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Using pulse shape analysis to improve the position resolution of a resistive anode microchannel plate detector

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ABSTRACT

Digital signal processing techniques were employed to investigate the joint use of charge division and risetime analyses for the resistive anode (RA) coupled to a microchannel plate detector (MCP). In contrast to the typical approach of using the relative charge at each corner of the RA, this joint approach results in a significantly improved position resolution. A conventional charge division analysis utilizing analog signal processing provides a measured position resolution of 170 μm (FWHM). By using the correlation between risetime and position we were able to obtain a measured resolution of 92 μm (FWHM), corresponding to an intrinsic resolution of 64 μm (FWHM) for a single Z-stack MCP detector.

1. Introduction

Position-sensitive microchannel plate (MCP) detectors are a powerful and widely used tool in imaging of electrons, photons and ions [1]. Since their inception in the late 1950s [2], they have been used in a variety of applications ranging from ion–molecule reaction scattering experiments [3] to fast neutron radiography [4]. In this detector, an incident electron, photon, or ion ejects an electron from the micorchannel plate. The microchannel plate acts as a continuous dynode electron multiplier with millions of independent channels providing a typical amplification of $\approx 10^3$. Two MCP plates (chevron configuration) or three plates (Z-stack configuration) can be stacked to achieve higher gains. Different methods exist for measuring the position of the electron cloud exiting the microchannel plate thus determining the position of the incident particle. The principal techniques are: multi-anode [5], helical delay line [6], cross-strip anode [7], induced signal [8], and resistive anode [9]. The resistive anode (RA) technique is particularly appealing for its simplicity. The electron cloud emanating from the MCP stack is incident on a two-dimensional resistive sheet. Readout of the charge at the four corners of the sheet provides a measure of position of the incident particle *via* charge centroiding. Utilizing this simple approach a position resolution of 134 μm (FWHM) for a chevron configuration has been achieved [10]. Although for many application a chevron stack of two microchannel plates provides sufficient amplification, the detection of low-intensity signals near the one electron limit requires configurations involving three (Z-stack) or more MCPs. For a Z-stack configuration the best reported resolution is 100–200 μm (FWHM) [11]. By use of more complex MCP stack configurations and through the use of retarding potentials, position resolution as good as 50 μm (FWHM) has been realized [12–14]. In this work, we investigate the use of pulse shape analysis to improve the position resolution obtained with a simple Z-stack MCP-RA detector.

2. Experimental setup

Depicted in Fig. 1 is the experimental setup used to determine the position resolution of the MCP-RA detector. Alpha particles from a ^{241}Am radioactive source (**A**) are emitted towards a secondary electron emission foil (**C**). Electrons are emitted by the passage of an α particle through the 1.5 μm thick aluminized mylar foil. Ejected electrons are accelerated to an energy of ≈1.3 keV by the potential difference between the aluminized foil and a wire grid (**D**). The electrons then pass through slits in a stainless steel mask (**E**) directly in front of the microchannel plate stack (**F**) before impinging on the front surface of the MCP-RA detector. The precision mask, fabricated by laser micro-machining [15], has 10 slits each measuring 100 μm by 7620 μm and spaced by either 4.2 or 4.5 mm apart. Electrons that pass through slits in the mask are amplified by the Z-stack MCP and detected on a resistive anode (**G**). Alpha particles traverse the aluminized mylar foil and are detected by a fast scintillator/photomultiplier tube (PMT) assembly (**B**) placed directly behind the aluminized foil. The MCP used was a standard Z-stack (APD 3 40/12/10/12 D 60:1) with 10 μm diameter microchannels provided by Photonis USA [16] which was

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coupled to a 40 mm diameter RA from Quantar Technology Inc. [17]. Further details of the experimental setup can be found in Ref. [18].

The entire assembly presented in Fig. 1 is housed in a vacuum chamber that is evacuated to a pressure of 4×10^{-8} torr. The microchannel plates were biased to a voltage of +3139 V using a ISEG NHQ224M low-noise, high voltage power supply (HVPS). The RA was biased to +3284 V, also using a ISEG NHQ224M HVPS. The secondary electron emission foil and photomultiplier tube were biased to voltages of −300 V and −1800 V using HK 5900 and Bertan 362 HVPS respectively. Signals detected at each corner of the resistive anode were amplified by a high quality charge sensitive amplifier (CSA) [19] operated in vacuum. The four CSAs are situated approximately 13 cm from the MCP-RA to minimize cable capacitance. The output signals from the CSAs are coupled to a 250 MS/s digitizer (Caen DT5720B) [20]. Readout of the digitizer is triggered by the coincidence of a fast signal extracted from the back of the MCP detector and the PMT. The digitizer is readout by a standard PC and waveforms are recorded for subsequent analysis. For the analysis subsequently described the waveforms associated with a total of 260,000 coincident triggers were recorded.

Indicated in Fig. 2 is the reverse pincushion shape of the resistive anode along with the circular outline of the 40 mm diameter MCP detector. Superimposed on the RA is the image of the 10 slits provided by the stainless steel mask. The four corners of the MCP-RA are designated Q_1, Q_2, Q_3, and Q_4 as evident in Fig. 2. Along with the relative position of the MCP-RA and mask, shown in Fig. 2 are the signals measured at two locations on the RA. One set of digitized traces (red solid line) correspond to an electron cloud incident at the bottom slit of the RA as indicated by the red, solid square. The other set of traces (black dashed-dot-line) correspond to a position close to the center of the RA as indicated by the black, solid circle. The waveforms associated with these two positions are markedly different. When the position signal arises from the center of the detector all the waveforms are essentially the same as is expected. However, when the signal originates at the bottom of the RA, while the two corners nearest the signal exhibit a fast risetime followed by an exponential decay, the upper corners of the RA manifest a significantly slower risetime. This risetime, dictated by the RC of the resistive anode thus provides a measure of the particle's position. Motivated by prior work which utilized the risetime of signals in resistive silicon detectors to achieve position sensitivity in one dimension [21], we elected to characterize the RA waveforms by their risetime. The risetime (RT) of each signal was defined as the time required for the signal to go from 10% to 90% of its maximum value. As the slits in the mask are oriented to probe the *Y* dimension of the RA, for the remainder of this work we focus on the position information in that dimension.

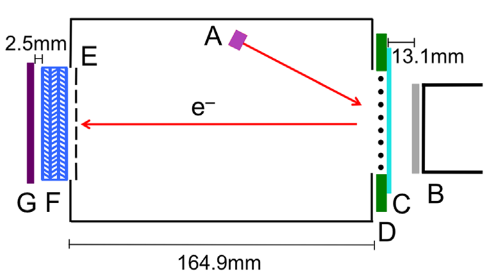

Fig. 1. Experimental setup used to measure the position resolution of the Z-stack MCP-RA detector [18]. See text for details.

3. Signal risetime analysis

Signals obtained from the CAEN digitizer are processed through a series of mathematical operations using a standard C++ code calling ROOT [22] libraries. In the present investigation the sampling resolution is 4 ns since the digitizer used has a sampling frequency of 250 MS/s. The obtained signals are corrected for the DC offset and gains for different channels for CSA's on an event-by-event basis.

Presented in Fig. 3 is the correlation between the risetime observed for signals at the two bottom corners if the RA namely Q_3 and Q_4. Given the exponential dependence of the signal amplitude on the RC of the resistive anode, the correlation is examined on a logarithmic scale. Individual slits are clearly evident in Fig. 3 with low numbered slits exhibiting shorter risetimes and higher numbered slits associated with longer risetimes. An overall linear dependence between $\log(RT_{Q3})$ and $\log(RT_{Q4})$ is observed as one moves from the bottom of the RA (s0) to the top (s9). Interestingly, a large jump in risetime is observed between slit 5 (s5) and slit 6 (s6), indicating a high sensitivity of the risetime to position in the center of the detector. Moreover, these two slits, in contrast to the other slits manifest a broad range of risetimes in at least one of the two risetimes. Electrons associated with these slits often do not show a strong correlation between the risetime of Q_3 and the

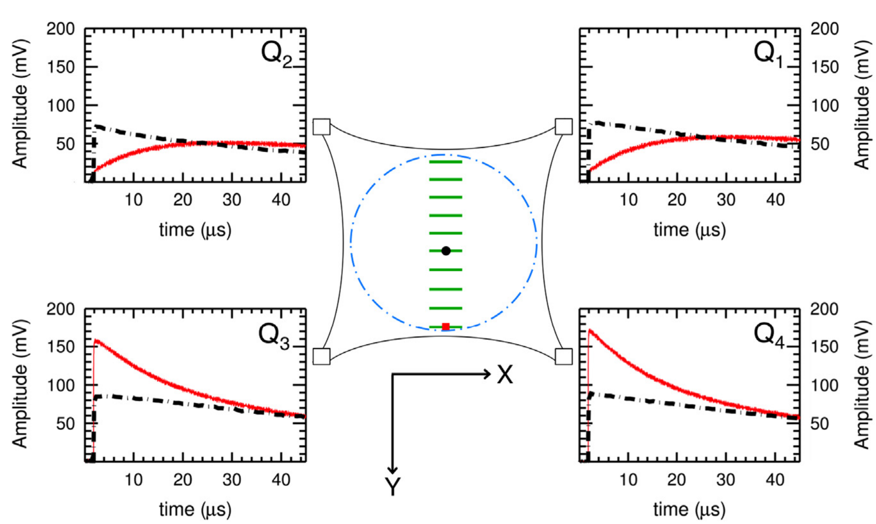

Fig. 2. Schematic of the RA along with the outline of the 40 mm diameter MCP and slits in the stainless steel mask. Pulse shapes associated with the electron cloud incident on two locations of the RA are also shown. Slit 0 (s0) corresponds to the bottom slit and slit 9 (s9) to the topmost slit. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)