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DIRECT HIGH POWER LASER DIAGNOSTIC TECHNIQUE BASED ON FOCUSED ELECTRON BUNCH*

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Abstract

In laser produced plasma EUV source, high intensity pulse CO_2 laser is essential for plasma generation. To achieve high conversion efficiency and stable EUV power, we desire to measure laser profile at the collision point. However, focused laser profile has not been observed directory by existing techniques. 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. This method is suitable for a high intensity laser, but very small spot size of electron beam is required. To achieve small spot size, we use S-band photocathode rf gun and specially designed solenoid lens. The beam size was simulated by General particle tracer (GPT) and directory measured by Gafchromic film HD-810. We have succeeded in observing minimum beam size of about 20 µm rms. We are preparing beam scanning system, pulse CO_2 laser and a detector for Compton signal. In this conference, we will report the results of focused electron beam measurement and future prospect.

INTRODUCTION

Extreme ultraviolet lithography (EUVL) is next generation lithography for integrated circuit fabrication at 22nm half pitch mode [1]. It use 13.5 nm light and is cost-effective method of producing integrated circuit. In EUVL, several 100 W EUV light is produced by Sn plasma of CO_2 laser irradiation. 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 at the collision point. However, focused laser profile has not been observed directory by existing techniques.

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

$$\sigma = \sqrt{\sigma_{\text{laser}}^2 + \sigma_{\text{electron}}^2} \quad (1)$$

where σ_{laser} is the laser beam size, σ_{electron} is the electron beam size. To scan electron beam from various direction and reconstruct image used CT (Computed Tomography) technique, we can obtain 2D laser profile.

A small spot size of electron beam is required for this method. The more electron beam is focused, the higher resolution laser profile we can obtain. In addition, we need high energy and high charge electron beam to detect enough LCS signal. We use low emittance electron accelerator and specially designed solenoid lens, it is able to produce 5 MeV energy and 20 µm spot size. In this paper, we discuss focused electron beam generation, scanning system and future prospect.

ACCELERATOR SYSTEMS

At Waseda university, a S-band photocahode rf gun have been developed. Because of high gradient of electric field on the photocathode, it can generate small emittance and short bunch length electron beam. We have been performed the high quality electron beam generation and applied research experiments, such as laser Compton scattering X-ray generation [2] and pulse radiolysis [3].

The cavity structure is based on BNL-Type IV design. We have been improved the structure to achieve a higher Q value and reduce dark current [4]. The rf frequency is S-band 2856 MHz. The cavity is able to produce low emittance beam with 5 MeV beam energy. We use Cs-Te photocathode which has quantum efficiency of about 0.1 %. It can generate electron beam with 1 nC/pulse. The seed laser is Nd:YLF mode lock oscillator with 119MHz repetition rate. The generated IR pulse laser is picked by LN intensity modulator which chooses the number of pulses from 1 pulse to 100 pulses. The picked pulse trains are amplified by Yb fiber amplifier and LD pumped 4-pass amplifier system. After two stage amplifications, IR pulses are converted to UV pulses by LBO (SHG) and BBO (FHG) crystal.

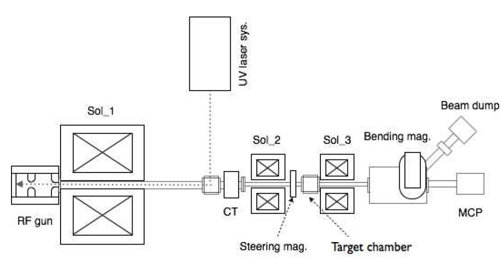

Figure 1: Schematic design of Waseda beam line.

The experimental setup is shown in Fig. 1. The setup consists of the rf gun, the pulse UV laser system, various magnets and diagnostic tools. Our accelerator system is quite compact, the total length is less than 3 meter. At the exit of the gun, the solenoid (Solenoid1) is located to compensate emittance growth. Solenoid2 focuses electron beam

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to the collision point, and Solenoid3 refocuses the beam to lead beam dump after 45 degree dipole magnet. A current transformer measure beam charge and pulse train stability. The beam energy is measured by dipole magnet and beam position monitor. Three alumina fluorescent plate (Demarquest Co.) profile monitors and steerings are located to guide the beam.

FOCUSED BEAM GENERATION

The GPT Simulation

For this experiment, we designed new solenoid (Solenoid2, Solenoid3). The solenoid shape and magnetic field was studied POISSON simulation code. To focus 5 MeV electron beam, we designed to achieve that a maximum magnetic strength is 0.6 T.

A simulation model of the accelerator has been constructed by the 3D space charge code General Particle Tracer (GPT) [5] to optimize various parameters. The field of rf cavity and solenoid were calculated by SUPPERFISH and POISSON. Figure 2 shows the beam size as a function of a distance from the cathode. Table 1 shows the parameters of this simulation. Solenoid2 strongly focuses the beam, the beam was focused to 15 µm at 1.274 m. The beam after focus point was refocused by Solenoid3 to maintain the beam size. Solenoid3 plays a significant role for a background reduction in LCS experiment.

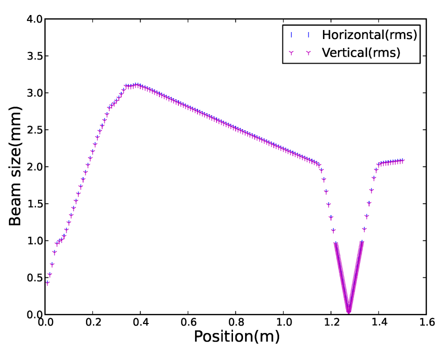

Figure 2: Beam size as a function of distance from the cathode.

Table 1: Parameters of GPT Simulation

Number of particles	1000
Space Charge	3D
Charge	50 pC
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
Solenoid 3 strength	0.5 T

Measurments

Gafchromic radiochromic film [6] was used for measuring the beam intensity distribution. The conventional beam size measurement method for such a small beam is OTR method, but our electron beam is not able to generate enough radiation. The film is discolored by ionizing beam irradiation. We chose 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 that the beam wasn't expanded much in active layer (6.5 µm thickness). Optical density (OD) of HD-810 was measured by a cold CCD camera. For dose calibration, we irradiated electron beam with various irradiation time, and we use the calibration curve for beam size measurements [7].

We measured focused electron beam size by HD-810. The beam profile measured by HD-810 is shown in Fig. 3. Figure 4 show beam size as a function of Solenoid2 strength. The plots of Fig. 4 show average size of three measurements. The beam was 50 pC, 3.5 MeV and the irradiation time was 1 s. We achieved about 20 µm spot size. This result shows that our accelerator system successfully achieved an electron beam required for high power laser profiler.

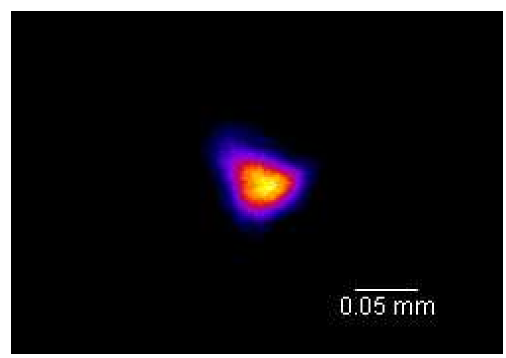

Figure 3: Beam profile measured by HD-810 film.

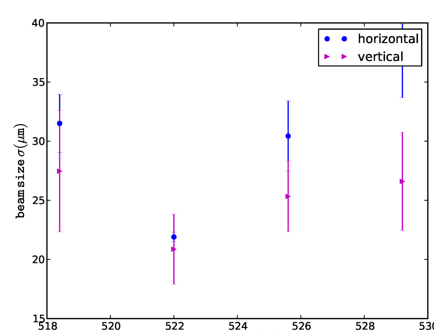

Figure 4: Beam size as a function of Solenoid2 strength.

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SCANNING SYSTEM

As preliminary experiments of LCS, we operated metal wire scanning using focused electron beam. The distribution of bremsstrahlung from a collision of electron beam and metal wire is a convolution of electron beam profile and metal wire profile. We used the steering located between Solenoid2 and the collision point to scan electrons on the metal wire. The steering strength is 117 μA. A material of the metal wire is aluminum. It is 1mm radium and cut off a quarter of the circle. We desired our system is able to reconstruct this asymmetrical wire shape. We scanned the wire from two direction (wireA and wireB), tried to reconstruct two thickness distributions. The thickness distribution of wires are shown in Fig. 5.

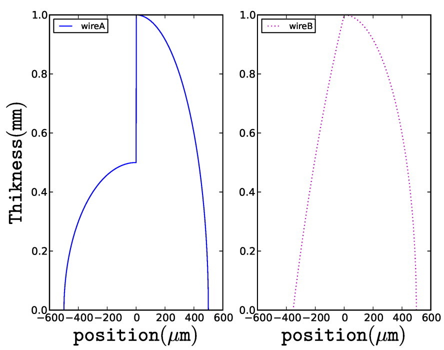

Figure 5: Thickness distribution of metal wires.

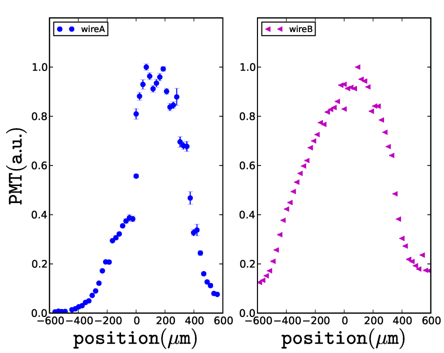

Figure 6: PMT signal distribution of metal wires.

The photomultiplier tube (PMT) with LYSO scintillator was measured the intensity of bremsstrahlung. Figure 6 show PMT signal distribution as a function of electron beam position. Compared Fig. 5 with Fig. 6, our electron beam scanning system achieved to reconstruct asymmetrical 1mm radium wire shape. However, there are differences where the wire thickness is deep. The reason of this difference was the electron beam energy. The beam energy was not enough for 1 mm metal wire. This is the particular problem of metal wire, and does not affect LCS experiment.

From this result, the scanning electron system will be able to measure high power CO_2 laser. We are preparing more thin wire and accurate rotation system for metal wire, and try to reconstruct 2D wire shape.

CONCLUSIONS

At Waseda university, 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. The electron bunch is generated by photocathode rf gun and focused by the solenoid. We achieved a beam size of 20 μm, this is satisfied beam size for laser profiler. Electron beam scanning system has been installed. We operated metal wire scanning using the focused beam to evaluate our system. The asymmetrical wire profiles were measured based on bremsstrahlung. This result indicated that our scanning electron beam system will be able to measure high power laser.

We have already installed a micro channel plate (MCP) which can detect Compton scattering photons. A background reduction is performed while observing MCP signal. LCS experiments will be carried out to obtain CO_2 laser profile in near future.

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