# DIRECT DIAGNOSTIC TECHNIQUE OF HIGH-INTENSITY LASER PROFILE BASED ON LASER-COMPTON SCATTERING*

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*Abstract*

A high-intensity laser is essential for plasma generation for EUV (Extreme Ultraviolet) lithography, which is studied as the next generation of ultra-fine semiconductor lithography. Nevertheless, there is no way to directly measure profile of high-intensity laser at the present day. Therefore, we have been developing a method for measuring high-intensity laser profile based on the laser-Compton scattering using Cs-Te photo cathode RF-Gun at Waseda University. Specifically, laser profile is obtained by scanning the electron beam which is focused to about 10 µm by solenoid lens. We have simulated beam size focused by solenoid lens using tracking code GPT (General Particle Tracer) and optimized the beam parameter to obtain beam size of 10 µm. Then, we have installed solenoid lens and generated focused beam. We measured beam size using radiochromic film called GAFCHROMIC dosimetry film type HD-810. In this conference, we will report the result of GPT simulations, beam size measurements, the present progress and future prospects.

## INTRODUCTION

The lithography light source at 13.5nm called EUV (Extreme Ultraviolet) is required by semiconductor industry as a next generation lithography technique. LPP (Laser Produced Plasma) is one of the techniques for generating EUV [1]. In LPP technique, EUV is generated by Tin plasma which is produced by high-intensity $CO_2$ laser collided with Tin droplet. In order to increase and stabilize the conversion efficiency of EUV, it is important to measure high-intensity laser spot profile and position stability at focus point for precision laser alignment. However, direct diagnostics technique of such a high-intensity laser profile is not achieved by the recent technology. Under the circumstance, expanded profile high-intensity laser profile is measured by using lenses instead of direct diagnostics of profile. Otherwise, we extracted a part of the laser beam and measured it instead of the real profile. Nevertheless such profiles are different from the profile at the focus point because of thermal lens effect.

Therefore, we have been developing a technique for measuring high-intensity laser profile directly based on the laser-Compton scattering by using Cs-Te photo cathode RF-Gun at Waseda University. Specifically, focused electron beam of about 10 µm size scans laser with laser-Compton scattering photons emitted. It is possible to measure high-intensity laser profile directly by measuring the scattering photons distribution because the intensity of laser-Compton scattering photons is in proportion to intensity of laser and bunch charge of electron beam (This technique is like SEM techniques). The schematic design of diagnostic technique of laser is shown in Fig.1. This technique is fitted for measuring high-intensity laser profile because higher intensity laser generates a large amount of scatted photons.

Furthermore, if we scanned the electron beam from various directions by rotating laser, the 2D laser profile can be obtained like a CT (Computed Tomography) image.

In order to achieve this concept, we need to develop three systems; (1) generating focused beam size of about 10 µm by using solenoid lens, (2) scanning electron beam system (3) detection system of scatted photons. In this conference, we will report about generating focused beam.

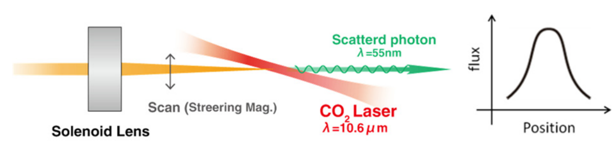


Figure 1: Schematic design of direct diagnostic technique of laser.

## BEAM SIZE SIMULATION

### *Photo Cathode RF-Gun System*

The electron beam is generated from photo-cathode RF-Gun at Waseda University, which is low emittance, thus it can be focused to extremely small spot. The schematic design of RF-Gun system is shown in Fig.2. RF-Gun is composed of BNL type 1.6 cells cavity. The electron beam is emitted from Cs-Te cathode by the irradiation of UV laser light. The pulse repetition frequency of laser is synchronized with accelerating RF. UV laser is generated from IR laser by using two nonlinear optical crystals. The parameters of RF-Gun and laser system are listed in Table 1 [2]. Solenoid lens 1 is used for emittance compensation and solenoid lens 2 is used to focus the beam stlongly.

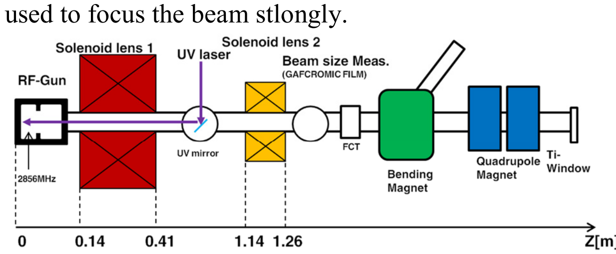


Figure 2: Schematic design of beamline.

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Table 1: The Parameter of RF-Gun System

| | |
|---|---|
| Wavelength of UV laser | 262 [nm] |
| Repetition Rate of RF | 2856 [MHz] |
| Bunch charge | ~1 [nC/bunch] |
| Maximum bunch number | 100 [bunches] |
| Maximum energy | ~5 [MeV] |

We have simulated electron beam size which is focused by solenoid lens using beam tracking code GPT (General Particle Tracer) [3]. We have modelled beam line of photo cathode RF-gun at Waseda University in GPT. Electron beam is emitted from cathode at z=0 m, solenoid lens 1 is located at the position of z=0.15 m and solenoid lens 2 is located at the position of z=1.14 m. Fig.3 shows evolution of the normalized emittance and the rms beam size along the beam line (*i.e.* z-position). Parameters used in this simulation are summarized in Table 2. The results show solenoid lens 1 is used for suppression of normalized emittance and solenoid lens 2 is used to focus the beam strongly.

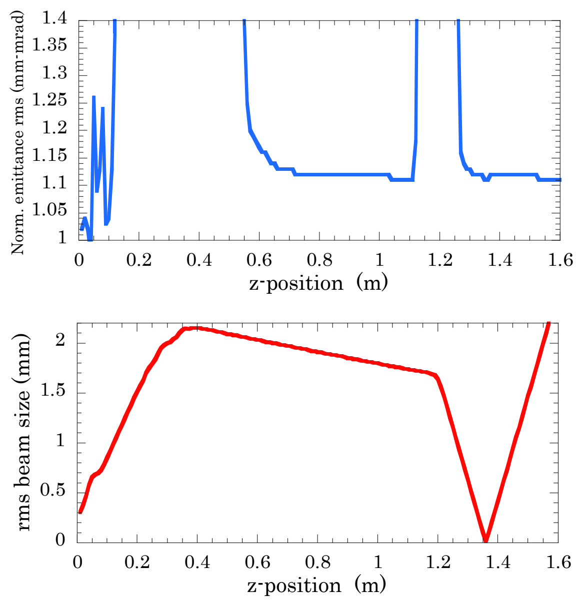


Figure 3: Simulated normalized emittance (upper plot) and rms beam size ( bottom plot) along the beam line.

Table 2: Parameters of This Simulation

| | |
|---|---|
| Number of particles | 1000 |
| Space charge model | 3D |
| Bunch charge | 50 [pC/bunch] |
| Electric field at cathode | 100 [MV/m] |
| Initial bunch length | 4.25 [ps] |
| rms laser spot size | 0.3 [mm] |
| Magnetic field strength of solenoid lens1 | 0.13 [T] |
| Magnetic field strength of solenoid lens2 | 0.5 [T] |

## *Dependence of Beam Size on Solenoid Lens 2*

We have simulated the dependence of rms beam size on magnetic field strength of solenoid lens 2. In this simulation, we have adopted the z-position by adjusting to minimize the beam size in each plot (The focal distance decreases as magnetic field strength increases). Fig.4 shows the result of this simulation. The result shows that beam size becomes smaller as magnetic field strength increases.

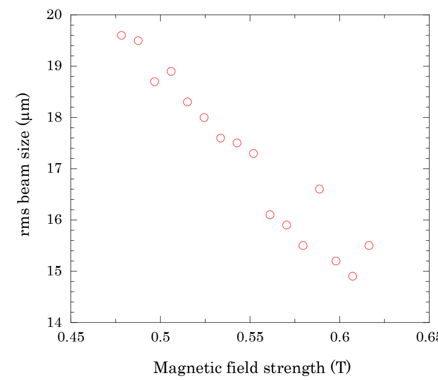


Figure 4: Simulated dependence of rms beam size on magnetic field strength of solenoid lens 2.

## *Bunch Charge Versus Beam Size*

We have simulated the dependence of normalized emittance and rms beam size on charge of electron beam. The results are shown in Fig.5. In each plot, the parameters are optimized to minimize beam size at the focal distance. Both beam size and normalized emittance increase linearly as charge increases. We found that charge of 50 pC is required in order to achieve σ=10 μm.

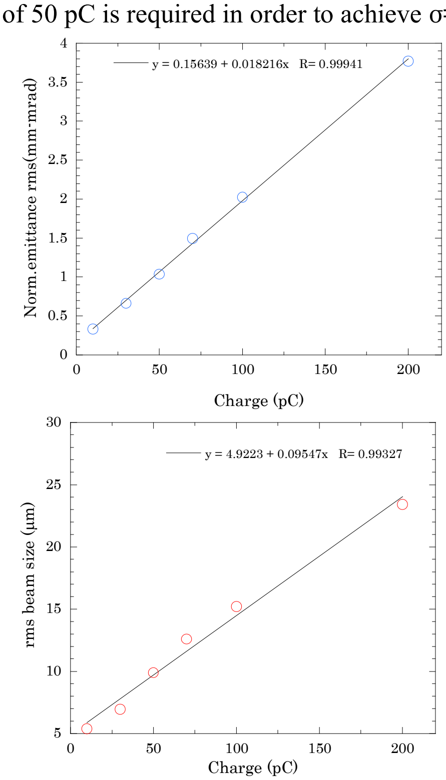


Figure 5: Simulated the dependence of normalized emittance (upper plot) and rms beam size on charge of electron beam (bottom plot).

## BEAM SIZE MEASUREMENT

### *GAFCHROMIC FILM*

In order to measure very small beam size even in low charge and low energy beam, we used GAFCHROMIC rtdeHD-810 radiochromic film (ISP) [4] which changes into blue by ionizing beam irradiation. We simulated the divergence of electron beam in the film using Monte Carlo simulation code EGS5. According to the result, we have confirmed that electron beam didn't spread in the active layer of the film (thickness=6.5 µm). For this reason, we can measure such small beams.

We have fixed the film to the linear feed through.

Optical Density (O.D.) of the irradiated film was measured with cooled CCD camera through a band pass filter. The film was placed on the white light illuminator in the dark box during measurement. For the dose calibration, we measured various O.D. films (*i.e.* various irradiation time). The dose rate was 28.6 Gy/sec at the Ti window. The calibration curve is shown in Fig.6, and we used it to converted O.D. into Gy.

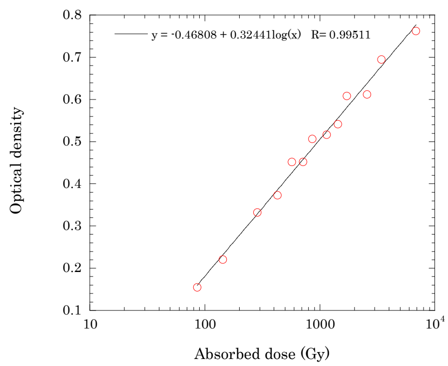


Figure 6: The calibration curve of HD-810 film.

### *Beam Size Measurements*

We have measured beam size which is focused by solenoid lens2 using photo cathode RF-Gun at Waseda University.Figure7 shows the beam profile measured by GAFCHROMIC FILM.Fig.8 shows measured rms beam sizes with various magnetic field strength of solenoid lens 2.We have succeeded in observing small beam with rms size of about 20 µm.

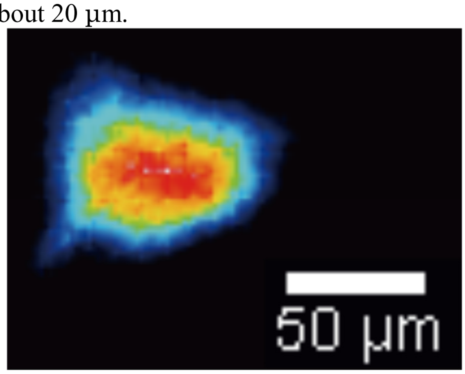


Figure 7: The focused beam profile measured by GAFCHROMIC FILM.

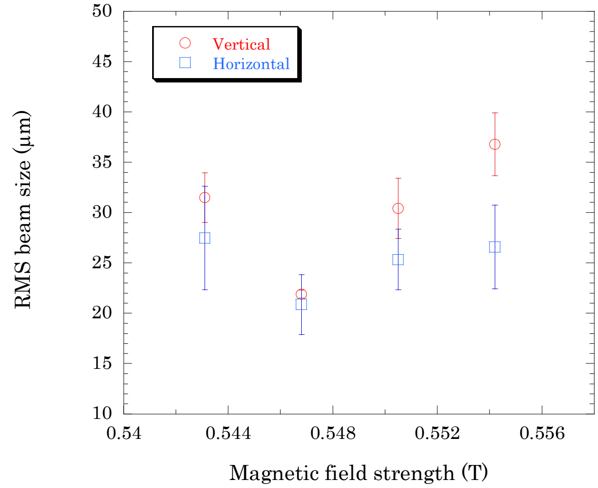


Figure 8: Measured rms beam sizes with various magnetic field strength.

## CONCLUSIONS AND PROSPECTS

We have begun to develop a technique for measuring high-intensity laser profile based on the laser-Compton scattering using photo cathode RF-Gun at Waseda University. The results of simulation show that it is possible to generate beam size of about 10µm by using solenoid lens2 with bunch charge of 50 pC/bunch. Moreover, we have succeeded in observing small beam with rms size of about 20 µm by using the GAFCHROMIC FILM.

We are planning to measure profile of the thin metal-wire as a preliminary experiment instead of measuring laser profile. As a result of our studies, the charge of electron beam would be 50 to 100 pC in order to achieve small beam size. However, such a low charge will decrease the number of scattered photons. In this background, we will use multi-bunch electron beam with very short bunch spacing. Moreover, we will obtain the 2D laser profile by rotating laser like a CT technique in near future.

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