MULTI-DIAGNOSTIC TRANSVERSE PROFILE MONITOR CHAMBER FOR EXTREME ULTRAVIOLET LITHOGRAPHY*

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Abstract

RadiaBeam Technologies has developed a compact transverse beam profile measurement system for the Extreme Ultraviolet Lithography (EUL) experiment at the Brookhaven National Laboratory-Accelerator Test Facility (BNL-ATF). The EUL experiment requires fine e-beam and laser alignment across multiple passes. To accomplish this, the system consists of four profile monitor diagnostics: Interaction Point (IP), upstream, downstream, and a sub-micron resolution diagnostic 11.5 mm downstream of the IP. Care was taken in the design to minimize footprint, avoid possible diagnostic collisions, and maximize ease of assembly and alignment. This paper will review the requirements for the dimensional and optical constraints and solutions for this experiment.

INTRODUCTION

Extreme ultraviolet sources in the 7-15 nm range are needed for next-generation integrated circuit fabrication [1]. High quality sources in this range are large and cumbersome and therefore difficult to implement in an industrial setting. Inverse Compton Scattering (ICS) sources, such as the proof-of-concept EUL experiment at BNL-ATF, promise a smaller footprint per photon. In this scheme, a recirculated pulsed CO_2 laser is collided head-on with a 60-MeV electron beam, producing a higher-energy 13-nm photon. Both the laser and electron beam are focused to 50 µm or less at the IP with a minimized electron beam spot size of 22 µm measured.

CHAMBER DESIGN

Four different beam diagnostics are needed to monitor a 50-µm RMS beam size at the IP. They need to fit between two opposing, off-axis parabolic mirrors arranged equidistant from the IP focus which are used to focus and re-collimate the laser. The required separation distance is 120 cm, which caused a particularly challenging limitation for fitting in so many diagnostics. The parabolic mirrors are placed inside larger chambers upstream and downstream of the multi-diagnostic assembly. These three chambers are kept separate for ease of installation and serviceability in the experimental hall (see Figure 1).

Dual Position Profile Monitors

To monitor the transverse profile of the beam, both cerium-doped yttrium aluminum garnet (YAG:Ce) crystals and aluminum-coated silicon wafers are used as optical transition radiation (OTR) screens and are placed in the upstream and downstream profile monitors. Both the OTR and YAG screens are 100 µm thick and placed perpendicular to the electron beam on a multi-position pneumatic actuator. Each screen is backed by a 45° turning mirror (an aluminized silicon water) and viewed by CCD cameras through viewports, allowing for uniform magnification across the screen surface. These upstream and downstream profile monitors are mounted on pneumatic actuators to allow for high (25 µm) repeatability and fast extraction from the beam path (see Figure 2 and Table 1).

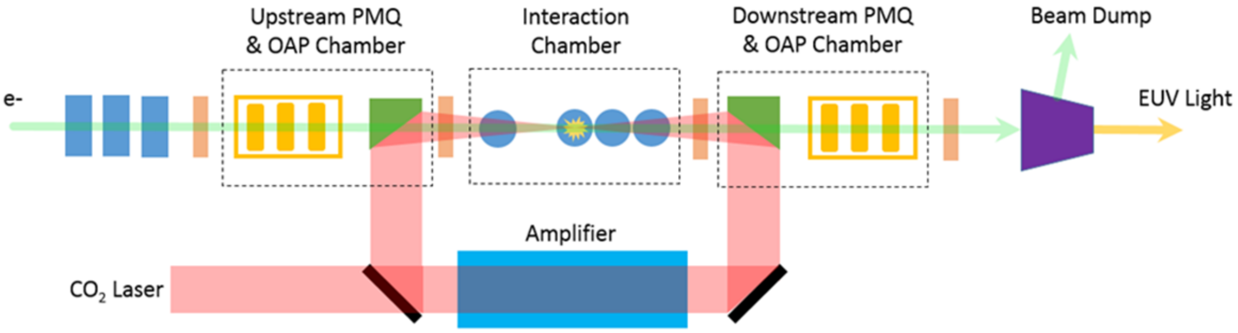

Figure 1: Full EUL Experiment including upstream quadrupole triplet (blue) and steering magnets (Orange).

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*Work supported by DOE SBIR Grant No DE-SC0007703
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ISBN 978-3-95450-176-2

Germanium Target and Pinholes

A 500-µm thick germanium OTR target is installed at the IP at a 45-degree angle to align the CO_2 laser. In addition, germanium was chosen to synchronize the electron and CO_2 beam. The 10.6 µm wavelength normally passes through the germanium. However, the passing electron beam produces a plasma at the germanium surface that the 10.6 µm radiation cannot penetrate. Measuring the reflected CO_2 laser power and adjusting a delay stage allows synchronization of the CO_2 laser and electron beam. Below the germanium wafer, a pinhole array is mounted perpendicular to the beam for precise alignment. The pinhole array is made of 1-mm thick tungsten and contains five pinholes of progressively decreasing diameter: 500 µm, 350 µm, 250 µm, 225 µm, and 200 µm. The laser and electron beam trajectory are passed through progressively smaller pinholes while transmission is monitored, allowing a straightforward method of alignment.

The pinhole array is adjustable in three dimensions (insertion, horizontal, and tilt) so that the pinhole array can be aligned to the ideal orbit defined by the permanent magnet triplet. A stepper motor actuator controls the insertion position while also allowing cycling through the different pinholes. Horizontal motion is adjustable using a manual micrometer mounted to a commercially available gimbal. The gimbal was modified in-house to fit the tight space requirements of this experiment.

The tilt motion is controlled by a fine adjustment screw mounted in a locking sleeve. This linear shift provides the fine positioning required to align the pinholes to the beam axis with a resolution of 1 µm. Although tilt motion is available, it was not used since the motion is not gimbaled about the beam and therefore couples to vertical (insertion) position.

Once the CO_2 and electron beam are aligned to the largest pinhole, the next smaller pinhole is inserted, thus increasing the alignment accuracy.

Table 1: Diagnostic Type, Location, and Purpose

Type	**Distance from IP**	**Purpose**
YAG & OTR target	85.7 mm upstream	Measure transverse profile
Germanium target & Pinholes	IP	CO_2 laser optics and e-beam positioning
High Resolution OTR target	11.5 mm downstream	Sub-micron transverse profile measurement
YAG & OTR target	85.7 mm downstream	Measure transverse profile

High-Resolution Profile Monitor

The high-resolution profile monitor consists of an OTR target mounted at 45 degrees to the beam, a 10x magnifying in-vacuum microscope objective (NA = 0.25), a re-entrant style viewport, and out-of-vacuum imaging optics mounted inside the viewport tube. This profile monitor is used to view spot sizes in the range of 50-75 µm with a resolution of approximately 1 µm/pixel [2].

The high-resolution profile monitor is pneumatically actuated on a linear shift mechanism. The linear shift allows for rigid insertion of the precisely aligned optics and screen. The high-magnification optics are mounted inside a re-entrant viewport and move along with the diagnostic.

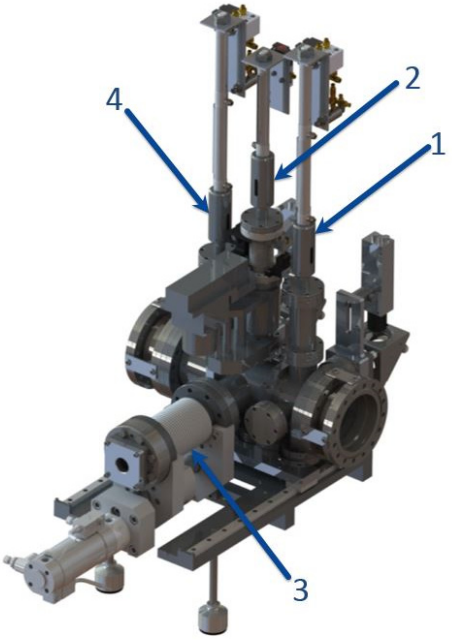

Figure 2: The beamline placement of the diagnostics reference in Table 1. (1) YAG & OTR screen, (2) germanium & pinholes, (3) high-resolution OTR screen, and (4) YAG & OTR screen.

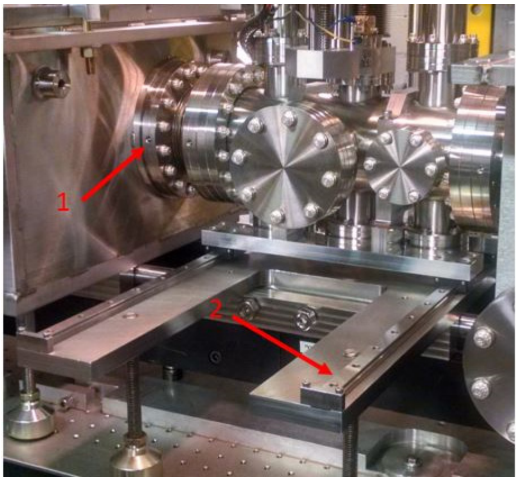

Figure 3: (1) Bellows and (2) rail system for ease of maintenance. This picture shows the assembly without the high-resolution profile monitor connected.

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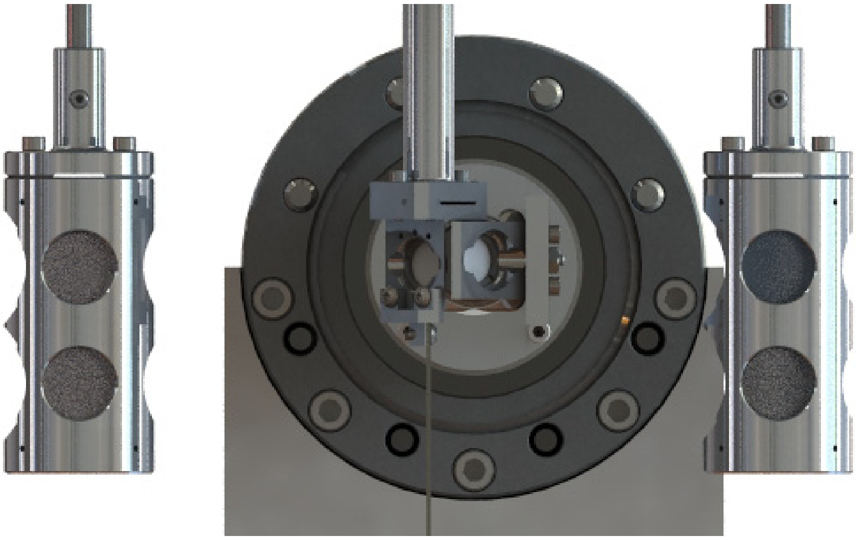

Figure 4: Collision is avoided when the YAGs, Germanium wafer, and High Resolution OTR screen are inserted at the same time.

Serviceability

The high power density of the EUL system will likely require the scintillators, OTR targets and pinholes to be replaced at regular intervals. In order to make this process quick and easy, the multi-diagnostic chamber mates to the beamline using two 6.00” Conflat (CF) flange-mounted bellows. The flanges have four tapped holes around the perimeter to allow for tabs to be secured. When it came time to remove the multi-diagnostic chamber from the beamline, the CF flange was disconnected from the chambers upstream and downstream and the bellows were locked in a compressed position using the tabs and bolts. These tabs both secure and support the bellows during removal for servicing.

The entire multi-diagnostic chamber is mounted on a moving rail system, as seen in Figure 3, which allows the user to easily slide the assembly out of the beamline. The rails provide smooth motion and high repeatability to ensure that minimal realignment is needed once the assembly is reattached to the beamline. The rail carriages are then locked in place to prevent movement during the experiment.

Each insertable diagnostic is removable via a single CF flange connection. Once the diagnostic sub-assembly has been removed, the YAGs and OTR screens are replaceable by removing a single lens mount retaining ring from each holder position. This allows for quick and easy changing of all of the diagnostic components [3].

Cameras

A CCD camera is mounted to each viewport using a custom mounting bracket. These brackets allow for each camera assembly to be mountable using two bolts and two off-the-shelf alignment rods. This makes the multi-diagnostic chamber compatible with commercially available cage plate optical assemblies (see Figure 4). All three analog cameras mounted to the side of the chamber have a 768 (H) x 493 (V) active pixel resolution with a 2/3 inch sensor format.

The high-resolution profile monitor is observed using a 100 mm focal length lens and a UV sensitive CCD camera with an observation wave length of 350 nm. This GigE Vision camera has a ½ inch sensor format and GigE data transfer interface. The resulting field of view in the image obtained is 1.3 mm x 1.0 mm.

CONCLUSION

The single pass experiment was run earlier this year and was a success. The first x-rays were obtained using this compact system on June 4th, 2015 [4]. Further tests are scheduled to be performed later this year to obtain multi-pass data.

ACKNOWLEDGMENT

The authors would like to thank the staff at BNL-ATF for their expertise and the operation of their facilities. Work is supported by DOE SBIR Grant No. DE-SC0007703.

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