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Studies of anode blades for gas proportional detectors[1]

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Abstract

The use of a thin metal edge, or blade, to generate controlled electron multiplication in a gas has been studied. Measurements with X-rays have been made on assemblies of an anode blade and two adjacent cathodes to determine optimum operating parameters in gas proportional mode, with the goal of producing position sensitive detectors with good position resolution and high counting rate. Under specific conditions, energy resolution comparable to that from a wire proportional chamber can be achieved. The devices are very rugged and can be tailored to a curved geometry for the purposes of eliminating parallax error for small and large angle X-ray scattering experiments. The design of detectors suitable for use with synchrotron radiation, is discussed.

Keywords: Anode blade

1. Introduction

The intense photon beams from second and, particularly, third generation synchrotron sources require the utmost performance from position sensitive detectors in terms of position resolution, count rate and stability. As an outgrowth of investigations on microstrip gas chambers, our group has been studying electron multiplication properties in a gas along a metal edge, or blade. Similar techniques have been developed previously by other groups. These concentrated on operation in the limited streamer mode [1], or the gas proportional mode [2], but were not been developed specifically for synchrotron experiments. Our efforts have focussed on operation in the gas proportional mode, with emphasis on small electrode spacing to maximize count rate. Systematic studies are being carried out to optimize overall performance for synchrotron applications.

2. Experimental setup

A schematic of the test detector is shown in Fig. 1. The anode is steel shim stock, whose thickness (t) is 25 μm (unless specified otherwise), sandwiched between two cathodes, separated by a distance, d, using two fiberglass spacers. The spacers are recessed below the edge of the blade by about 1.8 mm (h) to prevent charge buildup. The useable length of the electrodes (into the diagram) is 6 cm. In this initial work we have used d = 2.4 mm

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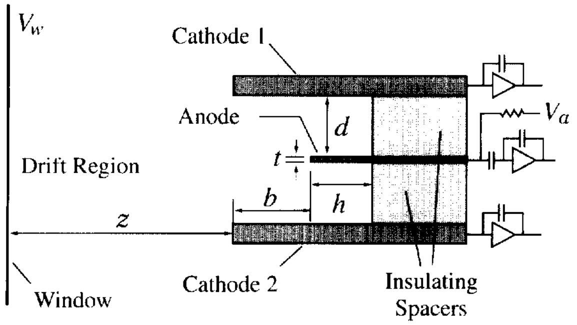

Fig. 1. A schematic of the test chamber cross-section.

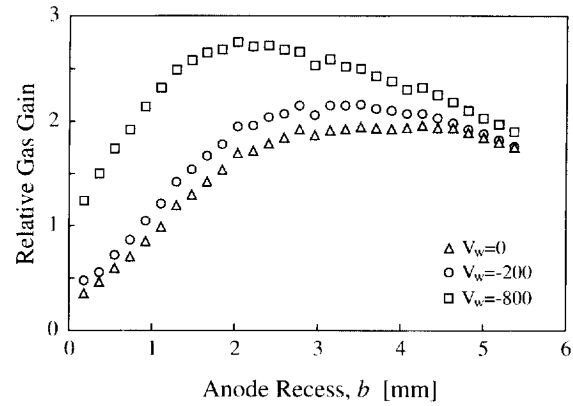

Fig. 2. Gas gain variation as a function of anode recess. A collimated X-ray beam was centered over the anode blade. $V_a = 2250$ V, $V_w = -200$ V.

(3/32 in), which provides a relatively short path for positive ions, created in an avalanche, to travel from the anode to cathode, and provides a footprint of cathode induced charge that conveniently permits the use of an interpolating cathode technique for position sensing. The anode is connected through a preamplifier and shaping amplifier to a PHA. The two cathodes are individually connected to their own electronic channels, whose outputs are analyzed on a dual parameter PHA. Results reported are taken with 1 μs delay line shaping amplifiers. The window to cathode distance, z, was maintained at about 1 cm, providing good detection efficiency for Cr K_α X-rays (5.41 keV) in a gas mixture of Ar/20%CO_2, with which all the measurements reported here were carried out. With the anode at positive bias and the cathodes at ground potential, a window voltage of $V_w = -200$ V generated a drift-field that was sufficient to transport electrons to the anode without loss.

3. Results and discussion

3.1. *Effect of anode recess*

In this set of measurements, the cathodes were fabricated, simply, from 254 μm thick steel shim stock. The recess, b, of the tip of the anode blade, with respect to the cathodes, influences the gas gain at a given anode voltage and the uniformity of the gain in the direction across the anode. It also affects the acceptance aperture in the drift region. The anode blade was tilted such that b changed from zero at one end to about 5.5 mm at the other end. This arrangement made it possible to study the dependence of anode gain on the magnitude of its recess, by simply scanning a collimated X-ray beam along the length of the blade. Fig. 2 shows the anode pulse height variation from these measurements. When the recess is less than the anode–cathode spacing, the gas gain increases as the recess increases. However, this trend stops and even reverses itself as the recess becomes larger than the anode–cathode spacing. The reversal is more evident with the presence of a higher drift field. This behavior is believed to be the result of diminishing influence of the drift field on the anode tip as it recesses more deeply into the shielding of the cathodes.

Gain variation across the anode blade was investigated by scanning a collimated beam at right angles to the blade direction. Fig. 3 demonstrates the influence of the anode recess on the gain uniformity across the blade, as well as the acceptance aperture in the drift region. A deeper recess improves the gain uniformity, but decreases the acceptance aperture. Many synchrotron experiments require an acceptance aperture of typically 10 mm in a one-dimensional detector. It is also desirable that the anode maintains a fairly uniform gain across this aperture. Since $b = 4$ mm satisfies both

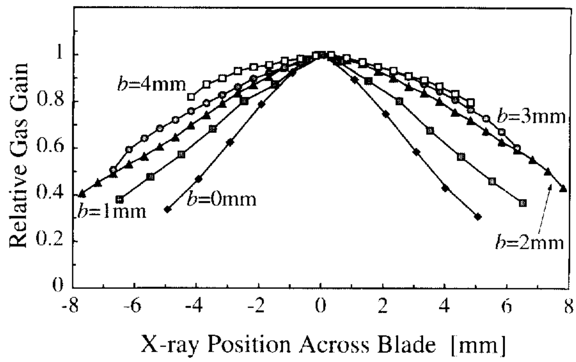

Fig. 3. Gas gain variations from scans of a collimated X-ray beam across the blade at different anode recesses. $V_a = 2250$ V, $V_w = -200$ V. The maximum pulse height of each scan has been normalized.

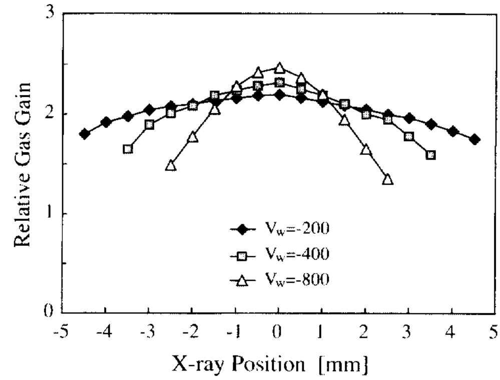

Fig. 4. Gas gain variations from scans of a collimated X-ray beam across the blade under different window bias voltages. Anode bias voltage remains at 2250 V.

of these criteria reasonably well, this value was selected to make further studies.

3.2. *Effect of drift field and blade thickness*

Pulse height measurements across the blade were made, at the position where $b = 4$ mm, as a function of drift field. The results, shown in Fig. 4, clearly illustrate that gain variation increases as the magnitude of the drift field increases. In general, the profile of the electric field near the tip of the anode varies from a strong, near cylindrical field in the middle, to a weak, near parallel plate field on the sides. Thus, the gas gain is dependent upon the incident angle of the electrons at the anode tip. Fig. 5a and b show the calculated electron drift lines from the drift region ending on the anode for $V_w = -200$ V and at a higher field ($V_w = -800$ V). At the lower drift field, field lines from a broad section of the drift region terminate, in a narrow angle, at the anode. In contrast, at the higher drift field, only lines from a restricted section of the drift region terminate at the anode, with a much wider angular spread, resulting in a larger gain variation. Fig. 4 also shows that the acceptance aperture of the detector is reduced as the drift field increases, in accord with the field line pattern in Fig. 5. Further investigations are in progress to study the role of the blade thickness and shape of tip in gain uniformity.

The uniformity of gain along the length of the blade was measured with a constant anode recess, $b = 4$ mm, along the full 55 mm length. A scan of the collimated X-ray beam revealed the gain was reasonably uniform, within $\pm 10\%$, over this length. The energy resolution is also quite good for a collimated X-ray beam, with a FWHM $\sim 25\%$ for 5.4 keV X-rays at 0.1 pC anode charge level. An anode charge level of 2 pC was achieved in this setup, which demonstrated its stability.

3.3. *Positive ion collection*

In a gas proportional chamber, the gas gain will decrease gradually as the signal rate increases due to the buildup of slow moving positive ions in the space surrounding the anode. Electrons from the drift region travel mostly along field lines that connect window and anode. However, diffusion and the spread of avalanche on the anode surface transfer some positive ions to field lines that terminate on the cathodes. This effect has been studied by uniform irradiation of a short length of the detector, and measuring the ratio of current in the entrance window to that of the anode as a function of anode recess, photon rate and drift field. The results, in Fig. 6, show that a lower drift field and deeper anode recess (forming a narrower path for electrons landing on the anode, thereby a greater diffusion effect), and a higher signal rate (higher

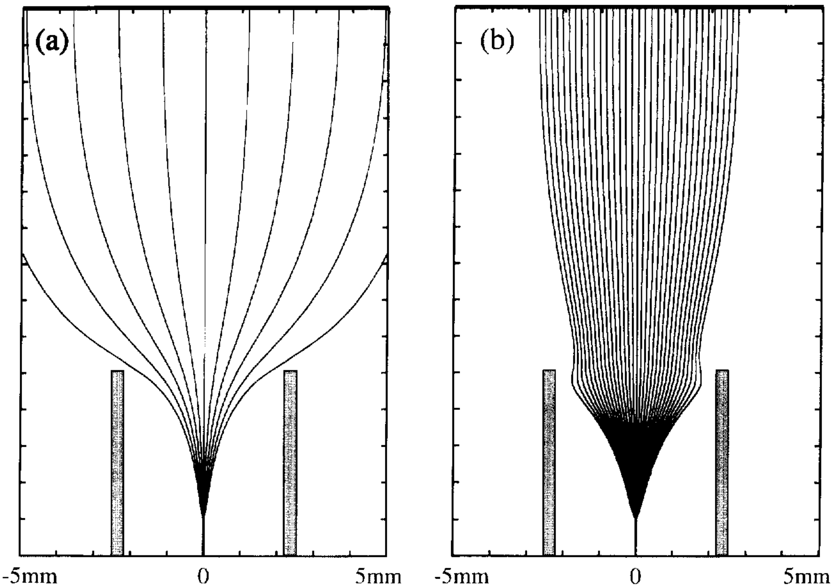

Fig. 5. Computer simulated electric field lines in the test setup with window bias voltage of (a) − 200 V and (b) − 800 V. Only those field lines that connect both the anode blade and the window are shown. Cathodes are grounded, $V_a = 2250$ V.

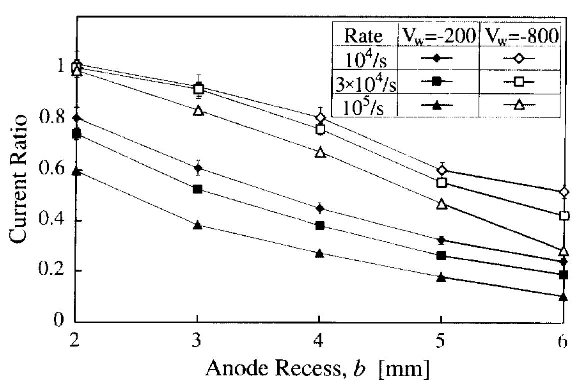

Fig. 6. Ratio of window current to anode current as a function of anode recess, photon rate and drift field. X-ray beam cross-section is about 1.3 mm (along blade) by 10 mm (across blade). The anode charge level was set at 0.1 pC throughout the measurement.

positive ion density, greater repulsive force) all contribute to a smaller window to anode current ratio. These results provide further justification for selecting an electrode arrangement in which $b > d$. Very recent measurements suggest that a smaller value of d decreases even further the window to anode current ratio.

3.4. *Anode avalanche angular localization*

In gas proportional detectors using induced cathode charge for position encoding, it is important to understand the effect of anode avalanche angular localization [3]. 2D histograms of the two cathode signals from uniform irradiation are shown in Fig. 7. Some interesting phenomena are revealed.

Clearly the induced charges on the two cathodes are not always equal. Instead of forming a narrow band along a 45° angle, the events forms a wedge shape with a finite opening angle, which reflects the degree of asymmetry in the two cathode induced charges. For this particular electrode geometry, the angle is dependent on the anode width, being significantly larger for the 76 μm blade. Further measurements have shown that the opening angle reduces at smaller shaping time (since the positive ions are all closer to the anode) and is largely independent of anode charge level.

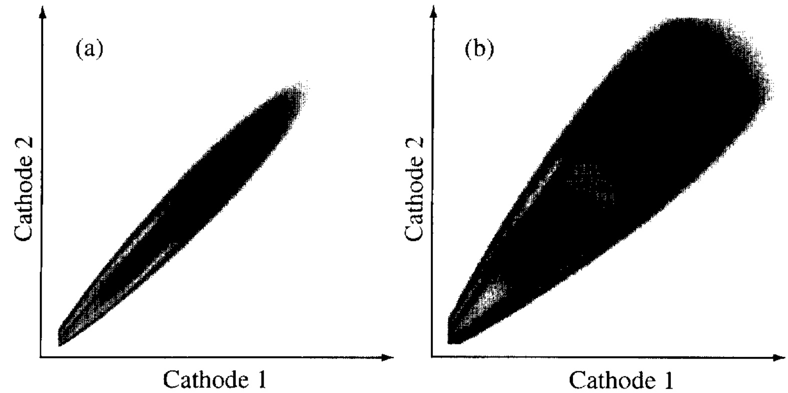

Fig. 7. 2D histograms of the induced charge correlation on the two cathodes: (a) 25 μm blade with V_w of − 200 V; (b) 76 μm blade with V_w of − 800 V. The anode charge level was set at about 0.1 pC for both measurements. b = 4 mm. Uniform irradiation over about 6 mm length across the anode. Intensity scale is logarithmic.

3.5. *Induced charge profile on the cathode*

A convenient way to extract avalanche position information from this electrode configuration is to use an interpolating technique to sample the induced cathode charge, as is common in various types of proportional wire chambers [4]. Using printed circuit board, a test cathode was fabricated that consisted of a continuous plane of copper except for two sets of strips that run along and across the blade length; this replaced one of the metal shim cathodes. The induced cathode charge profiles across and along the blade direction were measured by sampling the charge on these two sets of strips. The charge distribution along the blade, shown in Fig. 8, can be fitted closely to the empirical single parameter Gatti distribution [5]. The induced charge profile across the blade shows some level of asymmetry, at least in part because of asymmetry in the positive ion movement across the blade. These charge profiles provide the information required for designing position interpolating cathode structures with low differential non-linearity.

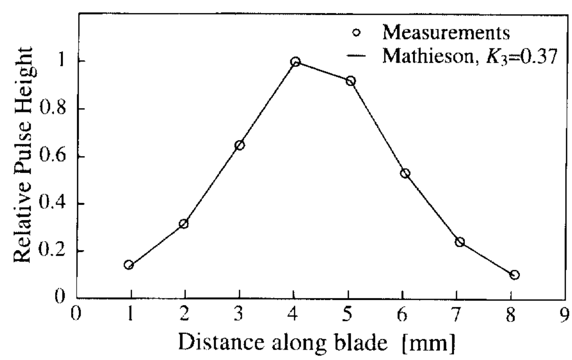

Fig. 8. Induced charge profile along the blade as measured by a set of 1 mm wide cathode strips.

4. Synchrotron applications

We are in the process of constructing 1D position sensitive X-ray detectors using blade anodes for large angle X-ray diffraction experiments at Brookhaven's National Synchrotron Light Source, utilizing the optimized electrode spacings studied in this work. In order to eliminate parallax errors at large diffraction angles, the anode blade and other electrodes are curved, as illustrated in Fig. 9, which shows an exploded view of one detector. It covers an angle of 45°, has an arc length of about 20 cm with a radius of curvature of 25 cm. The blade is fabricated from 25 μm steel sheet using electric discharge machining, and the two cathodes are made of printed circuit boards, with 128 copper strips running radially on each cathode facing the anode blade. Corresponding facing cathode strips are

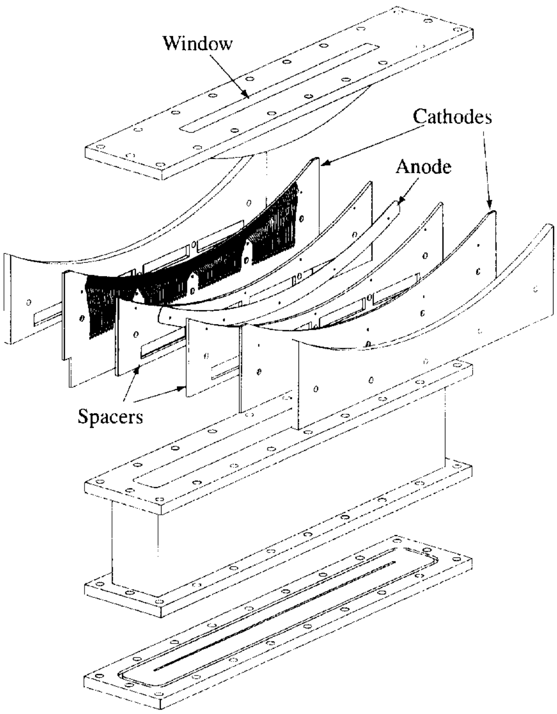

Fig. 9. An exploded view of a 1D curved blade detector assembly. Not shown in this diagram are additional electrodes to enhance the electron drift.

electrically connected together, each such pair being connected to a preamplifier and shaper. (Thus, virtually all the cathode charge is utilized for position encoding.) The amplifier outputs will be digitized by a set of free running ADCs, with position information determined by digital centroid finding electronics. This will be capable of decoding multiple simultaneous hits and providing a rate capability estimated to be several MHz.

Acknowledgements

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