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Achieving high spatial resolution using a microchannel plate detector with an economic and scalable approach

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ABSTRACT

A second generation position-sensitive microchannel plate detector using the induced signal approach has been realized. This detector is presently capable of measuring the incident position of electrons, photons, or ions. To assess the spatial resolution, the masked detector was illuminated by electrons. The initial, measured spatial resolution of 276 μm FWHM was improved by requiring a minimum signal amplitude on the anode and by employing digital signal processing techniques. The resulting measured spatial resolution of 119 μm FWHM corresponds to an intrinsic resolution of 98 μm FWHM when the effect of the finite slit width is de-convoluted. This measurement is a substantial improvement from the last reported spatial resolution of 466 μm FWHM using the induced signal approach. To understand the factors that limit the measured resolution, the performance of the detector is simulated.

1. Introduction

Microchannel plates (MCPs) are a powerful and widely used amplifier in imaging detectors due to their: high gain, sub-nanosecond time response, low power consumption, and stable operation in magnetic fields. MCPs are particularly useful as they are sensitive to a variety of particles including: electrons, ions, UV radiation, X-rays, slow neutrons, and fast neutrons [1–3]. Since their inception in the late 1950's [4], position-sensitive MCP detectors have been used in several applications including but not limited to: distance-of-flight mass spectrometry [5], neutron radiography [2,3], time-of-flight positron emission tomography [6], and beam imaging at radioactive beam facilities [7,8]. Different methods exist to extract the position of an incident particle via measurement of the electron cloud emanating from an MCP including: multi-strip anode [9], helical delay line [10,11], cross-strip anode [12], sense wires [13,14], resistive anode [15–17], and Medipix2/Timepix CMOS detector [3,18].

The induced signal approach is inherently different from other technologies, as the electron cloud emanating from an MCP is sensed rather than collected. This inherent difference means that the signal amplitude is ~10 times smaller than in the direct collection of the electrons. Nonetheless, the unique induced signal shape compensates for this reduced signal amplitude. The state-of-art in position-sensitive MCP technology is the Medipix2/Timepix CMOS readout, which can achieve from 15 to 55 μm FWHM spatial resolution, but is fairly expensive and has a small area (14 × 14 mm^2 per chip) [3]. To realize a larger sensor at low cost, a resistive anode approach is often used [15]. However, to achieve 50 μm FWHM spatial resolution with a resistive anode requires the use of complex MCP arrangements and retarding potentials [19–21]. Moreover, this approach is limited to count rates lower than 100 kHz due to the large resistance of the anode and suffers from non-negligible image distortions at the edges.

While both the Medipix2/Timepix and resistive anode rely on charge integration to measure the position of the incident particle, some of the most exciting advances in electronics are being made in the domain of high speed sampling and processing of signals. We therefore opted to investigate the limit of position resolution that could be achieved with high speed digital sampling of the induced signals. In the present work, we demonstrate that the induced signal approach provides a low cost alternative with competitive spatial resolution. The low cost of this approach makes the coverage of large areas feasible by using multiple detectors each capable of sustaining a high rate. As the detection of a single electron represents the ultimate in sensitivity, we utilize electrons to establish the position resolution of the induced signal approach. In this article we describe the next generation of a MCP sense wire (MCP-SW) detector that encodes position using a delay line readout. This delay line approach has been successfully employed at rates up

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to 10 MHz [22]. Optimization of the spatial resolution of this detector and simulations to understand the factors limiting the measured spatial resolution are described.

2. Experimental setup

The overall concept for the induced signal approach is illustrated in Fig. 1. An electron of sufficient energy impinges on the front of a microchannel plate and ejects an initial electron. This electron is amplified by a MCP Z-stack to an electron cloud consisting of 1×10^7 – 1×10^8 electrons. This electron cloud is accelerated past a sense wire harp, which consists of parallel wires mounted on a printed circuit board (PCB). The induced signals are inherently bipolar, where the negative and positive lobes of the induced signal correspond to the approach and recession of the electron cloud relative to the sense wires respectively. The zero-crossing point in the induced signal is the time at which the centroid of the electron cloud passes the wire harp. As indicated in Fig. 1, the electron cloud sensed by the wires propagates to the delay line where the signal splits. The time difference between the two signals arriving at the ends of the delay line is related to the position of the electron cloud. When the electron cloud is closer to the top of the detector, as indicated in Fig. 1, the arrival of the Y_{up} signal precedes that of the Y_{down} signal. Consequently, the Y_{up} signal is less attenuated and experiences less dispersion in the delay line as compared to Y_{down}. After passing the wire harp, the electron cloud is collected on a stainless steel anode. This metal anode preserves the excellent timing properties associated with non-position sensitive MCPs, and will be used as a reference time in the subsequent analysis.

To realize the induced signal concept described above, a PCB was fabricated. This sense wire board has an outer dimension of $\sim 8 \times 12$ cm^2 with a 50×50 mm^2 cutout. Across this cutout, 50 gold-plated tungsten wires with a diameter of 25 μm are strung with a 1 mm pitch using standard wire winding techniques. To efficiently read out this sense wire harp, a delay line is utilized thus minimizing the number of signals required to provide spatial information. The delay line consists of a continuous 7771 mm long trace on a 10 layer Rogers 4350 PCB with ~ 1.14 ns/tap. The width of the trace was chosen to be 0.122 mm to maintain 50 Ω impedance. Construction of the delay line with a high quality PCB material, such as Rogers 4350, is essential to minimize signal degradation. In contrast to the first generation detector [13], this MCP-SW detector decouples the sense wire board from the delay line board. This decoupling makes the detector more compact as shown in Fig. 2. Moreover, separating the delay line onto an independent PCB facilitates the efficient testing and implementation of different delay line designs. In addition, it allows the use of two delay boards to read out even and odd wires independently. In the following work, although two delay boards were connected to the sense wire plane due to limited number of digitizer channels available, only the signals from the even numbered wires were acquired and analyzed.

Depicted in Fig. 3 is the experimental setup used to determine the spatial resolution of the MCP-SW detector. Alpha particles from a ^{241}Am radioactive source impinge on a secondary electron-emission foil. Passage of an α-particle through the 1.5 μm thick aluminized, mylar foil results in the ejection of electrons. Alpha particles that traverse the aluminized, mylar foil are detected by a fast scintillator/photomultiplier tube (PMT) assembly placed directly behind the aluminized foil. Typically, ~6 electrons are ejected from the foil [7,23]. The ejected electrons are accelerated to an energy of ≈1 keV before drifting in a field free region for 16 cm and illuminating a stainless steel mask. The mask is mounted directly to the entrance MCP bias ring, which is 1 mm upstream from the MCP active area. The precision mask, fabricated by laser micro-machining [24], has ten slits each measuring 50 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 MCP stack and are subsequently detected by the sense wire harp. The MCP used was a standard Z-stack MCP (APD 3 40/6/5/12 D 60:1) with 5 μm diameter microchannels [25].

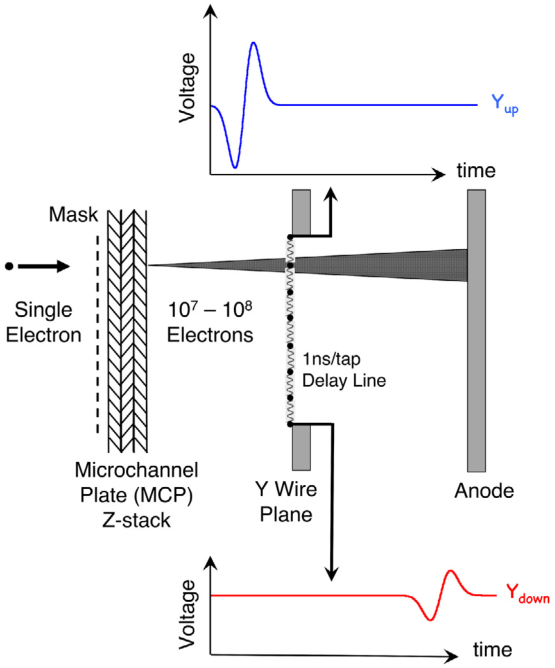

Fig. 1. (Color online) Cartoon illustrating the concept used in the induced signal MCP-SW detector.

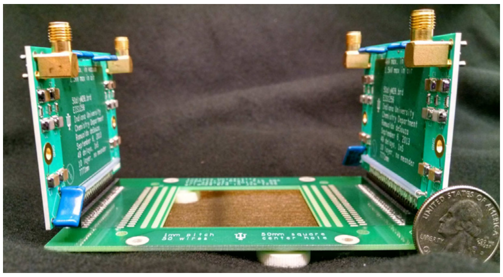

Fig. 2. (Color online) Photograph of the sense wire board coupled to delay line boards. Either a single delay board can be used to readout all fifty wires or two delay boards can be utilized to read out the even and odd wires independently.

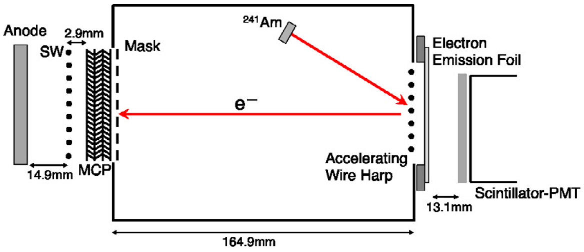

Fig. 3. (Color online) Experimental setup used to test the position sensitivity of the MCP-SW detector.

The entire assembly presented in Fig. 3 is housed in a vacuum chamber that is evacuated to a pressure of 4×10^{-8} torr. The entrance of the MCP stack was held at ground, while the MCP exit and sense wires (SW) were biased to potentials of +2528 V and +2755 V respectively. Both MCP and sense wires were biased using a ISEG NHQ224M low-noise, high voltage power supply (HVPS). The anode was biased to +2805 V using a ISEG NHQ226L HVPS. The secondary electron-emission foil and PMT (Burle 8575) were biased to voltages of −1000 V and −1800 V using a HK 5900 and Bertan 362 HVPS respectively. The signals arriving at either end of the delay line are designated Y_{up} and