XPAD: A Photons Counting Pixel Detector for Material Sciences and Small Animal imaging

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Abstract

Experiments on high flux and high brilliance 3rd generation synchrotron X-ray sources are now limited by detector performance. Photon counting hybrid pixel detectors are being investigated as a solution to improve the dynamic range and the readout speed of the available 2D detectors. The XPAD2 is a large surface hybrid pixel detector (68 x 65 mm^2) with a dynamic response which ranges from 0.01 photons/pixel/s up to 10^6 photons/pixel/s. High resolution data have been recorded using the XPAD2. The comparison with data measured using a conventional setup shows a gain on measurement duration by a factor 20 and on dynamic range. A new generation of pixel detector (XPAD3) is presently under development. For this, a new electronic chip (the XPAD3) has been designed to improve spatial resolution by using 130 µm pixels and detector efficiency by using CdTe sensors. XPAD2 is also operated with PIXSCAN, a CT-scanner for mice.

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Keywords: Hybrid pixels, photon detector, photon counting, CT-scanner

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I. Introduction

Hybrid pixel detectors were developed at the Centre de Physique des Particules de Marseille (CPPM for vertex trackers of high energy physic experiments (DELPHI and ATLAS at CERN, Geneva). Applied to photons detection, because of their high performances in readout speed, detection efficiency, low noise, high dynamic range and energy selection, we expect relevant progress with respect to the standard detectors based on CCD's. In order to test it for material sciences, we have built a large surface detector with the XPAD2 chips [1], which were mounted on a goniometer arm. This paper describes the XPAD2 detector and presents results of X-ray scattering experiments performed in the D2AM-ESRF beam line [2]. Encouraging results demonstrating a significant gain in data acquisition time and large dynamic range led us to develop a new chip, the XPAD3, in submicronic technology to reduce the size of the pixels to 130 x 130 µm^2. The XPAD2 was also used in X-ray CT-scanner for small animal imaging.

II. The XPAD2 detector

The XPAD2 detector is a hybrid pixel detector built with the XPAD2 electronic chip designed in AMS 0.8 µm technology [1]. This chip has 600 pixels of 330 x 330 µm^2. Its input comprises an enable/disable switch used to eliminate bad pixels, and to serve as a fast electronic shutter. Each pixel includes a charge amplifier, a discriminator and a 15 bits counter. The discriminator thresholds are set for the whole chip and a fine adjustment (6 bits) is allowed for each pixel. A calibration charge can be injected in the charge amplifier via a small capacitor. The pulse width is 50 ns FWHM.In recurrent mode, a count rate of 10 MHz/pixel can be reached. Bump-bonded on silicon sensor its maximum random rate amounts to about 10^6 ph/pixel/s. 8 XPAD2 are bump-bonded on a 65 x 8 mm^2 area by 0.5 mm^3 thick silicon sensors. The thickness of the sensor gives an efficiency of 78% at 15 keV and 21% at 25 keV. These bare modules are glued and wire bonded to a printed circuit board (class 6), which serves as a routing PCB and as a mechanical support. 8 of these modules are tiled to make a 6,8 x 6,5 cm^2 detector of 38400 pixels (Fig. 1, left). Data can be read out during exposure time by scanning the pixel counters (15 bits) overflow at a rate higher than the counter filling and adding it an external 16 bits counter. Thus, a dynamic range of 10^9 can be achieved. Since each module has its own readout system, one can increase the number of modules without changing the readout time. At the end of the data acquisition, a fast readout system based on a Nios Altera board allows for reading the full detector in less than 2 ms. The system includes enough local memories to store either 423 frames with 15 bits per pixel or 210 frames with 31 bits per pixel. Finally, all data are transferred on the acquisition PC using a 100 MB ethernet link. The detector and its readout system are mounted in an air-cooled box that can be easily mounted on a goniometer arm, as shown on the Figure 1 (right).

III. X-ray scattering experiments

Several synchrotron X-ray scattering experiments have been realized to compare the performance of the XPAD2 detector with common CCD or scintillator detectors currently available detector. We give here the results of only two of them: a powder diffraction experiment and a time resolved experiment.

A. Powder diffraction

The powder diffraction is well suited for the study of real catalytic processes: it allows for knowing accurately the structure of molecular sieves. However it takes often a long time to record the diffraction pattern with the needed accuracy. We have compared high quality data recorded with a scintillator counter (1 mm receiving slit at 1 m from the sample, 60° 2 θ at 16 keV X-rays) using an angular step of 0.006° and XPAD data recorded using the same settings, but with wider angular steps and the same exposure time at each step. Data have been processed to build a Debye-Scherrer and to measure the angular distribution of the intensity. This distribution is represented on the Figure 2 and one can see that the XPAD detector is very good to measure weak signals since the signal from the water is well separated from the empty cell, while the signal from the CCD is not. Thus, it is possible to record high quality data within 1/20th of the time used with a conventional CCD detector. This reduces the experimental time from more than 8 hours to about half an hour, taking into account the motions.

B. Time resolved experiment

Acquiring 220 images with 32 bits per pixel and only 2 ms dead-time per image make it possible to record the quench of refractive oxides from their liquid state. For this experiment, the conventional settings do not allow to get data at a high enough rate to follow the crystallization process. Moreover, to avoid detector saturations, it is common to reduce the beam intensity by an absorber, which reduces acquired statistics event further. A small (CaO, 2 Al_2O_3) sphere was heated above its melting point by a laser. XPAD data were then recorded during the quench. 220 images of 20 ms separated by a dead time of 2 ms were recorded with 17 keV X-ray photons. The detector was located at 142 mm from the sample, leading to a pixel size of 0.13° and an angular aperture of 27°. The reaction is represented in Figure 3 as a 3D plot of the number of photons as a function of angle and time, where the advent of the crystallization peak can be seen.

IV. Next step

We are building an improved version of the XPAD. The aim is to reduce the pixel size in order to improve spatial resolution. We have designed a new chip with pixels of 130 x130 µm^2, precise threshold adjustment and very fast (< 2ms) frame readout. The chip size is 10 x 17mm^2. 7 chips and 8 of these modules will be assembled to form a detector of 12 x 7,5 cm^2. To improve the detection efficiency, we will also build modules with CdTe, but of smaller size (2 x 1,7 cm), due the lack of large size CdTe wafers.

The XPAD2 detector is also interesting for bio-medical imaging and we build an X-ray CT-scanner (named PIXSCAN) for small animal imaging [3].

V. Conclusions

We have shown that the XPAD2 hybrid pixel detector allows improving the data quality and reducing the data acquisition time by a factor of 20 (1/2h instead of 8h). Nice time resolved experiments are also possible by using this detector. Further progress will be made on the next chip generation (XPAD3) that has recently been submitted to foundry.

VI. References

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Figure caption list:

Fig. 1. The XPAD2 detector plate (left) and the XPAD2 mounted on the goniometer arm of the D2am-CRG/ESRF (right).

Fig. 3. Radial distributions obtain with XPAD and CCD (dashed).

Fig.4. Crystallisation of CaO, $2Al_2O_3$ from the liquid state, 20 ms frames recorded during the 4s quench process.

Fig.1.

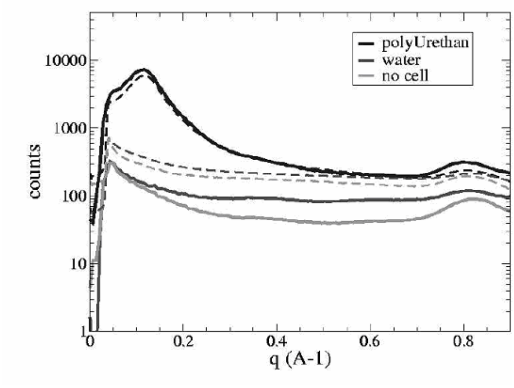
polyUrethan
water
no cell
10000
1000
100
10
1
counts
0
0.2
0.4
0.6
0.8
q (A-1)

Fig.2

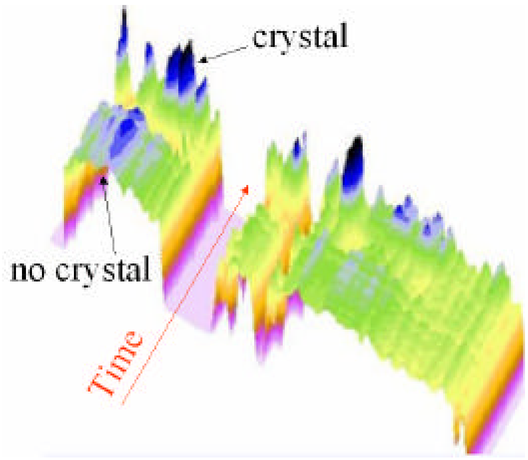

Fig.3