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Design and performance of a 2-D multi-wire position sensitive X-ray detector

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Abstract. A 2-D multi-wire position sensitive detector for X-ray diffraction and small angle X-ray scattering studies is described. The detector has an active area of 100 mm × 100 mm and consists of an anode plane with 10 μm SS wires at 3 mm spacing and a pair of orthogonal cathode read-out planes with 25 μm SS wires placed at 1.5 mm spacing. The position information is obtained using charge division method and recorded using a laboratory built data acquisition system. The resolution and gas gain was measured for 5.9 keV X-rays (^{55}Fe-source) as a function of the anode wire voltage and gas pressure. It was observed that the proportional region of the PSD at 100 kPa pressure extended up to a high voltage value of around 1.5 kV and it shifted to high values up to 2 kV for gas pressure of 300 kPa. The energy resolution improved from 18% (FWHM) to 12% with increase in pressure. The spatial resolution of the PSD also showed improvement, with a value of 1.2 mm × 1.4 mm at 300 kPa gas pressure. A maximum gain of 5×10^4 is obtained.

Keywords. Radiation detectors; gas filled proportional counters; position sensitive detectors; X-ray diffraction and scattering.

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1. Introduction

Multi-wire position sensitive detectors are commonly used in the detection of X-rays, neutrons and charge particles [1,2] because they can be built in large size, have relatively good energy and position resolution, high efficiency, good uniformity over the sensitive volume and show no radiation damage as compared to the solid state and scintillation detectors. As a part of our programme on development of position sensitive detectors for X-rays and neutrons [3–5], we have designed and built a 2-D position sensitive detector (2-D PSD) based on multiwire proportional chamber with resistive wire read-out. The detector is useful for X-ray studies such as X-ray diffraction and small angle X-ray scattering. The salient features of the design and the test results on resolution and gas gain have been described in this paper.

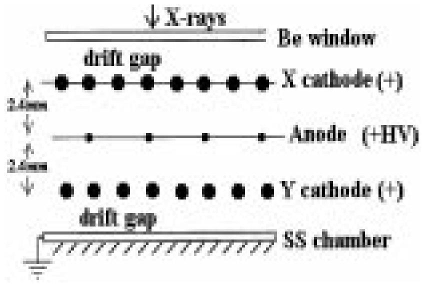

Figure 1. Schematic drawing of the 2-D PSD.

2. Detector design

Figure 1 shows a schematic diagram of the multiwire position sensitive proportional counter geometry. The basic configuration consists of three wire planar electrodes with the anode at the center and two orthogonal cathodes one above and one below the anode. The anode grid consists of 32, 10 μm stainless steel wires stretched uniformly and placed at a pitch of 3 mm and bridged together. The cathode grids are fabricated of 25 μm stainless steel wires attached in the zigzag fashion. Each cathode forms one long resistance read-out wire with a total resistance of approximately 12.25 kΩ. The spacing between each read-out wire is 1.5 mm. The anode to cathode spacing is 2.4 mm. The sensitive area of the grids is 100 mm $\times$ 100 mm. The three grids are assembled and placed symmetrically in a gas tight circular, stainless steel enclosure capable of withstanding high pressures. The distance between the cathode planes and the grounded surface of the pressure vessel (drift gap) is 4.6 mm. The charge gain of the detector is controlled by the various gaps in and between the electrodes. The pressure container is provided with a 250 μm-thick beryllium window for X-rays to enter and it is matched to the active area of the detector. The beryllium window is slightly concave shaped so that it can withstand high pressures. The inner wall of the pressure container is lined with aluminium foil to minimize back scattering of X-rays. For filling the detector with its operating gas mixture it is evacuated continuously for several hours at 10^{-3} mbar and filled with P-10 gas, a pre-mixed mixture of Ar (90%) and CH_4 (10%) at required pressure. A compact valve seals the detector off from the filling system and it is ready for use.

3. Detector operation

The anode provides the high electric field required for proportional counter operation. When high voltage is applied to the anode grid, in the vicinity of each anode wire, equipotential lines which are concentric to the wires are developed. The electrostatic field near each anode wire in the multiwire proportional counter [6] is given by

$$E = \frac{V}{d/2\,(\pi l/s - \ln(\pi d/s))} \tag{1}$$

where d is the anode wire diameter, s the wire spacing, l the anode–cathode gap and V the anode voltage.

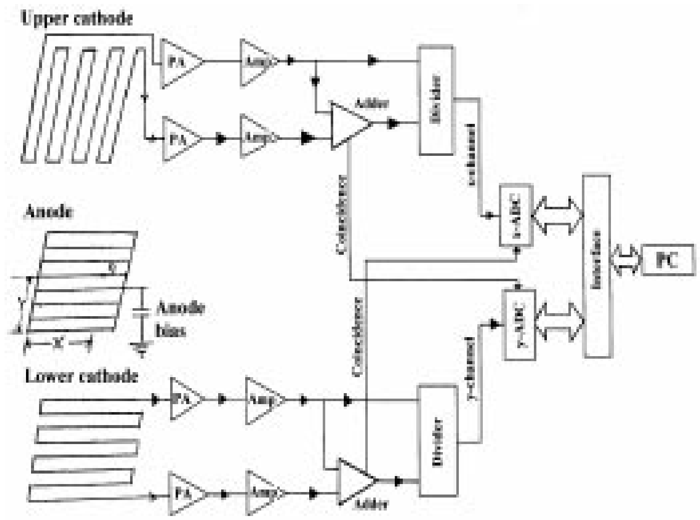

Figure 2. Charge division method for position encoding in 2-D PSD.

An incident X-ray interacts with the chamber gas producing a photoelectron. The free electrons generated by the slowing down of the photoelectron drift to anode plane generating an avalanche on one of the wires. As the charge is being collected, an opposite signal is induced on the nearest wire in both the cathode read-out planes. The induced charge on the cathode planes gets divided in the inverse proportion of the resistances of the two segments and flows towards the ends. The two signals from each cathode are amplified, added and then fed to a pulse divider whose output is proportional to the ratio, signal from one end to the sum of signals from both the ends. This ratio is a measure of the position on the cathode plane where charge is induced. The method is therefore, called as charge division method. Since the two cathode read outs are orthogonal to each other, a coincidence between the two gives the X and Y coordinates of the ionization event. A multichannel analyzer can thus records the complete scattered intensities over the whole area of the detector simultaneously. Figure 2 shows the electronic system required to implement charge division method for position read out. A laboratory built data acquisition system [7] and a 3-D display graphics routine [8] are used to acquire and analyze the data. The detector is tested with P-10 gas at 100, 200, and 300 kPa pressures and for every pressure the characteristics of the detector are investigated using a collimated beam of 0.60 mm diameter from 5.9 keV ^{55}Fe X-ray source.

4. Detector performance

Figure 3 shows a typical pulse height spectra for ^{55}Fe X-rays at an anode voltage of 1500 V and 100 kPa gas pressure. Two peaks corresponding to the total absorption peak (5.9 keV) and the argon escape peak (2.93 keV) are clearly seen. There also exists a third peak with intensity of about 1% and at the position 25% of the main peak. This is clearly shown in figure 4 using a logarithmic scale. We speculate that this peak corresponds to

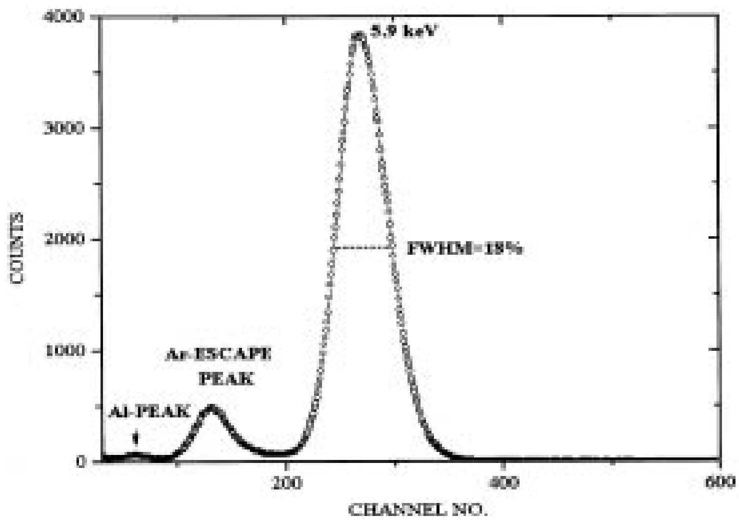

Figure 3. Pulse height spectrum for ^{55}Fe X-rays with P-10 gas at 100 kPa and anode voltage of 1500 V.

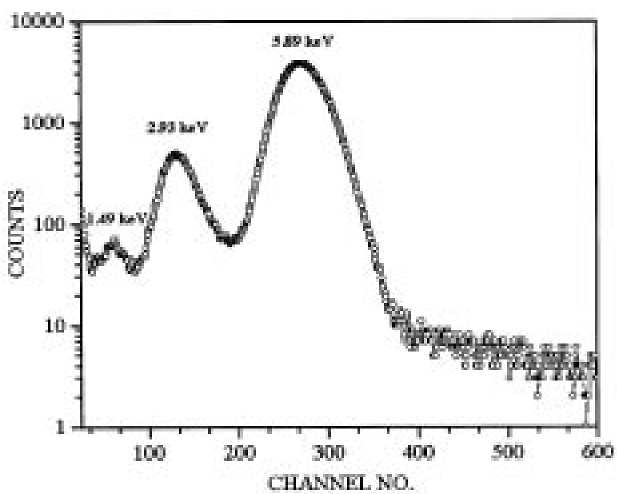

Figure 4. Pulse height spectrum of figure 3 in a logarithmic scale, showing the three distinct X-ray energy peaks.

characteristic X-rays of Al (1.49 keV) originating from the aluminum base plate used for mounting anode–cathode grid assembly that absorbed the 5.9 keV photons. However, this peak is not noticeable at higher gas pressures. Similar observations have been reported recently in the study of an X-ray proportional counter [9].

The electron multiplication process in high electric field is one of the prominent characteristics of proportional counters. The formation of electron avalanches results in gas amplification or gas gain. The overall performance of a proportional counter is expressed in terms of its gain which depends upon adjustable parameters such as detector geometry, operating voltage, gas pressure and its chemical composition. The energy resolution and spatial resolution (in case of PSDs) of the detector also depend upon these parameters. Variation of energy resolution (FWHM) with anode voltage at different gas pressures is shown in figure 5. It is seen that the energy resolution remains almost constant in the proportional region for a particular gas pressure. Any upward deviation from this value indicates the onset of gas gain saturation and degradation of the energy resolution. It is also seen that the proportional region shifted to higher voltage range with increase in the gas pressure. A maximum energy resolution of ∼12% (FWHM) is obtained for 300 kPa gas pressure and at anode voltage of 2200 V.

The gas gain as a function of the anode voltage is determined for P-10 gas at pressures equal to 100, 200, 300 kPa. For each measurement, gas gain M is calculated using the equation

$$M = \frac{WC_\mathrm{f}v}{Xe}, \tag{2}$$

where W is the ionization energy of the gas (26 eV for P-10 gas), X the energy of the photoelectron almost equal to that of incident X-rays, v the preamplifier output, C_f is the feed back capacitance of the preamplifier and e the electron charge. The gas gain curves, i.e., the logarithm of gas gain as a function of the applied anode voltage are presented in figure 6. It can be seen from the graph that gas amplification (M) is the exponential function of the applied voltage in the whole range of gas gains, $10 < M < 5 \times 10^4$ and appears as a line on the semi-log plot. The high voltage required for the same gas gain increased

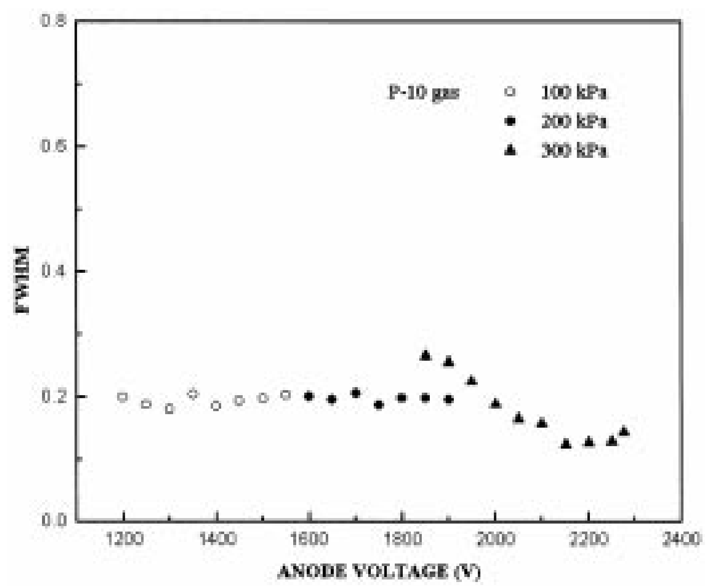

Figure 5. Resolution (FWHM) of the main peak as a function of anode voltage for different gas pressures.

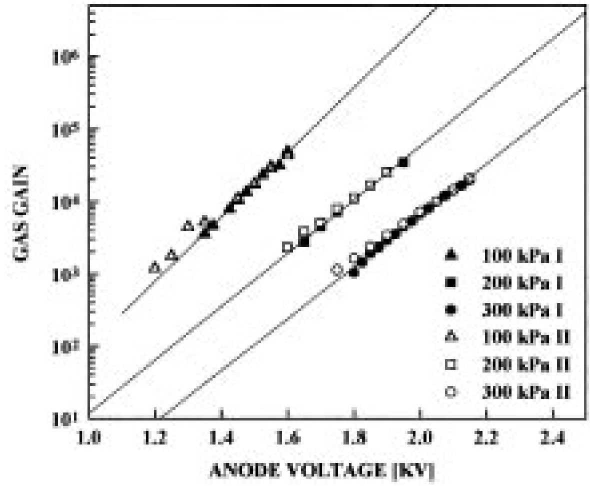

Figure 6. Gas gain as a function of anode voltage for various P-10 gas pressures. Two sets of data are shown for each pressure.

with the increase in gas pressure. In order to compare the present results with the previous measurements, the gas gain data are fitted on the Diethorn formula [10]

$$\ln M = \frac{V}{\xi}\,\frac{\ln 2}{\Delta V}\,\left(\ln\frac{V}{pa\,\xi} - \ln K\right) \tag{3}$$

where V is the applied voltage, ξ the design parameter of the detector and is given by $\xi = \ln(b/a)$ for the detector with cylindrical geometry and $(\pi l/s - \ln(\pi d/s))$ for 2-D detector with multiwire geometry [6], a and b the anode and cathode radii and p the gas pressure. The parameters l, d, and s have their meanings as given in eq. (1). ΔV corresponds to the potential difference through which an electron moves between successive ionization events and K represents the minimum value of E/p below which multiplication cannot occur. The parameters ΔV and K depend only on the gas mixture. The previously reported values for these parameters for the P-10 gas by Wolff [11] are 23.6 V and 48 kV/cm·atm respectively and those by Okuno *et al* [9] are 27.8 V and 37 kV/cm·atm respectively. Our results, $\Delta V = 23.65$ V and $K = 48.62$ kV/cm·atm, obtained by fitting our data to eq. (3) for multiwire geometry are consistent with these reported values.

Position resolution is determined by measuring the detector response to a 1 mm collimated X-ray beam incident normally on the window and recording position spectrum along the X and Y grids in steps of 4 mm. A typical position spectrum recorded along X-axis is shown in figure 7. A 3-D position spectrum is also recorded and position resolution is calculated by noting the FWHM in both X and Y directions. Spatial resolution (FWHM) of 1.7 mm $\times$ 1.8 mm, 1.5 mm $\times$ 1.6 mm and 1.2 mm $\times$ 1.4 mm is obtained at 100, 200, and 300 kPa gas pressures respectively. Figure 8 shows position spectrum of the character 'S' traced by keeping X-ray source on the active area. Uniformity of response, i.e., efficiency over complete active area of the detector is highly desirable for X-ray diffraction. This can be tested by irradiating the detector with a beam of X-rays of uniform intensity per unit area, and measuring the position spectrum. Figures 9a and b show the X-axis and Y-axis

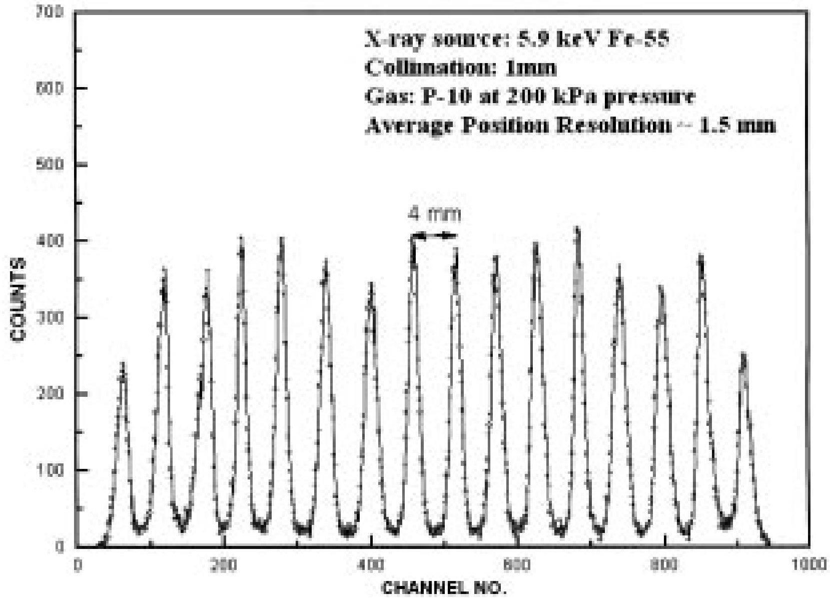

Figure 7. Position response of the detector along X-direction.

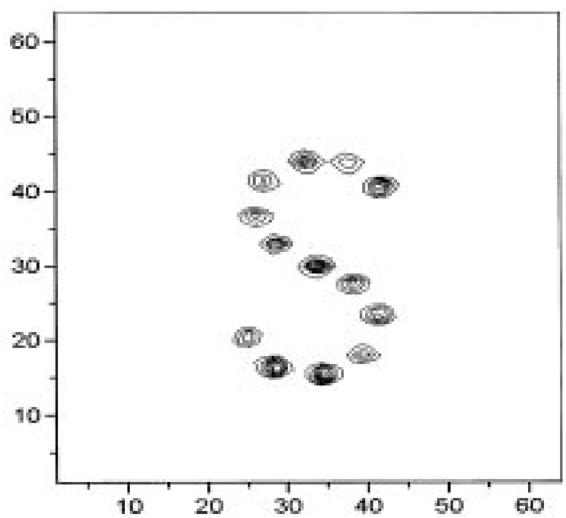

Figure 8. Position spectrum of the character 'S' traced by keeping the X-ray source on various positions of the active area.

responses, respectively, from the detector to a ^{55}Fe source placed some 30 cm above it so as to give an approximately flat distribution. In X-axis, there is a modulation due to the discrete cathode wire locations and the spectrum shows the period of cathode wire spacing. No such cathode wire quantization is seen in the Y-axis response except

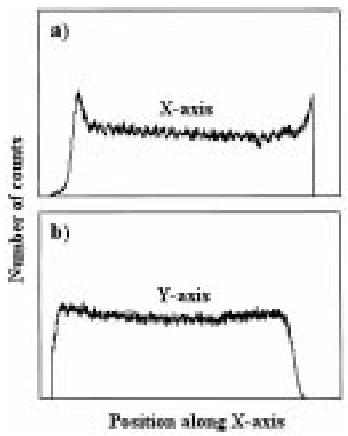

Figure 9. Uniform irradiation response of the detector. (**a**) The upper X-cathode response and (**b**) lower Y-cathode response.

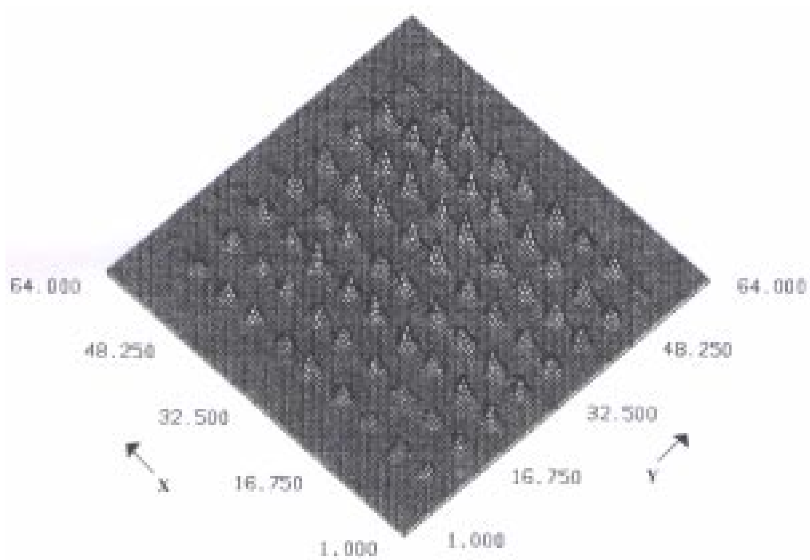

Figure 10. Position spectrum obtained with detector covered with a grid containing uniform holes and flooded with X-rays.

low amplitude wrinkles across the whole field. Figure 10 shows position spectrum recorded by placing a lead mask containing uniform holes pattern, on the window of the PSD and flooding with X-rays. The PSD shows uniform efficiency over complete active area. The overall efficiency of the detector for the 5.9 keV X-rays is found to be 67% at 100 kPa gas pressure and 76% at 300 kPa. X-ray images of objects in various shapes cut from a lead sheet are recorded. The images recorded at 300 kPa gas pressure are sharp.

5. Conclusions

A multi-wire 2-D position sensitive detector for X-ray diffraction and small angle X-ray scattering studies has been designed and fabricated and its performance tested with 5.9 keV X-rays. The position information is obtained using charge division method and recorded using a laboratory built data acquisition system. The present 1.5 mm pitch of cathode read-out planes provide an angular resolution of 0.8° in X-ray pattern when the detector is kept at 5 cm from the crystal. In this ongoing work, new devices and techniques are being developed to minimize parallax errors in planar detectors and large curvilinear detectors are under development. Even though the performance of the 2-D PSD filled with P-10 gas has been reported here, experiments with gas mixtures like $Kr + CH_4$, $Xe + CH_4$ and others are being performed.

References

[1] P Convert and J B Forsyth (eds), *Position sensitive detection of thermal neutrons* (Academic Press, London, 1983)
[2] G Charpak and F Sauli, *Nucl. Instrum. Methods* **162**, 277 (1979)
[3] Y D Dande, *Indian J. Pure Appl. Phys.* **27**, 592 (1989)
[4] A K Patra, S R Chinchanikar, J N Joshi, Y D Dande, R S Udyavar, S S Desai and R S Kothare, *Indian J. Pure Appl. Phys.* **31**, 418 (1983)
[5] A M Shaikh, A K Patra, J N Joshi and N D Kalikar, *Solid state physics (India)* **40C**, 468 (1997)
[6] F Sauli, CERN Scientific Report, RD/233 (1977)
[7] J N Joshi, A K Patra, N D Kalikar and A M Shaikh, *Solid state physics (India)* **40C**, 454 (1997)
[8] B Jayaswal, A computer code for drawing three dimensional graphs, maps and histograms, in single or multiple colours, for mono or stereoscopic viewing, *BARC Report* 1369 (1987)
[9] H Okuno, N Khalatyan, Y Nakamura, K Fuji, K Hoshina, Y Kato, Y Kurihara, H Kuroiwa and O Nitoh, *Nucl. Instrum. Methods* **A447**, 459 (2000)
[10] G F Knoll, *Radiation detection and measurement*, Second Edition (John Wiley & Sons, 1989) p. 170
[11] R S Wolff, *Nucl. Instrum. Methods* **115**, 461 (1974)