that a maximum magnetic strength is 0.6 T.

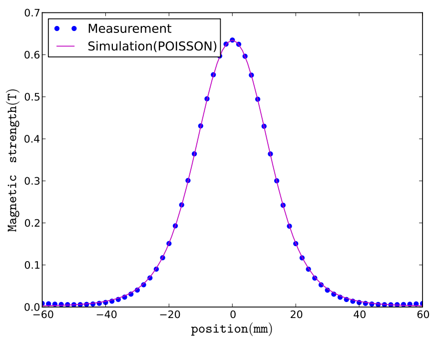

Figure 2: Magnetic field of Solenoid 2.

BEAM TRACKING BY GPT

We calculated focused electron beam by General Particle Tracer (GPT) [4]. The field of rf cavity and solenoid magnets were calculated by SUPERFISH and POISSON. Parameters of GPT are shown in Table 1. Number of particles seems very little, but there are no significant deference in results of beam size and emittance. Therefore, we used results of 1k data to optimize beam parameters and solenoid lens strength.

Figure 3 show beam size as a function of distance from cathode. The rf cavity accelerate the beam, and the emittance growth is controlled by Solenoid 1. The new solenoid lens, Solenoid 2, is placed 1.2 m downstream. It strongly focus the beam, Fig. 3 show the beam was focused to 15 μm at the position of 1.314 m.

Table 1: Parameters of GPT Simulation

Number of particles	1000
Space Charge	3D
Charge	50pC
Electric filed at cathode	100MV/m
Initial laser spot size	0.3 mm
Solenoid 1 strength	0.13 T
Solenoid 2 strength	0.5 T

Figure 4 show beam size at the focus point as a function of Solenoid 2 strength. The smaller beam spot is achieved as strong magnetic strength. On the other hand, a strong focusing make short focus distance and short focus spot. These characterization are obstacle to focus on the collision point.

Beam size and emittance versus beam charge is shown in Fig. 5. Smaller beam spot is also available by lower charge. 10 μm beam spot was achieved with 50 pC beam charge. In LCS, Compton signal flux depends on electron beam charge and laser intensity. Smaller beam spot and higher beam current are need, it is a contradictory demand. We plan to operate 50 $\sim$ 100 pC beam charge at LCS experiment. In this situation, calculated photon number is 8×10^4 photons / pulse, which is large enough for detecting LCS signal.

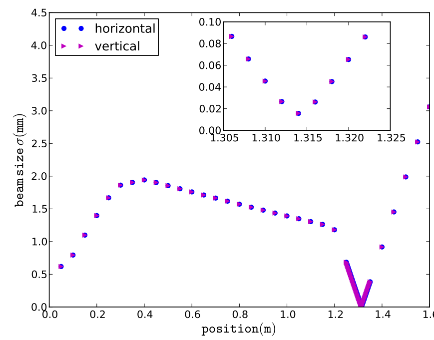

Figure 3: Beam size as a function of distance from cathode.

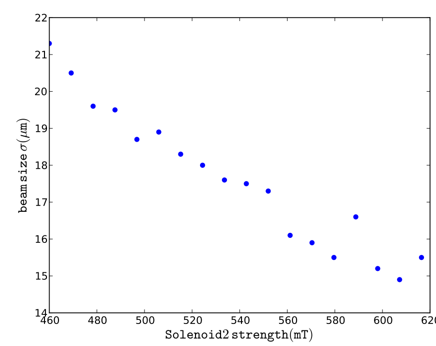

Figure 4: Beam size as a function of Solenoid 2 strength.

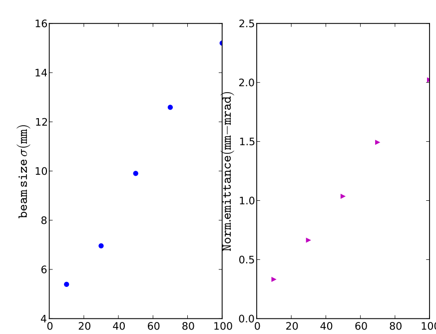

Figure 5: Beam size (left) and normalized eimttance (right) as a function of beam charge.

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BEAM SIZE MEASUREMENT

Gafchromic Film

Gafchromic radiochromic film [5] is used for measuring a beam intensity distribution. The film is discolored by ionizing beam irradiation. We choosed HD-810, this film is commonly used for the measurement of absorbed dose of high energy photons. First, we calculated divergence of electron beam in HD-810 by Monte Carlo simulation code EGS5. The results show the beam was't expanded in active layer (6.5 μm thickness).

Optical density (OD) of HD-810 was measured by a cold CCD camera. For the dose calibration, we irradiated electron beam with various irradiation time. Figure 6 show the result, and we used this calibration curve for beam size measurements.

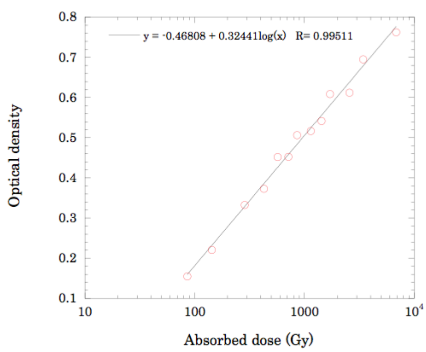

Figure 6: Calibration curve of HD-810 film.

Beam Size Measurement

We measured focused beam size by HD-810. The beam profile measured by HD-810 is shown in Fig. 7, focused beam size as a function of Solenoid 2 strength is shown in Fig. 8. The plots of Fig. 8 show average size of 3 measurements. In this experiment, the beam was 50 pC, 3.5 MeV and the irradiation time was 1 s. We achieved about 20 μm spot size. This results show our accelerator system fulfills the demand for high intensity laser profiler.

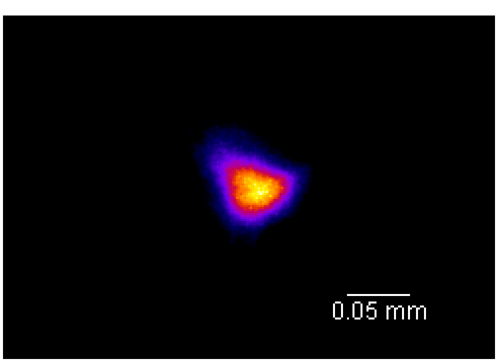

Figure 7: Beam profile measured by HD-810 film.

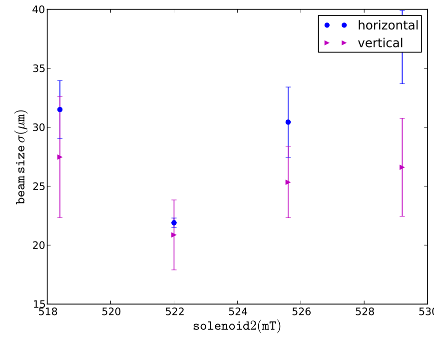

Figure 8: Beam size as a function of Solenoid 2 strength.

CONCLUSION

At Waseda university, we have been developing laser profiler based on LCS. Laser profile can be measured by scanning electron beam while measuring Compton scattering signal. Focused electron beam is a key issue of this method, so we designed new solenoid lens and measured beam size using HD-810. We achieved beam size of 20 μm, this is satisfactory beam size for laser profiler.

To produce small beam size, we have to operate with low beam charge. Therefore, we plan a multi bunch generation to 1 pulse of CO_2 laser. Our seed laser repetition rate is not satisfied this concept, so we will use optical delay line to change repetition rate. The UV pulse separate by PBS, and the pulse which is leaded to optical delay line return the initial line with 350 ps (2856 MHz) delay time.

We are preparing high repetition system, pulse CO_2 laser and the spectroscope to detect Compton scattering signal. In this winter, LCS experiments will be held to obtain CO_2 laser profile.

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[2] K. Sakaue, et al., Radiat. Phys. Chem. 77 (2008) 1136-1141

[3] Y. Hosaka, et al., Radiat. Phys. Chem. 84 (2013) 10-13

[4] General Particle Tracer; `http://www.pulsar.nl/gpt/`

[5] Gafchromic film; `http://www.gafchromic.com/`