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LCLS-II FEL PHOTON COLLIMATORS DESIGN*

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Abstract

The unique capabilities of LCLS, the world's first hard X-ray FEL, have had significant impact on advancing our understanding across a broad range of science. LCLS-II, a major upgrade of LCLS, is being developed as a high-repetition rate X-ray laser with two simultaneously operating FELs. It features a 4 GeV continuous wave superconducting Linac capable of producing ultrafast X-ray laser pulses at a repetition rate up to 1 MHz and energy range from 0.25 to 5 keV. The LCLS-II upgrade is an enormous engineering challenge not only on the accelerator side but also for safety, machine protection devices and diagnostic units. A major part of the beam containment is covered by the FEL beam collimators. The current photon collimator design is no longer suitable for the high power densities of the upcoming LCLS-II beam. A complete new design has been conceived to satisfy this new constrains. Moreover, a special FEL miss-steering detection system based on a photo diodes array has been designed as an integral part of the photon collimator as additional safety feature. This paper describes the new LCLS-II FEL Collimators, their mechanical design and encountered challenges.

INTRODUCTION

Due to the possibility of having a X-ray FEL beam stray from its nominal path and strike surfaces of beamline components no able to handle the FEL power, the installation of collimators along the Front End layout is required to stop this mis-steered photon beam and also to only let pass the beam size defined by their aperture to the downstream components. The collimators are equipped with a fault detection mechanism that consists of four photo diodes that shall detect the beam scattering from miss-steered beam and inform the Machine Protection System (MPS) which will take actions such as deviating or even tripping off the beam if required.

LCLS-II BEAM PARAMETERS

The LCLS-II SXR beamline will be driven by the new superconducting radio-frequency Linac (SCRF) while the HXR beamline can be driven either by the SCRF Linac or by the normal copper radio-frequency Linac (CuRF).

The much higher average power possible with the SCRF Linac compared with the current LCLS FEL beam presents new challenges to the thermal management of the beam optics, diagnostics, slits and absorbers (see Table 1 and table 2).

Table 1: LCLS-II Soft X-ray Beam Parameters at 0.1 MHz, 300 Pc

Energy [eV]	Beam divergence [µrad]	Max integrated power [W]	Max single pulse fluence [mJ]
250	11.8	880	8.8
750	4.6	570	5.7
1250	3.2	339	3.4

Table 2: LCLS-II Hard X-Ray Beam Parameters at 0.3 MHz, 100 Pc

Energy [eV]	Beam divergence [µrad]	Max integrated power [W]	Max single pulse fluence [mJ]
1500	2.8	519	1.73
3250	2.0	185	0.62
5000	3.3	1.8	0.06

MECHANICAL DESIGN

Collimators in the Layout

A total of ten collimators are considered in the baseline for LCLS-II, five will be installed on the SXR line and five on the HXR. The Table 3 and Table 4 show the different aperture sizes and location of each collimator along the x-ray transport system. Aperture size was determined by beam stay clear and ray trace.

Table 3: HXR Collimators Location and Apertures Sizes (1.5 keV for the SC Linac and 1.5 keV for Cu Linac)

Coll. ID	Location# [m]	Beam size Ø [mm] SC/Cu	Beam Stay Clear Ø [mm] SC/Cu	Coll. aperture Ø [mm]
PC1H	84.2	2.92/2.44	7.69/6.73	8
PC2H	93.2	3.09/2.59	8.12/7.12	2.5
PC3H	100.9	3.24/2.72	8.49/7.46	2.5
PC4H	104.6	3.31/2.79	8.67/7.62	2.5
PC5H	98.2	3.19/2.68	8.37/7.34	2.5

#Location from the end of the undulator.

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Table 4: SXR Collimators Location and Aperture Sizes (0.4 keV SC Linac)

Coll. ID	Location* [m]	Beam size Ø [mm] SC/Cu	Beam Stay Clear Ø [mm] SC/Cu	Coll. aperture Ø [mm]
PC1S	41.1	4.41	10.24	12
PC2S	75.6	6.32	14.41	16
PC3S	94.3	7.36	16.67	12
PC4S	97.3	7.53	17.04	12
PC5S	100.4	7.70	17.40	12

*Location from the end of the undulator.

Vacuum Chamber and Cooling System

The collimators design consists of a vacuum pipe with two fixed DN100 flanges. See Figure 1. Inside the vacuum chamber there are three main assemblies:

- A photo diodes array with their internal cabling going to a feedthrough.
- A stack of a 750 µm thick and 55 mm Ø CVD Diamond, 10 mm thick SiC and 10 mm Tungsten.
- A "keep-alive" system with two 660 nm pulsed visible emitters or LEDs with their internal cabling going to a second feedthrough.

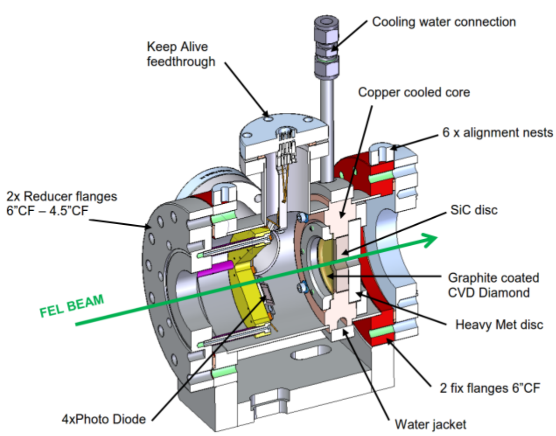

Figure 1: Photon collimator assembly section view.

A central oxygen-free (OFHC) copper core brazed to the stainless-steel chamber works as a holder for the stack-up of materials and provides cooling for the CVD Diamond through a stainless steel water jacket. Two pipes connect the device to the main water cooling system through Swagelok fittings.

The whole collimator assembly sits on top of an adjustment stage with spherical washers and pushers for alignment of the component.

Diode Array and "Keep-Alive"

In the event that the photon beam mis-steers it will hit the front surface of the diamond creating x-ray scattering which will be detected by four AXUV100Al photo diodes with a 150 nm aluminium filter on the front surface. There is sufficient visible spectrum transmission through the Al filter layer for the "keep-alive" system to confirm the diodes are working. See below Figure 2.

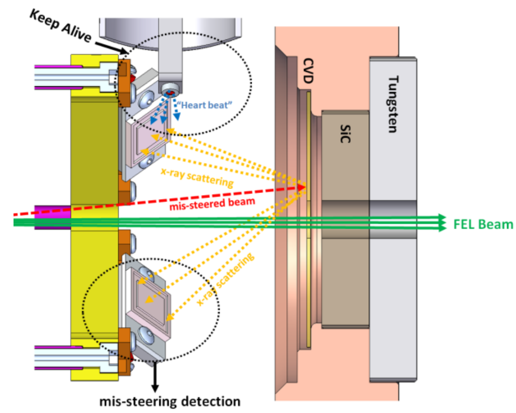

Figure 2: Section of the collimator showing half of the diodes array and keep-alive system.

The fault detection mechanism, works together with a keep-alive system that ensures the health of the photo diodes verifying their health periodically.

CVD Diamond and Graphite Coating

Due to the high power density (W/cm^2) and extremely high peak fluence (J/cm^2 per pulse) a material with high thermal conductivity and low Z number as the CVD diamond was the most suitable. [1]

To mitigate the damage of the diamond near carbon edge photon energies (~ 283 eV) and deal with the instantaneous heating of the pulsed FEL beam, a pyrolytic graphite coating of 3 µm has been applied with chemical vapor deposition. The coating absorbs the intensive pulsed beam while the diamond underneath only deals with the average power with its temperature remaining almost constant, see Figure 3.

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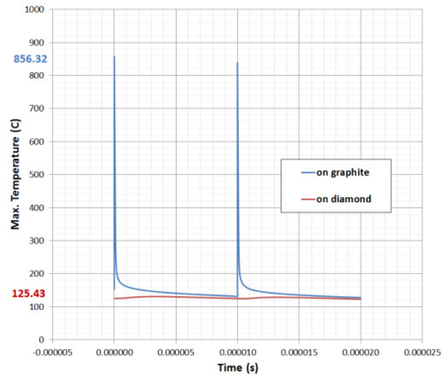

Figure 3: At 2 mJ/pulse, with energy of 290 eV for 1 ns heating and 10µs cooling, attenuation of the graphite coating from each pulse while the diamond material remains at near constant temperature 2 mJ/pulse at 290 eV for 1 nsec heating and 10µs cooling).

The diamond disc is fixed to the copper body with an aluminum clamp and using Belleville washers to control the pressure applied. As thermal interface between the diamond and the copper heat sink an indium 100µm thick gasket has been chosen.

THERMAL STUDIES

Analyses have been performed of the collimator installed in the SXR beamline at 40 m downstream of the last undulator (see Table 5). Simulations have been done with the beam hitting the edge of the aperture as is where we observed the highest temperature and stress. [2]

Table 5: Cases of Study, Most Upstream Collimators for SXR and HXR Beamlines

Parameters	PC1S SXR Collimator	PC1H HXR Collimator
Distance to End of Undulator [m]	41.1	101.5
Photon Energy [eV]	750	1500
Divergence [µrad]	4.8	2.8
Beam size [rms, mm]	0.3	0.38
Incident Power [W]	400	519
Surface peak power density [W/mm^2]	712	558

Other studies with higher power and carbon edge energies showed that the diamond may not be safe once the input power exceeds 550W (see Table 6).

Table 6: Combined Temperature Steady State and Instantaneous for PC1S Collimator, SXR Beamline

Energy / Power	340 W	550 W	880 W
250 eV	422 °C	810 °C	1761 °C
290 eV	1479 °C	2386 °C	4123 °C
750 eV	993 °C	1999 °C	>4500 °C

Stress analyses were done and for boundary conditions, the peak tensile stress observed is of 57 MPa, which is less than the allowable tensile stress of 500 MPa, and the peak compression stress is of 665 MPa, which is also below the 1900 MPa of allowable compressive stress.

Looking at the results of temperature and stress, a "bootstrap strategy" will be applied. The beam power will be gradually increased while the diamond will be monitored in order to define new safe operation conditions.

MANUFACTURE AND INSTALLATION

Ten photon collimators are currently being assembled at SLAC. The chambers were received in April. In the next weeks the diodes and keep-alive systems will be assembled and tested. See Figure 4 where the chambers are shown.

Figure 4: Photon collimator chambers received.

The installation on their support stands inside the LCLS tunnel will be during the long shutdown (starting on December 2018 until December 2019) with the rest of Front End components.

CONCLUSION

A whole new LCLS-II photon collimator design has been fabricated and this incorporates a new fault detection system with a keep-alive that ensures and certifies the health of the photo diodes.

A diamond with graphite coating is appropriate to absorb the FEL photon beam and this solution has been applied in the rest of photon stoppers and apertures for the new LCLS-II.

A bootstrap strategy will be needed during commissioning in order to identify safe operation conditions for the collimators and the diamond inside them.

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