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Optimization of Solid Angle and Count Rate Capability of an X-ray Detector with Backscattering Geometry

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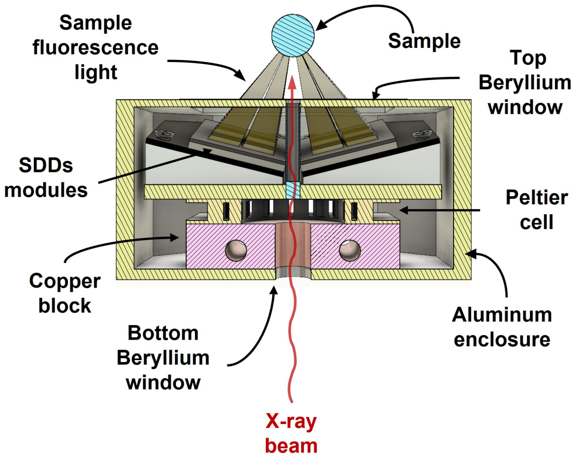
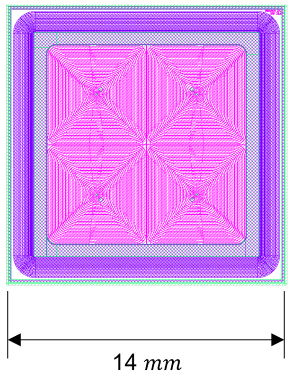
Abstract. We study here an optimized geometry for an X-ray detector with hole in the center, as key component for ASCANIO: an innovative 16-channels SDD based spectrometer specifically designed for X-ray fluorescence microscopy (XFM) imaging in synchrotron beamlines. The detector will feature a backscattering geometry with a tilted SDD layout achieving 1 sr solid angle at 8 mm sample distance and a potential Output Count Rate higher than 20 $Mcps$. The 1 mm thick SDD provides 65 % absorption efficiency at 20 keV while preserving a good energy resolution better than 150 eV thanks to a dedicated cooling system and a low noise front-end electronics. In this paper, the optimization of the detector geometry, in terms of solid angle vs sample distance and maximization of the Output Count Rate introducing a tilting of the SDD units, is discussed.

1. Introduction

Nowadays, synchrotron facilities with their new cutting-edge beamlines make use of powerful X-ray fluxes requiring high count rate and low noise fluorescence detectors in order to reduce measurements time while preserving a good energy resolution. To address these requirements we have recently developed the ARDESIA-16 [1] that is a 16-channels SDD-based detector used in X-ray fluorescence experiments and XFM imaging providing an overall solid angle of 0.4 sr and an Output Count Rate up to 17 $Mcps$. Starting from the ARDESIA spectrometer, we have started a new project, supported by DESY, for the developement of an innovative and improved X-ray detector called ASCANIO which is expected to operate at Output Count Rate higher than 20 $Mcps$ with a total solid angle of 1 sr at 8 mm sample distance from its entrance window. This paper focuses specifically on the criteria adopted for the maximization of the solid angle and on how to make uniform the response of the different SDD units, by introducing a tilting strategy, in order to maximize the overall counting rate.



(a) The working principle of the detection module of ASCANIO: the X-ray beam crosses the detector hitting the sample and the fluorescence light is collected by four tilted SDD modules, of four channels each.



(b) Each SDD array features a squared 14 *mm* side geometry with 4 channels, each one composed by 5×5 mm^2 active area SDD.

Figure 1: ASCANIO Working principle and SDD Layout.

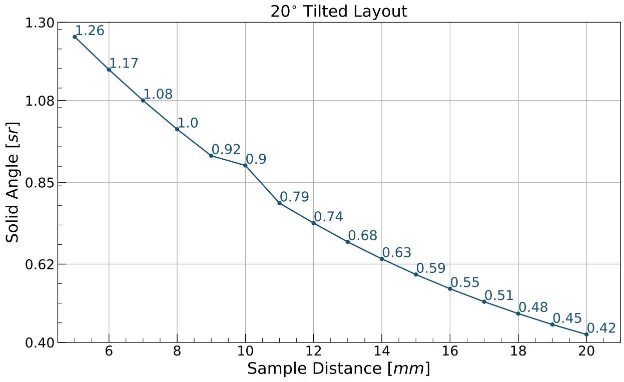
2. Working Principle of the SDD Detection Module

ASCANIO, the acronym for "Annular SDD Configuration for Advanced Nanoprobing Imaging and Observations", is a new SDD-based X-ray spectrometer designed to reduce the measurement time thanks to two main features:

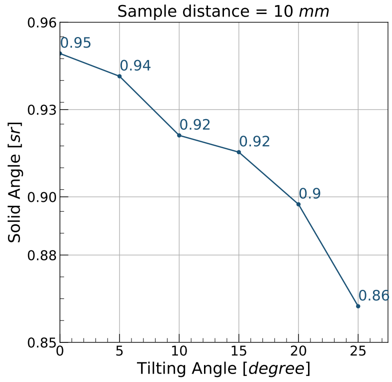
- A backscattering geometry, that has been already introduced by the Maia detector [2], to improve the solid angle;
- A new SDD-tilted configuration that allows a more uniform fluorescence light distribution among pixels.

The detector working principle is presented in Figure 1a. The X-ray beam crosses the bottom beryllium window and runs through the whole detector by means of a molibdenum needle that absorbs backscattered photons from the top beryllium window. The focused beam exits the detection module hitting the sample whose fluorescence light enters the top beryllium window and it is absorbed by the SDD arrays. The SDD arrays have been tilted to optimize the solid angle and count rate uniformity among units. The front-end electronics is based on an ultra low-noise CMOS charge preamplifier named CUBE [3, 4, 5] that provides good energy resolution at short peaking time (below 150 eV at 100 ns) allowing high count rate measurements.

ASCANIO Detection Module is made by an aluminum support which is glued on a thermoelectric cooling device that is used to cool down the SDDs decreasing leakage current. This aluminum block, that hosts the PCBs and the SDDs, has been designed with a tilted geometry in order to improve the total Output Count Rate of the detector as explained in Section 4. The X-ray beam passes through the detector itself thanks to a 2 mm Molybdenum needle that is placed in the detection module center. Four molibdenum collimators will be glued on top of each SDD in order to prevent charge sharing between adjacent pixels and they will be designed to minimize active area losses. The detector is composed by four 1 mm thick SDD devices provided by Fondazione Bruno Kessler with a 2 mm wide guard ring; each SDD is made by four pixels with 5 mm pitch and its geometrical layout is showed in Figure 1b. The 1 mm



(a) The solid angle as a function of the sample distance with a 20 ° tilted geometry and a collimator focused at 10 mm sample distance.



(b) The solid angle as a function of the tilting angle with a sample distance equal to 10 mm.

Figure 2: ASCANIO Solid Angle Analysis.

thickness allows a good absorption efficiency even at 20-25 keV as stated in Table 1, but an effective cooling system is required to reduce leakage current preventing an energy resolution degradation.

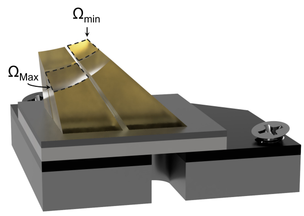
Table 1: The Absorption Efficiency of a 1 mm thick SDD as a function of the impinging X-ray energy is reported [6].

Energy	Absorption Efficiency
10 keV	$\approx$ 100 %
15 keV	$\approx$ 90 %
20 keV	$\approx$ 65 %
25 keV	$\approx$ 45 %
30 keV	$\approx$ 28 %

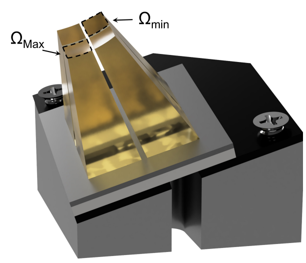
3. Solid Angle Study

The fluorescence light flux impinging on the SDD array is related to the solid angles between the sample and the SDD active area. Solid angles have been evaluated considering the SDD tilting angle, the sample distance from the Be window and the collimator that reduces the SDD active area. For example, assuming a 20° tilted SDD configuration, the solid angle has been analyzed as a function of the sample distance from the Be window and results are presented in Figure 2a. A solid angle equal to 0.9 sr for a considered sample distance of 10 mm from the window can be achieved. However, the solid angle is larger than 1 sr when the sample is placed at a distance shorter than 8 mm. It has to be noted that the collimator geometry has been optimized to maximize the solid angle at a given distance. This explains the peak of solid angle at 10mm, as in this simulation the collimator has been optimized for a 10mm sample distance, although the solid angle has been calculated also for other distances, keeping the same collimator geometry [7].

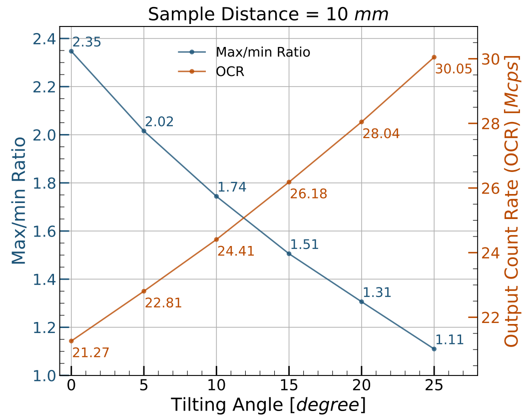
As another example, Figure 2b shows the solid angle as a function of the tilting angle when the sample is placed at 10 mm from the window: the solid angle decays as the tilting angle



(a) In a planar geometry the central channel, close to the needle, has a solid angle (Ω_{Max}) that is more than twice that Ω_{min}.



(b) The tilted geometry allows a more uniform light distribution among channels providing Ω_{min} = 90% Ω_{Max} with 25 ° tilting.



(c) OCR and Max/min Ratio as a function of the tilting angle with a sample distance equal to 10 mm.

Figure 3: Three dimensional images of the impinging photon flux on the SDD module and OCR analysis.

increases, but the new geometry presents advantages in term of Output Count Rate because it provides a more uniform light distribution among pixels, as will be explained in the Section 4.

4. Total Output Count Rate

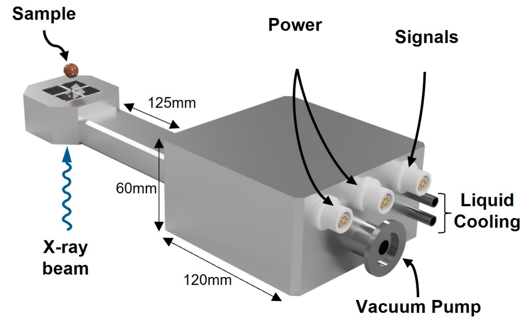
As already stated, the advantage of a tilted SDD configuration is a more uniform light distribution among pixels. This concept is shown in Figure 3 where one ASCANIO SDD module out of four is presented. In particular, as can be noted from Figure 3a, there is a relevant difference between the maximum and the minimum solid angle when the SDDs have a planar geometry providing $\Omega_{min} = 42.6\%\ \Omega_{Max}$. This means that the four ASCANIO outer channels are not collecting photons as they could, when the inner units are operated at the maximum count rate, leading to a sub-optimal total Output Count Rate. This gap can be compensated with a tilted layout, for example a 25 ° tilting angle leads to $\Omega_{min} = 90\%\ \Omega_{Max}$ so that every channel collect approximately the same amount of photons as illustrated in Figure 3b. The advantage of such geometry has been evaluated in Figure 3c where the Total Output Count Rate and the Max/Min Ratio, defined as $\Omega_{Max}/\Omega_{min}$, are reported. As the tilting angle increases the Max/Min Ratio is closer to 1 providing an improved OCR. Just as an example, we have quantified this maximum OCR assuming that the highest solid angle channel is processing events with a maximum count rate equal to $\phi_{max} = 2\ Mcps$ while other channels work at ϕ_{max} weighted by their solid angles according to Equation 1. The considered value of 2 $Mcps$ is today achievable with modern, model-based, digital pulse processors [8].

$$OCR = \phi_{max} \sum_{i=1}^{16} \frac{\Omega_i}{\Omega_{Max}}\ [Mcps] \tag{1}$$

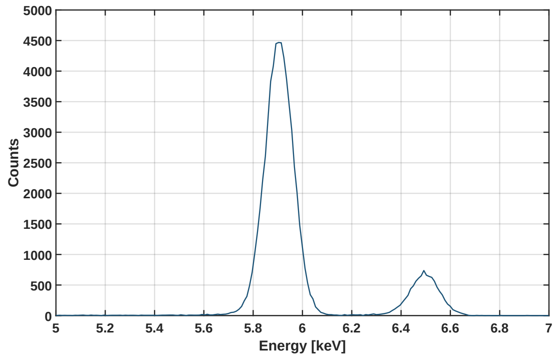
From our estimations reported in Figure 3c, it can be noted that a total OCR as high as 30 $Mcps$ can be in principle achieved at a sample distance of 10mm and a tilting angle of 25°.

5. Conclusions

The initial design of the ASCANIO detector has been performed showing that tilted SDDs with a backscattering geometry are key features to achieve large solid angles with a high OCR. A very preliminary drawing of the complete ASCANIO spectrometer is showed in Figure 4a; the development and construction of the first prototype of the detector is on the way. In particular, the cooling system is actually under investigation targeting a SDD temperature close to -30 ° in order to reduce leakage current. Further future developments will be focused on collimator and needle mounting techniques. The last plot, presented in Figure 4b, shows the ^{55}Fe spectra acquired by a single pixel of the ARDESIA spectrometer with a 1 mm thick SDD: the spectra features a FWHM of 135 eV (at Mn Kα) with a peaking time equal to 2 μs. To see more about ARDESIA energy resolution as a function of the total input count rate refer to [1]. Similar energy resolution results are expected from the ASCANIO detector since it implements the same SDD technology (from Fondazione Bruno Kessler) and the same front-end electronics.



(a) ASCANIO preliminary mechanical drawings.



(b) ARDESIA single pixel spectra with 1 mm thick SDD array: it provides a FWHM equal to 135 eV (at Mn Kα) with a peaking time of 2 μs.

Figure 4

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