A 1MPixel Fast CCD sensor for X-ray imaging

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Abstract—This paper describes the performance of a 1MPixel Frame Store CCD sensor for soft X-ray applications at synchrotron light sources. This camera can be operated in frame store mode with a 1MPixel imaging area running at 200fps, or in full frame mode with a 2MPixels imaging area running at 100fps. The CCD has 192 outputs that are serviced by custom-designed integrated circuits that perform correlated double-sampling signal processing and digitization. The digitized data is acquired by a custom made image acquisition and camera controller board based on the Advanced Telecommunication Computing Architecture system. Results obtained during a test run at the Advanced Light Source are presented demonstrating the X-ray camera performance.

INTRODUCTION

Many experiments at soft X-ray synchrotron facilities such as the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL) are performed with X-rays that range from a few hundred electron volts (eV) to around 8keV in energy. Direct X-ray detection using silicon detectors is very efficient in this energy range. The limiting efficiency factor for low X-ray energies is the thickness of the entrance window. A thinner entrance window increases the detection efficiency. For higher energy X-rays, the limiting factor is the detector thickness. A thicker detector will provide higher collection efficiency.

Recent X-ray detector developments in this area have focused on direct detection and high frame rate. Examples of such developments are the pn-CCD [1] and the compact fast CCD (cFCCD) at LBNL [2]. The latter is a 480 x 480 sensor matrix with 30μm square pixels read out at up to 200 frames per second (fps) [3]. In this paper we present the X-ray characterization for the second generation of LBNL fast CCDs called 1k Frame Store CCD (1kFSCCD) [4]. This detector has a matrix of 1920 x 960, 30μm square pixels, read out in an almost column parallel configuration with 192 output ports running at a maximum 200 fps when operating in frame store mode. Besides the frame store mode this camera can operate in full frame mode reading the entire pixel matrix at a reduced frame rate of 100 fps. Figure 1 shows an image of the CCD sensor.

Figure 1 - Sensor image of the 1920 x 960 1kFSCCD.

The remainder of this paper is organized as follows: Section I describes the detector system. Section II shows the X-ray characterization of this camera system. Section III concludes the paper and presents suggestions for future work.

I. DETECTOR SYSTEM DESCRIPTION

The 1kFSCCD detector system includes (i) a camera head, (ii) a Camera Interface Node board (CIN), (iii) a readout system, (iv) a power supply and (v) a cooling system. Figure 2 shows the block diagram of the camera system and how each block interacts with one another to implement a complete system.

Figure 2 - 1kFSCCD camera block diagram.

The camera head contains the detector, clock and bias electronics, digitizer cards and cooling system. To operate the detector the digital clock information, which is generated at the CIN, are sent via LVDS lines to the clock and bias board
where they are converted into analog signals. The sensor is readout on two sides via two independent digitizer boards. A buffer chip can be installed between the sensor and the digitizer card for gain enhancement. The digitized data is sent to the camera interface node, also through a set of LVDS lines. In the frame FPGA, on the CIN module, the data from all digitizers is assembled to form an image. The image is sent to a RAID array for storage via 10GbE or to a user interface computer via 1GbE. Figure 3 shows a picture of the camera head (top left), camera interface node (CIN) board (top right) and ATCA based readout system (bottom). For a detailed description of the system, please, refer to [4].

II. EXPERIMENTAL RESULTS

The camera system was fabricated, assembled and several sub-systems tested, such as the detector, the analog to digital converter (called FCRIC2), the CIN node and the power supply. The full camera system, including the ATCA readout, has been characterized with X-rays at the ALS. These results apply to a camera head in which the buffer chips are not installed between the CCD sensor and the FCRIC2. A first characterization of the camera system has been performed at the Detector and Instrumentation Development beamline at the ALS. A sketch of the experimental setup is illustrated in Fig. 4. The camera head is mounted via an 8° CF flange onto a vacuum chamber downstream from the shutter and monochromator chamber. A sample holder is mounted inside the vacuum chamber at a 45° angle with respect to the primary X-ray beam. The sample holder can be moved in the two directions perpendicular to the beam direction by means of a remotely controlled, vacuum-compatible translation stages. With this arrangement, different samples can be positioned on the primary X-ray beam without having to open the vacuum chamber.

Figure 4 - Sketch of the experimental setup used for X-ray characterization at the LBNL Advanced Light Source (ALS)

During the experiment the intensity of the beam and the exposure time of the camera were set in such a way that only sparse, single photon events were being recorded. Under this condition it is possible to analyze each X-ray interaction and extract information about its position, energy and number of pixels that collected charge. The energy information of the events that collected all the charge in a single pixel is used to generate an energy spectrum for each sample. Figure 5 shows the energy spectra for Zn, Cu and Ni foil. The spectra show a clear distinction between the Ka and Kβ emission lines for each sample demonstrating the energy resolving capabilities of the 1kFSCCD system. Figure 6 shows the sensor output as a function of X-ray energy. The plot includes data fitted from the Zn, Cu and Ni spectra reported in Fig. 5, plus data obtained from Fe (Kα = 6.40 keV, Kβ = 7.06 keV) and Ti (Kα = 4.51 keV, Kβ = 4.93 keV) foils.

Figure 5 - Fluorescence spectra obtained with Zn, Cu and Ni foils. The energies corresponding to the Ka and Kβ emission lines for each sample are reported in the inset.
Figure 6 - Sensor output as a function of X-ray energy. The plot includes data fitted from the Zn, Cu and Ni spectra reported in Fig. 13, plus data obtained from Fe (Kα = 6.40 keV, Kβ = 7.06 keV) and Ti (Kα = 4.51 keV, Kβ = 4.93 keV) foils.

The 1kFSCCD sensor has 192 outputs. Out of these a noise measurement of 47 consecutive outputs was performed. Figure 7 shows the mean noise measure of 25e− with an RMS of 1.06. This demonstrates that the outputs have a very similar noise characteristic.

III. REMARKS AND CONCLUSIONS

In this paper we presented a new X-ray camera system that has been built at the Lawrence Berkeley National Laboratory. This system uses a 1kFSCCD with 1920 x 960 pixel matrix. The sensor operates in two modes (frame store and full frame) with maximum frame rates of 200 fps.

Initial tests have been done and some of the X-ray system characteristics have been reported. Future work will include a full characterization of the camera using X-ray sources with energies lower than 1keV and with the buffer chip installed to validate the performance enhancements it brings to the system.

ACKNOWLEDGMENT

We gratefully acknowledge the contributions from George Zizka, Bryan Holmes and Todd Alan Hayden for the board layout and Jacque Bell, Rhonda Witharm, and John Emes for assembling the substrates. Robert Abiad, Geroge Chao, Dario Gnani, and Brad Krieger were part of the FCRIC2 design team. Richard Celestre for his support during the execution of the sensor tests at the Advance Light Source.

REFERENCES


