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DESIGN OF APPARATUS FOR A HIGH-POWER-DENSITY DIAMOND IRRADIATION ENDURANCE EXPERIMENT FOR XFELO APPLICATIONS

S. P. Kearney*, D. Shu, T. Kolodziej, K.-J. Kim, R. Lindberg, S. Stoupin†, D. A. Walko, J. Wang, Y. Shvyd'ko, Argonne National Laboratory, Lemont, IL 60439, USA

Abstract

We have designed apparatus for an irradiation setup capable of achieving greater than 10 kW/mm^2 power density of x-rays on a diamond single crystal under ultra-high-vacuum conditions. The setup was installed at the 7-ID-B beamline at the Advanced Photon Source (APS) for an irradiation experiment, demonstrating the capability of diamond to endure x-ray free electron laser oscillator (XFELO) levels of irradiation (≥ 10 kW/mm^2) without degradation of Bragg reflectivity [1]. Focused white beam irradiation (50 µm x 20 µm spot size at 12.5 kW/mm^2 power density) of a diamond single crystal was conducted for varying durations of time at different spots on the diamond in a vacuum environment of 1x10^{-8} Torr and an additional irradiation spot in a "spoiled" vacuum environment of 4x10^{-6} Torr. Here we present the apparatus used to irradiate the diamond consisting of multiple subassemblies: the fixed masks, focusing optics, gold-coated UHV irradiation chamber, water-cooled diamond holder, chamber positioning stages (with sub-micron resolution), and the scattering detector.

DIAMOND IRRADIATION APPARATUS

A type IIa single crystal diamond in the [100] orientation was irradiated with focused white beam x-rays (50 µm x 20 µm spot size at 12.5 kW/mm^2 power density) to demonstrate the capability of diamond to endure XFELO levels (≥ 10 kW/mm^2) of irradiation without degradation of Bragg reflectivity [1]. The diamond was irradiated at different spots on the diamond for varying durations and environments, which required scanning stages. In addition, two vacuum environments were tested, 1x10^{-8} Torr and a single irradiation spot with a "spoiled" vacuum environment of 4x10^{-6} Torr.

Figure 1(a) shows the entire apparatus, which was temporarily installed at the 7-ID-B beamline at the Advanced Photon Source (APS) [2]. The main components of the apparatus are identified in Fig. 1(a) and will be discussed in detail. Figure 1(b) is a diagram of the entire beamline layout showing the distances of the main components from the x-ray source.

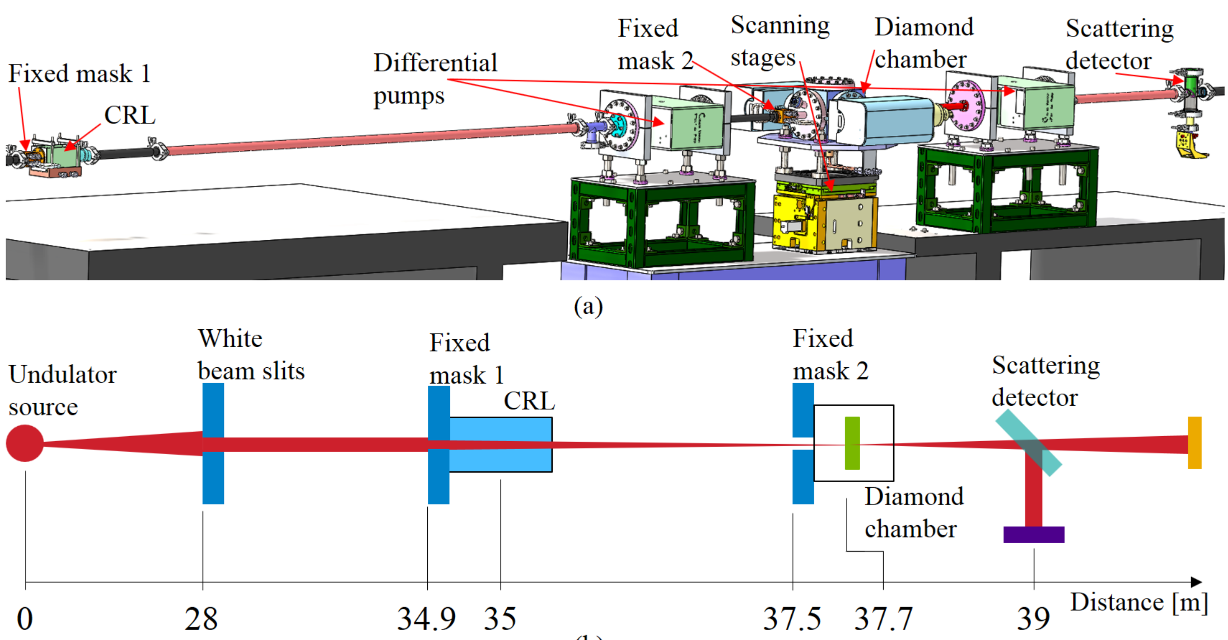

Figure 1: (a) Model of the diamond irradiation apparatus. The beam direction is from left to right and the main components are identified. (b) Diagram of the setup showing the distances from the source of the main components.

* skearney@aps.anl.gov
† Now at Cornell High Energy Synchrotron Source, Cornell University, Ithaca, NY 14853, U.S.A.

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Water Cooled Fixed Masks and CRL

Figure 2 shows the two water cooled fixed masks, and the compound refractive lens (CRL) holder. Both masks were made from Glidcop^{TM} and the mask apertures were machined using wire electrical discharge machining (EDM). The first water cooled mask (3) in Figure 2, has a minimum 1 mm diameter aperture and 4° sloped wall to protect the entrance aperture of the CRL holder (2). Standard Kwik-Flange^{TM} flanges were machined into the mask. The CRL holder, which was directly mounted to the first mask, was also water cooled by an oxygen free high conductivity (OFHC) copper mounting base (1). The second fixed mask (4) is mounted to the vacuum chamber and had an aperture 1 mm larger than the diamond profile to protect the apparatus during diamond scanning process. Knife edge flanges were machined into the single Glidcop^{TM} piece.

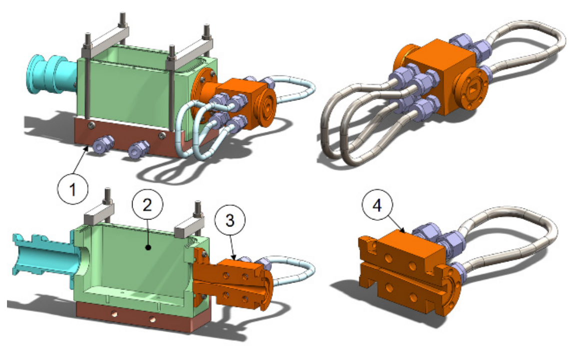

Figure 2: On the left is the CRL holder and first fixed mask and on the right is the second fixed mask, section views are shown on the bottom row. The listed components are: 1) CRL water cooled mounting base, 2) CRL holder, 3) first fixed mask, and 4) second fixed mask.

Gold Coated Diamond Irradiation Chamber

Figure 3 shows the diamond irradiation chamber (2) with an isometric view on the top and a section view on the bottom. The entire chamber was designed to move, eliminating the need for UHV compatible stages for the diamond scanning. The chamber assembly was mounted using spherical washers (3) to level and align the height. Two (75S, Gamma Vacuum) ion pumps (1) were positioned on the sides of the irradiation chamber and used to reach $1x10^{-8}$ Torr, compared to $4x10^{-6}$ Torr without these pumps (to provide a comparison of diamond's endurance in a lower-quality vacuum). In addition, differential pumps (100 L, Gamma Vacuum) were positioned upstream and downstream of the chamber, to protect the chamber from the lower vacuum of the CRL and scattering detector chambers. The chamber internal walls (5) were coated with a 50 µm thick gold layer to avoid carbon contamination from scattered x-rays hitting the stainless steel components of the vacuum chamber [3]. The diamond holder (4) was water cooled using an OFHC copper cooling finger (6), which was brazed to a stainless steel flange.

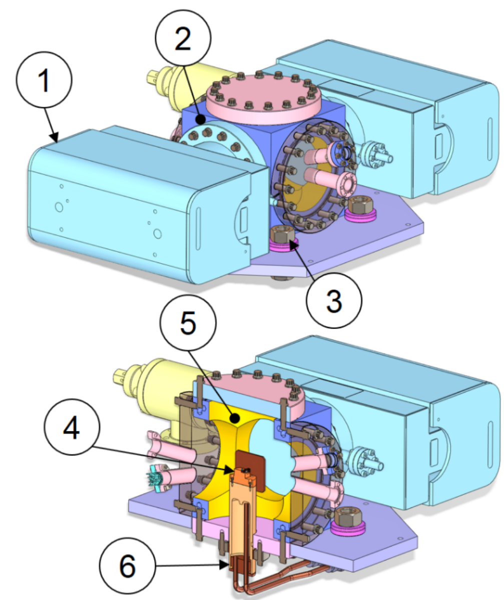

Figure 3: On the top is an isometric view of the diamond irradiation chamber and on the bottom is a section view along the beam vertical plane. The listed components are: 1) 75 L ion pump, 2) diamond irradiation chamber, 3) spherical washers, 4) diamond holder, 5) inner chamber wall gold coating, and 6) water cooled cooling finger.

Diamond Holder

Figure 4 shows the OFHC copper diamond holder (2). It was mounted to the cooling finger with 100 µm thick silver foil (1) in-between to decrease thermal contact resistance. A strain limited clamp was used to hold the diamond (3). The diamond also had 100 µm thick silver foil on either side to reduce strain as well as decrease thermal contact resistance. An OFHC copper shield (4) was placed on either side of the diamond to stop x-ray scattering towards components that were not gold coated (the outboard shield was removed from the image for clarity).

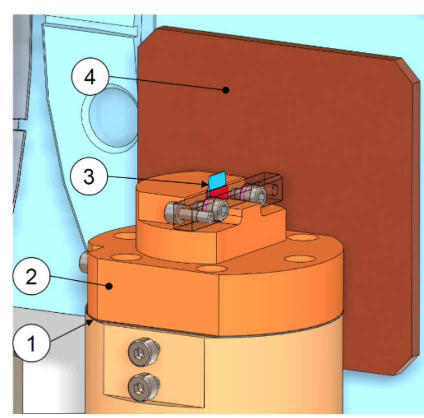

Figure 4: The diamond holder components: 1) Silver foil, 2) OFHC copper diamond holder, 3) CVD diamond, and 4) OFHC copper shield.

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Scanning Stages

For scanning the sample during irradiation the entire assembly is designed to move in the plane perpendicular to the beam. Moving the entire assembly rather than the sample greatly reduces the complexity inside the chamber and again assures a cleaner UHV environment by reducing the number of internal wires, metallic objects, and screw hardware. The scanning stages can be seen in Figure 5, and consisted of a vertical (1) and horizontal stage (3) with submicron resolution, 12.7 mm travel range, and 90 kg load capacity; in addition, a manual rotation stage (4) was used to align the diamond surface perpendicular to the beam. The vertical and horizontal stages were driven by stepper motors with 50:1 harmonic drives (PK523HPB-H50S, Oriental Motor Corp.). Closed loop control of the diamond scans was performed using EPICS experiment-control software and two (MicroE MII6000, Celera Motion) linear optical grating encoders (2).

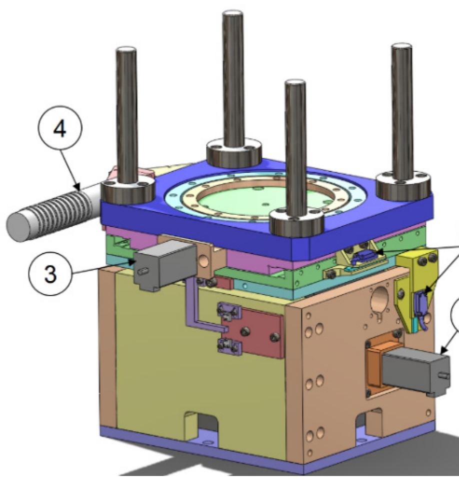

Figure 5: The scanning stages: 1) vertical stage, 2) MicroE optical encoders, 3) horizontal stage, and 4) manual rotation stage.

Scattering Detector

Figure 6 shows the scattering detector. It used a thin aluminium foil sheet (1) mounted at 45° to the beam plane and a calibrated photo diode (3) next to a beryllium window (2) to measure x-ray flux.

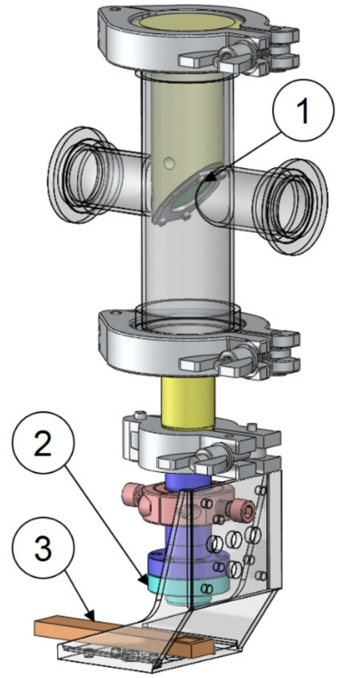

Figure 6: The scattering detector: 1) thin aluminium foil mounted at 45°, 2) beryllium window, and 3) pin diode detector.

CONCLUSION

A diamond irradiation setup was designed to handle high power density x-rays. The experiment used 8 keV x-rays with a power density of 12.5 kW/mm^2 and a 50 μm x 20 μm spot size. The diamond was irradiated in 1x10^{-8} Torr and 4x10^{-6} Torr vacuum environments. During irradiation, the diamond was scanned over an area of 50 μm x 60 μm for 12 hours in each environment. This resulted in an equivalent 4-hour irradiation over the x-ray spot size.

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