Influence of working gas properties on MWPC anode wire modulation effect *

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Abstract: For MWPCs used for X-ray position detection, simulation studies of the anode wire modulation effect of the detector were carried out using the Garfield program. Different gas mixtures were used as the working gas in the simulation, so as to obtain the influence of the X-ray cross section and electron diffusion coefficient of the working gases on the anode wire modulation effect of an MWPC with anode wire spacing of 2 mm. Results show that, though a working gas with higher X-ray cross section implies a larger average drift distance for the ionized electrons, such gas mixtures are of little use in improving the anode wire modulation effect of MWPCs. It is found that the transverse electron diffusion coefficient is the determining factor for the extent of the anode wire modulation effect in the detector.

Key words: Garfield simulation, anode wire modulation, working gas, MWPC

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1 Introduction

Position-sensitive detectors based on Multi-wire Proportional Chambers (MWPCs) are widely used in neutron and X-ray detection. MWPC have many advantages for particle detection, such as stability, cost, and ability to produce a large area detector. However, because the anode plane of an MWPC is made of a set of parallel wires, the anode wire modulation effect is one of the main factors that limits the spatial resolution in the direction across the anode wires of the detector.

There are many factors that affect the magnitude of the MWPC anode wire modulation effect, including anode wire spacing, drift distance of the ionized electrons, and electric field in the drift region. As mentioned in Ref. [1, 2], by applying a cathode wire plane with wires parallel and in alignment with the anode wires, the anode wire modulation effect can be reduced significantly. Results in Ref. [2, 3] also show that the deeper the drift region is, the smaller anode wire modulation effect. The simplest way to obtain a larger drift region depth is to increase the thickness of the working gas volume, but a thick working gas volume implies much more parallax error for planar type gas detectors. For X-ray detection, since the attenuation of the X-ray beam in matter obeys the $I=I_0e^{-ud}$ rule, most X-rays will be absorbed near the entrance window if working gas with a high X-ray cross section is used, and this means most ionized electrons will experience longer drift distances than those in working gases with low X-ray cross sections. Therefore, applying a working gas with high X-ray cross section might be a way to reduce the anode wire modulation effect of the MWPC. Meanwhile, since the diffusion of the electrons can affect the sharing of ionized electrons on the anode wires, working gases with different diffusion coefficients correspond to different anode wire modulation effects of the MWPC. Till now, few works have focused on the influence of these gas properties on the anode wire modulation effect of MWPCs.

In this paper, the anode wire modulation effect of an MWPC with anode wire spacing of 2 mm is studied. The influence of the electron diffusion coefficient and X-ray cross section on the anode wire modulation effect of the detector are investigated.

2 Method

The anode wire modulation effect of MWPCs arises from the fact that all avalanches caused by an incident particle can only occur around an anode wire. Therefore, no matter what the actual position of the particle is, its measured position along the axis across the anode wires is always the position of the corresponding anode wire. When applying uniform irradiation, the measured

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positions of the particles incident on the detector will not be a uniform distribution, but will have most counts at the locations of the anode wires. The uniform irradiation response of the detector can therefore be used as a reference for the anode wire modulation effect of the MWPC.

In this paper, we use Garfield [4] software to simulate the uniform X-ray irradiation response of an MWPC. Though it is known that MWPCs with small anode wire spacing suffer a lower degree of anode wire modulation effect, the small anode wire spacing implies much more difficulty in detector manufacturing. In this work, an MWPC with a commonly used anode wire spacing of 2 mm was studied, since if the anode wire modulation can be eliminated at this anode wire spacing it can obviously be eliminated at anode wire spacings smaller than 2 mm. The structure of the MWPC is shown in Fig. 1. It mainly consists of a drift region and an amplification region. The depth of the drift region is 20 mm. The anode plane and the cathode wire plane both have a wire pitch of 2 mm, and the distance from the anode plane to the nearest two cathode planes is also 2 mm. The diameter of the anode wire and cathode wire used in the simulation is 20 μm and 50 μm respectively. In practical use, the lower cathode plane is usually made of metal strips with direction perpendicular to the anode wires.

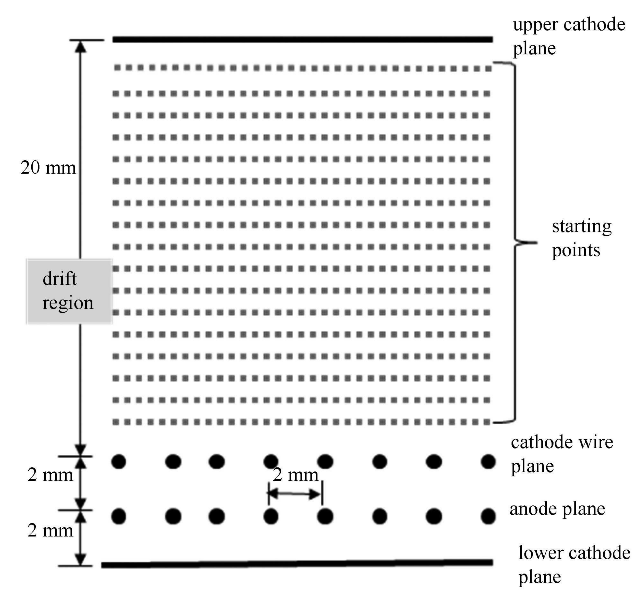

Fig. 1. Structure of the MWPC.

In the simulation, a series of uniformly distributed starting points were selected in the drift region of the MWPC. For the gas mixtures used for X-ray detection, the average ionizing energy is about 30 eV [5]. Therefore, at each starting point, 200 electrons were set to drift towards the anode plane, so as to simulate an X-ray with energy of several keV being absorbed at the starting point. Because different gas mixtures have different X-ray cross sections, the number of simulated X-rays was not the same for all starting points, but differed from each other according to the distance from the starting points to the entrance window (upper cathode plane). Gas mixtures including $Ar/CH_4(90/10)$, $Ar/CO_2(70/30)$, $Xe/CO_2(70/30)$, $Ar/CO_2(90/10)$ and $Xe/CO_2(90/10)$ were used in the simulation, since they have different electron diffusion coefficients and X-ray cross sections. Fig. 2 shows the calculated electron transverse diffusion coefficient obtained by Garfield simulation. As shown in the figure, for electric field ranging from 200 V/cm to 5000 V/cm, $Ar/CH_4(90/10)$ has the largest electron diffusion coefficient, followed by $Ar/CO_2(90/10)$ and $Xe/CO_2(90/10)$, while $Ar/CO_2(70/30)$ and $Xe/CO_2(70/30)$ have the lowest electron diffusion coefficient.

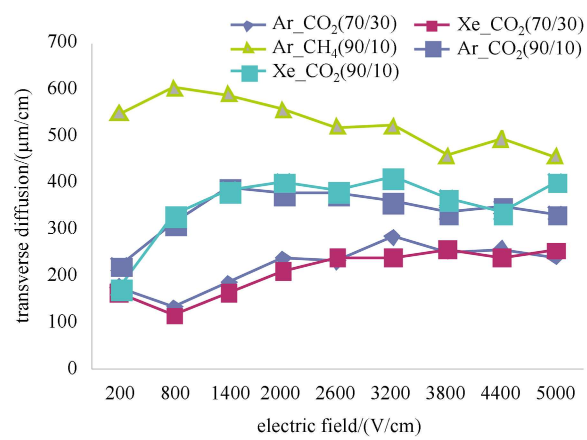

Fig. 2. Transverse diffusion of the gas mixtures.

Using the X-ray cross section database XCOM [6], the attenuation of 5.9 keV X-rays in different working gases can be calculated, and the results are shown in Fig. 3. According to Fig. 3, xenon-based gas mixtures have a much larger attenuation coefficient than argon-based gas mixtures. For $Xe/CO_2(90/10)$ gas mixture, more than 96% of the incident X-rays will be absorbed in the upper half of the drift region shown in Fig. 1, while the value is only 70% for $Ar/CH_4(90/10)$. When applying uniform X-ray irradiation, the mean electron drift distance in the drift region is 17 mm for $Xe/CO_2(90/10)$, compared to 11 mm for $Ar/CH_4(90/10)$.

In the anode modulation effect simulation, primary electrons were let drift from the starting points in the drift region. The number of events (an event represents a simulated X-ray, which corresponds to 200 primary electrons being generated at the starting point) at each starting point was chosen according to the curve shown in Fig. 3, that is, the closer the starting point to the entrance window the more events it has. The

Drift_MC_Electron subroutine in the Garfield program was used to track the ending location of each electron, and the measured position of a simulated X-ray was obtained by calculating the center of gravity of the electron position distribution on the anode plane. By recording the measured position of simulated X-rays from all starting points, the uniform irradiation response of the detector could be obtained.

Figure 4 shows the calculated uniform irradiation response of a previously constructed X-ray detector with working gas of $ArCO_2$(90/10). The structure of the detector is similar to the structure shown in Fig. 1, with the only difference being that the cathode wires are at a spacing of 1 mm and not in alignment with the anode wires. From Fig. 4, we can see that the anode modulation effect of this structure is quite large. Fig. 5 is the measured position distribution of the same detector for a 0.3 mm×5 mm collimated X-ray beam, with the slot of the collimator perpendicular to the anode wires. As shown in Fig. 5, the measured data of the detector also shows an obvious anode wire modulation effect. In the experimental test, the noise of readout electronics, the displacement and gain uniformity of the anode wires, the non-uniformity of the X-ray beam in the collimator etc, will all contribute to the position response of the detector. Thus the measured position distribution is not exactly identical to the calculated one. By comparing Fig. 4 and Fig. 5, however, we can see that the shapes of the position distributions are quite similar. Therefore, the result obtained by the calculation is reliable.

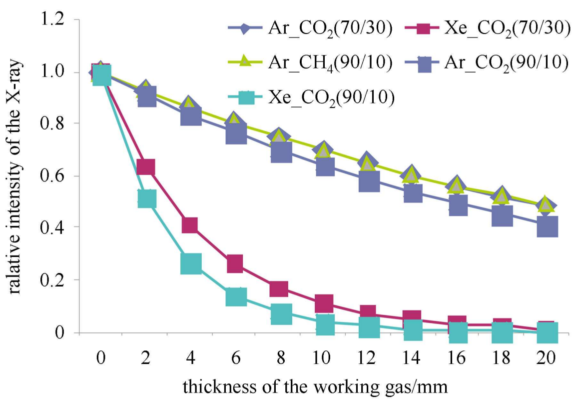

Fig. 3. (color online) X-ray attenuation in different gas mixtures.

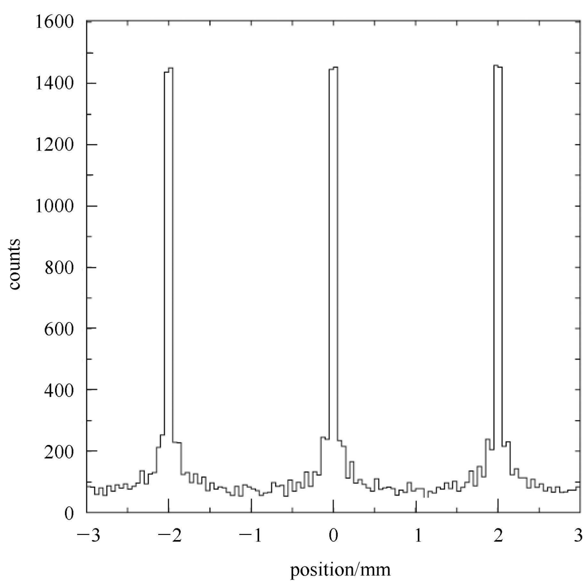

Fig. 4. Calculated uniform irradiation response of a detector with cathode wire spacing of 1 mm.

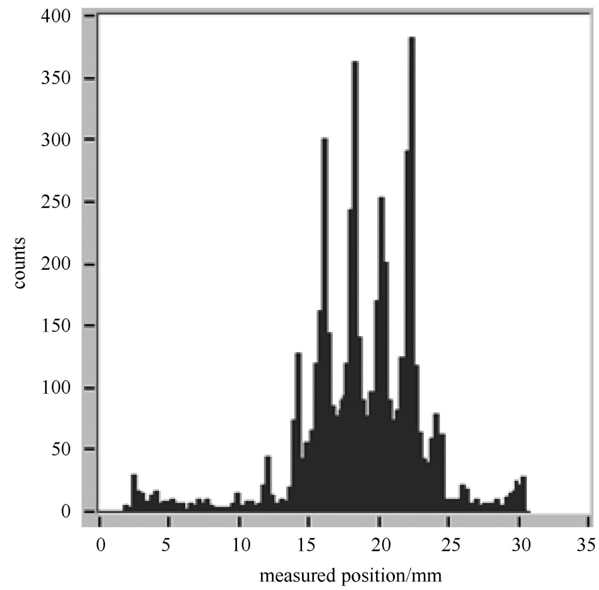

Fig. 5. Measured position response of the detector for a collimated X-ray beam.

3 Simulation results

3.1 Optimization of the drift field

The electric field in the drift region is mainly determined by the upper cathode voltage of the MWPC. As mentioned in Refs. [2, 3], the anode wire modulation effect is strongly affected by the electric field in the drift region. For a given MWPC structure and working gas, there is an optimized drift electric field with which the detector obtains the best linearity. Fig. 6 is the calculated uniform irradiation response (UIR) of the MWPC under different upper cathode voltages. The working gas used in Fig. 4 is Ar/CH_4(90/10). As can be seen, the measured position distribution is almost uniform when the voltage of the upper cathode is set to −1000 V, but the response linearity get worse at both lower and higher cathode voltages. Therefore, in the simulation below, in order to get the best uniform irradiation response (UIR) of the detector, the drift field (cathode voltage) was first adjusted and optimized.

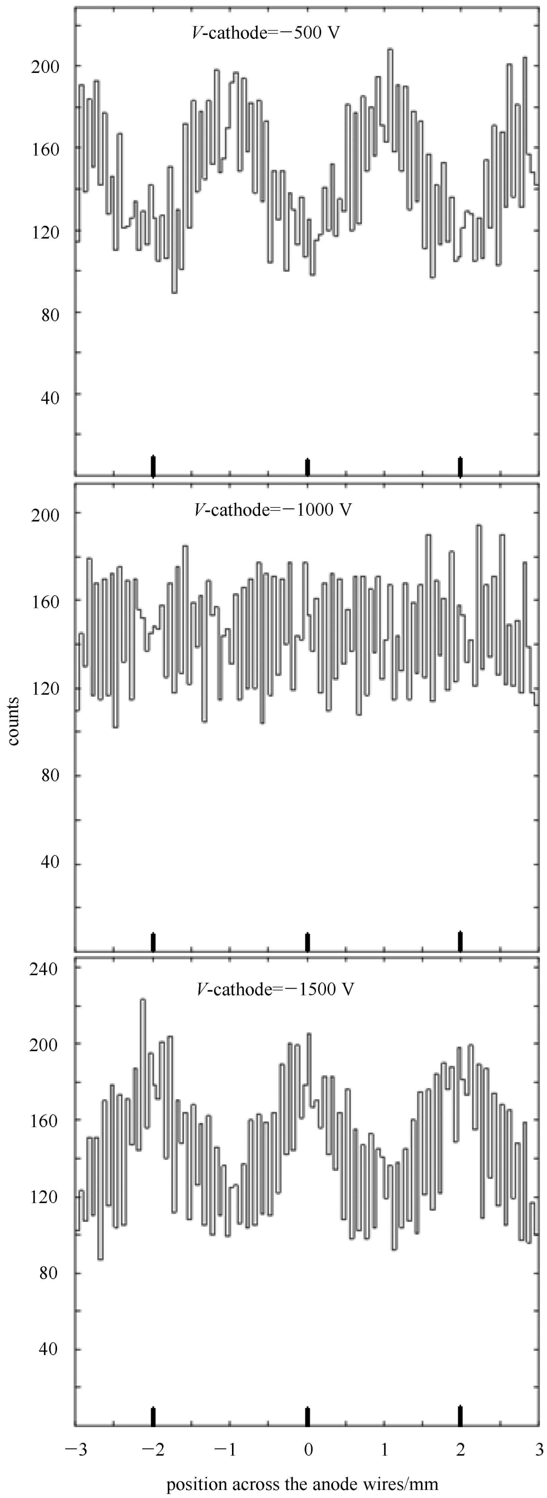

Fig. 6. UIR of the detector under different cathode voltages. The anode wires are located at 0, ±2 mm.

3.2 Best UIR for different working gases

In order to investigate the anode wire modulation effect under different drift region depth, the best uniform irradiation response (UIR) of the MWPC with drift regions of 20 mm and 12 mm were calculated. For each working gas, the best UIR of the detector was obtained by adjusting the upper cathode voltages of the MWPC. By our calculation, the optimized drift field for different gas mixtures ranges from 400 V/cm to 1100 V/cm.

For drift region depth of 20 mm, the calculated best UIR of the detector using different working gases is shown in Fig. 7. As can be seen, the best UIR of the detector using Ar/CH_4(90/10), Ar/CO_2(90/10) and Xe/CO_2(90/10) is almost a uniform distribution, which means there is almost no anode wire modulation effect in this condition. However, for working gas of Ar/CO_2(70/30) and Xe/CO_2(70/30), the best UIR of the detector still shows a modulation. Though Xe/CO_2(70/30) has larger X-ray cross section, the degree of anode wire modulation effect is higher in Xe/CO_2(70/30) than in Ar/CO_2(70/30), though the period of the modulation is reduced to half of the anode wire pitch.

Figure 8 shows the calculated best UIR of the detector using different working gases with drift region depth of 12 mm. From Fig. 8, we can see that the best UIR of the detector is quite similar to the situation for drift region depth of 20 mm. That is, there is almost no modulation for detectors using Ar/CH_4(90/10), Ar/CO_2(90/10) and Xe/CO_2(90/10) as working gas. When using Ar/CO_2(70/30) and Xe/CO_2(70/30) as working gas, the anode wire modulation effect still exists, but with the period of the modulation being reduced to half of the anode wire pitch.

4 Discussions and conclusions

Among the gas mixtures examined, Ar/CO_2(70/30) and Xe/CO_2(70/30) have the lowest electron diffusion coefficients. The results show that, even applying optimized drift field, detectors using these two gas mixtures cannot eliminate the effect of anode wire modulation. Xe/CO_2(90/10) has the largest X-ray cross section, but also has a larger diffusion coefficient than Xe/CO_2(70/30) and Xe/CO_2(70/30). Since detectors using Ar/CO_2(90/10) or Xe/CO_2(90/10) all have a uniform UIR distribution, as shown in Fig. 5 and Fig. 6, we can deduce that it is the higher electron diffusion coefficient rather than the larger X-ray cross section of Xe/CO_2(90/10) that diminish the anode wire modulation effect of the detector.

For the cell structure shown in Fig. 1, which has an anode wire plane and a cathode wire plane both with a wire pitch of 2 mm, by comparing the best X-ray UIR of the three groups of gas mixtures ($ArCH_4$(90/10), Ar/CO_2(70/30) and Xe/CO_2(70/30), Ar/CO_2(90/10) and Xe/CO_2(90/10)), the following conclusions can be made.

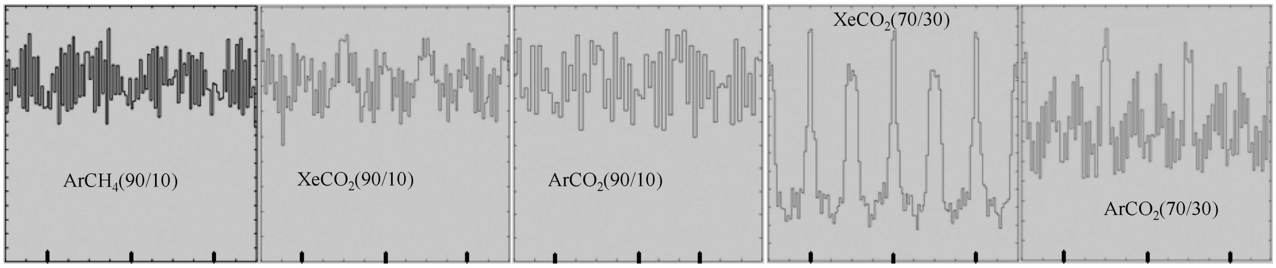

Fig. 7. Best UIR spectrum of the detector using different working gases with drift region depth of 20 mm; the markers on the x-axis represent the positions of the anode wires.

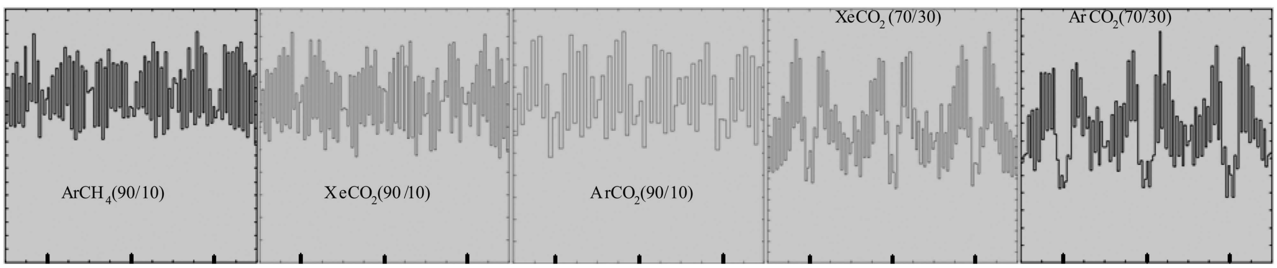

Fig. 8. Best UIR spectrum of the detector using different working gases with drift region depth of 12 mm; the markers on the x-axis represent the positions of the anode wires.

(1) A working gas with high X-ray cross section is of little use in eliminating the effect of anode wire modulation. Though xenon-based gas mixtures have larger X-ray cross sections than argon-based gas mixtures, the anode wire modulation effect of the detector is almost the same for these two types of gas mixture if their transverse electron diffusion coefficient is identical.

(2) Detectors with drift region depths of 20 mm and 12 mm have quite a similar best uniform irradiation response, which means that the anode wire modulation effect cannot be effectively reduced by increasing the drift region depth.

(3) The transverse diffusion coefficient of the working gas is the determining factor that influences the extent of the anode wire modulation of the detector. A detector with working gas of $Ar/CH_4(90/10)$, $Ar/CO_2(90/10)$ or $Xe/CO_2(90/10)$ can get a nearly uniform position response when applying a simulated uniform X-ray irradiation. For detectors using $Ar/CO_2(70/30)$ and $Xe/CO_2(70/30)$, however, the anode wire modulation still cannot be eliminated. Considering the difference in the transverse electron diffusion coefficients of the gas mixtures shown in Fig. 2, we can deduce that if the average transverse diffusion coefficient can be kept larger than about 300 μm/cm at fields from 400 V/cm to 1100 V/cm, the anode wire modulation effect can be eliminated.

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