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Readout for a large area neutron sensitive microchannel plate detector

Yiming Wang [a,b], Yigang Yang [a,b,*], Xuewu Wang [a,b], Yuanjing Li [a,b]

[a] *Department of Engineering Physics, Tsinghua University, Beijing, PR China*
[b] *Key Laboratory of Particle & Radiation Imaging, Tsinghua University, Ministry of Education, Beijing, PR China*

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ABSTRACT

A neutron sensitive microchannel plate (MCP) detector was developed for neutron imaging on the beamline of a compact pulsed hadron source (CPHS). The detector was set up with a Wedge-and-Strip Anode (WSA) and a delay line anode readout to compare the spatial resolution and throughput with these two anodes. Tests show that the WSA readout is suitable for small area imaging with a spatial resolution of 200 μm with low energy X-rays in a 50 mm diameter MCP–WSA assembly. However, the spatial resolution deteriorated to ~2 mm in a 106 mm diameter MCP–WSA assembly because the noise caused by the parasitic capacitance is 10 times larger in the larger assembly than in the 50 mm diameter assembly. A 120 mm by 120 mm delay line anode was then used for the 106 mm MCP readout. The spatial resolution was evaluated for various voltages applied to the MCP V-stack, various readout voltages and various distances between the MCP V-stack rear face and the delay line. The delay line readout had resolutions of 65.6 μm in the x direction and 63.7 μm in the y direction and the throughput was greater than 600 kcps. The MCP was then used to acquire a neutron image of an USAF1951 Gd-mask.

1. Introduction

Neutron sensitive microchannel plates (MCPs), which contain high cross-section neutron absorption nuclides, have been used by various researchers [1–6] for neutron detection with high detection efficiencies, high spatial resolutions and high throughput. A neutron imaging detector was developed for the beamline of the compact pulsed hadron source (CPHS) at Tsinghua University, which first produced neutrons in 2013, using a self-designed neutron sensitive MCP [7]. The performance of the neutron sensitive MCP detector was evaluated with two readout anodes. A Wedge-and-Strip Anode (WSA) [8] and a delay line anode [9,10] were evaluated to investigate their suitability for large area neutron imaging.

2. System overview

A schematic diagram of the neutron sensitive MCP detector is shown in Fig. 1. 3 mol% $^{nat}Gd_2O_3$ was doped into the glass of the normal MCP to form the neutron sensitive MCP which is the upper MCP in Fig. 1. The internal conversion and auger electrons after the $^{155,157}Gd(n,\gamma)^{156,158}Gd$ reaction induce the ionization and an avalanche process in the pores of the neutron sensitive MCP and the normal MCP, which is the lower MCP in Fig. 1, when a high voltage is applied to the "$MCP_{neutron}$–MCP_{normal}" V-stack to provide the necessary electric field to accelerate the secondary electrons emitted from the pore surfaces. The readout anode was placed under the normal MCP to collect the multiplied electrons. The electronics (not shown in Fig. 1) collect the signals from the electrons and extract the spatial and temporal information of the incident neutron. WSA and delay line readouts are compared in this paper.

3. The WSA readout

Fig. 2 shows how the multiplied electrons are extracted from the pores of the normal MCP and collected by the WSA anode. The different shapes of the three sub-anodes, the wedge, strip and zigzag shapes, enable the WSA to determine the position of the incident radiation from the fractions of the charges each of them receive. Eqs. (1) and (2) show how the charge fractions received by the strip and wedge give the position information along the x and y directions.

$$x = \frac{Q_S}{Q_W + Q_S + Q_Z} \quad (1)$$

$$y = \frac{Q_W}{Q_W + Q_S + Q_Z} \quad (2)$$

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[*] Corresponding author at: Key Laboratory of Particle & Radiation Imaging, Tsinghua University, Ministry of Education, Beijing, PR China
E-mail address: yangyigang@mail.tsinghua.edu.cn (Y. Yang).

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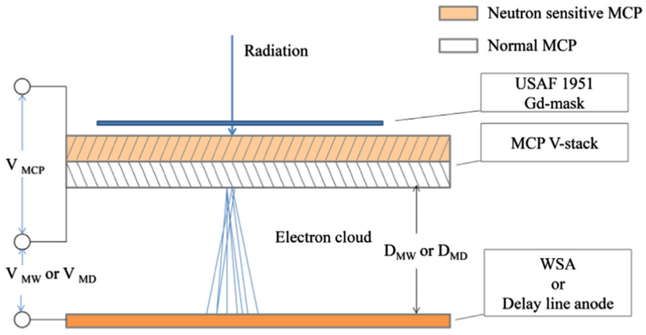

Fig. 1. Assembly of the MCP V-stack and readout anode.

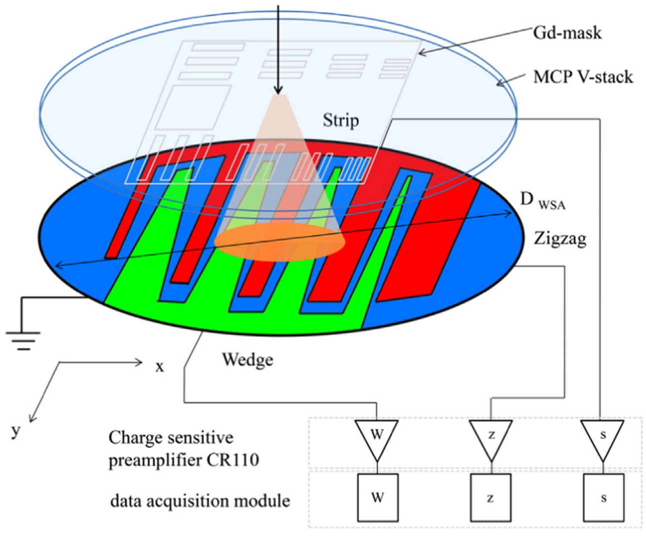

Fig. 2. MCP detector with the WSA anode.

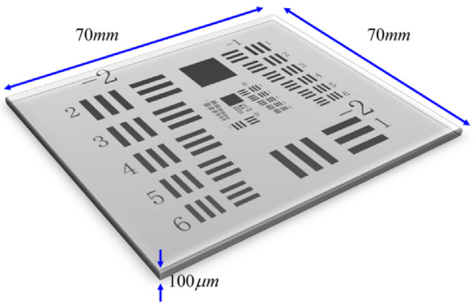

Fig. 3. USAF 1951 Gd-mask used for the X-ray and neutron imaging.

where Q_W, Q_S and Q_Z are the charges collected by the wedge, strip and zigzag sub-anodes, respectively. The charges collected by the wedge, strip and zigzag sub-anodes must be accurately measured to calculate the position of the incident radiation from Eqs. (1) and (2). A charge sensitive preamplifier, CR110 from the FAST ComTec Company [11], is used with each sub-anode to eliminate the ballistic deficit effect. An earlier 50 mm diameter neutron sensitive MCP detector had a spatial resolution of 200 μm [12,13].

The spatial resolution was then worse with a 106 mm diameter neutron sensitive MCP (Fig. 3). Fig. 4 shows a 15 kV X-ray image of the USAF 1951 Gd-mask shown in Fig. 3 acquired using the 106 mm MCP V-stack-WSA-CR110 assembly. The spatial resolution of this image is worse than the 200 μm resolution with the 50 mm MCP. The reduced spatial resolution is mainly caused by noise of the charge sensitive preamplifier related to the capacitance of the WSA anode. As the MCP diameter increases, the area of the WSA anode also increases. Since the lengths of the wedge, strip and zigzag sub-anodes are proportional to D_{WSA}^2, the parasitic capacitance is also proportional to D_{WSA}^2; hence, the equivalent noise charge (ENC) of the preamplifier is

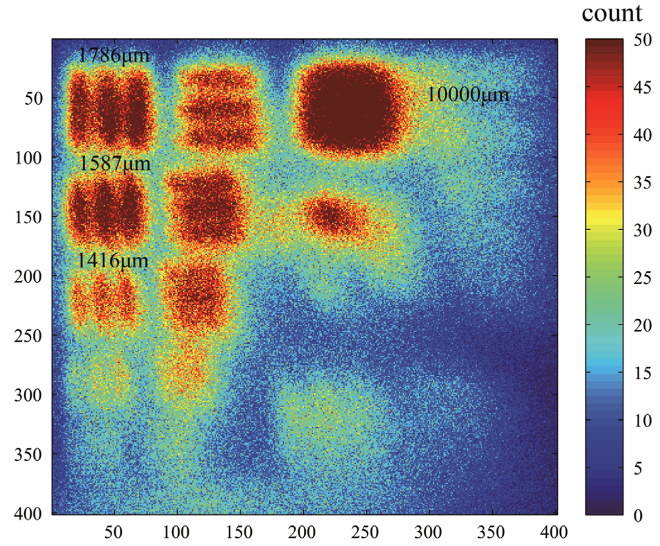

Fig. 4. X-ray image acquired with the 106 mm MCP V-stack and the WSA anode.

$$\mathrm{ENC} = Q_0 + k\frac{D_{WSA}^2}{4}\pi \tag{3}$$

where Q_0 is the ENC RMS of the CR110 and k is related to the ENC slope of the CR110 [11]. Therefore, the spatial resolution in the x or y direction is

$$\mathrm{FWHM}_{x,y} = 2.355\frac{\mathrm{ENC}}{Q_{\max}}D_{WSA} = 2.355\frac{Q_0}{Q_{\max}}D_{WSA} + 2.355\frac{k\pi}{4}\frac{D_{WSA}^3}{Q_{\max}} \tag{4}$$

where $Q_{\max}$ is the maximum charges that can be collected by the CR110 [11]. Since Q_0 is 0.03 fC and $Q_{\max}$ is 4.2 pC [11], the spatial resolution contributed by Q_0 is 1.7 μm and it can be neglected relative to the second term in Eq. (4). Thus, the spatial resolution is proportional to D_{WSA}^3; hence, it will be about 10 times worse when the 106 mm WSA is coupled with the 106 mm MCP.

In addition to the limited spatial resolution of the large area readout with the WSA anode, the WSA anode also has a relatively low throughput. The decay time constant of the CR110 is 140 μs [11]; hence, the throughput cannot be greater than 10,000/s with negligible signal overlap.

4. The delay line readout

Unlike the charge sensitive analysis of the WSA readout, accurate temporal information of the signal is analyzed by the delay line readout to reconstruct the position of the incident radiation. The resolving time of the electrical signal is reduced because the charge integration of large decay time constant is not necessary, so the throughput is significantly enhanced. The spatial resolution is also enhanced when the readout time resolution is improved.

The structure of the delay line readout is shown in Fig. 5. The multiplied electrons are collected by the delay line anode whose details can be seen in Fig. 5. The delay line anode has four wires, x_{sig}, x_{ref}, y_{sig} and y_{ref}, where x_{sig} and x_{ref} are used to determine the x position and y_{sig} and y_{ref} are used for the y direction. The “sig” and “ref” leads are in parallel for both the x and y directions. The 1 mm distance between “sig” and “ref” wires is far less than D_{MD} (see Fig. 1), the distance between the MCP V-stack rear face and the delay line, so the “sig” and “ref” signals will only differ when