A 2D position sensitive germanium detector for spectroscopy and polarimetry of high-energetic x-rays

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Abstract. We report on a first prototype 2D μ-strip germanium detector, developed at IKP-Jülich, and its performance test at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. Beside an accurate determination of the detector response function, the polarization sensitivity has been addressed in this study. For this purpose photon beams at energies of 60 keV and 210 keV have been used.

1. Introduction

The x-ray spectroscopy program of the SPARC collaboration at the future FAIR facility [1] relies strongly on the development of two-dimensional, energy dispersive strip detectors with their inherent advantages concerning spectroscopy and imaging capabilities as well as polarization sensitivity [2, 3]. For the case of atomic structure studies [4, 5], these systems are of outmost importance for the 1s Lamb Shift studies based on the application of high resolution x-ray spectrometers, such as the two-arm FOCAL spectrometer [6, 7], as it has been demonstrated very recently [8, 9]. Also on the basis of 2D position sensitive solid state detectors, Doppler tuned experiments [10], an alternative to the application of transmission crystal spectrometers, appear now to be a realistic approach for accurate photon spectroscopy in the energy range between 50 keV to 100 keV. Even more, because of their position sensitivity in the sub-mm regime, they appear a very promising tool for future lifetime experiments [11]. Here one may profit considerably from the fact that beam foil experiments can now be performed without a movement of the detector because a broad range of distances will be covered simultaneously by one detector. With respect to atomic collision studies, the new field of polarization spectroscopy opens up allowing to address the linear polarization feature of radiative processes in ion-electron and ion-atom collisions. A first precursor experiment, addressing the polarization features of radiative electron capture transitions occurring in relativistic collisions involving bare uranium ions, has already been demonstrated the strength of this technique [12, 13]. On the basis of 2D position sensitive strip detectors, an extension of this technique to the alignment of

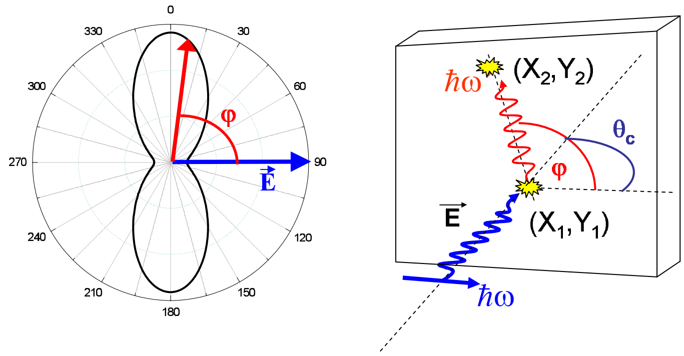

Figure 1. Left side: The definition of the azimuthal scattering angle within Compton scattering, where $\vec{E}$ denotes the polarization vector. The full line depicts the azimuthal intensity distribution following the Klein-Nishina formula. Right side: The principle of a Compton polarimeter based on a x- and y- position sensitive detector system. The x- and y-sensitivity is obtained via a segmentation into strips. Using the intrinsic energy resolution of each strip at the front and back side, the x- and y- coordinates are unambiguous assigned to each of the two interaction points (Compton interaction: (X_1,Y_1); photoabsorption of the Compton scattered photon (X_2,Y_2)).

innershell transitions [14] produced by capture or excitation processes appears now to be in reach. One may also mention the application of such devises for diagnostic purposes such as they have been proposed recently for the diagnostics of femtosecond x-ray pulses produced by Thomson scattering off laser accelerated electron bunches [15] or the identification of spin-polarized particles involved into atomic collisions [16].

2. The experiment

The prototype 2D μ-strip germanium detector used in our studies has been developed at IKP-Jülich [17]. This germanium diode has on the front contact 128 strips on an area of 32 mm x 56 mm (pitch of 250 μm) and on the rear contact 48 strips (pitch of 1167 μm), respectively. For an accurate determination of the response characteristics of this detector (accuracy in position determination and polarization sensitivity), in-beam test measurements were performed at the European Synchrotron Radiation Facility (ESRF) in Grenoble. At the ESRF, the high energy beam line ID15A has been chosen where 98% linearly polarized synchrotron radiation at energies of 60 keV and 210 keV were provided for the experiment. The beam size on the detector was close to 50 μm x 50 μm, ideally suited for this test purpose. For the experiment, each detector segment was connected to a separate electronic readout. This allowed us to register simultaneously for every segment the energy deposition and the hit probability as a function of the beam position on the detector. For the latter purpose, the photon beam was scanned over the active detector area in steps of 50 μm. From this scanning technique detailed information for the effects of electronic cross talk and in particular of charge splitting for the different photon energies used is obtained.

A further important aspect of this study was to utilize the detector as a Compton polarimeter and to investigate its polarization sensitivity. This technique exploits the sensitivity of the Compton scattering process on the linear polarization of the initial photon [3]. Following the Klein-Nishina formula, the differential cross-section for Compton scattering of a photon with initial energy $\hbar\omega$ is given by

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\theta\cos^2\varphi\right), \tag{1}$$

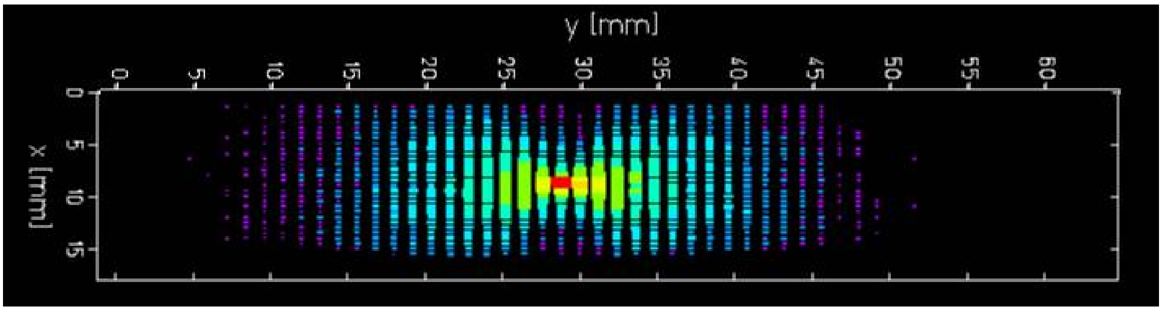

Figure 2. 2D image for Compton scattering of almost 98% linearly polarized x-rays (210 keV) (preliminary result). The image displays the spatial distribution of Compton scattered photons which exhibit an energy of 149 keV corresponding to a scattering angle of $\theta = 90°$. The image was recorded during a detector performance test at the ESRF synchrotron facility.

where $\hbar\omega'$ denotes the energy of the scattered photon, θ the scattering angle between the initial and the scattered photon, and φ the azimuthal angle between the electric polarization vector of the initial photon and the propagation direction of the scattered one (compare Fig. 1). For completeness we add the elementary relation between the $\hbar\omega'$ and the scattering angle θ, given by

$$\hbar\omega' = \frac{\hbar\omega}{1 + \frac{\hbar\omega}{m_e c^2}(1 - \cos\theta)}, \tag{2}$$

where $m_e c^2$ denotes the rest mass of the electron (in keV).

Experimentally, the Compton polarimetry is accomplished by exploiting the multi-hit capability of the detector as well as its energy sensitivity. Compton polarimetry requires to identify the position of the initial Compton interaction via registration of the Compton recoil electron as well as the identification of interaction point for the second interaction where photoabsorption of the Compton scattered photon takes place (compare Fig. 1). Since both interactions happen simultaneously, within the time resolution of the detector, an unambiguous assignment of the x- and y-coordinates to each of the interaction points is accomplished by the energy resolution of the strip detector system. A sample 2D image for Compton scattering of 210 keV photons is depicted in Fig. 2 for 90° scattering. Utilizing the kinematical relation between the Compton scattering angle and the energy of the scattered photon (see Eq. 2), the scattering angle θ was unambiguously determined. In other words, only such events are displayed where the energy of the Compton photon amounts to 149 keV whereas for the recoil electron the remaining energy of 61 keV was detected. In figure 2, an almost dipolar intensity pattern is observed. This finding visualizes that for our initial energy of 210 keV, Compton scattering is in particular sensitive to the linear polarization at scattering angles close to 90°. In Fig. 3 we display the intensity distribution for 90° scattering along an arbitrarily chosen radius vector of 5 mm around the center of the image (position of the beam spot on the detector). The solid line displayed gives the result of the Klein-Nishina formula (calculated for a scattering angle θ of 90° and 100% linearly polarized light, see Eq. 1). An excellent agreement between the data and the calculation must be stated, demonstrating the superior performance of strip detector system used as Compton polarimeter.

3. Summary and Outlook

A 2D μ-strip detector system has been commissioned a the ESRF synchrotron facility, allowing for a detailed study of the response characteristics of the detector with respect to position and

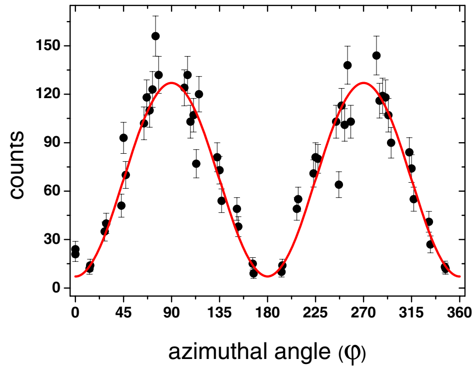

Figure 3. Preliminary result for the azimuthal intensity distribution for Compton scattering of 98% linearly polarized photons (210 keV) at a scattering angle of 90°. The distribution refers to the absolute count rate measured at a distance of 5 mm from the origin of the initial point of interaction where Compton scattering occurred.

polarization sensitivity. The presented results demonstrate the superior performance of such a detector system which makes it a very important tool for future x-ray spectroscopy program for atomic physics dealing with hard x-rays. However, with respect to applications as a Compton polarimeter, the limitation to x-ray energies above 120 keV must be mentioned. To overcome this barrier, a prototype silicon based, 1.5 cm thick 2D-detector is currently getting developed which is expected to be soon available for first test experiments [18]. Using such segmented Si(Li) detectors, the polarization studies can be extended to energies as low as 50 keV allowing to address even innershell transitions in heavy ions.

Acknowledgments

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