Design and experimental study of a two-dimensional position sensitive X-ray detector

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Abstract A prototype of a two-dimensional position sensitive X-ray detector was designed and constructed for small angle X-ray scattering experiments at BSFR (Beijing Synchrotron Radiation Facility). The detector is based on MWPC with cathode strip readout, and has a sensitive area of 200 mm×200 mm. The spatial resolution (FWHM) of about 210 μm along the anode wire direction was obtained from the ^{55}Fe X-ray test of the detector.

Key words Garfield simulation, X-ray detector, MWPC

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1 Introduction

X-ray diffraction and scattering techniques are widely used in material structure studies. At BSFR (Beijing Synchrotron Radiation Facility), the small angle X-ray scattering (SAXS) experiments and some other experiments require large numbers of position sensitive X-ray detectors. Multi-wire proportional chambers (MWPCs), which have a good spatial/time resolution, with large areas that can be made, have long been used in X-ray detection.

In this paper the design and construction of the prototype of a two-dimensional position sensitive X-ray detector were reported. Garfield[1] program was used in detector geometry design.

The performances of the detector were tested with ^{55}Fe 5.9 keV X-ray. The spatial resolution of about 210 μm along the anode wire direction was obtained. The following results were also obtained：The rate of full energy photo-electron peak and escape peak was 1.964 and the energy resolution of 5.9 keV X-ray was 23%.

2 Detector design

2.1 Detector structure

The geometry structure of the two-dimensional X-ray detector is shown in Fig.1. There are one anode plane, one cathode plane and two orthogonal readout planes. The distance between the anode plane and the two readout grid planes is d=3 mm, while the distance between the upper readout plane (Readout plane y) and the cathode plane is l=15 mm. The anode plane is made of 20 μm diameter gold plated tungsten wires, at a spacing of s=2 mm. All anode wires are connected together to get the energy loss signal, and used as readout system triggering. The upper readout plane is made of 50 μm diameter gold plated tungsten wires, at a spacing of w=1 mm; each four wires are connected together forming a readout strip. The lower readout plane is made of 3 mm wide copper strips and the spacing between two adjacent strips is 4 mm. The position of the injection X-ray is determined by the center of gravity of the induced charge distribution on the readout planes.

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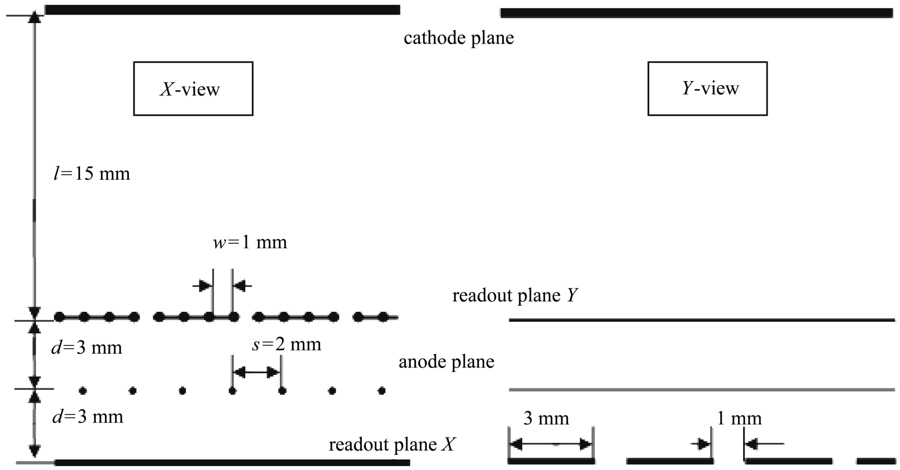

Fig. 1. Cell structure of the two-dimensional MWPC.

2.2 Simulation

The geometry of the wire planes, working gas properties and some other parameters of the detector were studied and optimized with Garfield program.

2.2.1 Geometry

Gas gain on the anode wires was determined by the geometry of the wire planes (including wire radius, wire spacing, wire planes spacing, etc.), bias of the electrodes and the working gas properties.

For X-ray with energy of several keV, Ar+CO_2(90/10) is often used as the absorb medium. In order to get a good signal to noise ratio, a gas gain of larger than 10^4 is generally needed in this gas mixture. By increasing the anode voltage, a higher gas gain can obviously be obtained, but this may also cause an electric discharge. So the geometry of the wire planes should be set in a way that the detector can work at an acceptable anode voltage. Table 1 is the Garfield simulation result of the gas gain of different wire plane structures (d and s) under the same conditions. The parameters used in the simulation are, 20 μm anode wire diameter, 50 μm readout wire diameter, Ar+CO_2(90/10) gas mixture, the same electrodes bias (V_{anode} = 1850 V, V_{cathode} = −1600 V). The readout wire spacing is set as w =1 mm if $d \geqslant 2$ mm, and $w = d$ if $d \leqslant 1.5$ mm. From Table 1, we can see that a small distance between the anode plane and the readout plane (d) is needed by small anode wire spacing (s). Since there will be difficulties in manufacture if the anode wire spacing s is too small, the anode wire spacing of this detector is chosen as s=2 mm. The distance d is set to 3 mm, so the gas gain of about 2.5×10^4 can be obtained according to Table 1.

The induced charge distribution on the readout planes is determined by the distance d between the anode plane and the readout plane. The simulated induced charge distribution on the readout plane is shown in Fig. 2. From Fig. 2, we can see that a large signal width on the readout plane can be obtained by long distance d. This is important in choosing the width of the readout strips. As discussed in Ref. [2], the optimum ratio of sensing electrodes width (readout strip spacing) to readout plane-anode plane distance is about 1. So, for single strip readout, if the distance d is small, large numbers of readout channels

Table 1. Gas gain under different wire planes geometries; d is the distance between the anode plane and the readout planes; s is the anode wire spacing.

d/mm	s/mm			
	0.5	1	1.5	2
0.5	2.2×10^8	6.2×10^{10}		
1	1.4×10^4	8.0×10^6	5.8×10^8	
1.5	2.5×10^2	6.8×10^4	1.7×10^6	
2		3.7×10^3	9.0×10^4	
2.5		5.4×10^2	1.0×10^4	1.4×10^5
3		1.4×10^2	2.2×10^3	2.5×10^4
3.5			6.7×10^2	6.3×10^3
4			3.6×10^2	2.0×10^3

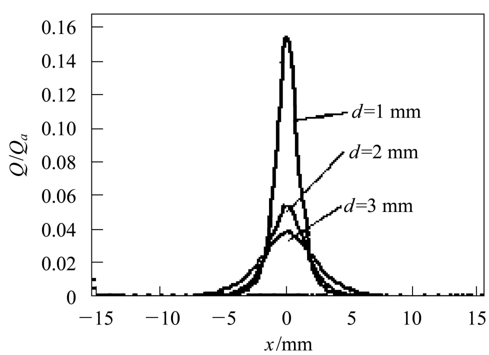

Fig. 2. The induced charge distribution on the readout planes; x is the position on the readout plane; y is the ratio of induced charge on a readout strip to the total avalanche charge.

will be needed. For the situation of d=3 mm, the signal width on the readout plane is about 15 mm. The width of the readout strip is set to 4 mm, so there could be at least 3 strips to be used in the X-ray position calculation, and there will be totally 100 readout channels for the 200 mm×200 mm detector.

2.2.2 Electric field

The region between the upper readout plane (Readout plane y) and the cathode plane is called drift space. The X-ray detection efficiency is mainly determined by the thickness of the drift space. The electric field in the drift space must be lower than that in the region between the anode plane and the readout planes (here defined as anode-readout region), so as to avoid the primary electrons collecting on the readout wires. The electric field in the anode-readout region and in the drift space is determined by the bias on the electrodes. The relationship between the electrodes bias and the electric field can be given by Garfield simulation, and thus the working bias can be optimized.

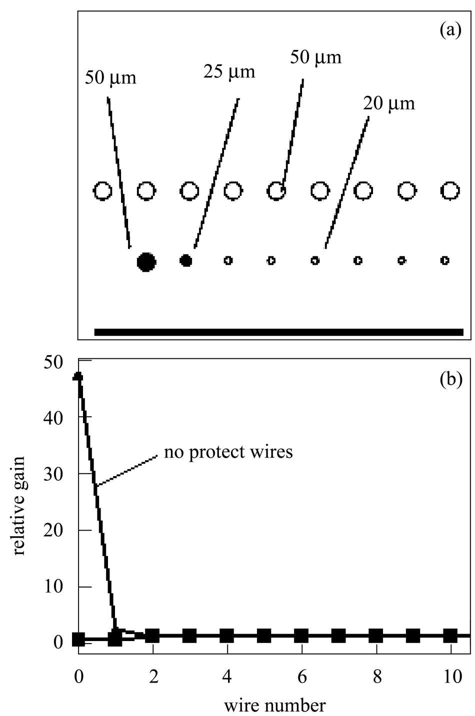

Fig. 3. (a) Arrangement of the protection wires; (b) Gas gain reduction after using protection wires.

On the anode plane, the electric field on the end wires is larger than that on the others. In order to avoid electric discharges on these wires, protection wires of larger diameters should be used at the boundaries. The arrangement of protection wires is shown in Fig. 3(a), two protection wires with the diameter of 25 μm and 50 μm are placed at the boundaries of the anode plane, while the diameters of the other anode wires are all 20 μm. Fig. 3(b) shows the reduction of gas gain at the boundaries after using protection wires.

2.2.3 Gas properties

In Ar+CO_2 (90/10) mixture, in order to get a 5.9 keV ^{55}Fe X-rays absorption efficiency of 60%, the gas volume thickness of about 21 mm is needed[3]. The X-rays first interact with the working gas when they enter the detector, generating a number of primary electrons. The primary electron cloud then drifts to the anode, where an avalanche takes place. While drifting through the gas, the electrons will diffuse, both in the longitudinal and in the transverse direction. The longitudinal diffusion spreads the arrival time of the primary electrons, and thus adds errors in time measurement. The transverse diffusion directly deteriorates the spatial resolution. The diffusion of the electrons depends on the gas characteristics, the drift distance, and the drift field. The diffusion coefficient as a function of the electric field from our Monte Carlo simulation with Garfield is given in Fig. 4. In order to minimize the electron diffusion, the electric field should be smaller than 600 V/cm, which corresponds to a cathode voltage of about 800 V for our detector.

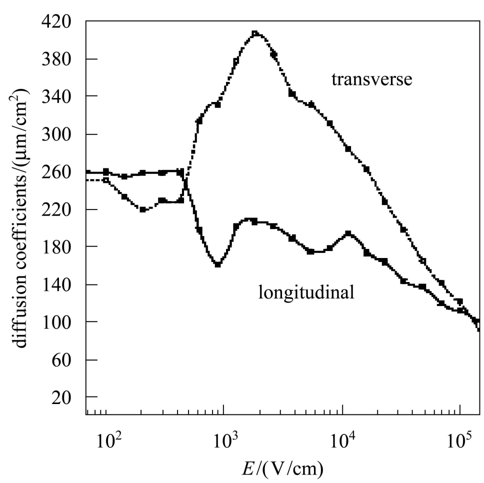

Fig. 4. Diffusion coefficients as a function of electric field.

3 Detector construction

All the electrodes except the cathode plane are made of circuit boards. The lower readout plane is made of circuit board with 3 mm wide copper strips on its surface. The anode plane and the upper readout plane are made by soldering the gold plated tungsten wires on the 1.5 mm thick circuit boards. The tension of the anode wires and the readout wires is 30 g and 40 g respectively. Spacers are used to keep the distance between two electrodes.

The electrodes are all built on a base plate of an aluminum container (See Fig. 5). The electric feedthroughs, gas inlet and outlet are also set on the base plate. On the back of the base plate, front end electronics are mounted. The entrance window for the X-ray is on the front cover of the container. The entrance widow, which also serves as the cathode, is made of 50 μm thick Mylar film with 10 μm thick aluminum coating layer. The distance between the cathode and the upper readout plane is 15 mm, so as to get sufficient X-ray detection efficiency. O-ring is used to seal between the base plate and the front cover.

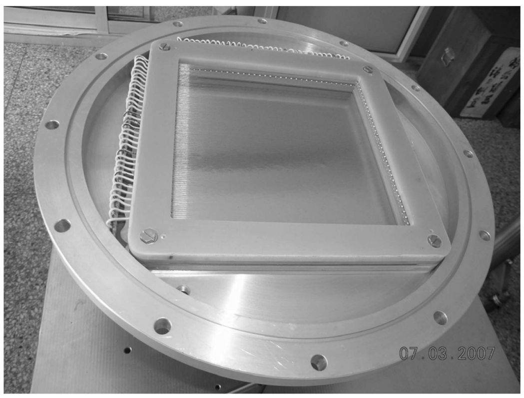

Fig. 5. Picture of the base plate of the container.

4 Performances of the detector

4.1 Experimental setup

For energy spectrum and gas gain measurements, anode signal was first collected by a charge sensitive preamplifier (made in IHEP, CAS), and then amplified by a spectrum amplifier (ORTEC 672). The output of the spectrum amplifier was then sent to a pulse height analyzer (Trump-2k ORTEC), which finally get the energy spectrum. High precision pulse generator (ORTEC448) was used in the calibration of the system.

The readout electronics for X-ray position measurement was based on the CAMAC-ADC system. Each readout strip was connected to a charge sensitive preamplifier[4] mounted on the back of the detector. Output of the charge sensitive preamplifiers were then directly digitized by ADCs (LRS 2249 W). The gating signals of the ADCs were given by anode signal after being amplified by a fast current sensitive amplifier. The data were collected by the computer, and the X-ray position was calculated offline.

4.2 Experimental result

4.2.1 Energy spectrum and gas gain

The energy spectrum of ^{55}Fe 5.9 keV X-ray is shown in Fig. 6(a), and the gas gain is 10^4. The ratio of full energy photo-electron peak and escape peak is 1.964, and the energy resolution (FWHM) for 5.9 keV X-ray is 23%. Fig. 6(b). shows the experimental result of the gas gain as a function of anode voltage.

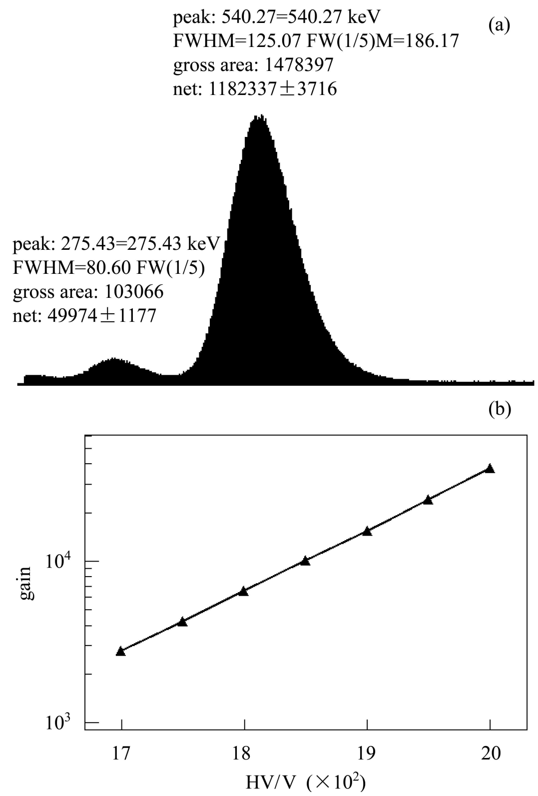

Fig. 6. (a) Energy spectrum of 5.9 keV X-ray; (b) Gas gain as a function of anode voltage.

4.2.2 Spatial resolution

The spatial resolution was tested through a 0.3 mm collimated X-ray beam. Fig. 7 shows the reconstructed position distribution along the anode wires, the σ of the Gaussian distribution is approximately 123 μm. If the width of the collimator is defined as cw, then its contribution to the error of measurement is $\sigma_c = cw/\sqrt{12}$, so the accuracy of the

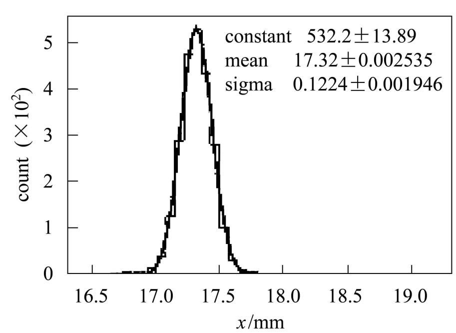

Fig. 7. Spatial resolution along anode wire.

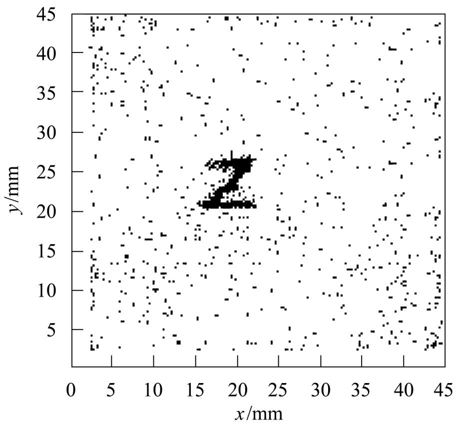

Fig. 8. Image of a "Z" collimator.

detector is $\sigma_x = \sqrt{\sigma^2 - \sigma_c^2} = 88$ μm. So, taking the width of the collimator into account, the spatial resolution (FWHM) along the anode wire is about 210 μm. As being modulated by the anode wire, the accuracy in the direction across the anode wire is $\sigma_y = s/\sqrt{12}$, which corresponds to a resolution (FWHM) of about 1.4 mm.

4.2.3 Two-dimensional image

Let X-ray enter a "Z" shape collimator, the detector gets a clear image shown in Fig. 8. The collimator is 5 mm×5 mm, and the width of the collimated slot is 0.3 mm. So the detector has a good two-dimensional response.

5 Summary

A simulation study of a two dimensional X-ray detector was carried out before the construction of a prototype of the detector. By ^{55}Fe X-ray test, the prototype works well. The spatial resolution (FWHM) along the anode wire direction is about 210 μm. The energy resolution (FWHM) for 5.9 keV X-ray is 23%. There is good proportionality of gas gain as a function of anode voltage, and the imaging experiment with X-ray is successful and satisfactory.

A complete detector that reads out with fast electronics based on VME system will be constructed in the near future.

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