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A high pressure xenon gamma-ray spectrometer using a coplanar anode configuration

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Abstract

A new design of a high pressure xenon ionization chamber has been fabricated in an attempt to eliminate the problems associated with acoustical vibrations of the Frisch grid. The function of the traditional Frisch grid has been accomplished by employing a coplanar anode system capable of single polarity charge sensing. Two different detector designs have been fabricated using both cylindrical and parallel plate geometries. Each is filled with highly purified xenon gas at a pressure of approximately 57 atm. The designs of these new spectrometers and their measured characteristics will be presented.

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1. Introduction

High pressure xenon ionization chambers have been widely used for decades due to their high efficiency for stopping gamma rays, ease of construction, and stability in a variety of conditions [1,2]. Xenon as a detection medium is quite efficient due to its relatively high atomic number ($Z = 54$). Due to the relatively high ionization energy (21.9 eV/ion pair) detectors based on high pressure xenon can be operated over a wide range of ambient temperatures. However, these detectors tend to suffer from energy resolution degradation due, in part, to acoustical noise between the Frisch grid and the anode. The microphonic noise occurs as a result of movement of the grid caused by vibrations in the environment. Despite many advances in the design of these detectors, they have yet to attain an energy resolution close to the predicted statistical limit of approximately 0.5%.

Recent advances in semiconductor detector design have lead to the fabrication of coplanar anodes capable of performing single polarity charge sensing in the same manner as a Frisch grid [3,4]. In the case of CdZnTe and other semiconductors, this has lead to a significant improvement in the energy resolution since the generation of signal is no longer based on the movement of the easily-trapped holes.

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This same principle of coplanar anode design has now been applied to high pressure xenon detectors. By creating a dual anode system, it is possible to obtain single polarity charge sensing while removing the need for a grid, thus potentially eliminating the acoustical noise problem. A coplanar high pressure xenon detector has merits over semiconductors since it can be built arbitrarily large without concern of material defects.

2. Detector designs

Two different detector designs have been developed for this work. The first detector constructed was the helical detector, which consisted of two wires wound helically about a central core made of Macor ceramic. A schematic of the anode design is shown in Fig. 1. The pitch of the wires was 2 mm, the anode rod was 2.54 cm in diameter, and the cathode–anode separation was 5 cm with an active volume of approximately 735 cm^3 and a density of 0.5 $\mathrm{g/cm}^3$.

The second design used in this work is a simple, parallel plate chamber. This configuration was chosen because the resulting electric fields are much easier to characterize. It also eliminates the possibility of inductive coupling of the anodes as is theoretically possible with the helical design. The pressure vessel and gas purification technique used have been previously documented [5]. The active volume of this detector is approximately 59 cm^3.

The cathode–anode separation was chosen to be 3 cm so that, with a cathode bias of -6 kV, the resulting electric field would be 2 kV/cm. Fields of this strength are required to prevent significant trapping of electrons, a problem that must be minimized for good energy resolution [6].

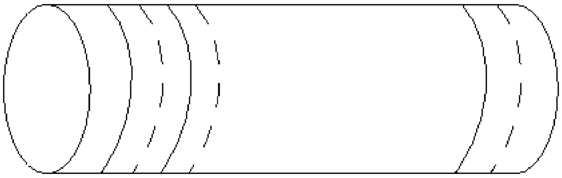

Fig. 1. Drawing of anode configuration of the helical detector. The solid and dashed lines represent two different wires wound about the ceramic core comprising the collecting and non-collecting anodes.

Significant effort was devoted to the optimization of the coplanar anode pattern. It has been shown that the normalized induced charge or weighting potential in a coplanar detector can vary as much as ±20% as a function of position [7]. This variation can lead to fluctuations in the energy resolution as a function of position, resulting in an overall degradation in the net resolution of the system. Based on the work done to optimize coplanar anodes for CdZnTe detectors, an anode was designed made of three electrodes: the collecting and non-collecting anodes and a peripheral electrode. The final design, shown in Fig. 2, illustrates that the sizes of the outer-most portions of each electrode vary in order to keep the weighting potential as symmetric as possible. The purpose of the peripheral electrode is to balance the weighting potentials of the two central anodes. The weighting potential for each anode was calculated with the Coulomb 3-D electrostatic simulation program and is shown in Fig. 3 [8]. Several different dimensions for the outer portions of the electrodes were examined to determine the dimensions that provided the smallest difference in weighting potentials

Fig. 2. Spiral pattern used for the planar HPXe detector. The outer electrode is the boundary electrode used to balance the weighting potential. The inner two spirals are the collecting and non-collecting anodes.

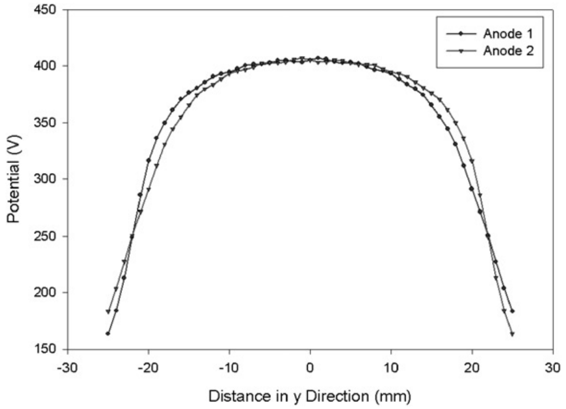

Fig. 3. The calculated weighting potential 4 mm below the anode surface with 1000 V applied to the anode of interest.

between anodes. Once the design of the coplanar anodes was finalized, it was constructed by metalizing a layer of gold onto an alumina ceramic surface.

3. Results

The helical detector was designed as a first attempt at a coplanar high pressure xenon detector. Unfortunately, there were various problems with the detector that prevented it from working in coplanar mode. The key problem was that it was not able to achieve a high enough potential difference between the anodes without sparking to collect all of the electrons on the collecting anode. When the pulse waveforms were analyzed, pulses were clear on the collecting anode. However, those on the non-collecting anode were frequently of the same polarity as the collecting anode, indicating charge sharing between the two anodes. The fact that the detector sparked at potentials less than that required for complete charge collection indicated that it would not function in coplanar mode and was the basis for the construction of the parallel plate detector.

The parallel plate detector was constructed to be more analogous to the coplanar anode semiconductor detectors. In this case, the weighting potential is linear and easily characterized analytically.

During biasing it was found that the detector sparked at biases greater than -4.5 kV, less than the required -6 kV for a field of 2 kV/cm. It was decided that the detector would operate at a bias of -4 kV. While this does not allow for the optimum electric field, it was hoped that the effects of electron trapping at this reduced field would not be overwhelming.

A series of pulse waveforms were obtained as the potential between the two anodes, ΔV, was increased. As ΔV was increased, it was observed that the pulses induced on the non-collecting anode gradually became opposite in polarity of the collecting anode, indicating that the detector was functioning in the coplanar mode. At a potential difference of $\Delta V = 240$ V, the pulses seen on the non-collecting anode were all opposite in polarity of the collecting anode, which is the expected characteristic of the coplanar operation. A sample of the coplanar pulses is shown in Fig. 4.

As ΔV was increased, it was observed that the baseline of the preamplifiers began to fluctuate. This fluctuation increased with ΔV until it was approximately ± 20 mV when ΔV was 240 V. It was not a function of radioactive source placement as the fluctuation was seen even when the source was not present. It was neither constant in

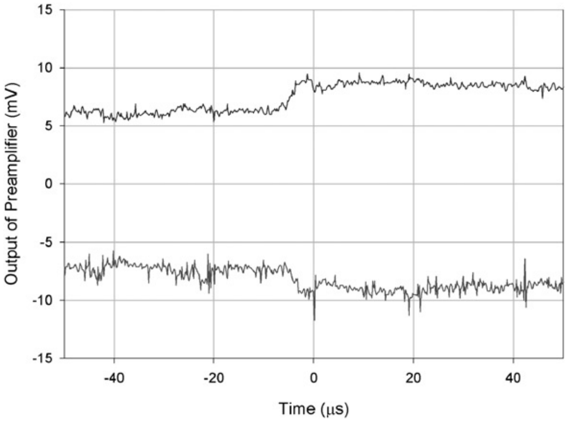

Fig. 4. Sample coplanar pulses for the parallel plate detector. The collecting anode (at the higher potential) is the upper waveform while the non-collecting anode (grounded electrode) is the lower waveform. The cathode bias was -4 kV and $\Delta V =$ 300 V. The shaping amplifier (not shown) was used as a trigger to collect these pulses.

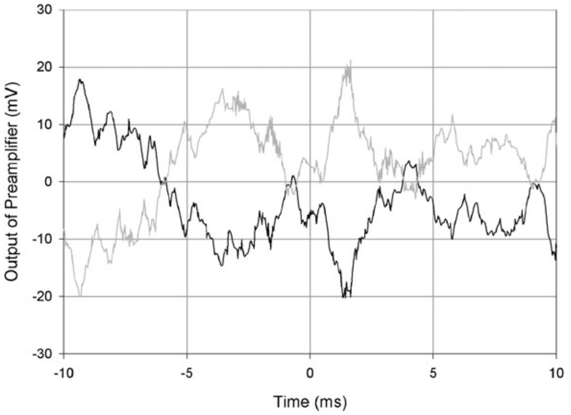

Fig. 5. Example of the baseline fluctuation problem for $\Delta V = 300$ V with no triggering.

amplitude nor frequency. An example of this fluctuation can be seen in Fig. 5. It is important to note that the fluctuation is of opposite polarity between the two anodes. This would indicate that the cause was most likely between the two anodes, a hypothesis supported by the fact that it was still seen with a cathode bias of 0 V while maintaining $\Delta V = 240$ V.

Effort was placed into shaping this fluctuation out both by varying the integration and differentiation shaping times. However, the time scale of the fluctuations relative to the pulses associated with gamma rays did not easily allow for that. When the two anode signals were subtracted and the subtracted pulses were shaped, the resulting spectrum was simply exponential in shape. This is because the pulses due to gamma-ray interactions occurred randomly relative to the baseline fluctuation. Since the fluctuation was opposite in phase, the difference between the two signals was twice that of the fluctuation. The pulses of gamma rays would be superimposed on the fluctuation and, since it could not be filtered by the shaping amplifier, the resulting spectrum was a random distribution from 0 mV to the full fluctuation of 40 mV with no photopeak.

Since it was shown in Fig. 4 that the coplanar operation was possible with this detector, emphasis was placed on eliminating the fluctuation. It was clear that there was a problem between the two anodes since the fluctuation was always opposite in polarity. In order to correct this problem, the detector pressure vessel was opened to determine if there was any damage. During this inspection, it was found that one of the anode wires was not properly connected. The wires for all of the electrodes are connected to a high-voltage feedthrough by a spot weld. The spot weld connection of one of the anodes failed, resulting in a poor connection to the electrode. When this weld was redone, the baseline fluctuation disappeared. The pressure vessel was filled and work has begun to obtain the coplanar pulses again and measure gamma-ray spectra.

4. Conclusions

The method of coplanar anodes to replace the Frisch grid in a high pressure xenon ionization chamber has been demonstrated to work. However, due to the problems of baseline fluctuation within the detector, it has not yet been possible to obtain a spectrum from these detectors. It is clear based on these results that the weighting potential of the detector needs to be carefully examined, especially in the case of non-linear fields such as those created in a cylindrical detector with a $1/r$ field. It is also evident that special consideration should be made on the choice of materials for the anode surface.

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