Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Recent progress in high resolution X-ray customised detection systems

To cite this article: A Vacchi *et al* 2022 *J. Phys.: Conf. Ser.* **2380** 012095

Recent progress in high resolution X-ray customised detection systems

A Vacchi[1,2], D Cirrincione [1,2], M Altissimo [3], M Antonelli[1], G Aquilanti [3], P Bellutti [4,5], G Bertuccio [6,7], G Borghi [4,5], I Carlomagno[3], G Cautero [3,1], F Ficorella [4,5], M Gandola [4], A Gianoncelli[3], D Giuressi [3,1], G Kourousias[3], F Mele [6,7], R H Menk [3,1], L Olivi [3,1], G Orzan [1], A Picciotto [4,5], A Rachevski [1], I Rashevskaya [5], L Stebel [3], G Zampa [1], N Zampa [1], N Zorzi[4,5]

[1] INFN - Trieste, Trieste, Italy
[2] Dep. of Mathematics, Computer Science, and Physics, University of Udine, Udine, Italy
[3] Elettra-Sincrotrone Trieste S.C.p.A., Trieste, Italy
[4] Fondazione Bruno Kessler, Trento, Italy
[5] TIFPA – INFN, Trento, Italy
[6] Politecnico di Milano, Como, Italy
[7] INFN Milano, Milano, Italy

E-mail: andrea.vacchi@uniud.it

Abstract. The results of a collaborative development activity aimed to the realization of multi-cell detectors based on monolithic SDD pixel technology will be described. Two kind of detection systems, skilled for the light lines at synchrotrons, have been brought to high levels of finalization and integration; a 64 cells detection system dedicated to absorption spectroscopy (XAFS) and a 32 cells detector for the X-ray microscopy (TwinMic). The main targets of this effort, led in a tight collaboration with the beam lines scientists, were large sensitive area, high rate capabilities, state of the art efficiency and energy resolution. The aim is to reduce the beam time demand for each single measurement while delivering a cutting edge analytical power.
All basic elements of those detection systems, from the detector's design and production to the front-end and read-out electronics including the final engineering of the integrated system were customized to the specific use addressed.

1. Introduction

As an answer to the requirements expressed by the users and beam-line scientists for optimising the exploitation of machine time, monolithic multi-pixel Silicon Drift Detector (SDD) customized sensor designs dedicated to specific applications in XRF (X-Ray Fluorescence spectroscopy) and XAFS (X-ray Absorption Fine Structure) were developed and integrated in a complete detection system [1].

2. Monolithic arrays of SDD

Since the inception of the original SDDs [2, 3, 4] the parallel evolution of this devices production technology, design and simulation, has made it possible to develop high performances monolithic multipixel SDD showing excellent performances at near room temperatures. Within this scenario a large number of projects were brought ahead within the framework of the INFN collaboration named ReDSoX (REsearch Drift for SOft X-rays). We describe the main results from the two main Synchrotron Radiation (SR) dedicated developments: 64 channels XAFS-SESAME and 32 channels TwinMic detection systems.

3. XAFS-SESAME: Integrated Detection System

Specially designed for the X-ray absorption spectroscopy beam-line at the Jordanian synchrotron light source SESAME [5], which provides a photon beam with an energy range between 3 and 30 keV, the XAFS-SESAME integrated detection system has been delivered and made operative by December 2019.

3.1. Brief description

The detection system, shown in figures 1 and 2, is composed of 8 rectangular monolithic SDD arrays each carrying 8 cells, with a total of 64 channels reaching a sensitive area of 570 mm^2. The readout anodes of every SDD cell are wire bonded to SIRIO [6, 7, 8] charge preamplifiers. This Ultra Low Noise CMOS Charge Sensitive Preamplifier has been specifically designed by Politecnico of Milano for these high resolution SDDs based X-ray spectrometers.

This modular detection system where the eight planes supporting SDD and electronics are arranged in an aluminum case completely closed and screened in a temperature controlled ambient [9, 10]. The cooling system based on Peltier elements and chilled liquid cooling has the function of granting temperature stability across the system.

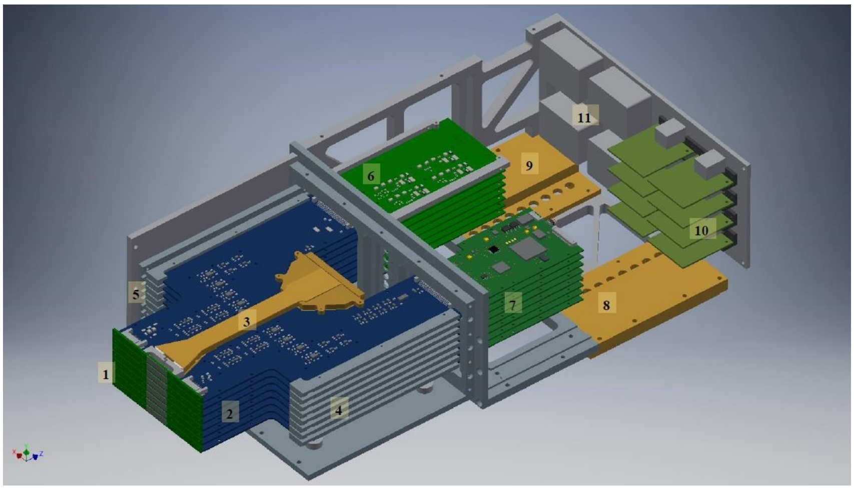


Figure 1. Scheme of the detection system: (1) detectors and related PCBs, (2) Front-End PCBs, (3) brass profile for liquid cooling, (4) insertion guides at the flanks of detecting heads, (5) rails for eight detection heads, (6) power supply and filters PCBs, (7) Back-End PCBs, (8, 9) cooling distribution inlet and outlet, (10) ethernet PCBs, (11) power supply connectors [10].

3.2. Aspects of the operation

Once the temperature stabilization of the whole system is attained the calibration and alignment of the 64 channels procedure takes place. This operation is fully automatized through the FICUS software developed by ELETTRA Sincrotrone Trieste (fig. 3).

To confirm the ability of the system to work at the relevant needed count-rate, while maintaining low dead time and a good energy resolution, a preliminary test was performed.

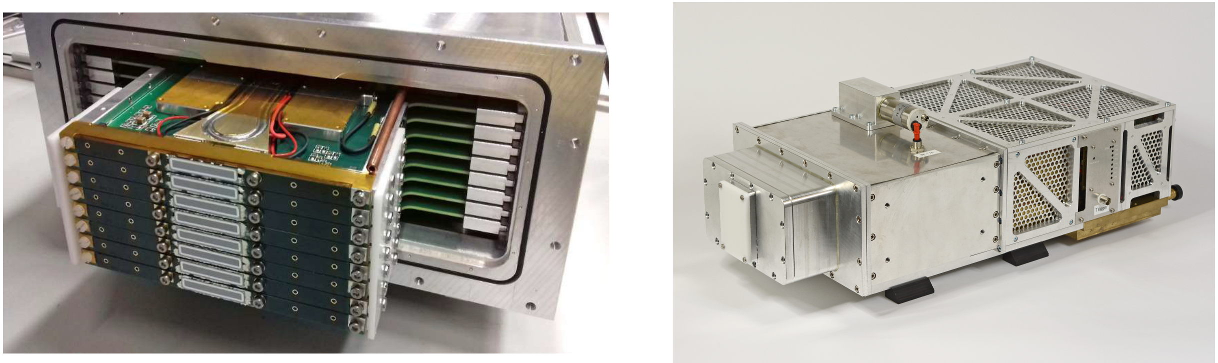


Figure 2. On the left: the 64-channels SDD detector head. On the right: a perspective view of the integrated XAFS-SESAME detection system [11].

Figure 3. Screenshot from the FICUS software: simultaneous live acquisition of the 64 channels with the calibration sample (K, Ti, Mn, Zn, Br, Zr). As one can see all channels are uniform in characteristics and performance [11].

Subsequent experimental results confirmed the design parameters i.e. an output count-rate (OCR) of 15.5 Mcount/s for the entire 64 elements detector [1].

3.3. Results

The results obtained from the measurements made with the XAFS SESAME detector system confirm the excellent performance for which it was designed.

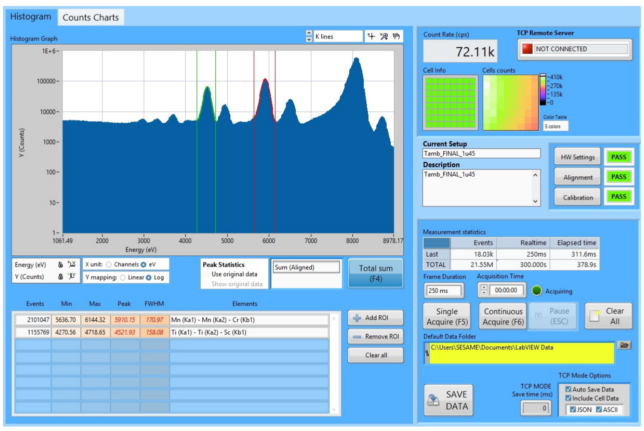


Figure 4. Acquisition screen shot of data collected from the 64 channels aligned at room temperature (27 °C) and with a peaking time of 1,45 μs [11].

In particular, figure 4 shows a a screen shot of the calibration sample (signal sum of 64 channel aligned) acquired at room temperature and with a peaking time of 1,45 μs. In figure 5 the energy resolution (FWHM) for the Mn K_α emission line at 5.9 keV is shown as a function of the peaking time, revealing little difference between the cooled detector (red line) and room temperature operation (black line), demonstrating the very low noise level associated with the SDD leakage current and the effectiveness of the temperature stabilization across the system[11, 12].

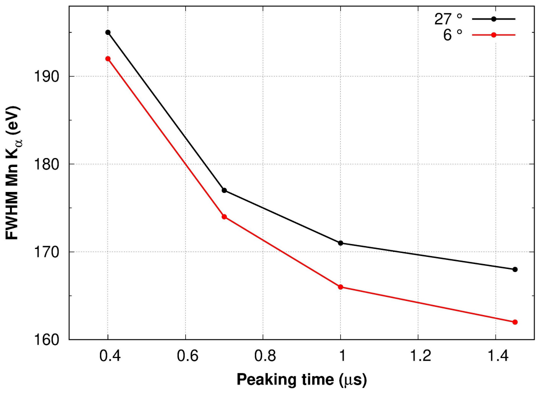
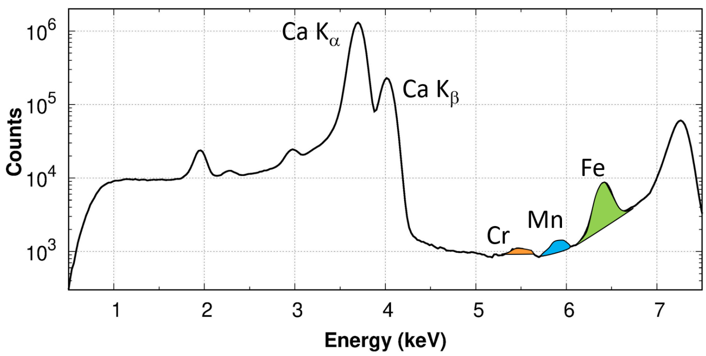


Figure 5. Energy resolution versus peaking time at room temperature (black line) and for the cooled detector (red line) with an average temperature of the sensors of 27 °C, and of 6 °C, respectively. [11, 12]

To demonstrate the performance of the system, a scientific sample of known composition by type and quantity of elements was analyzed. The XRF spectrum shows the evidence of spectral lines due to traces of elements present down to about 3 ppm (Fig. 6) [12].



	Fe (ppm)	Mn (ppm)	Cr (ppm)
C9	400 (±20)	38 (±2)	2.9 (±0.1)
C11	130 (±1)	13 (±1)	2.9 (±0.1)
C13	130 (±1)	20 (±1)	3.5 (±0.2)
C20	210 (±10)	13 (±1)	4.5 (±0.2)

Figure 6. On the left XRF spectrum (sum signal of the 64 aligned channels) of the C20 sample: the fluorescence intensities are shown in log-scale, the Fe, Mn and Cr K_α fluorescence signals are emphasized in colour. On the right the Table with concentrations (in ppm) of Fe, Mn and Cr in the investigated samples. Uncertainties are reported in parentheses [12].

3.4. On-going work

Gathering from the acquired experience and the adjourned specifications of the beam line specialists of XAFS Sincrotrone Trieste a new detector system is under construction. This system carries an improved electronics, a new temperature stabilization system and is equipped with collimators delimiting the sensitive areas. The results obtained and the comparison of the characteristics and performances between the two 64-channel detection systems will be discussed in detail in a following work.

4. New approach to the TwinMic detection system

This detection system is specially designed for TwinMic beam-line at ELETTRA Sincrotrone Trieste that provides a photon beam with an energy below 2 keV [13].

4.1. Brief description
Four monolithic SDD arrays covering a total non-collimated active area of 1232 mm^2, and a total collimated active area of 1113 mm^2 are used in this new system. Each trapezoidal-shaped sensor is composed of 8 square SDD cells of 6.2 x 6.2 mm^2 [14, 1]. The focused synchrotron beam exits from the centre of the detector system and hits the specimen placed just in front of the detectors. In figure 7 and table 1 a brief comparison is shown between the current detector of the TwinMic beamline and the new detection system.

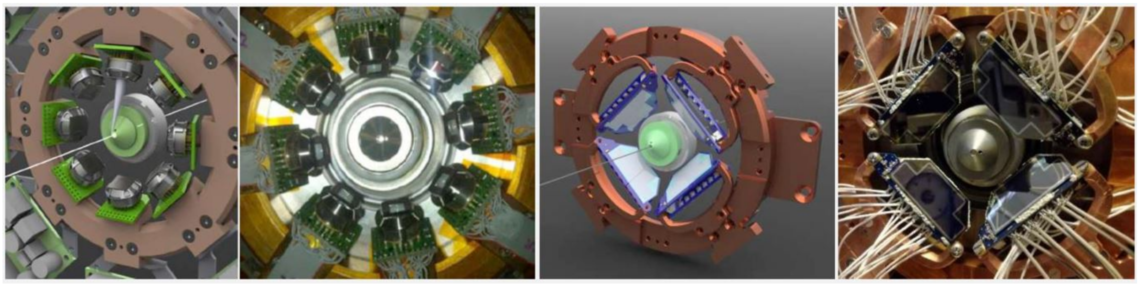


Figure 7. Comparison between the rendering and the photos of the current detector of the TwinMic beamline, on the left, and, on the right, of the new detection system under construction.

Table 1. Comparison between the characteristics of the current detector of the TwinMic line and of the new detection system.

	Current TwinMic detector system	Novel SDD detection system
Active area [mm^2]	240	1230
Solid angle [%]	4	27
Counts [kcounts/s]	35	195
Exp time equiv. [hh:mm]	10:00	01:48

4.2. Results and next steps
A set of measurements made with the new detector system was analyzed (fig. 8) to exploit the angular dependence of XRF detection in order to carry out the topographical study of the specimen [15]. The final detection system for TwinMic beam-line is being optimized and engineered. New tests and comparisons will be carried out on the final system.

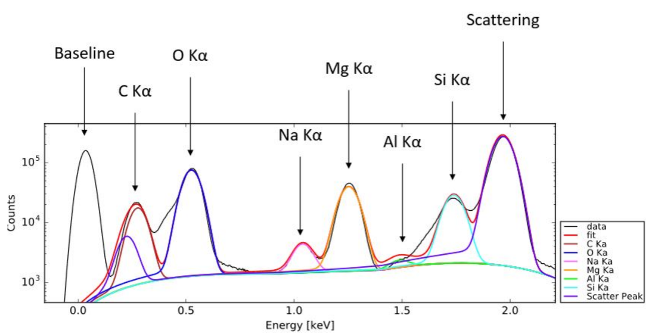


Figure 8. Analysis results of data collected from the channel 4 of the trapezoidal number 1 at temperature of -6,5 °C

5. Conclusions

The availability of those integrated detection systems represents for the XAFS and TwinMic beamlines an important improvement. This results has been made possible by a transversal professional collaboration between all actors for each specific technology: detector design, detector production, Front End Electronics development, complete engineering and of all other aspects. In each of this direction dedicated state of the art elements were developed on purpose. It is so that the 64-channel XAFS detector and the large solid angle TwinMic detector were able to reach unique results and will represent an important starting point for the next steps which the collaboration is planning while being open to new contribution.

Acknowledgments

This work has been made within the ReDSoX-2 INFN research project, supported with the contribution of the Italian Ministry of Education, University and Research within the EUROFEL Project and FBK-INFN agreement 2015-03-06. The ReDSoX collaboration thanks INFN for the continuum support to the SESAME project.
Acknowledgments are due to my colleagues of the ReDSoX Collaboration and of the Optical X-ray laboratory and XAFS beamline of Elettra Sincrotrone Trieste.

References

[1] Bufon, J., et al. Large solid angle and high detection efficiency multi-element silicon drift detectors (SDD) for synchrotron based X-ray spectroscopy. AIP Conference Proceedings. Vol. 2054. No. 1. AIP Publishing LLC, 2019.
[2] Gatti, E., and Manfredi, P. F. Processing the signals from solid-state detectors in elementary-particle physics. La Rivista del Nuovo Cimento (1978-1999) 9.1 (1986): 1-146.
[3] Gatti, E., and Rehak, P. Review of semiconductor drift detectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 541.1-2 (2005): 47-60.
[4] Vacchi, A., et al. Performance of the UA6 large-area silicon drift chamber prototype. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 306.1-2 (1991): 187-193.
[5] Synchrotron-light for Experimental Science and Applications in the Middle East, http://sesame.org.jo/sesame_2018/
[6] Bertuccio, G., et al. X-ray silicon drift detector–CMOS front-end system with high energy resolution at room temperature. IEEE Transactions on Nuclear Science 63.1 (2016): 400-406.
[7] Bertuccio, G., et al. A Silicon Drift Detector-CMOS front-end system for high resolution X-ray spectroscopy up to room temperature. Journal of Instrumentation 10.01 (2015): P01002.
[8] Bertuccio, G., et al. A CMOS charge sensitive amplifier with sub-electron equivalent noise charge. 2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). IEEE, 2014.
[9] Cirrincione, D. First characterization of the detector system for the XAFS beam-line of the synchrotron light source SESAME. Il nuovo cimento C 42.5 (2019): 1-8.
[10] Rachevski, A., et al. The XAFS fluorescence detector system based on 64 silicon drift detectors for the SESAME synchrotron light source. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 936 (2019): 719-721.
[11] Cirrincione, D. New versatile monolithic multi pixel detector system based on Silicon Drift Detectors. PhD Thesis University of Udine (2020).
[12] Carlomagno, Ilaria, et al. Trace-element XAFS sensitivity: a stress test for a new XRF multi-detector. Journal of Synchrotron Radiation 28.6 (2021).
[13] Gianoncelli, A., et al. A new detector system for low energy X-ray fluorescence coupled with soft X-ray microscopy: First tests and characterization. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 816 (2016): 113-118.
[14] Bufon, J., et al. A new large solid angle multi-element silicon drift detector system for low energy X-ray fluorescence spectroscopy. Journal of Instrumentation 13.03 (2018): C03032.
[15] Kourousias, G., et al. XRF topography information: Simulations and data from a novel silicon drift detector system. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 936 (2019): 80-81.