# Fast microchannel plate detector for particles

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In this article we report on the timing capabilities of a new microchannel plate detector we designed and built. The detector assembly has an impedance-matched transition line (50  $\Omega$  line resistance) from anode to cable connector which is considerably smaller than other, commercially available solutions and at the same time has about four times the active area. The detector was tested with an alpha particle source and excellent time response was achieved. Using 10  $\mu$ m pore size channel plates, a rise time of 300 ps and a pulse width of 520 ps are obtained. The details of the signal analysis are also given in the article. © *1996 American Institute of Physics*. [S0034-6748(96)02805-X]

# I. INTRODUCTION

At our institute we develop and build mass spectrometers to characterize plasma distributions in extraterrestrial space. Of particular interest are measurements of the ionic, elemental, and isotopic composition of the solar wind, magnetosphere, planetary and cometary atmospheres, and the interstellar medium. Since these instruments are flown on satellites or spacecraft, there are very exacting requirements concerning their size, weight, and performance. Only small, sophisticated devices can be used. In order to maximize the sensitivity of these instruments, detectors with large active areas are used which allow for large geometric factors of the particle entrance system. To meet the requirements concerning weight, active area, and timing accuracy, microchannel plate (MCP) detectors are the best and probably the only choice for fast particle detection.

The current generation of mass spectrometers for these applications is based on the time-of-flight (TOF) technique for mass identification.<sup>1–4</sup> Basically, a TOF instrument measures the time it takes a single particle (atom or ion), or a packet of ions, of known energy to travel a certain distance. From this time measurement the mass of the particle can be inferred. Therefore, the precise measurement of the flight time is a crucial aspect of TOF instruments.

The maximum achievable time resolution, and therefore the maximum achievable mass resolution, is, to a significant degree, limited by the time spread of the signal pulse processed by the data acquisition electronics. Some part of the time spread is intrinsic to the MCPs, given by the statistical electron multiplication process inside the MCPs, and some part is due to broadening during signal transmission. Usually time resolutions of 1 ns or less are necessary for these TOF instruments. Depending on the type of mass spectrometer, either the rise time or the pulse width of the charge pulse from the detector is the important quantity influencing the mass resolution of the instrument. Time-to-digital converters (TDCs) are usually used for single particle detection, where the time measurement is triggered by the leading edge of the charge pulse. On the other hand, transient recorders are usually used for detection of ion packets. Transient recorders directly digitize the analog detector signal with high temporal resolution, and measure not only the precise flight time of the ion packet but also the peak area, which is proportional to the actual number of ions in the packet.

In a previous paper we introduced a new design for a fast channel plate detector, which features both a fast rise time and a short pulse width.<sup>5</sup> The design makes use of a bipolar geometry and is flexible to accommodate differing experimental needs. We chose to optimize the design for small overall size with good temporal response at the same time. To operate the detector at optimal conditions, the electronic system for signal pickup and signal transmission must have a line impedance of 50  $\Omega$  to couple the pulses to a standard transmission line with minimal reflections.

It was surmized earlier that the rise time and the pulse width of a channel plate detector depend on the pore size of the individual channels.<sup>5,6</sup> Experimental data to support this hypothesis are given in this article. Measurements are reported from two sets of channel plates, one with 25  $\mu$ m and one 10  $\mu$ m pore size of the channels, in the otherwise identical detector and measuring setup.

#### **II. DESIGN**

The key element of a fast channel plate detector is the transmission line, which has to transfer the charge pulse collected on the geometrically extended anode to the small 50  $\Omega$ cable and to the amplifier. A good impedance match of the transition line from the anode to the cable connection is crucial for short signal pulses. In our design, the transition line yields directly into the output connector with no adaptor piece in between. A SMA-type connector is used, which is standard for high-frequency applications. The mathematical details of the detector design were given in a previous paper.<sup>5</sup> A drawing of the actual detector design is shown in Fig. 1. In the cut-out the curved shapes of the inner and outer wave guide of the transition line can be seen. The enveloping circles of the wave guide are members of an orthogonal family of circles in a bipolar geometry. The outside of the detector assembly is optimized for minimum weight and ease of assembly. Two different sets of channel plates have been used: one with a pore diameter of 25  $\mu$ m and one with a pore diameter of 10  $\mu$ m. Both sets of channel plates were purchased from Galileo (type 1330-3320 and type 1330-8007, both of nonimaging quality). These channel plates have an



FIG. 1. Cut-through image of the actual design of the channel plate detector assembly. The 50  $\Omega$  anode with the transition line in bipolar geometry yields directly into a standard high-frequency connector (SMA type).

active area of  $\emptyset$ 40 mm. The channel plate with 25  $\mu$ m pores is rimless, the other channel plate has a solid glass border. The channel plates are mounted in Chevron configuration.

Only materials compatible with an ultrahigh vacuum (UHV) environment were used for the detector: the transition line—that is, the outer and inner wave guide—is made out of aluminum and plated with gold to give low surface resistance; the channel plates are held with ceramic fixtures; and all electrical contacts are made through metalized polyimide foils. The clamping ring is made out of polyetherimide. An etched gold grid (92% transmission) terminates the detector at the entrance side. In the design, great care has been taken that the detector has good outgassing capabilities, which do not interfere with the electrical properties.

Sometimes, an additional requirement for the detector is high voltage floating, in order to have the entrance grid at ground potential or at some other potential depending on the experimental needs. Therefore, a suitable capacitor has to be put somewhere in the signal transmission line between the anode and the preamplifier, which operates at ground potential. If one wants to avoid signal distortions, the best place is to build the capacitor directly into the front surface of the anode. This is achieved by a thin insulating foil placed directly on the anode, which is metalized on both sides to establish the capacitor. We used a polyimide foil, which is specified to hold electric fields up to 320 kV/mm. With a polyimide foil of 0.075 mm thickness, the detector can float  $\pm 24$  kV. We tested the foil up to  $\pm 10$  kV, which is enough for our application. With that foil thickness, a capacity of 400 pF is achieved, which is sufficient for good signal transmission (high pass with a cut-off frequency of  $f_g = 80$  MHz.

# **III. MEASUREMENTS**

The electrical circuit supplying the high voltage (HV) to the channel plates is shown in Fig. 2. Panel (a) shows the detector without high voltage floating and panel (b) shows the detector with high voltage floating. With  $R_1$ , secondary electrons emitted from the front surface of the first channel plate are drawn into a channel, which improves the detection efficiency.  $R_2$  and  $R_4$  define the channel plate voltage ( $\approx 1000$  V). With  $R_3$ , an electric field is applied between the channel plates to accelerate the electrons released by the first



FIG. 2. Circuit diagram showing the high voltage power supply for the detector without HV floating [panel (a)] and the detector with HV floating using the anode capacitor for voltage floating [panel (b)].

channel plate toward the second channel plate, which significantly shortens the width of the output pulse.<sup>7</sup> With  $R_5$ , the electrons emitted from the second channel plate are accelerated toward the anode. It is important to have the capacitors *C* across the resistors for fast timing. These capacitors provide the charge during the electron amplification process in the channel plate. The capacitors have to hold the high voltage and should have good high-frequency performance (e.g., ceramic capacitors,  $\approx 1$  nF). It is clear that with this circuit a careful HV design has to be realized.

The measurements were performed in a vacuum chamber with a base pressure in the low  $10^{-8}$  mbar range. The radiation source was an alpha particle source which illuminated the entire detector. Inside the vacuum chamber, the signal output of the detector was connected to an UHV feedthrough  $[50 \Omega \text{ SMA} (\text{subminiature-A coaxial connector: IEC})]$ 169-15 (Int.); CECC 22 110 (EU.); MIL-C-39 012 (USA) type] by a 1 m cable. The output pulses were recorded directly with a Tektronix oscilloscope (model 7104) with a bandwidth of 1 GHz. Pulse forms recorded on the oscilloscope were photographed. These images were scanned into a computer and digitized, giving about 600 points on the time axis and about 400 points for the voltage. This corresponds to a digitization interval of about 8 ps on the time axis, which is more than sufficient for signal analysis. Similarly, the resolution of the voltage is sufficient.

Evaluating several measurements for the detector using the 25  $\mu$ m pore size channel plates, the measured rise time is 450±20 ps (10% to 90% of signal) and the measured pulse width is 750±50 ps (full width at half-maximum), with no corrections applied to account for the bandwidth of the measuring electronics. This will be discussed in detail below. The detector using the 10  $\mu$ m pore size channel plates showed an improvement in timing with a measured rise time

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FIG. 3. Measured MCP response using channel plates with 25  $\mu$ m pores [panel (a)] and with 10  $\mu$ m pores [panel (b)]. The rise times are 433 and 335 ps, and the pulse widths are 739 and 582 ps, respectively.

of  $360\pm20$  ps and a pulse width of  $600\pm50$  ps. Figure 3 shows typical output pulses for detectors using the 25 and 10  $\mu$ m pore size channel plates. Measurements are only reported for the detector without high voltage floating, since the detector with the anode capacitor was only used with the 25  $\mu$ m pore size channel plates. However, the anode capacitor improved the timing performance of the detector somewhat (rise time  $420\pm20$  ps pulse width  $680\pm50$  ps), probably because of a better isolation between HV ground and signal ground.

The errors quoted above are only to a small part caused by the limitations of the measurement itself. There are actual fluctuations in rise time and pulse width from pulse to pulse. Whether these fluctuations in rise time and pulse width are of the same origin as the fluctuations in gain from pulse to pulse (i.e., differences in the gain of individual channels and the stochastic nature of the secondary electron emission) is unknown so far. We also observed a minor correlation of the pulse height and the pulse width. Larger pulses are wider, which could be caused by space charge effects in the channel.



FIG. 4. Schematic circuit representing the measuring setup

# **IV. SIGNAL ANALYSIS**

Since the signal pulse from the channel plate detector and the instrument response function of the measuring device-the oscilloscope-are both in the subnanosecond range, the measured signal is a convolution of these two. To obtain a better idea of the actual performance of our detector we have to remove the effect of the measuring device by deconvolution with the oscilloscope response function. The bandwidth of the analog oscilloscope we used for the measurements (BW=1 GHz) corresponds to a rise time of  $t_R = 340 \text{ ps} (t_R \approx 1/(3\text{BW}))$ .<sup>8</sup> The schematic representation of the equivalent circuit used for signal analysis is given in Fig. 4. To avoid reflections and ringing of the signal, the MCP assembly output must be terminated with a 50  $\Omega$  resistor on the amplifier side. The signal amplification in the oscilloscope is described by two blocks: a transfer function in the frequency ( $\omega$ ) domain  $H_M(\omega)$ , normalized to unity dc gain, followed by an amplifier with constant amplification G for proper display of the signal. Then, the impulse response of the oscilloscope in the time domain is  $h_M(t) = F^{-1} \{H_M(\omega)\},\$ with the inverse Fourier transform  $F^{-1}$ .

The measured signal for an impulse v(t) is a convolution of the original signal  $v_D(t)$  and the oscilloscope response function  $h_M(t)$ :

$$\nu(t) = \nu_D(t) \otimes h_M(t) = \int_{-\infty}^{\infty} \nu_D(\tau) h_M(t-\tau) d\tau, \qquad (1)$$

where the original signal is considered to be the signal provided to the oscilloscope. Using the well-known properties of Fourier transforms we get  $V(\omega) = V_D(\omega) \cdot H_M(\omega)$  with  $V_D(\omega)$  the Fourier transform of the original signal. From the calibration and the measurement of the rise time,<sup>8</sup> we know that the response of the oscilloscope is well described by a simple low-pass filter with a cut-off frequency  $\omega_e$ :

$$H_M(\omega) = \frac{1}{1 + i\omega/\omega_g}.$$
(2)

Using a Wiener–Helstrom filter<sup>9</sup> we get for the original signal in the frequency domain

$$V_D(\omega) = V(\omega) \frac{H_M^*(\omega)}{|H_M(\omega)|^2 + \frac{\langle |N(\omega)|^2 \rangle}{\langle |V_D(\omega)|^2 \rangle}}$$
$$\approx V(\omega) \frac{H_M^*(\omega)}{|H_M(\omega)|^2 + \gamma}, \tag{3}$$

where  $\langle |N(\omega)|^2 \rangle$  and  $\langle |V_D(\omega)|^2 \rangle$  are the ensemble-averaged spectra of the noise and the signal, respectively. We used an

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FIG. 5. Deconvoluted MCP response using channel plates with 25  $\mu$ m pores [panel (a)] and with 10  $\mu$ m pores [panel (b)]. The rise times are 389 and 298 ps, and the pulse widths are 671 and 451 ps, respectively. The original data from Fig. 3 is reproduced for comparison.

approximation for this filter where  $\gamma = 1/(SNR)$  and SNR is the signal-to-noise ratio, which has been described in Ref. 10. The effect of the filter is to limit the noise which is introduced by the digitization process. We can estimate the signal-to-noise ratio by evaluating

$$P_{S} = \int_{0}^{\omega_{C}} |V(\omega)|^{2} d\omega,$$

$$P_{N} = \frac{1.5\omega_{\max}}{\omega_{\max} - \omega_{C}} \cdot \int_{\omega_{C}}^{\omega_{\max}} |V(\omega)|^{2} d\omega$$
(4)

with the signal contained within the frequency region  $0 < \omega < \omega_C$ . The estimated signal-to-noise ratio is then  $SNR = P_s/P_N$ .

To evaluate the measured pulse forms, the digitized pulse forms were used (Fig. 3). Then, Eq. (3) was evaluated numerically using a cut-off frequency in  $H_M(\omega)$  of  $\omega_g = 2\pi \cdot 1$  GHz. The cut-off frequency between the signal and the noise has been determined as 20 GHz, and a signalto-noise ratio of 35 dB is obtained. The obtained results are displayed in Fig. 5. As expected, the deconvoluted pulses show faster rise times and shorter pulse widths. The deconvoluted rise times are  $410\pm30$  and  $300\pm30$  ps, and the pulse widths are  $670\pm60$  and  $520\pm57$  ps for the channel plates with pore diameters of 25 and 10  $\mu$ m, respectively. Since the deconvolution removes the effect of the low-pass filter, the high frequencies are preferably amplified, thus the small bit noise from the digitization is exaggerated and shows up as noise in the deconvoluted spectra. This is an artifact of the deconvolution and not a true signal.

In a detailed theoretical investigation, Cova and co-workers<sup>11</sup> studied the limitations on timing of channel plate detectors combined with fast amplifiers. They showed that using a 1 GHz preamplifier will add approximately 10 ps in timing uncertainty for edge detection due to electronic circuit noise. Furthermore, the transient time spread of channel plate detectors is less than 50 ps.<sup>6</sup> Thus the total time resolution of an instrument equipped with this detector should be better than 100 ps for single particle detection.

Finally, as a comparison with other realizations of fast channel plate detectors, the high-speed detector from Galileo has a rise time of "less than a nanosecond" and a pulse width of "typically one nanosecond" using channel plates with a pore size of 10  $\mu$ m and an active area of  $\emptyset$ 20 mm.<sup>12</sup> The high-speed detector of Hamamatsu has a rise time of 250 ps and a pulse width of 600 ps using channel plates with a 6  $\mu$ m pore size and  $\emptyset$ 18 mm active area.<sup>13</sup> Assuming the correlation between pore size of the channels and pulse width is valid down to 6  $\mu$ m pore size, we anticipate further improvement in the impulse response of our detector.

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