SLAC-PUB-16185

Detectors in Extreme Conditions

G. Blaj*, G. Carini, S. Carron, G. Haller, P. Hart, J. Hasi, S. Herrmann, C. Kenney, J. Segal, A. Tomada

***Abstract*—Free Electron Lasers opened a new window on imaging the motion of atoms and molecules. At SLAC, FEL experiments are performed at LCLS using 120Hz pulses with $10^{12} - 10^{13}$ photons in 10 femtoseconds (billions of times brighter than the most powerful synchrotrons). This extreme detection environment raises unique challenges, from obvious to surprising.**

Radiation damage is a constant threat due to accidental exposure to insufficiently attenuated beam, focused beam and formation of ice crystals reflecting the beam onto the detector.

Often high power optical lasers are also used (e.g., 25TW), increasing the risk of damage or impeding data acquisition through electromagnetic pulses (EMP). The sample can contaminate the detector surface or even produce shrapnel damage.

Some experiments require ultra high vacuum (UHV) with strict design, surface contamination and cooling requirements - also for detectors.

The setup is often changed between or during experiments with short turnaround times, risking mechanical and ESD damage, requiring work planning, training of operators and sometimes continuous participation of the LCLS Detector Group in the experiments.

The detectors used most often at LCLS are CSPAD cameras for hard x-rays and pnCCDs for soft x-rays.

***Keywords*—X-ray detectors, free electron lasers, detector damage, LCLS, CSPAD, pnCCD.**

I. INTRODUCTION

Free Electron Lasers opened a new window on imaging the motion of atoms and molecules. At SLAC, FEL experiments are performed at LCLS using 120 Hz pulses with $10^{12} - 10^{13}$ photons in 10 femtoseconds (billions of times brighter than the most powerful synchrotrons). This extreme detection environment raises unique challenges, from the obvious (e.g., radiation damage) to surprising (e.g., shrapnel damage and electromagnetic pulses - EMP). The detectors used most often at LCLS are CSPAD cameras for hard x-rays and pnCCDs for soft x-rays.

II. METHODS

At LCLS currently there are 6 instruments: AMO, SXR, XPP, XCS, CXI and MEC. Typically only one of the 6 LCSL instruments is performing experiments at a time, unlike synchrotrons. This results in a tight schedule and low tolerance for instrument malfunction.

The detectors used most often at LCLS are CSPADs [1] for hard x-rays and pnCCDs [2] for soft x-rays. The CSPAD cameras are typically stationed at one instrument. The pnCCD cameras were initially designed to be used at AMO. However, due to high demand, they are traveling between AMO, SXR, XCS and CXI.

The results presented here are based on several years of experiments at LCLS with 3 CSPAD 2.2Mpixel cameras, about 12 CSPAD 140Kpixel cameras and 2 pnCCD cameras.

Manuscript received December 31, 2014. SLAC-PUB-16185.

G. Blaj, G. Carini, S. Carron, G. Haller, P. Hart, J. Hasi, S. Herrmann, C. Kenney, J. Segal, A. Tomada are with SLAC National Accelerator Laboratory, Menlo Park, CA 94025.

* Corresponding author: g.blaj@slac.stanford.edu

III. RESULTS

A. Radiation Damage

Radiation damage is a constant threat due to accidental exposure to insufficiently attenuated beam, focused beam and formation of ice crystals reflecting the beam onto the detector [3]. This manifests either as permanent spots or damaged ASICs. While the incidence of damaged ASICs was greatly reduced by using high Z shields [3], the spots continue to appear.

B. High Power Optical Lasers

High power optical lasers are often used (e.g., 1J/40fs = 25TW at MEC), increasing the risk of damage or impeding data acquisition through electromagnetic pulses (EMP). A recent example of damage produced by an optical laser at CXI is shown in Figure 1. Data acquisition at MEC was also initially unreliable due to electromagnetic pulses (EMP).

C. Sample Damage

The sample often contaminates the detector surface (Figure 1B) or even produces shrapnel. To reduce the damage rate while fulfilling the requirements of the different experiments, different front shields have been produced: black polyimide, aluminum-coated polyimide, black aluminum-coated polyimide, beryllium, with a central beam pipe for the large cameras.

These shields greatly reduce detector surface contamination but do not eliminate it completely. They also protect the detectors from spurious signals induced by stray light. They are not very effective against shrapnel. The shields need to be replaced often.

D. Ultra High Vacuum

Many CSPAD and all pnCCCD cameras are operating in ultra high vacuum (UHV) with strict design, surface contamination and cooling requirements. About twice a year, a detector module loses thermal contact with the cooling circuit and overheats rapidly. Temperature and bias current interlocks prevent damage and alert operators by stopping the detector.

Submitted to IEEE Xplore.

SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-76SF00515.

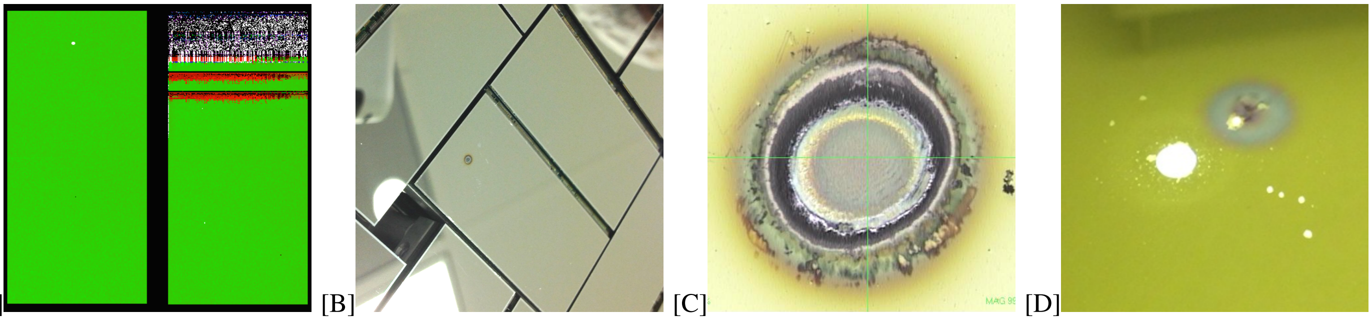

Fig. 1. Optical laser damage on CSPAD module at CXI. [A] Dark frame: focused beam damage (spot, left) and diffuse reflection damage (ASIC, right). [B] Sensor damage by laser ablation (small dark spot); also semicircular surface contamination is visible near the central beam opening (white, near central beam opening). [C] Microscope close-up of damaged spot on the sensor. [D] Damaged front shield (Al coated polyimide). Visible: central aperture (large bright spot), laser damage (small bright spots), diffuse laser reflection damage (discolored area).

E. Time Pressure

The setup is often changed between or during experiments with short turnaround times, risking mechanical and ESD damage. Various incidents have been observed: moving stages in tight setups resulting in collisions and damaged front filters (about twice a year), changing camera deployment resulting in damaged wire-bonds (4-5 times a year), electrostatic discharge damaging detector or DAQ electronics (5-6 times a year), faulty cooling circuits resulting in water leakage and detector electrochemical damage (once).

F. pnCCD

The pnCCD is particularly sensitive in all these respects. When deemed safe, the LCLS Detector Group checks the detectors between experiments or upon unexpected behavior. Otherwise, the LCLS Detector Group actively participates and closely follows the experiment.

IV. Conclusion

At FELs, high intensity diffraction spots sometimes damage detectors instantaneously. Detector damage cannot be prevented. Detector modules should be viewed as consumables and the cameras should have a modular design facilitating rapid exchange of damaged modules.

Radiation damage on entire ASICs was greatly reduced by using high Z shields over the exposed ASIC balcony [3]. However, local damage cannot be prevented in high intensity imaging with hard x-rays. After damage, annealing only slightly improves the damaged areas. The most effective solution is regular replacement of the damaged detector modules (about one every month).

High power optical lasers should ideally not be directed at detectors, or at least they should be shielded with beam stops. Unfortunately this is not always possible due to existing experimental chamber constraints and continuously changing experiment setups.

Temperature and bias current interlocks in CSPAD detectors operating in vacuum proved useful. Currently they are being implemented in the pnCCD cameras.

We investigate immediately all other sources of damage and use the conclusions to update camera design and operating procedures in order to avoid recurrence. Disseminating the investigation results to operators greatly reduce the recurrence of incidents.

Acknowledgment

Portions of this research were carried out at the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory. LCLS and SSRL are Office of Science User Facilities operated for the U.S. Department of Energy Office of Science by Stanford University.

References

[1] P. Hart et al., *The Cornell-SLAC Pixel Array Detector at LCLS*, IEEE-NSS 2012

[2] S.Carron et al., *The LAMP Instrument and the pnCCD Sensors*, 2013 LCLS/SSRR Users Meeting

[3] A.Tomada et al., *High-Z Radiation Shields for X-ray Free Electron Laser Detectors*, IEEE-NSS 2012