ePixHRM320k- A Detector System for Soft X-ray Imaging for LCLS-II

Dionisio Doering, Lorenzo Rota, Aldo P. Perez, Bojan Markovic, Aseem Gupta, Dawood Alnajjar, Larry Ruckman, Donald Geranen, Marco Oriunno, Conny Hasson, Julie Segal, Christopher Kenney and Angelo Dragone

***Abstract*—LCLS-II, a Free Electron Laser (FEL) X-ray light source, operating at SLAC National laboratory, includes experiments with x-rays exploring energies in the soft x-ray regime (250eV to 1600 eV). A full frame detector with 320k pixels capable of sustaining readout rates higher than 5,000 frames per second called ePixHRM has been proposed for this type of application. The ePixHRM is composed of two ASICS, where the sensor includes active pixel circuitry, thinned to 200um and back processed to include a thin entrance window. The sensor is bump bonded to the readout ASIC which includes 4 rows of 192 ADCs, configuration logic using a custom interface called SACI and readout circuitry that transmits data serially to an associated FPGA system. To complete the detector active cooling and mechanics has been designed to enable the detector to be installed in a rotating arm inside a vacuum experimental chamber. Initial results from the prototype sensor/ASIC module are already available they are reported.**

***Index Terms*— Soft X-ray, detector, LCLS-II**

I. Summary

SLAC Detector R&D Program has been actively designing a family of detectors for Free Electron Laser (FEL) x-ray light sources where ePixHRM-320k is a custom detector for soft x-ray instruments that aims to measure x-rays in the range of 250 to 1600eV. LCLS-II [1] will produce up to 1,000,000 x-ray pulses per second when in full operation and the detector developments for such speeds are being designed in phases with the present ePixHRM enabling data acquisition up to 7,500 fps. Future detectors capable of running at the same rate as the beam are also in development but are beyond the scope of this paper. The ePixHRM-320k detector requirements are presented in Table 1 where each requirement contains three parameters. The “Threshold” is the minimum acceptable value, the “Objective” is the ideal parameter and the “ePixHRM-320k” is the delivered performance by the proposed instrument. In summary, the application requires a detector with >250k pixels capable of sustaining readout rates higher than 5,000 fps, a planar focal plane, operating in vacuum and have high quantum efficiency on the entire x-ray energy range.

The ePixHRM Monolithic Active Pixel Sensor has 50x50μm^2 pixels arranged in a 384 (H) x 192 (V) matrix with well depth of more than 1,000 photons at 530eV. The on-sensor amplifiers implement a gain switching strategy to achieve such dynamic range, high resolution and low noise. The analog signal from the pixels are transmitted to the Readout ASIC

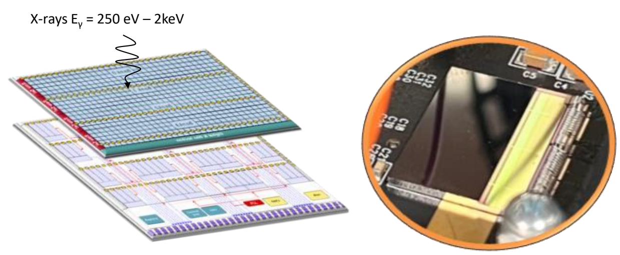

Fig. 1. 4x1 detector tile (left) and staggered half plane with 10 tiles assembled on a cooling and support stringer.

where it is converted to digital by 4 rows of 192 ADCs [2]. The ADCs design is shared with other detectors in the ePixHR family and has been presented in [3]. The latest version of the ASIC was optimized and operates at 7,500 fps which is beyond the minimum requirement for this phase of the project (i.e 5,000fps). Fig.1 (left) presents the ASIC sensor arrangement where the sensor is attached to the readout ASIC using standard micro-bumps. Fig.1 (right) shows a picture of the prototype ePixHRM.

The ePixHRM-320k (Fig.2 left) has been designed with a focal plane that instruments 4 sensor/readout ASIC modules on a 2x2 arrangement (Fig.2 right). Fig. 3 presents the picture of the first fabricated focal plane currently under testing. The focal plane is connected to a custom digital board that provides power supply, control signals and bias to all 4 sensor/readout modules.

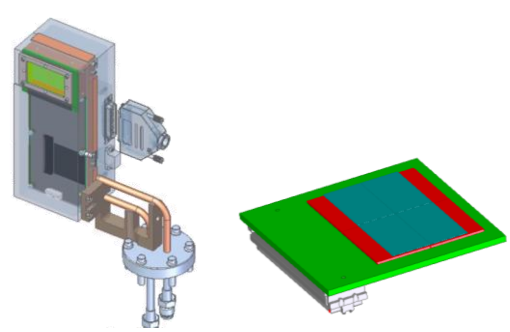

Fig. 2. 4x1 detector tile (left) and staggered half plane with 10 tiles assembled on a cooling and support stringer.

This abstract has been submitted in May 4, 2023.
Dionisio Doering, Lorenzo Rota, Larry Ruckman, Ryan Herbst, Donald Geranen, Marco Oriunno, Conny Hasson, Julie Segal, Christopher Kenney and Angelo Dragone are with SLAC National Laboratory, Palo Alto, CA 94025, USA (e-mail: ddoering@slac.stanford.gov).

TABLE I
KEY EPIXHRM-320k DETECTOR REQUIREMENTS

Parameter	Threshold	Objective	ePixHRM-320k
PIXEL PITCH (µm)	50	50	50
READ NOISE (e^- RMS)	15	10	12
FRAME RATE (KHz)	>5	10	7.5
ARRAY SIZE (PIXELS)	250kPix	1MPix	320kPix
WELL DEPTH (NUMBER OF 500eV PHOTONS)	1000	3000	>1000
QUANTUM EFFICIENCY (% 250-1600eV)	70	90	84
VACUUM COMPATIBILITY	< $2x10^{-8}$	< 10^{-8}	< $2x10^{-8}$
PHYSICAL PACKAGE ENVELOPE	100x175x75 mm	100x175x50 mm	75x175x58 mm
MAXIMUM POWER DISSIPATION	<100W	<50W	75

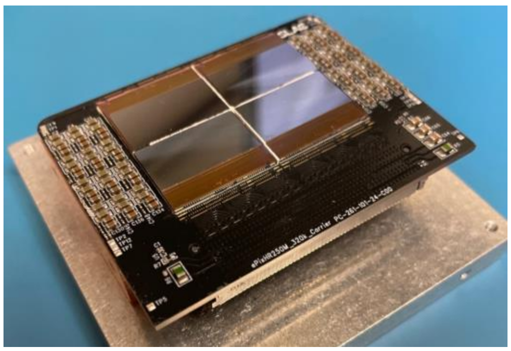

Fig. 3. ePixHR10k 2M complete detector assembly.

The ASIC control and configuration is implemented using an AMD/Xilinx Ultrascale FPGA. The data transmitted by the Readout ASIC when received in the FPGA is decoded based on the SSP protocol which includes error checking based on disparity. The data is then reformatted and transmitted to a DAQ computer using four parallel fiber optics lanes. The Amphenol LeapOn transceiver used in this detector has 12 lanes each one capable of 25gpbs. Due to the limitation on the selected FPGA these lanes are being used at a maximum of 16Gbps. The remaining lanes are used for control and monitoring, LCLS-II timing receivers that allows trigger and timestamp to be received by the detector level, and finally up to 3 lanes are dedicated to transmit pre-processed data to the edge computing layer that implements real time data reduction and classification using machine learning (called here EdgeML).

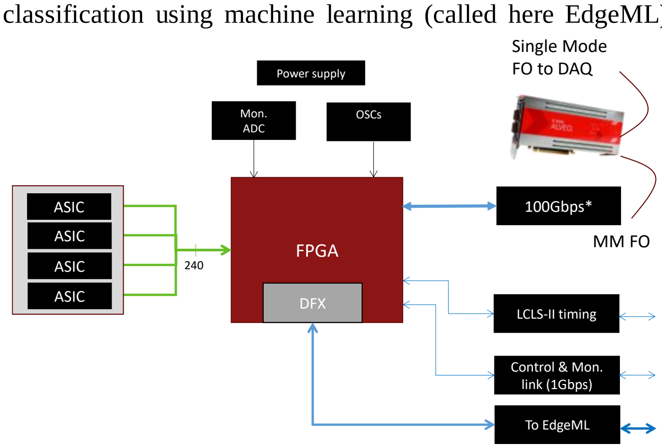

Fig. 4. ePixHRM-320k data flow.

The firmware and software are co-designed based on the SURF [4] and ROGUE [5] libraries. SURF includes several firmware building blocks, such as, ASIC register access (SACI), high-speed communication link and protocols for data stream and configuration. ROGUE implements the software modules for the elements that exist in SURF. In addition to the library building blocks, code is implemented in Python to customize the system for any detector.

Fig. 5 presents initial results for the ADC when excited by an external voltage source and a raw full frame image when the light of laser pointer is projected into the matrix.

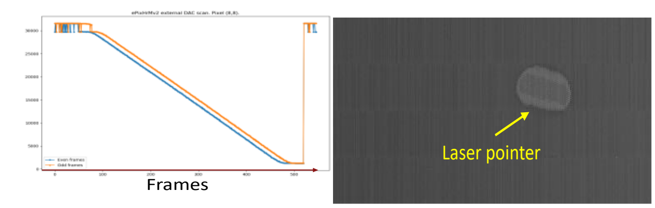

Fig. 5. ePixHRM-320k results. (Left) ADC response to an external DAC supplied a ramp waveform from 0 to 2.5V. (Right) A full frame image of a laser pointer demonstrates the entire matrix being digitized by the 768ADCs and readout using 24 data links.

II. Conclusion

The ePixHRM-320 soft x-ray detector has been presented. It is currently under test and initial results already show full system functionality. Further results including performance measurements of the full system will be available by the time the conference is held. These results will be presented together with a more in-depth system description.

References

[1] R. Schoenlein et al., “New science opportunities enabled by LCLS-II X-ray lasers,” SLAC Report, 2015, SLACR-1053.

[2] C. Tamma et al., "ePixM: a CMOS monolithic sensor for LCLS II," 2019 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Manchester, UK, 2019, pp. 1-4, doi: 10.1109/NSS/MIC42101.2019.9059784.

[3] P. Caragiulo et al., "Design and Characterization of a high-rate readout backend for ePix detectors at LCLS II," 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC), 2018, pp. 1-3, doi: 10.1109/NSSMIC.2018.8824482.

[4] SURF, [Online]. Available: https://github.com/slaclab/surf

[5] ROGUE, [Online]. Available: https://github.com/slaclab/rogue