Development and first tests of the Arc-detector: a Schottky CdTe Medipix3RX photon-counting detector for X-rays

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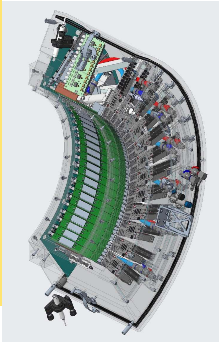

INTRODUCTION

The Detector Group (DG) at Diamond Light Source (DLS) is committed to develop detectors to meet the requirement of the 36 beamlines that DLS hosts, especially for those beamlines whose requirements cannot be fulfilled with commercially available detectors. This is the case of I15-1 beamline, which is optimised for X-ray pair distribution function (XPDF) measurements, collecting scattering data at 40, 65 or 76 keV, used by a diverse range of disciplines such as materials science, energy materials, earth sciences and pharmaceuticals.

These requirements (high energy and scattering angle) defined the development of a custom-made detector, the **Angularly-Resolved Cadmium telluride (*ARC*) detector,** with high-Z sensors arranged in an arc, with photon counting technology to reduce the background, and a pixel size smaller than 100 µm to exploit the characteristics of the beam size as the ideal detector for XPDF data collection on I15-1.

AIM

This work presents the ARC detector development consisting of e-Schottky CdTe sensor, Medipix3RX read-out ASIC photocounting detector of 55 µm pixel size arranged in an arc modular arrangement for XPDF synchrotron applications and the first beamline tests with the detector.

THE *ARC* DETECTOR

The Angularly-Resolved Cadmium telluride (*ARC*) detector has photon counting capabilities and high detection efficiency, making it the perfect tool for accurately measuring weak diffuse scattering data at high *Q*.

The detector head

The ARC with 4.7 megapixels consists of 24 individual 2D modules arranged on an arc at a radius of 250 mm, giving an angular 2θ coverage of 83° [1]. Each module has a 14.2 mm × 42.6 mm 1 mm thickness Schottky e-collection CdTe sensor InSn bump-bonded to 3×1 photon-counting Medipix3RX array [2]. The sensor carrier PCB provides HV to the sensor and has LV regulators, filter and thermal paths. The readout board connects two sensor modules at right angles to the Tinman connectors. With a total of 12 boards required, they have basic power regulation, buffering and fanout from the FPGA carrier board to the sensor modules. The FPGA is a Xilinx Artix 7 module mounted on a carrier board and data I/O is via a SFP socket and optical fibre. To facilitate servicing the detector, a modular structure allowing easy exchange of super-modules was implemented. A super-module consists of 4 sensor modules and 2 readout boards.

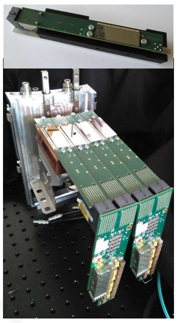

Figure 1. One module sensor and four modules in mounted in a super module

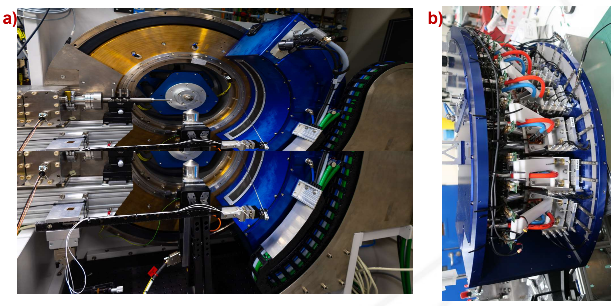

Figure 2. a) The completed ARC on its goniometer during testing on I15-1 b) internals of the ARC during assembly

The data acquisition unit

The data acquisition channel consists of a small data acquisition board, based on the Artix-7 FPGA, mounted on the detector head, which converts the 48 LVDS data of two modules to a serial data stream transmitted by 12 fibre optics links via a fanout self-designed board to the following data acquisition stage located a few metres apart on a 19" rack-based design. This electronics consists of two FEM-II data acquisition cards based on the Virtex7 FPGA. The data are then streamed at 25 fps (meeting I15-1 requirements) to a Linux server via 2 × QSFP+ on each FEM-II card which runs the Odin DAQ framework [3]. The system is completed by power and bias supplies and temperature, humidity, and current diagnostic sensors, which are monitored and controlled by the Linux server in order to periodically automatically cycle the bias supply and remove the polarization charge from the sensors.

Figure 3. a) FEM II readout board with Virtex 7 FPGA, b) Power and clock-trigger board, c) Rack DAQ unit

XPDF at I15-1 beamline at DLS

I15-1 specializes in XPDF experiments with a beam energy: 40.0 keV, 65.4 keV and 76.7 keV, providing a beam of 10 µm (v) × 700 µm (h) and a photon flux of $3{\cdot}10^{11}$ ph/s @ 76.7 keV 0.1% bandwidth $7{\cdot}10^{12}$ ph/s @ 76.7 keV 2.0% bandwidth.

ARC DETECTOR DATA

Modules tests

ARC detector modules were evaluated first and calibrated with photons from DG X-ray tube using the MERLIN readout system, which was adapted for its use with Schottky CdTe with a bias reset functionality.

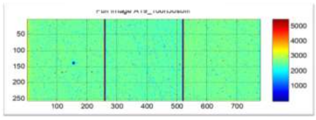

Figure 4. Flat field with Mo X-rays of a single module

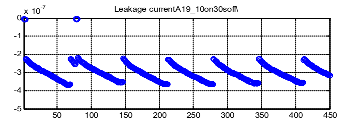

Figure 5. Leakage current bias refresh over time.

The mean counts and leakage current recovers to the sensor original performance after bias refresh, not showing over shooting.

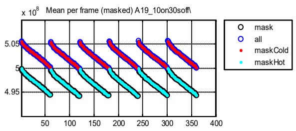

Figure 6. Mean counts per frame over time showing effect of bias refresh.

ARC PDF tests at I15-1

Then the ARC detector was assembled and mounted into its goniometer at I15-1 beamline for its commissioning and further characterization. The ARC runs in different modes, depending on the time-, reciprocal-, and real-space resolution requirements of the experiment. In rapid mode, the ARC collects data to a Qmax of 27 Å−1 (at 76 keV) at a rate of up to 50 Hz. Longer collections at two 2θ positions provide sample-limited PDF data with Qmax 51 Å−1 (at 76 keV), or Qmax 27 Å−1 at 40 keV if higher resolution reciprocal-space data is also needed.

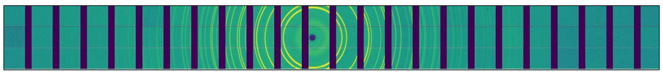

Figure 7. Scattering image collected with the ARC detector at I15-1 for XPDF experiment

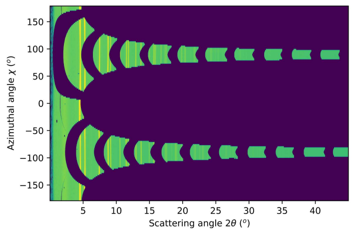

Figure 8. "Azimuthally re-grouped" data, i.e. pixel coverage as a fuction of scattering angle and aziumuthal angle

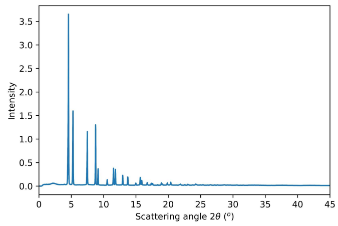

Figure 9. Merged 1-d dataset of the Fig. 8 data, onto a single scattering angle axis

Scattering image from the 24 module ARC detector that it is azimuthally regrouped as shown in Fig. 8. Then, the data is plotted onto a single scattering angle in Fig. 9 and how this data changes after time (Fig. 10) showing effects (e.g. highlighted with the red circle) of the sample atoms as they vibrate and move depending on the experimental conditions.

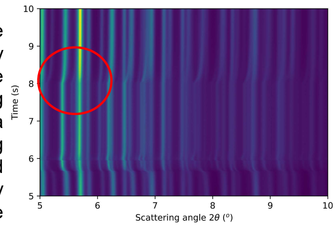

Figure 10. Time-series data showing scattering rapidly changing as a function of time.

CONCLUSIONS

Diamond has developed the 4.7 megapixel Angularly-Resolved Cadmium telluride (*ARC*) based on e- collection Schottky CdTe detector as the ideal detector for XPDF data collection on I15-1. Photon counting capabilities and high detection efficiency make it the perfect tool for accurately measuring weak diffuse scattering data at high *Q*. On going work is focused on evaluating the ARC performance for the different operational modes and I15-1 user applications.

REFERENCES

[1] Gimenez, E. N., et al. (2019) *IEEE Nuclear Science Symposium and Medical Imaging Conference*, 2019, 1-3.
[2] MEDIPIX Collaboration, CERN: http://medipix.web.cern.ch/medipix/
[3] Yendell G. et al. ICALEPS2017 Proceedings (2018). DOI:10.18429/JACoW-ICALEPCS2017-TUPHA212

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