First results of a novel Silicon Drift Detector array designed for low energy X-ray fluorescence spectroscopy

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A B S T R A C T

We developed a trapezoidal shaped matrix with 8 cells of Silicon Drift Detectors (SDD) featuring a very low leakage current (below 180 pA/cm^2 at 20 °C) and a shallow uniformly implanted p$^+$ entrance window that enables sensitivity down to few hundreds of eV. The matrix consists of a completely depleted volume of silicon wafer subdivided into 4 square cells and 4 half-size triangular cells. The energy resolution of a single square cell, readout by the ultra-low noise SIRIO charge sensitive preamplifier, is 158 eV FWHM at 5.9 keV and 0 °C. The total sensitive area of the matrix is 231 mm^2 and the wafer thickness is 450 μm. The detector was developed in the frame of the INFN R&D project ReDSoX in collaboration with FBK, Trento. Its trapezoidal shape was chosen in order to optimize the detection geometry for the experimental requirements of low energy X-ray fluorescence (LEXRF) spectroscopy, aiming at achieving a large detection angle. We plan to exploit the complete detector at the TwinMic spectromicroscopy beamline at the Elettra Synchrotron (Trieste, Italy). The complete system, composed of 4 matrices, increases the solid angle coverage of the isotropic photoemission hemisphere about 4 times over the present detector configuration. We report on the layout of the SDD matrix and of the experimental set-up, as well as the spectroscopic performance measured both in the laboratory and at the experimental beamline.

1. Experimental setup

The TwinMic spectromicroscope at Elettra Synchrotron (Trieste, Italy) is a multipurpose experimental station for full-field and scanning imaging modes and simultaneous acquisition of X-ray fluorescence (XRF). The actual Low Energy XRF (LEXRF) detection setup [1] consists of eight single-cell Silicon Drift Detectors (SDD) in an annular configuration providing results for different science communities, from life science [2,3] to new materials [4]. Even though they feature good performances in terms of both energy resolution and low-energy photon detection efficiency, they cover just a small fraction of the whole photoemission solid angle, which is a limiting factor for the LEXRF science. The XRF maps require acquisition times of the order of seconds or tens of seconds per pixel in order to acquire a statistically significant signal, resulting in overall scanning times from 6 to 12 h. The new system, composed of 4 trapezoidal multi-cell SDDs, increases the solid angle coverage of the isotropic photoemission hemisphere: a single SDD matrix is

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equivalent to the present detector configuration [5]. Shorter measurement times open the possibility both to analyze more specimens in a specific time, and to reduce the dose delivered to the specimen. In special cases such as 3D XRF mapping and XRF tomography, a detector with higher collection efficiency becomes even more crucial allowing us to acquire larger scans.

2. The detector

The detector is a completely depleted volume of n-type 450 μm thick silicon wafer with a resistivity of 9 kΩ cm organized as a trapezoidal shaped matrix with 8 cells of SDDs, which are 4 square cells, 39 mm^2 each, and 4 half-size triangular cells. On the detector front side, there is a shallow uniformly implanted p^+ entrance window common to all 8 drift cells of the matrix that enables good sensitivity down to few hundreds of eV. The detector total sensitive area is 231 mm^2. The detector backside is an arrangement of decreasingly negative biased p^+ rings (drift cathodes). The bias voltage is applied to the outermost drift cathode that separates the cells. In the center of each cell, there is a small n^+ pad (readout anode) and, close to it, the innermost cathode that is kept at the smallest negative potential among the drift electrodes. Voltage dividers, integrated separately for each cell, connect drift cathodes and generate potential drops between them, thus setting up a drift field. The entrance window is biased separately with respect to the detector backside in order to contribute to the full depletion of the detector bulk and to ensure an effective charge collection [6]. Outside of the sensitive area of the whole matrix, both on the backside and the front side, there are several floating p^+ rings (guard cathodes). They serve to scale down the bias voltage to the ground. The detector, featuring a leakage current below 180 pA/cm^2 at 20 °C and 8 collection anodes with capacitance of about 100 fF, was readout by the ultra-low noise SIRIO charge sensitive preamplifiers [7]. Using a non-collimated ^{55}Fe calibration source, we measured in a climatic chamber a single cell energy resolution of 158 eV FWHM at 5.9 keV and 0 °C. The front-end PCB houses one trapezoidal detector, 8 SIRIO ASICS, 8 preshapers and 2 analog multiplexers (one for each half-detector). The serialized signals are transmitted to a back-end PCB where they are sampled by two ADC managed by an FPGA that processes the data and sends them to a PC outside the experimental chamber.

3. Experimental results

During the December 2014 beam test, we focused on the following aspects for the new detector: capability to acquire simultaneously from many cells, vacuum operation of the acquisition electronics in close proximity to the SDDs, and possibility to increase dramatically the count rate widening the coverage of the photoemission solid angle. On the contrary, for that time we relaxed the energy resolution requirement since it was a first feasibility test. We mounted two out of four detectors foreseen in a cloverleaf configuration of the 32 cells complete system. To demonstrate the performance of the new system we acquired the signals coming from five cells, both square and triangular ones, of one trapezoidal matrix. First, we tested a standard reference sample: a 550 nm layer of MgF_2 deposited on a 100 nm thick Si_3N_4 membrane. These measurements (Fig. 1) demonstrated the detector sensitivity of at least up to photons of fluorine $K_{\alpha 1}$ emission line (676.8 eV). Second, we performed XFR mapping of a soybean root by scanning a section where we expected to detect Al, Na, Mg and Si along with the organic compounds elements such as C, N and O. The soybean root examination is part of a project for evaluating and studying Al toxicity in acidic soils. In order to assess the new detector system performance limits we mapped different areas of the soybean section, using different acquisition times per pixel in the raster scan (0.5 s, 1 s, 5 s, 10 s). Even though the detector energy resolution was not sufficient due to the not optimized readout strategy that we plan to overcome in the next version of the system, we could easily detect Na, Al and O. Finally, in order to make a comparison, we remounted the standard TwinMic LEXRF detection setup and used it to map equivalent sample areas in the same experimental conditions. The count rate of a single square cell of the new detector was about 4 times lower than the count rate of the whole standard setup. Accordingly, we expect that 32 cells in the new detector system will provide a count rate 4 times higher than in the standard setup. By optimizing the new detector position and geometry we will widen the intercepted solid angle and boost even further the count rate (Fig. 2).

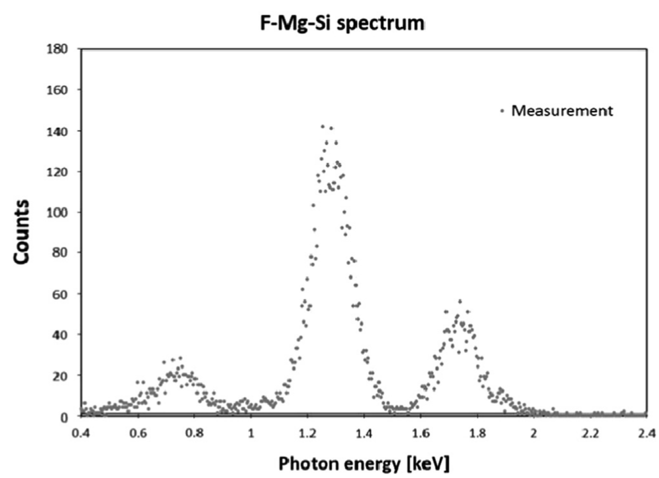

Fig. 1. Spectrum measured with a standard reference sample: a 550 nm layer of MgF_2 deposited on a 100 nm thick Si_3N_4 membrane. The peaks correspond to F (676.8 eV), Mg (1253.6 eV) and Si (1740 eV).

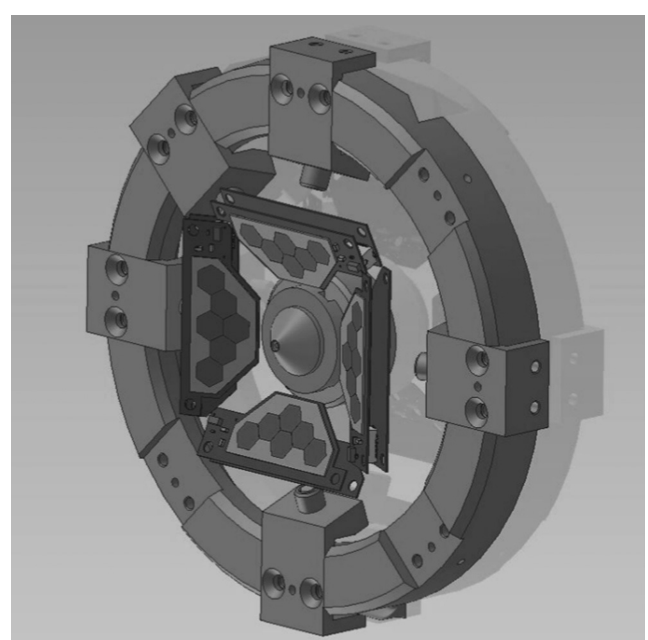

Fig. 2. Next iteration of the LEXRF detection system. Optimized matrices with 6 hexagonal SDD cells each will be used in the beam test scheduled in the 2015.

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