

A Two-dimensional event-counting detector for HV-CSA electrostatic analyzer at SpLine the Spanish CRG beamline at the ESRF

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Abstract. A novel 2D-detector has been designed, manufactured and installed on the high voltage cylindrical sector electrostatic analyzer (HV-CSA300/15) of the HAXPES station of SpLine the Spanish CRG beamline at the ESRF. This original 2D-detector constitutes an important improvement of the HAXPES station. A drawback of electrostatic analyzer in HAXPES, is that the electron counter must be raised to high voltages (up to 15 kV). Hence the development of a 2D detector system compatible with a high voltage electrostatic analyzer is a scientific instrumentation challenge. The developed two-dimensional event-counting detector consists of a 2D image intensifier (combination of scintillating screen and MCP) optically coupled with a CMOS-camera and a data processing system. The accumulated event image is transferred to the image processing software on the PC, where the events are classified by their position to give single detector readout. The energy window accepted by the area detector ranges from 100 meV to 50 eV, depending on the analyzer pass energy. Hence, for single shot measurements, i.e. without sweeping the pre-retarding lens voltages up to 200 detector channels can be used compared to a single channel. This results in a gain of the analyser transmission of at least a factor of 20. Thus we overcome the limitations imposed by the low count rate when dealing with high excitation energies and high kinetic-energy electrons.

1. Introduction

Hard X-ray photoelectron spectroscopy (HAXPES) is a powerful novel emerging technique for bulk compositional, chemical and electronic properties determination in a non-destructive way. It benefits from the exceptionally large escape depth of high kinetic energy photoelectrons to enlarge the information depth. The analysis of electrons with kinetic energies above 10keV gives the unique opportunity to probe bulk and buried interfaces in the depth range of several tens of nanometres [1]. The major disadvantage of HAXPES is the extremely low electron count-rate. Such a fact is mainly due to three factors: i) the tremendous decay of the photoionization cross-section with the increase of the incident photon energy. Although it depends on the principal and angular quantum numbers of the excited orbital, the typical decay with respect to conventional XPS ranges between 10^5 and 10^7 ; ii) the attenuation of the photoemission intensity during the electron transport through the material. Typical attenuation values range between 10^1 and 10^3 with respect to conventional XPS probing depth; and iii) the reduction of the electrostatic analyzer transmission with the electron kinetic energy increase. The

transmission for electrons with kinetic energies of several keV is typically 10^1 to 10^2 lower than for electrons of few eV kinetic energy. In this way, HAXPES typically deals with 10^7 lower electron count-rates than conventional XPS. The use of 3rd generation synchrotron radiation X-ray sources is mandatory together with high transmission electron analyzers equipped with high efficiency detectors.

The aim of the present work is the incorporation of a 2D detector to the High Voltage Cylindrical Sector Analyzer (HV-CSA) for parallel data acquisition with the consequent enhancement of the detected count-rate. A brief description of the HV-CSA analyzer together with the development of the 2D detector will be described in the next sections. An example that demonstrates the excellent capabilities of the developed detector will be also shown.

2. Description of the High Voltage Cylindrical Sector Analyzer (HV-CSA)

A schematic layout and a picture of the HV-CSA analyzer are shown in Fig. 1. The analyzer is a sector of a cylindrical mirror analyzer with a pre-retarding lens system [2]. The electrons enter the electrostatic field region with a central angle of 45° . A total deflection angle of 90° is undergone before reaching the exit slit. Only the electrons with the right energy will follow the correct trajectory up to the exit slit and will be focused (second order focusing on the dispersive direction and first order focusing on the non-dispersive direction [3]) on the electron detection system. Electrons with lower or higher energy are focused at a shorter or longer distance (energy dispersion). The sample-to-lens distance is 50 mm, the entrance-to-exit slit distance is 300 mm and the angular acceptance at the lens and deflection entrances are $\pm 15^\circ$ and $\pm 5.4^\circ$, respectively. Due to the large dispersion values the HV-CSA has a reduced dimension and a weight of only 30 kg, ideal for its integration on a multipurpose experimental setup. This is of extreme importance in our case as the electron analyzer is incorporated in an experimental synchrotron end-station devoted to the simultaneous combination of HAXPES and X-Ray diffraction [4].



Figure 1. Schematic layout (left) of the HV-CSA dispersive analyzer. A pre-retarding lens system produces an image of the sample at the analyzer entrance slit. The voltage present between the two cylindrical plates deflects the electrons with the correct energy up to the exit slit and focuses on the electron detection system. (Right) Front and side pictures of the HV-CSA analyzer. The low dimension and weight enables its incorporation on a multipurpose experimental set-up.

3. Development of a 2D event counting detector

2D detectors profit from the dispersive character of the electrostatic analyzers. For a given potential difference between the electrostatic plates, electrons with different energies are deflected to different detector positions. In this way, a 2D detector provides a parallel detection of electrons with different energies, reducing consequently the acquisition time. In the case of the HV-CSA there exist two main difficulties that should be overcome in order to implement a 2D detector: i) the energy resolution and transmission is not constant over the detector area for a 2D detector placed parallel to

the electrostatic plates or perpendicular to the electron trajectory; and ii) the detector should be at the same voltage as the inner electrostatic plate, in order to be in a field-free-region, that for the case of analyzing high kinetic energy electrons ($E_{kin}=15$ keV) the inner plate is at $V\sim 15$ kV.

In order to overcome the first difficulty we have resolved the complete three-dimensional trajectory of a charged particle on a cylindrical field [3]. The trajectory calculation includes the particle angular momentum which is present for particles entering the analyzer with an angle respect to the field lines. This is the case for extended sources. We have obtained a particular configuration of the 2D detector for which the energy resolution and transmission are constant over the complete detector area. The 2D detector should be placed, for a CSA with 45° entrance central angle, at the position where second order focusing occurs and with an angle of 153.46° with respect to the cylinder axis, as shown schematically in Figure 2a.

The second difficulty has been overcome by an optical coupling between an image intensifier (combination of scintillating screen and MCP), which is at high voltage, and a CMOS camera, which is grounded, that records the visible image produced by the electrons on the scintillating screen. This approach needs an algorithm that recognizes the events and associates them with an energy value. For that we have developed an optimized 2D event counting detector. Figure 2b illustrates the operation principle. The electrons create a visible image when they hit the image intensifier. Such an image is recorded by a fast CMOS camera (PCO 1200 hs) and transferred to the computer by a fast frame grabber (Matrox Odyssey). At the computer a fast event identification algorithm creates a matrix of events covering the detector area. A kinetic energy and intensity is then associated to each matrix element (camera pixel) after removing the camera dark counts (background). Such procedure is repeated each, typically, 5 ms. Such a processing frequency ensures enough events per image without having two or more events on the same scintillating screen position, that will be counted as a single event. The fast event identification algorithm fits the shape of each event component in an image with two Gaussian functions, along orthogonal directions, in order to discriminate neighbouring events.

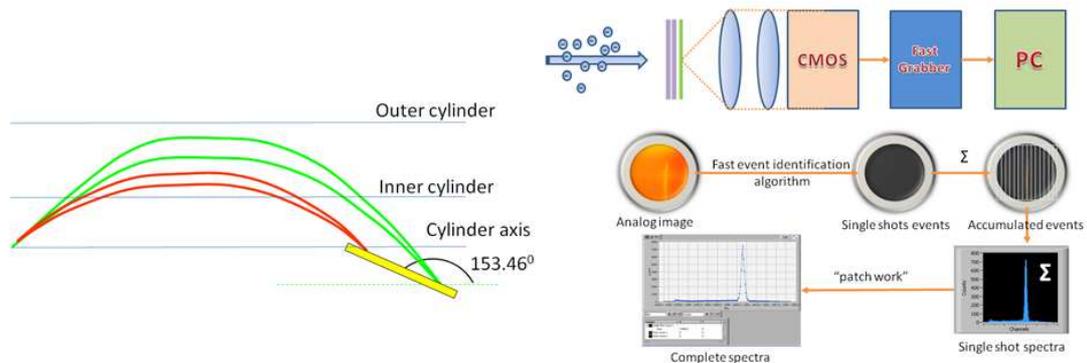


Figure 2. (Left) Schematic layout illustrating the position of the 2D detector for the HV-CSA analyzer with 45° entrance central angle, where the energy resolution and transmission are constant over the detector area. (Right) Schematic diagram of the working principles of the 2D event counting detector.

The figures of merit of the developed 2D detector can be summarized in: i) 2D detector composed of 1024×1280 camera pixels; ii) pixel size of $12 \mu\text{m}$. The energy resolution per pixel depends on the analyzer pass energy and ranges between 10 meV to 500 meV for a pass energy between 1 eV and 500 eV, respectively; iii) The accepted energy window is about 10% of the analyzer pass energy, ranging between 100 meV up to 50 eV for analyzer pass energy between 1 eV and 500 eV, respectively; iv) the gain factor respect to a single channel detection system depends on the number of counting channels, that is directly related with the analyzer pass energy and the energy step size. Typically the gain factor is about 20, but in special cases it can reach a factor 300.

4. Experimental test

The 2D event counting detector has been installed at the HV-CSA analyzer of the Spanish CRG beamline BM25-SpLine at the ESRF [4, 5]. Figure 3 shows the obtained Si 1s spectrum in the “single shot” mode, i.e., for a fixed voltage on the electrostatic plates, for a SiO₂ thin layer on a Si substrate for a photon energy of 14 keV, that corresponds to an electron kinetic energy of 12 keV. It can be clearly seen the well resolved photoemission peaks corresponding to the Si-Si bond and to the Si⁴⁺ component from the SiO₂ (Figure 3a). The two photoemission peaks can be also clearly seen on the image produced on the scintillating screen (Figure 3b). The spectrum was measured using analyzer pass energy of 200 eV, an energy window of 17 eV and a total number of channels of 200. The acquisition time was 20 seconds. The present example evidences the reduction of the acquisition time by the use of the 2D parallel detection. The measurement of such a HAXPES spectrum would take about 30 minutes if a single channel detection system is used instead.

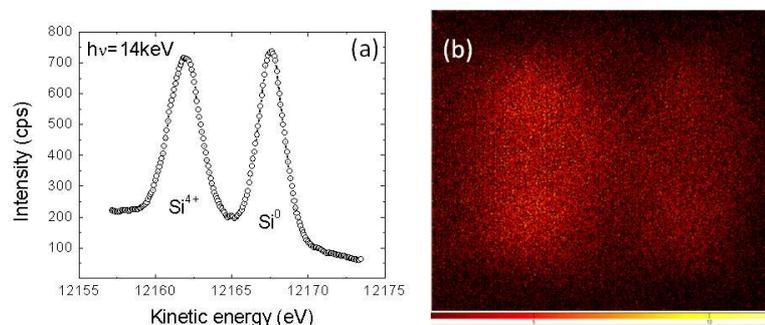


Figure 3. (a) Si 1s HAXPES spectrum for a SiO₂ thin film on a Si substrate taken with photon energy of 14keV. Two peaks can be clearly seen corresponding to the Si-Si bond and Si⁴⁺ components. (b) Recorded image at the scintillating screen. The two photoemission components can be clearly seen.

5. Conclusions

A 2D event counting detector has been developed for the HV-CSA analyzer and installed at the analyzer of the SpLine BM25 beamline at the ESRF. The developed two-dimensional event-counting detector consists of a 2D image intensifier (combination of scintillating screen and MCP) optically coupled with a CMOS-camera and to a single event counting system. The recorded image is transferred to the PC, where an algorithm classifies the events by their position to give single detector readout. The typical gain in transmission respect to a single channel detection mode is at least a factor 20. We have shown that the developed 2D detection system reduces the acquisition time for a HAXPES spectrum from 30 minutes if a single detection system is used to 20 seconds.

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