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A Micro-Strip Germanium Detector for Position Sensitive X-Ray Spectroscopy

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Abstract

For the current x-ray spectroscopy program at the ESR storage ring (GSI-Darmstadt) a position sensitive germanium detector system has been completed. The position sensitive structure of the detector has been realized on an area of 47 mm x 23.4 mm by an array of 200 strips (200 μ m wide and 23.4 mm long) separated by 35 μ m wide grooves etched through boron implanted contact. The thickness of the detector inclusive a 0.6 mm thick Li-diffused rear contact amounts to 4.1 mm. Each strip has been joined to a preamplifier placed outside the cryostat with printed leads inside the flexible Kapton foil. The energy resolution of the strips has been about 1.8 keV [FWHM] for 60 keV photons. Coincidences between neighbouring strips were measured whereby a time resolution of 70 ns [FWHM] was obtained. First preliminary results obtained with the detector mounted at the transmission x-ray spectrometer FOCAL demonstrated that an energy resolution better than 100 eV is achievable together with a high detection efficiency. Along with a new kind of x-ray spectrometer this detector may play a keyrole for the next step of high precision x-ray experiments, aiming on a precise test of quantum electrodynamics in the heaviest one-electron systems such as hydrogenlike uranium.

I. INTRODUCTION

In the x-ray energy region above 15 keV, germanium is probably the best suited semiconductor for the fabrication of detectors requiring submillimeter spatial resolution. The combination of a focussing crystal spectrometer with a position sensitive germanium microstrip detector permits the measurement of an energy spectrum wide enough to investigate the interesting peaks simultaneously. In addition, the good energy resolution enables discrimination against background events of the recorded spectra arising from various sources.

Two germanium detectors with the same position sensitive structure manufactured at Forschungszentrum Jülich, have already been realized. First of them was applied for the energy analysis of Compton scattered photons dispersed on the Rowland circle of a Cauchois-type cylindrically bent crystal [1]. An energy resolution of about 4 keV [FWHM] could be obtained for each of 200 strip elements. The second one, with only eight strip elements connected to the preamplifiers placed inside the cryostat, was thoroughly tested at ESRF-Grenoble [2]. Energy resolutions <2 keV, peak/valley ratios >1000 and count uniformities across the detector surface <1.5 % were achieved for energies below 60 keV. For the next generation of Lamb-Shift experiments on hydrogenlike high-Z ions at the ESR storage ring at GSI, a new kind of a transmission x-ray spectrometer has been designed [3], [4]. This instrument exploits the focusing compensated asymmetric Laue geometry (FOCAL) which focuses the radiation of a certain wavelength from an extended source to two single lines on the Rowland circle. For a certain wavelength, these Bragg-reflections arise from a cylindrically curved Si-crystal with a bending radius of 2 m. Its design is

optimized for photon energies in the range between 50 and 100 keV. In order to achieve the desired efficiency of 10^{-7} , a position sensitive microstrip germanium detector appears to be the most promising photon counting system. The energy resolution of such a detector should be as good as possible to enable effective background suppression and good timing capabilities. The desired pitch of 200 strips was about 250 μm . Based on the many year long experience in manufacturing of position sensitive germanium detectors at Institut für Kernphysik, Forschungszentrum Jülich [1], [2], [5]-[8], we started with the realization of the desired position sensitive germanium detector for the FOCAL-spectrometer at GSI-Darmstadt. The goal was to achieve an energy resolution better than 2 keV [FWHM] for each of the 200 strips properly connected to preamplifiers placed outside the cryostat.

II. DETECTOR DESCRIPTION

Fig. 1. The main part of the detector system without the cryostat-cap and the cover for the electronics. 200 commercially available low dissipation (50 mW) charge sensitive preamplifiers (CSPA 02.04 from KFKI-Budapest) are placed on both sides of the printed board outside the cryostat. 100 of them are visible on the picture. The octagonal housing for the preamplifiers has a diameter of 39 cm and 12 cm in depth. No ventilation of the housing is needed since the total thermal dissipation of the preamplifiers amounts to only 10 W. The consumption of liquid nitrogen amounts to ~ 3 l/day.

First a 4.1 mm thick germanium diode was produced with boron implanted front contact and about 0.6 mm thick Li-diffused rear contact. The position sensitive structure of the detector has been realized by an array of 200 strips, each of them 200 μm wide and 23.4 mm long, separated by 35 μm wide grooves etched through the boron implanted contact. This means that the position information can be obtained from an area of 47 mm x 23.4 mm (1100 mm²). A guard-ring which surrounds this area enables also relatively simple assembling. Each strip has been joined to a preamplifier placed outside the cryostat with printed leads inside the flexible Kapton-foil (Fig. 1). All connections between the strips and printed leads have been performed through bonded Al-wires. The Kapton-foil pressed between two Viton-seals serves at the same time as vacuum feedthrough. A 2 l/s Varian ion-pump maintains the pressure inside the cryostat below 5×10^{-7} mbar.

Thorough laboratory tests were performed using ^{241}Am γ -rays. A lot of effort is needed to avoid deterioration of the spectra caused by ground loops, microphonics, different pick-ups and high-frequency oscillations. By proper reducing of such effects the energy resolutions of the strips were found to be in the range of 1.6 to 1.9 keV [FWHM] for 60 keV γ -rays using a commercial shaping amplifier with 6 μs time constant. The main limitation of the resolution, as experimentally determined by testing the system without germanium detector, is caused by the Kapton-foil itself (inter-lead capacitance and dielectric loss effects) and its capacity to the grounded cryostat. Only slightly improved resolutions could be obtained by a very careful layout of the connection elements (Kapton-foil and vacuum feedthrough), especially for a high number of strip elements. Simultaneously with measuring the signals from the strips there is the possibility to process the signals obtained from the common rear contact. The measured energy resolution amounted to about 4 keV [FWHM]. Better resolutions (<2 keV) would be achieved by placing the first stage of the preamplifier inside the cryostat, near to the rear contact.

Fig. 2. A sample photon spectrum recorded with one individual strip. For this purpose, a standard ^{241}Am γ -ray source has been used. The energy resolution achieved corresponds to 1.8 keV [FWHM] at 60 keV.

For illustration we depict in Fig. 2 a sample photon spectrum recorded with one individual strip. Here, a standard ^{241}Am γ -ray source has been used. The energy resolution achieved corresponds to 1.8 keV [FWHM] at 60 keV whereby a shaping amplifier with 3 μs time constant has been applied. Within this first test, the individual shaping amplifiers for in total 32 strips were connected to 4K CAMAC ADC modules. In addition, the time signals of each strip (from timing filter amplifiers) were recorded by using CF threshold discriminators connected to 4K TDC CAMAC modules. Event-list readout of all strips (energy and timing) is triggered by a signal from any strip above a threshold of approximately 5 keV.

This technique allowed us to study the coincident photon spectra between neighbouring strips as well as to investigate the timing characteristics of the detector system used. As example, we display in Fig. 3 a sample time spectrum observed between two strips. Here, a time resolution of 70 ns [FWHM] is observed. Note, that for the planned experiments with heavy ion beams, a good time resolution for the x-

Fig. 3. A sample time spectrum observed between two neighbouring segments of the microstrip detector. Here, a time resolution of 70 ns [FWHM] has been achieved.

ray detection system is required since the photons will be exclusively detected in coincidence with down-charged ions [9]. Since, the latter will be accomplished by fast scintillator or multi-wire proportional counters, a time resolution of better than 50 ns should be achievable with the current micro-strip detector. This is by far sufficient to meet the criteria of the current x-ray spectroscopy program at the storage ring ESR at GSI. The registration of photon coincidences between strips does allow us in addition to reconstruct, at least partially, single photon events undergoing Compton Scattering or charge splitting inside the detector or which are accompanied by an escape photon.

Fig. 4. Reconstruction of one photon events leading to coincidences between two neighbouring strips. b) and c) the coincident spectra associated to the time spectrum displayed in Fig. 3. a) Energy spectrum produced by adding the spectra b) and c) event by event

In Fig. 4, the coincident photon spectra (associated to the time spectrum displayed in Fig. 3) are depicted (see Fig. 4b and 4c) which show an almost continuous energy distribution. However, adding the coincident spectra event by event, a photon

spectrum is produced with the 60 keV line of ^{241}Am as the most prominent feature. As a consequence of the summing-up procedure, the observed energy resolution amounts here to 2.5 keV [FWHM] at 60 keV. Beside the energy and timing capability, the position sensitivity is of course the most important feature of the detector system. To investigate the position sensitivity also a collimated ^{241}Am source was used. In Fig. 5 the corresponding event distribution obtained for three different positions is shown, using an energy condition for the 60 keV γ -line. The beam divergence leads to the observed position broadening of 0.8 mm. From the spectra displayed it is evident that the center of gravity of the lines can be determined with a precision of close to 100 μm . In particular, due to the energy condition applied, the position spectra are free of background events.

Fig. 5. Position spectra obtained with a collimated γ -ray source (60 keV, ^{241}Am) at three different positions.

III. FIRST TEST WITH THE "FOCAL"-SPECTROMETER

Very recently, the microstrip germanium detector has been tested in combination with the FOCAL spectrometer (Fig. 6) using an intense radioactive ^{169}Yb source. Even without any strict conditions on the photon energies for the individual strips, the intensity pattern observed with the microstrip detector as function of the position (i.e. strip number) identifies clearly the two x-ray lines of the $K\alpha$ -doublet from Tm and Yb (Fig. 7) which are separated by approximately 970 eV and 1030 eV, respectively. This demonstrates that in combination with the FOCAL spectrometer, an energy resolution better than 100 eV can be achieved along with a high detection efficiency.

IV. CONCLUSION

This paper describes the position sensitive germanium detector system for the hard x-ray regime (10-100 keV) which will be used, together with the FOCAL-spectrometer, for the current x-ray spectroscopy at ESR storage ring. Several important properties, like sufficient position sensitivity and a good energy resolution along with timing capability, make this detector system very well suited to fulfill the requirements of the FOCAL-spectrometer project. These two instruments used together at the ESR jettarget are foreseen for the next generation of Lamb-Shift

experiments on hydrogenlike high-Z ions. First experiments are planned for the year 2001. Furthermore, by exploiting all capabilities of the germanium detector, a broad range of new challenging experiments can be anticipated, e.g. precise lifetime and Doppler tuned experiments. Moreover, a lot of applications can be imagined at the synchrotron x-ray sources, also in combination with crystal spectrometers. Some application of such a germanium detector system for x- or γ -ray detection in medical diagnosis should be also taken into account.

A two-dimensional germanium detector system with 25x160 orthogonal strips is being under development.

Fig. 7. First preliminary result obtained with the germanium microstrip detector mounted at the FOCAL spectrometer in comparison with an x-ray spectrum recorded with a standard Ge(i) detector (resolution at 60 keV: ~ 500 eV). The intensity pattern as function of the position (energy) identifies well resolved the two components of the $K\alpha$ -doublet of Tm as well as those of Yb.

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VI. REFERENCES

- [1] A. Berthold, J. Degenhardt, S. Mourikis, J. R. Schmitz, W. Schülke, H. Schulte-Schrepping, F. Wohler, A. Hamacher, D. Protic and G. Riepe, "Performance of a Ge 200-Strip Detector for Inelastic X-Ray Scattering Studies", Nucl. Instr. Meth. in Phys. Res. A, vol. 320, pp. 375-380, 1992.
- [2] G. Rossi, J. Morse, D. Protic, "Energy and Position Resolution of Germanium Microstrip Detectors at X-Ray Energies from 15 to 100 keV", IEEE Trans. Nucl. Sci., vol. 46, no. 3, pp. 765-773, June 1999.
- [3] H. F. Beyer, "Characterization of Transmission-Type Curved-Crystal X-Ray Optics for Fast Ion-beam Spectroscopy", Nucl. Instr. Meth. in Phys. Res. A, vol. 400, pp. 137-148, 1997.
- [4] H. F. Beyer et al., "The Focusing Compensated Asymmetric Laue Spectrometer", GSI-Scientific Report 1999, p. 209, 2000.
- [5] G. Riepe, D. Protic, R. Kurz, W. Triftshäuser, Zs. Kajcsos and J. Winter, "A High Purity Germanium Position-Sensitive Detector for Positron Annihilation Experiments", Proc. 5th Int. Conf. Positron Annihilation, Japan 1979, p. 371.
- [6] A. Hamacher, H. Machner, M. Nolte, M. Palarczyk, D. Protic and G. Riepe, "Performance of Position-Sensitive Germanium Detectors in Nuclear Reaction Experiments", Nucl. Instr. Meth. in Phys. Res. A, vol. 295, pp. 128-132, 1990.
- [7] Chr. Bargholtz, K. Lindh, D. Protic, N. Ruus, P.-E. Tegnér, P. Thörngren Engblom, K. Wilhelmsen Rolander, "A Small Size Zero-Degree Spectrometer with Germanium Detectors", Nucl. Instr. Meth. in Phys. Res. A, vol. 390, pp. 160-166, 1997.
- [8] M. Betigeri, E. Bialkowski, J. Bojowald et al., "The Germanium Wall of the GEM Detector System", Nucl. Instr. Meth. in Phys. Res. A, vol. 421, pp. 447-457, 1999.
- [9] Th. Stöhlker, "Lamb Shift Experiments on High-Z Ions Performed at the ESR Storage Ring", Physica Scripta, T73, pp. 29-35, 1997.