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THE DESIGN OF LCLS-II PHOTON BEAM CONTAINMENT SYSTEM

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Abstract

LCLS-II will produce very powerful and collimated FEL photon beams. Unlike conventional synchrotrons, the LCLS-II beam containment components withstand not only the high average beam power and/or power density, but also the instantaneous thermal shocks from the pulsed beam structure, which can potentially reach 9mJ/pulse. With a beam repetition rate up to 1MHz, regular metal based beam collimators and absorbers used in synchrotrons will no longer work, because of the likelihood of fatigue failure. And because of the poor thermal conductivity, the old LCLS B4C based absorber would need very shallow glancing angle and take valuable beamline space. Hence, a low-Z and high thermal conductivity CVD diamond based photon beam collimator and absorber systems have been developed in LCSLII. The initial damage tests using LCLS FEL beam provided positive results that graphite coated CVD diamond can endure per pulse dose level to 0.5eV/atom. For the beamline and personnel safety, in addition to the passive CVD diamond collimators and absorbers, newly developed photon diode beam mis-steer detection systems and conventional SLAC pressurized gas burn-through monitors have been also introduced in the photon beam containment system design.

INTRODUCTION

At a typical third generation synchrotron light source, the photon beam divergence can range from a few mrads for undulator beamlines and up to 10 mrad for some wiggler beamlines. The beam containment systems are designed to trim the beam divergence and define a beam size that can be accepted for experiments, as well as addressing the beam mis-steering conditions. It is not the same case for LCLS-II photon beams, which have divergence ranging from a couple of μrad to a few tens of μrad and highly coherent. The conventional scheme for containing a synchrotron photon beam won't be appropriate for the LCLS-II photon beams. On the one hand, the collimators or apertures for LCLS-II are not used to define the size of the beam, and in contrary, the photon collimators apertures try to stay clear from the beam to avoid generating noises for the experiments. On the other hand, the collimators are still needed to contain the beams in case of beam mis-steered away from its normal course, i.e. the golden trajectory. Moreover, due to the FEL beam pulses may carry tremendous power that can damage most materials by single shot ablations, and high repetition rates (up to 1MHz) may cause the fatigue failure for most of the metals even for lower beam fluences. Therefore, low atomic weight (low-Z) materials that can tolerate thermal shocks with high repetition rates may be suitable for the construction of beam containment component. B4C is one of the low-Z materials used LCLS and other FEL facilities. However, because the LCLS-II beam can potentially have up to 880W of integrated power, good thermal conductivity becomes necessary for the application. In the meantime, large and thick chemical vapor deposition (CVD) diamond has become economically viable, hence, it has been chosen as the major heat absorption material [1].

In this article, firstly, a brief description of engineering design and analysis of the CVD diamond based beam containment components, i.e. collimators and stoppers, are presented. Secondly, in order to detect a breach caused by the FEL beam to the collimators and stoppers, diode and gas based sensing systems are also integrated with the design. And finally, the basic working principle of the photon beam containment system is briefly described.

LCLS-II BEAM PARAMETERS

Table 1 and Table 2 show the beam parameters that can produce the most thermal loads to the devices. In some extreme cases, the power load on the collimator upstream can be up to 1000 W/mm^2. For the soft-xray beamline, single pulse fluence (up to approx. 9mJ/pulse) may even induce damages that are not purely due to thermal effects, but directly breakdown of the bond between atoms.

GRAPHITE COATED CVD DIAMOND PHOTON ABSORBERS

To further improve the thermal shock resistance, a thin pyrolytic graphite is coated on all sides of the diamond used in collimators and stoppers. Figure 1 shows the transient behavior of a single pulse FEL beam hits the diamond absorber with 4μm coating. One can see that the sharp instantaneous temperature rise is located in the thin graphite coating. The temperature in diamond doesn't have this sharp rise. Figure 2 shows one of the damage tests done to the graphite coated diamond by taking LCLS beam with a fluence of approx. 0.6 ±0.15eV/atom. After 100,000 shots, one can visually observe the footprints of the beam, but no obvious morphological damage to the coating [2].

Figure 3 shows an absorber assembly with graphite coated CVD diamond and light-tight box installed.

A BRIEF DESCRIPTION OF LCLS-II PHOTON BEAM CONTAINMENT SYSTEM

Even equipped with graphite coated diamond absorbers, under extreme conditions, a few photon collimators upstream won't survive the extreme heat loads and ablations. As described previously, under normal operation conditions, the

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Table 1: LCLS-II Soft X-ray Beam parameters at 0.1MHz, 300pC

Energy (eV)	**Beam Divergence (μrad)**	**Max Integrated Power (W)**	**Max Single Pulse Power (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 0.3MHz, 100pC

Energy (eV)	**Beam Divergence (μrad)**	**Max Integrated Power (W)**	**Max Single Pulse Power (mJ)**
1500	2.8	519	1.73
3250	2.0	185	0.62
5000	3.3	1.8	0.06

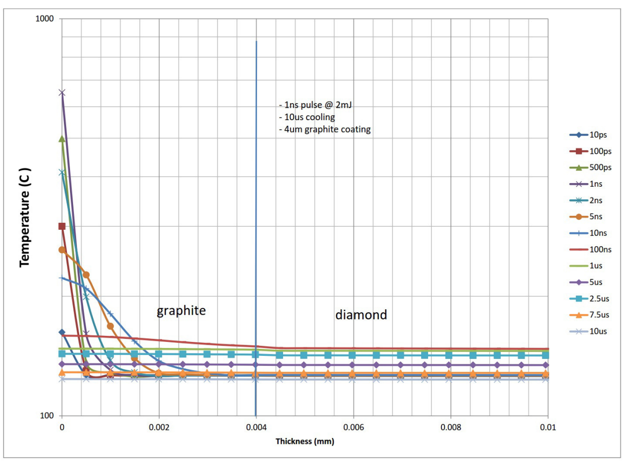

Figure 1: Instantaneous temperature rises in graphite coated diamond absorber.

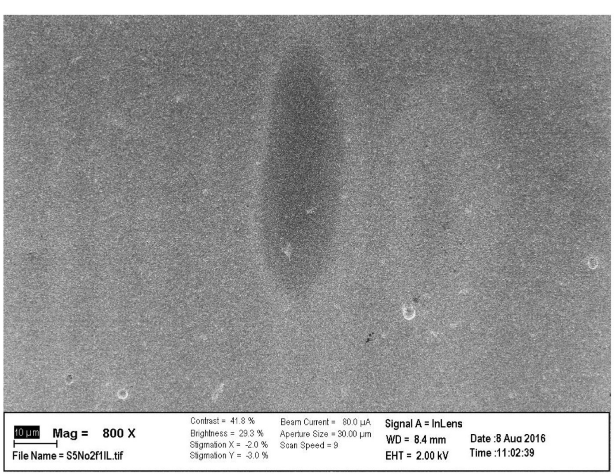

Figure 2: Damage test done to a graphite coated diamond specimen.

photon beam will stay clear from the collimators, and they will only take the beam when abnormal mis-steered conditions occur. Hence, the problem becomes how to detect the beam mis-steering conditions, and minimize duration of

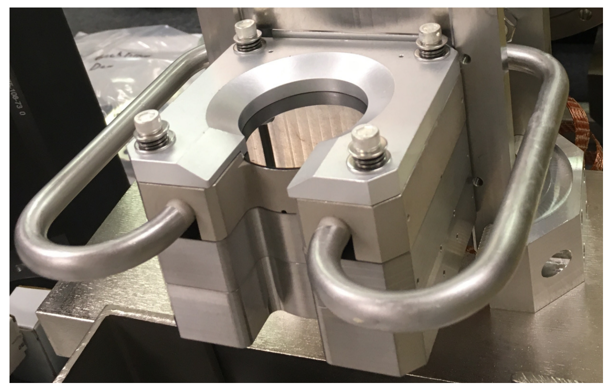

Figure 3: BCS photon absorber assembly.

the ablation time. To address this problem, a diode based sensing system is employed to provide fast feedback to shutdown the hazard as soon as it happens. To stop the beam from going downstream to the experimental stations, a redundant pair of diamond absorbers are integrated with the heavy metal for personnel safety (Figure 4). In the first absorber assembly, a fast diode based sensing system is kept in a light-tight box to detect any possible breaches of the diamond absorber. In the second absorber assembly, a gas based burn-through monitor (BTM) is sandwiched between the absorber and the heavy metal block. In case the photon beam breaks the absorbers and melt a hole on BTM chamber, the bleeding of gas will cause a pressure drop and in turn it will be trip the beam off by shutting down the RF directly.

For a safe operation of LCLS-II beamlines, especially during the commissioning phase, engineered interlock limits will be established based on modeled temperature from the optimized FEL yield and the controlled operating parameters. A temperature map from the optimized yield in photon energy is shown in Figure 5.

To stop the high harmonics and hard x-ray beams, SiC discs are also included in the absorbers. Diamond together with SiC absorbers will absorb and stop the beam up to 25keV.

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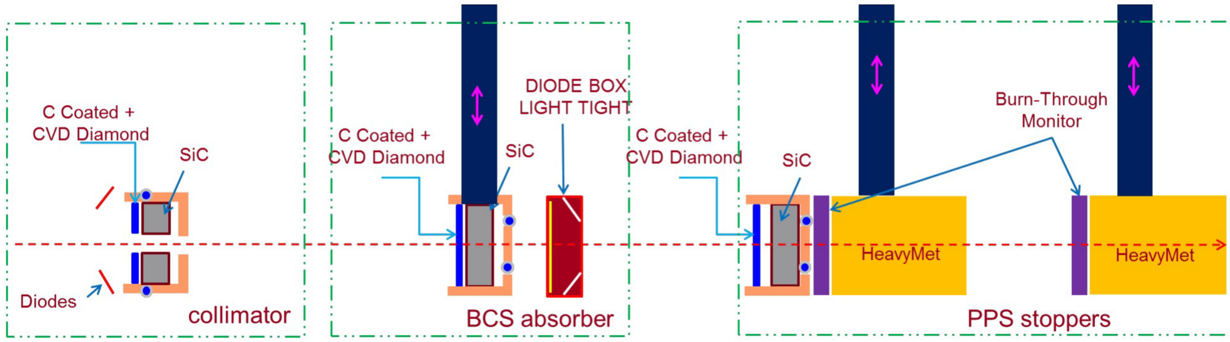

Figure 4: Schematic layout of the BCS system for Soft X-ray beamline.

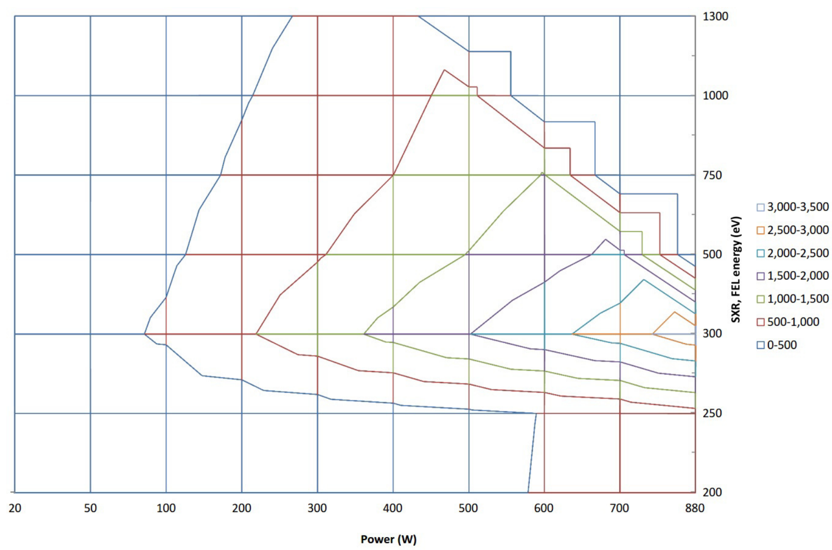

Figure 5: Temperature map on photon energy and power.

CONCLUSION

Diamond coated with graphite is a feasible solution to absorb and stop LCLS-II FEL beams, therefore, it has been used to construct the photon collimators and stoppers as major part of the beam containment system. Safe operation conditions have been estimated and mapped with input powers and photon energies.

ACKNOWLEDGEMENTS

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