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First characterization of the detector system for the XAFS beam-line of the synchrotron light source SESAME

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Summary. — A Fluorescence Detector System for X-ray Absorption Fine Structure (XAFS), composed of 8 monolithic arrays of Silicon Drift Detectors (SDDs), each having 8 cells of 9 mm^2 area, is being realized within the INFN ReDSoX Collaboration. It will be used for X-ray absorption spectroscopy at the Jordanian synchrotron light source SESAME, which provides a photon beam with an energy range between 3 and 30 keV. Detailed characterization tests at Elettra Sincrotrone Trieste have demonstrated an energy resolution at the Mn 5.9 keV Ka line, for the monolithic array, below 170 eV FWHM at room temperature.

1. – Introduction

SESAME, the Synchrotron-light for Experimental Science and Application in the Middle East, is a project that was born to promote technology and science, and to help improve the delicate situation in the Middle East. It is a 2.5 GeV third-generation synchrotron light source located in Jordan and has a scientific interdisciplinary program [1-4].

Italy, one of the Observer countries, has allocated, through the Ministry of Education, University and Research (MIUR), an *ad hoc* financing. This significant contribution to its implementation is managed by the Istituto Nazionale di Fisica Nucleare (INFN) in collaboration with Elettra Sincrotrone Trieste. One of such contributions, realized within the ReDSoX (Research Drift detectors for Soft X-ray) Collaboration by INFN-Trieste and Elettra, was the production of a multi-channel silicon detector for X-ray fluorescence measurements to be used at XAFS/XRF beamline at SESAME.

2. – Materials and methods: The detection system

The detector system was designed and implemented for X-Ray Fluorescence (XRF) and X-ray Absorption Fine Structure (XAFS) experiments. It is based on the state-of-the-art technology both for the sensor and for the readout electronics. It is composed of

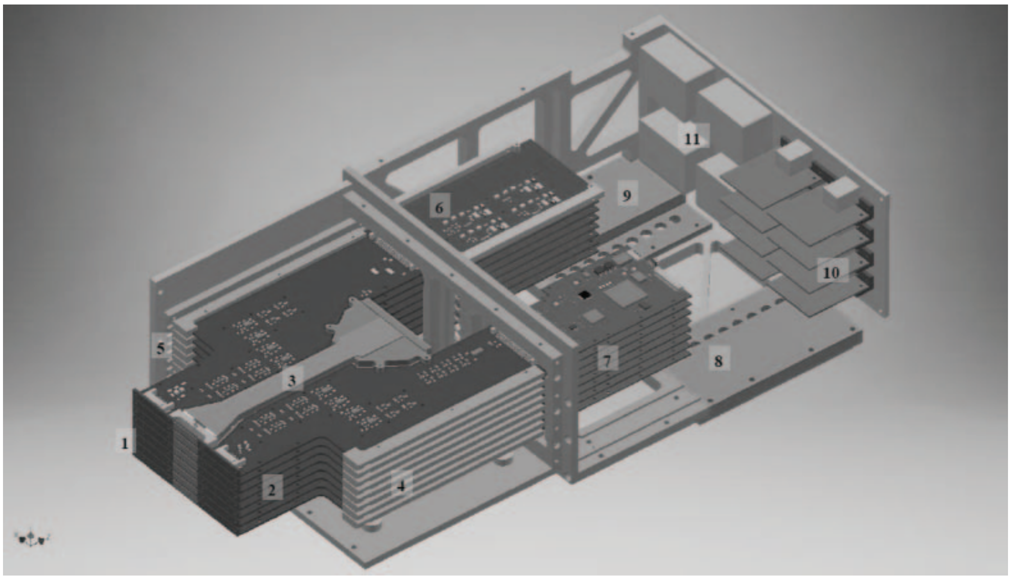


Fig. 1. – Detector system: (1) detectors and detector PCBs, (2) front-end PCBs, (3) brass profile with cooling liquid flowing inside, (4) insertion guides at flanks of detecting heads, (5) rails for eight detection heads, (6) power supply and filters PCBs, (7) back-end PCBs, (8) inlet cooling distribution, (9) outlet cooling distribution, (10) ethernet PCBs, (11) power supply connectors [5].

8 rectangular monolithic arrays of SDDs, with a total sensitive area of 570 mm^2. It was specially designed from the XAFS beamline scientists' requests and optimized to work in an energy range of 3–30 keV.

The detection system, schematically shown in fig. 1, is a modular system consisting of eight planes arranged in an aluminum case [5].

Before this final version of the detection system, two different prototypes were built and tested in laboratory and on the beamline at Elettra Sincrotrone Trieste [6, 7].

During operation, the system is completely closed and darkened. The SDDs, FE electronics, and the first part of the cooling system are subject to a moderate nitrogen fluxing in order to avoid dew condensation.

2˙1. *The sensor*. – The Silicon Drift Detector is a semiconductor detector invented by Gatti and Rehak in 1983 [8-10].

The SDDs of this detector system, fig. 2, are designed by INFN-Trieste and built by FBK-Trento. They were obtained from a high-purity, 450 μm thick n-type silicon wafer with a resistivity of 9 kΩcm. The detector, shown in fig. 2, is composed of 8 rectangular monolithic arrays of SDDs, each having 8 square cells of 9 mm^2 (called a strip) [5, 7, 10].

The monolithic array of 8 SDDs is mounted on a detector PCB, onto which 8 SIRIO charge preamplifiers [10-12] are glued. This detector board also provides anchor points for the coupling to the cold side of the cooling system.

2˙2. *Electronics*. – The readout anodes of every SDD cell are wire bonded to SIRIO [10-12] charge preamplifiers. This ultra low noise CMOS charge sensitive preamplifier was specifically designed by Politecnico of Milano for high-resolution X-ray spectrometry with SDDs.

Fig. 2. – SDD linear array comprising 8 square cells with a $3 \times 3\,\mathrm{mm}^2$ active area. Anode (top) and entrance window (bottom) sides.

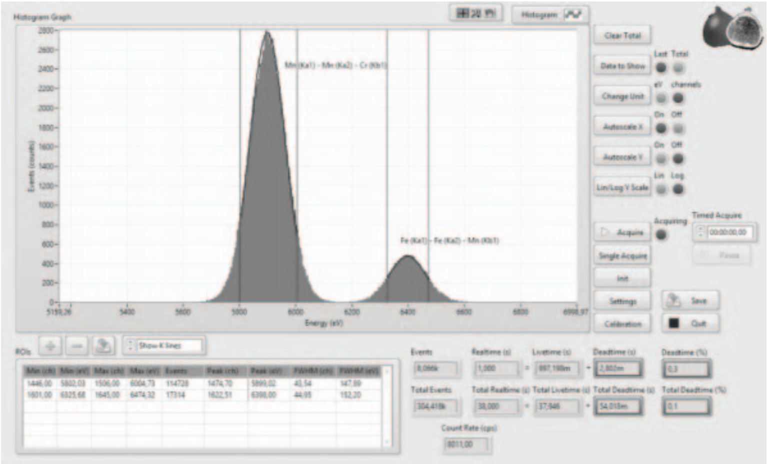
Connected to the FE PCB, the Back-End PCB includes an 8-channel, 12 bit ADC and an FPGA. Here the pre-shaped signals are sampled at a rate of 40 MHz and are filtered with an optimized finite impulse response (FIR) filter of variable length by the FPGA.

After the digital elaboration, the data are transmitted through the ethernet PCB via TCP/IP to a host computer in which there is a dedicated software for the control and the acquisition [5, 7, 13].

2˙3. *The cooling system.* – The cooling system is meant to stabilize the temperature of the detectors cooling them down moderately (0–10 °C): to stabilize the temperature of the detectors, water cooled to 18 °C by an external chiller is circulated in a distribution circuit which removes heat from the hot side of Peltier cells, whose other face, the cold side, is in thermal contact with the detector PCB and cools down the sensor [5, 7].

2˙4. *Software.* – A custom software was specifically designed, following the beamline requirements, for the tasks of data acquisition and instrument management: FICUS (Fluorescence Instrumentation Control Universal Software) (fig. 3).

Using this software, after a preliminary selection of measurement parameters, it is possible to perform the following tasks: data alignment of the cells, energy calibration,



Min (ch)	Min (eV)	Max (ch)	Max (eV)	Events	Peak (ch)	Peak (eV)	FWHM (ch)	FWHM (eV)
1446,00	5802,03	1506,00	6004,73	114728	1474,70	5899,02	43,54	147,89
1601,00	6325,68	1645,00	6474,32	17314	1622,51	6398,00	44,95	152,20

Timed Acquire: 00:00:00,00

Events: 8,066k
Realtime (s): 1,000 = Livetime (s): 997,198m + Deadtime (s): 2,802m
Deadtime (%): 0,3
Total Events: 304,418k
Total Realtime (s): 38,000 = Total Livetime (s): 37,946 + Total Deadtime (s): 54,018m
Total Deadtime (%): 0,1
Count Rate (cps): 8011,00

Fig. 3. – Simulation of the real-time analysis with the acquisition software FICUS.

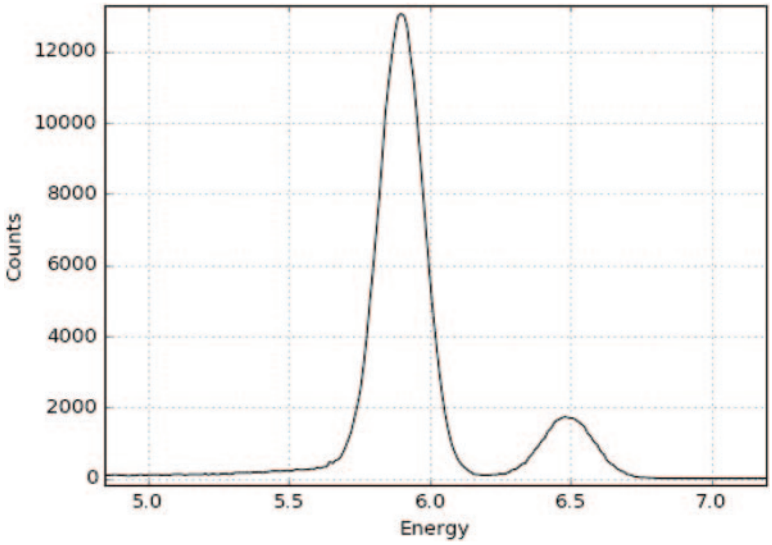


Fig. 4. – Acquisition with all the 8 channels of strip21 and ^{55}Fe source at room temperature. The resolution is 170 eV at Mn kα line at room temperature for a peaking time of 0.9 μs.

selection of the Region Of Interest (ROI). During the measurement it is possible, for example, to obtain a spectrum in real time with some information such as FWMH and peak centroid (in ADC channels and in eV), count rate and dead time.

3. – Test

After preliminary tests, every strip was mounted on board into the system and characterized in laboratory with radioactive sources. To carry out more detailed tests at higher energies and rates, the detection system was brought to the optical X-ray laboratory and on the XAFS beamline at Elettra Sincrotrone Trieste.

3˙1. *Test at the laboratory.* – The first test done on a strip (and, consequently, a complete plane) is the acquisition with both a pulser and a ^{55}Fe source to analyze the correct functioning of the cells, uniform and the resolution of the SDDs. The characterization tests were made for all the strips of the detector system (fig. 4).

3˙2. *Test at the optical X-ray laboratory.* – For the preliminary test we used the X-ray optical laboratory of Elettra Sincrotrone Trieste. In particular, we used an X-ray tube with an Ag anode as source and the detector system with only one module (strip).

A calibration sample was prepared and subsequently used to test the detector system. This sample was composed of Ti, Zn, and Mo; in this way we could make energy calibration in a large energy range, from 4 to 20 keV, and analyze the performance of the detector in detail. This task was performed using the PyMca X-ray Fluorescence Toolkit [14, 15]. Figure 5 presents the spectrum and the peak energy of the elements present in the calibration sample; this acquisition was done at room temperature. Table I shows the analysis of the FWHM of the elements present in the calibration sample.

The high flux provided by the X-ray tube allowed us to design and test a digital pile-up rejection circuit, within the FPGA, which enabled us to improve the detector

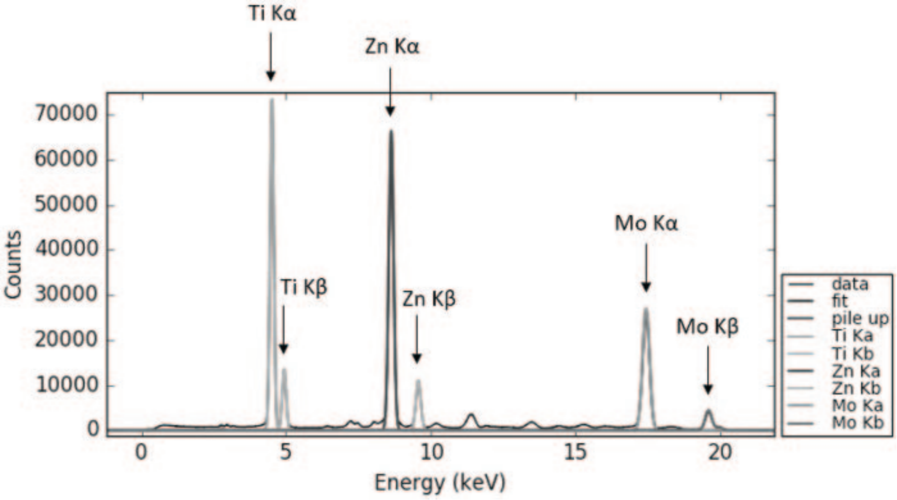


Fig. 5. – Analysis of the calibration sample (Ti, Zn, Mo), acquisition with strip8 at room temperature at the optical X-ray laboratory of Elettra Sincrotrone Trieste.

Table I. – *The analysis of the FWHM of the elements present in the calibration sample (Ti, Zn, Mo).*

Line	Energy [eV]	FWHM [eV]
Ti Kα	4509	155
Ti Kβ	4932	159
Zn Kα	8639	193
Zn Kβ	9572	201
Mo Kα	17479	257
Mo Kβ	19607	270

performance and to measure the Output Count Rate (OCR) as function of the Input Count Rate (ICR). The result of these measurements is presented in fig. 6. To perform the OCR *vs.* ICR scan we irradiated a Zn target (fluorescence lines Kα = 8639 eV and Kβ = 9572 eV): using a peaking time of 0.9 us, a single module produces an OCR of 1600 kcounts/s·cm^2, hence the complete detection system with 64 cells is expected to be able to operate up to 8 Mcounts/s [5]. There is not performance degradation at high ORC.

3·3. *Test on the XAFS beamline at Elettra Sincrontrone.* – The XAFS beamline at Elettra Sincrotrone Trieste covers an energy range from 2.4 to 27 keV. It combines X-ray Absorption Spectroscopy (XAS) with X-Ray Diffraction (XRD) to give important physical and chemical information to characterize the atomic structure of the samples under test [6, 7, 16].

This beamline uses for its experiments a KETEK GmbH AXAS-M silicon drift detector. It is composed of a single SDD cell of 100 mm^2 (80 mm^2 of effective collimated

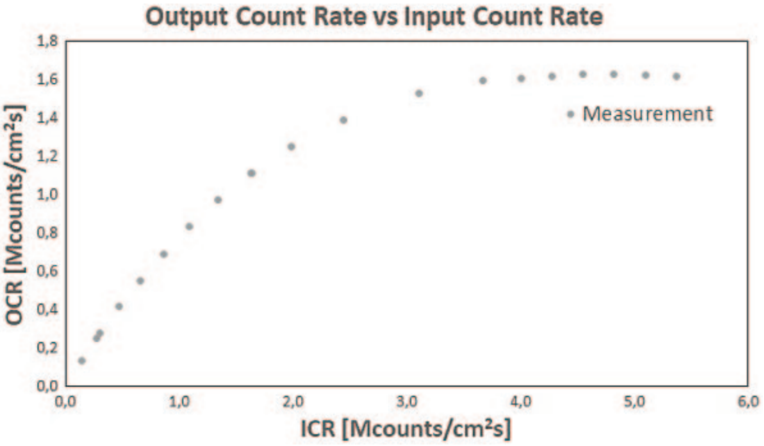


Fig. 6. – Output count rate (OCR) was measured with a single module as a function of the input count rate (ICR).

area) and has an energy resolution of about 170 eV for the Mn Kα line at 5.89 keV at a peaking time of 1.32 μs and cooling at −70 °C. This detector is limited at high count rates by dead time because it uses a large SDD cell (50% of dead time at an OCR of 1.3×10^5 counts s^{-1} of output) [17]. Our detector, designed specifically for the beamline requirements, is equipped with a segmented sensor with 64 cells of smaller area coupled with fast and low-noise electronics with independent read-out circuitry, allowing to operate with a low dead time at high count rates.

In February 2018, the detector system using two SDD modules was tested on the XAFS beamline [5].

The results of this last test allow us to compare the two detectors (the KETEK SDD against one 8-SDD module) [5]:

- The energy resolution is comparable.
- KETEK SDD stops working effectively at a maximum OCR just above 100 kcounts/s with a dead time of 50%.
- One module of 8 SDDs have an OCR of 1600 kcounts/s·cm^2 (that is 8 Mcounts/s for the complete system of 8 modules).

4. – Conclusions

While writing this article, the detector system proceeds to be definitely assembled, with last finalizing touch-ups for: SDD, preamplifier, tungsten collimators and cooling system. After this, it will be tested again, this time complete, on the XAFS beamline at the Elettra Sincrotrone Trieste and, finally, it will be installed on the XAFS/XRF beamline at the SESAME synchrotron.

We developed and tested a new detector system based on SDDs for the XAFS beamline at SESAME. The system was characterized in the INFN-Trieste laboratory, in the optical X-ray laboratory and XAFS beamline of the Elettra Sincrotrone Trieste. The detector has a monolithic array of SDDs with large area, low noise dedicated FE electronics, low pile-up and short dead time, as required by the scientists of the beamline. It demonstrated an energy resolution of 170 eV at Mn kα line at room temperature for a peaking time of 0.9 μs and will allow the scientists at SESAME to operate with very large photon fluxes to reduce the time required to measure a XAFS spectrum.

5. – Abbreviations

The following abbreviations are used in this paper:

BE	Back End
CSA	Charge Sensitive Amplifier
ENC	Equivalent Noise Charge
FE	Front End
FWHM	Full Width at Half Maximum
ICR	Input Count Rates
INFN	Istituto Nazionale di Fisica Nucleare
MIUR	Ministry of Education, University and Research
OCR	Output Count Rates
PCB	Printed Circuit Board
ReDSoX	Research Drift for Soft X-rays
RMS	Root Mean Square
ROI	Region Of Interest
SDD	Silicon Drift Detector
SESAME	Synchrotron-light for Experimental Science and Applications in the Middle East
XAFS	X-ray Absorption Fine Structure
XRF	X-Ray Fluorescence

* * *

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