Effect of Well Diameter upon MicroWell Detector Performance

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Abstract

MicroWell (MWD) detectors have been produced by laser micromachining of 125 μm thick Kapton™ polyimide foil. Wells produced with this technique have near-vertical sidewalls with less than 10° of slope. It is an ideal tool to produce MWD prototype arrays with different well diameters for an experimental determination of the optimum ratio of well diameter to substrate thickness. Arrays with four different well diameters (60, 100, 150, and 180 μm) were machined into 125 μm thick Kapton™ polyimide foil. Detectors with well diameters commensurate with the substrate thickness had better performance, with the best design being an array of 150 μm diameter wells on a 200 μm Cartesian grid. This design achieved a gas gain of 17,000 in a counting gas of 70% argon and 30% carbon dioxide. Other significant advantages of this design included good charge collection from the drift region and increased gas gain with higher drift fields.

I. INTRODUCTION

The introduction of the Microstrip Gas Ghamber (MSGC) in 1988 led to a widespread effort to produce micropatterned gas proportional counters using techniques developed for the microelctronics industry [1]. These detectors promise the traditional advantages of proportional chambers, such as intrinsic gain, low cost, and radiation hardness, packaged into element sizes commensurate with applications such as particle tracking and X-ray imaging. Many of these promised advantages are being realized in designs such as the GEM (Gas Electron Multiplier) [2], the MWD (MicroWell Detector) [3], the WELL [4], the Microgroove [5], and the CAT (Compteur a Trou) [6]. Operational experience with a wide variety of these detectors, included a systematic study of maximum gas gains, has recently been published [7].

Optimizing a detector design such as the MWD requires varying a design feature over a series of prototypes. Consider the simple picture of the MWD as a well with a uniform electric field, with an electron lens above the well. A drift electrode is located well above the cathode, defining an active region where electrons produced by ionizing radiation drift to the well. An example of an idealized MWD is shown in Figure 1, with a 100 μm diameter well in a 200 μm square unit cell. This plot of the potential distribution (color code) and electric field lines (red lines) was calculated with the OPERA/TOSCA electrostatic analysis package [8]. Symmetric boundary conditions were imposed, modeling the effects of the other MWD elements on a regular Cartesian grid. Electric field lines are generated with the "flux tube" option of TOSCA. A bias voltage of –600V was applied to the perforated cathode, with a drift field of 3 kV/cm and a grounded anode. One important design variable is the well diameter, expressed as the aspect ratio (defined as the cathode-side well opening divided by the substrate thickness). An aspect ratio that is too small distorts the lens section of the field, leading to poor collection from the drift region. An aspect ratio that is too large will not concentrate the field in the well sufficiently for good gas gain. In addition, there will be some maximum voltage determined by the breakdown voltage along the wall of the well. Optimizing the gas gain for a given detector substrate becomes a question of optimizing the geometry, within the limits of a particular fabrication technology.

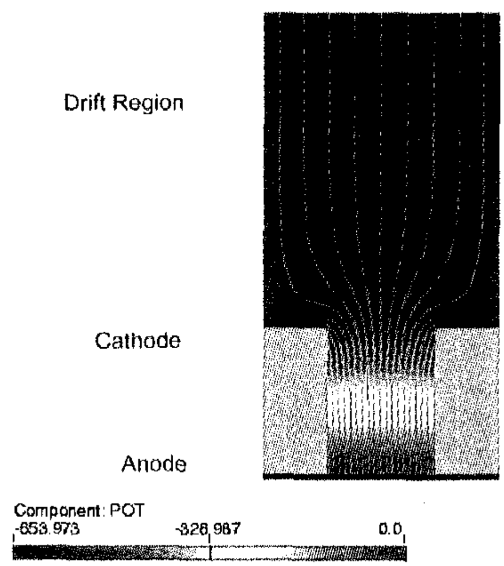

Figure 1: Electrostatic field calculation of a typical MWD, with 100 μm diameter wells on a 200 μm Cartesian grid.

One major advantage of the GEM, WELL, Microgroove, CAT, and MWD designs is that these designs may be

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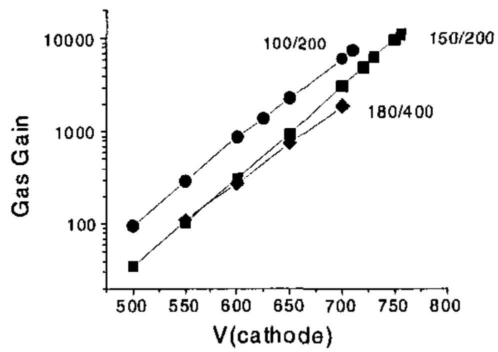

Figure 5: Measured gas gains for the tested MWD arrays for a –1.5 kV/cm drift field in a 70% argon/30% carbon dioxide gas mixture.

Comparative measurements of the gas gain for these three designs are shown in Figure 5. All these data were acquired at a relatively low drift field of –1.5 kV/cm, corresponding to –1 kV bias voltage on the drift electrode. These gas gains are measured after the detector has been operated at its respective bias voltage for approximately 30 minutes. This procedure more nearly approximates the "operational" conditions a detector would be expected to satisfy in an application. In addition, delaying the measurement of the gas gain allows the MWD array to charge. Charging typically resulted in a reversible gain drop of approximately 10-20%. The long-term charging is shown in Figure 6 for the 150/200 MWD operated at an initial gas gain of 3600. The X-ray rate was low, being only 10^4 Hz over the 3.6 cm^2 area of the detector. Similar charging effects were observed at higher gas gains.

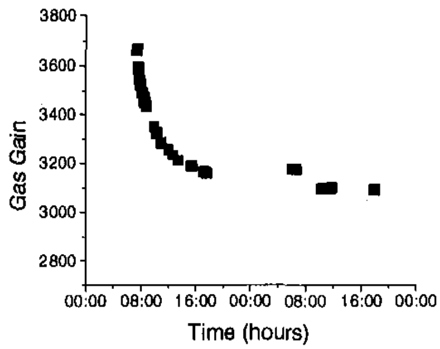

Figure 6: Charging of the 150/200 MWD arrays for a –1.5 kV/cm drift field in a 70% argon/30% carbon dioxide gas mixture.

The collection efficiency of the 150/200 MWD was very good (Figure 7), presumably due to the large open area (44%) of the wells. Note that full collection occurs even at relatively low applied voltages, which may allow a 150/200 MWD to be operated in a fast gated mode. In this mode, sending a fast, high voltage pulse to the drift electrode would turn the detector on. A similar trend was observed in the 100/200 MWD array, although higher voltages were required to fully collect electrons from the drift region.

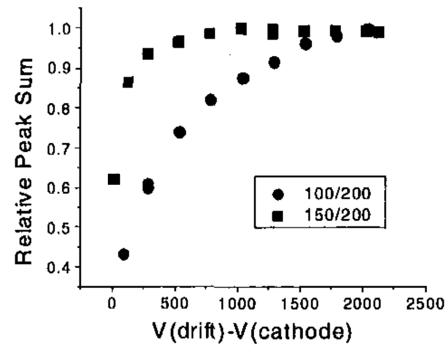

Figure 7: Variation of the collection efficiency with drift voltage for the 100/200 and 150/200 MWD arrays

An unexpected result was that the gas gain of the 150/200 design in the 70% argon /30% carbon dioxide gas mixture increased with drift field until the drift electrode would spark (Figure 8). This behavior is not seen in the 100/200 design, for example, which has a maximum and then decreases. This increase in gain with drift field is likely due to the 150/200 MWD having a large fraction (44%) of its anode open to the drift field. In addition to reducing the area of the cathode that can sink field lines, the electrostatic field lens extends further into the drift region.

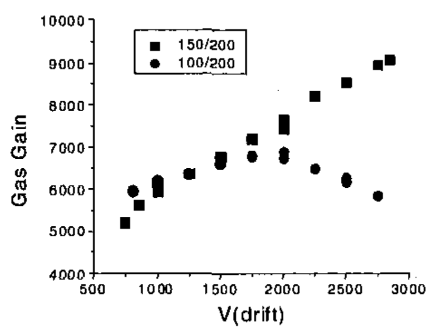

Figure 8: Variation of the gas gain with drift voltage.

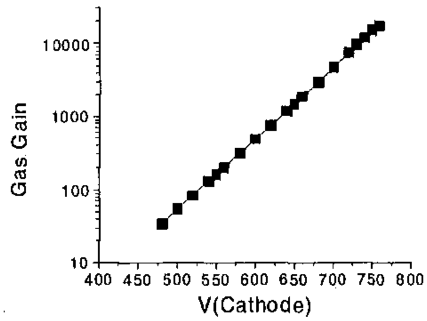

Figure 9: Gas gain of the 150/200 MWD, measured under ideal conditions.

An interesting feature of these measurements is that the maximum gas gain of the 150/200 design is much higher at higher drift field (Figure 9). During this test, the drift field was 3 kV/cm and the gas gain was measured immediately after ramping the cathode bias voltage. Under these circumstances, the maximum gas gain was 17,000. Charging would be expected to reduce this by approximately 15%. A sample spectrum at 17,000 gas gain and 1.5 μ sec shaping time is shown in Figure 10. The FWHM (full-width at half maximum) of the photopeak is 25%, even at this high gain. In general, the FWHM at lower gas gains (e.g. 10,000 or lower) was less than 20%. Spectra quality is an important test of MWD quality. Wells with differing gain result in widening of the photopeak and filling the area between the photopeak and the fluorescence peak at 3 keV. The small peak at approximately 1.3 keV is likely due to fluorescence X-rays emitted from the thick aluminum foil of the drift electrode.

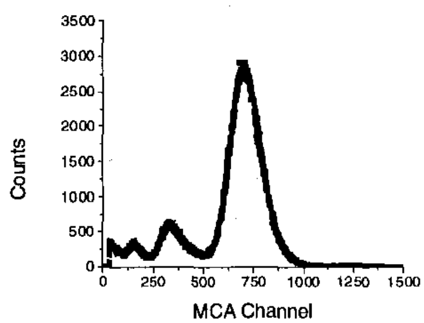

Figure 10: Detector response to 5.9 keV X-rays at 17,000 gas gain.

V. Future Plans

Testing the 150/400 MWD is required to finish this study of aspect ratio and its effect upon detector performance. With those test results, it will be possible to determine if the good performance of the 150/200 MWD is due to the aspect ratio, pitch, or combination of the two. Extension of the 150/200 design to the GEM design is a high priority, due to the open area of this MWD array. The combination of open structure and cylindrical well should result in a GEM with excellent electron transmission and no charging dependent gain shifts.

VI. Acknowledgements

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