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By

R. PERSING AND S.S. MEDLEY

PLASMA PHYSICS LABORATORY

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MICROCHANNEL PLATE RESPONSE TO HIGH-ENERGY NEUTRONS

R. Persing and S. S. Medley

Plasma Physics Laboratory, Princeton University

Princeton, New Jersey 08544

ABSTRACT

The response of a chevron microchannel plate (MCP) to high energy neutrons was measured. The large area (4.6 cm x 13 cm) multi-anode MCP performance characteristics in the saturated pulse counting mode of operation were examined prior to neutron testing. This established a linear operating regime in which the neutron detection efficiency was measured to be 0.17% for 2.5 MeV-DD neutrons and 0.64% for 14 MeV-DT neutrons. The higher response measured for the 14 MeV-DT neutrons is attributed to gamma ray contamination induced by neutron collisions with materials located between the neutron source and the MCP detector. Due to their lower energy, the 2.5 MeV-DD response measurements are expected to be relatively free of gamma contamination and, hence, indicative of actual response of the MCP detector to neutrons in the 1-10 MeV energy range.

I. INTRODUCTION

A chevron microchannel plate (MCP) with a multianode collector array is to be used to detect high energy hydrogenic ions in the charge exchange neutral analysis diagnostic for the Tokamak Fusion Test Reactor (TFTR). During TFTR experiments involving deuterium-tritium plasma operation, the high energy (1 - 14 MeV) neutron flux levels in the environment of the MCP detector are expected to range from 10^6 - 10^{11} neutrons/cm²/sec. In order to assess the performance characteristics and shielding requirements of the MCP detector in this hostile environment, data on the response of MCP detectors to neutrons in the MeV energy range is required. Since the required data is apparently unavailable in the literature, measurement of the MCP response to 2.5 MeV - DD and 14 MeV-DT neutrons was performed using the neutron test facility at PPL developed by H. Hendel.

A microchannel plate is a thin lead glass plate which contains a high density of small diameter pores extending from the front to the back surface. The front and back surfaces are metalized and serve as electrical contacts. Each pore, when energized with an appropriate bias voltage, acts as an electron multiplier. A charged particle striking the entrance wall of the pore will result in 10^3 to 10^4 electrons exiting the pore. More detailed discussions of microchannel plates are available in the literature.¹⁻⁶ Details concerning the plate used for the experiment are presented in Section III of this report.

II. EXPERIMENTAL ARRANGEMENT

Figure 1 illustrates the experimental layout for the 14 MeV-DT neutron response measurements. The neutron generator was situated behind a 180 cm

thick concrete wall which served to reduce extraneous signals resulting from activation of surrounding materials. An approximately 22 cm diameter penetration in the concrete wall provided collimation of the neutron fluence from the generator head. A 2 cm thick lead barrier inserted between the penetration exit and the MCP detector provided effective shielding against ~ 160 keV bremsstrahlung x-rays produced by the neutron generator head.

The neutron source was a Kaman Sciences Corp. Model A-711 neutron generator. Operated at a beam current of 3.5 mA and an accelerating potential of 160 kV, the neutron generator is expected to produce a flux of $\sim 5 \times 10^{10}$ neutrons per second total. The flux at the MCP detector as determined by exposing multiple copper foils and measuring the resultant ^{62}Cu activity was measured to be 6×10^4 neutrons/cm²/sec with a uniform spatial distribution over the area of the MCP detector.

For the 2.5 MeV-DD neutron response measurements a somewhat different experimental arrangement was used. At the same beam current and accelerating potential, the total flux under operation with the 2.5 MeV-DD generator head is reduced to $\sim 5 \times 10^8$ neutrons per second as a direct result of the interaction cross section. As a consequence of reduced source strength combined with less severe activation of surrounding materials under DD operation, the 2.5 MeV-DD measurements were performed with the generator head unshielded by the concrete wall and located 22 cm from the MCP detector. The 2 cm lead barrier remained between the generator and the detector to attenuate the 160 keV bremsstrahlung x-ray flux produced by the source. The 2.5 MeV-DD neutron flux onto the MCP detector was 5×10^4 neutrons/cm²/sec as determined by using indium foils and measuring the resultant ^{115}In activity. As in the DT experiments, several foils were placed on the outside of the MCP vacuum enclosure to verify uniformity of the MCP exposure to the neutron flux.

Figure 2 shows the layout of components inside the vacuum chamber. The MCP was positioned 8.5 cm away from the chamber wall. A simple electron gun was used to flood the face of the MCP with 600 eV electrons for determining the modal gain and other pertinent parameters of the MCP. An ion gauge was mounted at the wall of the chamber to monitor the pressure. It also served as a source of ions, used to excite the MCP.

The stainless steel vacuum chamber was maintained at a pressure of $2-5 \times 10^{-7}$ torr by means of a 7.6 cm, 160 l/sec, oil diffusion pump with a liquid nitrogen cold trap. The high voltage bias supplies and other support electronics were located near the vacuum chamber. The pulse pre-amplifier used to receive the signal from the MCP was located immediately adjacent to the electrical feedthrough in the vacuum chamber wall.

Figure 3 is a block diagram of the instrumentation used to record the pulse height distribution and to calibrate the system. An Ortec Model 104 charge sensitive pre-amp was used to sense the signal from the MCP anode. The tail pulse output was in turn fed to a Canberra 1713 shaping amplifier which provided the necessary gain and pulse shaping to feed a Nuclear Data Model ND66 pulse height analyzer. An Ortec Model 480 pulse generator was used to calibrate the gain of the system. The Tektronix Model 465 oscilloscope was used to set the amplitude of the calibrating pulses. Figure 4 shows the linearity of the pulse height distribution recording system. Note that the onset of non-linearity is at a level which corresponds to a gain of 4×10^7 which is considerably higher than any signal of interest. The system is shown to have good linearity at the very low levels (Fig. 4b) which is the region of most interest.

The biasing arrangement for the microchannel plate is shown in Fig. 5 along with a schematic representation of the electron gun used for determination of modal gain. Each plate of the chevron structure was biased by an independent power supply module. The supplies provided a bias of 1000 volts per plate in the chevron MCP while the anode is maintained 100 volts more positive than the output electrode. The pre-amp was operated at a ground potential. Hence the electrons exiting the second plate are accelerated towards and collected by the more positive anode.

The electron gun is operated at a bias which is 600 volts more negative than the input electrode of the MCP. Electrons exiting the electron gun structure will be accelerated towards the MCP and impact with an energy of 600 eV. The rheostat, R_1 , is used to control the current and hence the temperature of the filament. This allowed reasonable control of the electron flux impinging on the face of the MCP.

III. THE MICROCHANNEL PLATE

The MCP used for these experiments was custom fabricated by Galileo Electro Optics, Sturbridge, Massachusetts to specifications set forth by the Princeton Plasma Physics Laboratory. The plate characteristics are listed in Table I.

Figure 6 shows the unique geometry of the MCP. The 75 anode system is an array of 3 rows with 25 independent anodes in each row. Each anode has an active area of 0.4 cm^2 ($0.4 \text{ cm} \times 1.0 \text{ cm}$) and can be addressed by means of a contact pin on the rear of the anode plate. Three separate pins provide electrical connection of the bias voltages. Each of the 75 anodes is surrounded by a guard band to minimize crosstalk. The anode and guard structure is formed by evaporating gold on a ceramic substrate which is fitted

with the appropriate connector pins. A thin metal mask placed between the two plates of the chevron defines the active surface area of the MCP as well as assisting in dividing the plate into three rows as shown.

During the course of production the MCP was tested by the manufacturer and found to have a modal gain of 1.1×10^7 , a FWHM of 140% and a strip current of 13 μ a when operated at a bias of 1000 volts per plate.

For the purposes of these experiments the MCP anodes were configured into two basic group types, as shown in Fig. 7. One type was comprised of single anodes located at the top end (TE), center (CC), and bottom end (BE) of the microchannel plate anode array. The second type was comprised of the remaining 24 anodes in each of the rows designated top row (TR), center row (CR), and bottom row (BR) in Fig. 7. The 24 anodes associated with a designated row were wired together to provide a single output signal. This arrangement thus provided six independent signal outputs. For all experiments, the guard electrode was grounded via its dedicated connector pin.

IV. MCP RESPONSE TO ELECTRONS

To ensure characteristic operation of the MCP and to provide a reference for assessing possible changes during the course of neutron testing, the MCP was subjected to various tests with the electron gun acting as a means of excitation. Figures 8 and 9 show the effect on modal gain caused by changes in various operating parameters. Figure 10 shows the variation in FWHM as a function of detected pulses per second per square centimeter.

Referring to Fig. 8A, modal gain versus plate bias, an operating point of 1000 volts per plate was considered optimum. The apparent increase in gain at bias levels greater than 1 kV is attributed to ion feedback effects and does not represent a true increase in gain. A bias of 1 kV per plate offers the highest gain without apparent ion feedback.

Figure 8B shows the effect of a bias applied between the anode plane and the chevron plate exit face. It is seen that the modal gain increases with increasing positive bias on the anode up to the point where the anode is 100 volts more positive than the output electrode. Beyond 100 volts bias there is no significant increase in modal gain.

The effects of input flux magnitude on modal gain (as determined by the detected counts per second) are shown in Fig. 9. Although no attempt was made to intentionally limit the input flux during the neutron phase of testing, it can safely be concluded that the detected pulse rate was always low enough so as not to introduce any significant changes in MCP operating characteristics.

Variation of the full width half maximum (FWHM) of the pulse height distribution with count rate is shown in Fig. 10. A modest increase in the FWHM is observed at the higher count rates. During neutron response experiments, the count rate was in the $10^2 - 10^3$ CPS range and no effect on the collected data due to changes in FWHM was observed.

Measurements of the MCP dark count, operating with the standard bias conditions of 1 kV per plate, show a low level of roughly 10 counts per minute. It should be noted that care must be exercised during dark count measurements, since strong electrostatic fields or ion gauges can excite the plate giving erroneous results.

Based on the measurements reported above, an optimum operating condition for the MCP during neutron testing was established to exist with a bias voltage of 1 kV per chevron plate with the anode at a potential of 100 volts positive relative to the output of the exit chevron electrode. These operating conditions were used for all neutron response measurements reported in this paper.

V. MCP RESPONSE TO NEUTRONS

The procedure used to obtain the neutron response data was to accumulate pulse height distributions (PHD) over a period of approximately 15 minutes for the following three experimental conditions: 1) the MCP excited only by 600 eV electrons using the electron gun located within the vacuum chamber, 2) a composite spectrum in which the MCP was excited both by the electron gun and the neutron source, and 3) with the MCP excited only by the neutron source. This procedure was repeated to collect data independently for each of the six anode groupings depicted in Fig. 7. For each pulse height distribution, the "live" or actual spectrum accumulation time was preset at 120 seconds.

Representative pulse height distributions accumulated for determining the MCP response to 2.5 MeV-DD neutrons are shown in Figs. 11 and 12. For these PHD, the signal was collected from a single anode at the center of the multi-anode array (anode CC in Fig. 7).

Fig. 11(a) shows the characteristic peaked response of the chevron MCP obtained by exciting the plate with 600 eV electrons. The spectrum yields a modal gain of 3.1×10^6 and a full width half maximum (FWHM) of 194%.

Introducing a neutron flux while still exciting the MCP with the electron gun yields the PHD shown in Fig. 11B. It is interesting to note that the peaked response is still present and the modal gain has not changed. There is, however, a notable increase in count accumulation in the low gain (low pulse amplitude) region of the PHD. This is shown clearly in Fig. 11C where the electron gun has been turned off and the only source of excitation is due to primary and secondary effects of the 2.5 MeV neutron flux.

The neutron PHD of Fig. 11C is reproduced in Fig. 12 with a logarithmic count scale (ordinates) while the abscissa (pulse amplitude) remains linear. Counts in channel numbers above ~ 125 are due to background radiation, such as cosmic rays. The linear portion below channel ~ 125 indicates that the neutron spectrum decreases exponentially with pulse height amplitude. This phenomenon is reported elsewhere for gamma ray response⁷ and is attributed to excitation throughout the bulk of the microchannel plates rather than at the pore entrance.

The corresponding pulse height distributions for 14-MeV-DT neutron response measurements are illustrated in Figs. 13 and 14. For these measurements, the count rates due to electron and to neutron excitation are comparable which leads to a washing out of the spectrum peak feature under combined electron and neutron excitation [Fig. 13(b)]. The neutron-only PHD of Fig. 13(c) is reproduced in Fig. 14 with a logarithmic count axis and exhibits an exponential dependence in pulse amplitude similar to the 2.5 MeV-DD case shown in Fig. 12.

The detection efficiency is extracted from the pulse height distribution data in the following manner. The MCP detector count rate, Γ_d , normalized to unit detector area can be expressed by

$$\Gamma_d = \frac{\Gamma_T}{t \cdot A} \quad (1)$$

where Γ_T = summation of counts in the PHD

t = actual count accumulation time (sec).

A = total area of the anode collection surface (cm^2).

For a single anode, $A = 0.4 \text{ cm}^2$, while for a group of 24 anodes $A = 9.6 \text{ cm}^2$.

A ratio is now formed between the detected counts/sec/cm², Γ_d , and the measured neutron incident, flux Γ_o (neutrons/sec/cm²). This ratio is then expressed as a percentage:

$$\xi = \frac{\Gamma_d}{\Gamma_o} \times 100\% \quad (2)$$

where ξ is the detection efficiency. The detection efficiency of the MCP is presented in Table II. Averaged over the six anode collector groups, the MCP detector exhibits an efficiency of 0.64% for detection of 14 MeV-DT neutrons and an efficiency of 0.17% for 2.5 MeV-DD neutrons.

VI. DISCUSSION

As far as the authors are aware, measurements of the response of microchannel plates to high energy neutrons are not available in the literature. The response to high energy gamma rays, however, has been investigated.^{8,9} Data on the MCP gamma ray response was extracted from a paper⁹ by J.P. Macau et al. and is reproduced in Fig. 15. Added to the figure are the two neutron detection efficiencies obtained in the present work. The data suggest that the MCP response to MeV neutrons is lower than that for gamma rays of comparable energy by a factor of 5-10.

The primary source of error in the reported neutron detection efficiencies arises due to contamination of the influx to the detector by hard x-ray and gamma ray fluxes. The main source of x-ray contamination is the 160 keV bremsstrahlung production by the generator head. As will be discussed shortly, effective shielding of the detector from this source was provided. The other source of contamination is production of gamma radiation induced by

collisions of the neutrons with material (concrete, lead, and stainless steel) necessarily interposed between the generator head and the MCP detector. This effect, which produces gamma rays of comparable energy to that of the neutrons involved, is expected to be negligible for 2.5 MeV neutrons but significant for the higher energy 14 MeV neutrons.¹⁰ Furthermore, shielding of the MCP detector against this contamination source is not practicable.

Although the flux of collision induced gamma rays was not measured, this contamination is believed to be the cause of the enhanced efficiency reported for the 14 MeV-DT case. An estimate of the gamma flux level which is necessary to cause the apparent enhancement of the 14 MeV neutron efficiency can be derived as follows. Letting α be the fraction of the gamma contamination in the total flux incident on the MCP detector, we can write

$$\alpha \xi_Y + (1 - \alpha) \xi_n = \xi_m$$

where ξ_Y = gamma ray detection efficiency

ξ_n = true 14 MeV neutron detection efficiency

ξ_m = apparent measured 14 MeV neutron efficiency (0.64%).

If we assume $\xi_n = 0.17\%$, the value measured for the relatively contamination free 2.5 MeV efficiency, and use Fig. 15 to estimate a value of $\xi_Y = 2\%$ for the gamma efficiency, then solution of the above equation yields $\alpha = 0.25$. Thus a 25% gamma contamination of the detector influx, which is conceivable, would account completely for the enhanced neutron efficiency observed for 14 MeV neutrons relative to 2.5 MeV neutrons.

The importance of shielding the detector from the 160 keV source bremsstrahlung x-ray flux was demonstrated by making DD and DT efficiency

measurements with the 2 cm lead barrier removed. The results are shown in Table III. The 14 MeV-DT neutron efficiency measurements are artificially enhanced by a factor of order two due to removal of the lead barrier. On the other hand, the 2.5 MeV-DD measurements are erroneously high by factors of 250 or more. The following explanation of this behavior is offered. In the 14 MeV-DT case, two effects combine to minimize interference of the 160 keV x-ray flux with the efficiency measurements. First we note that the 160 keV x-ray flux level for the DD and DT cases is the same since the x-ray production depends on the generator head current and accelerating voltage which was the same in both cases. As noted earlier, the production rate for 14 MeV-DT neutrons is two orders of magnitude greater than that for 2.5 MeV-DD neutrons. Thus the first reason for the small x-ray effect on the DT measurements is that the gamma fraction in this case is two orders of magnitude less than the DD case. The second, a perhaps dominant reason, is that the DT generator head was located ~ 260 cm away from the MCP in the DT experimental arrangement whereas for the DD measurements the distance between the generator head and the MCP was about 22 cm. Thus in the DD case, the detector intercepts a significantly large fraction of the radiated x-ray flux. The 160 keV x-ray flux level was not measured. However, if Fig. 13 is used to define the MCP efficiency for detection of 160 keV x-rays as 12%, then in order to obtain the apparent efficiency noted for the DD case in Table III, the 160 keV x-ray flux must be the order of 3-4 times greater than the 2.5 MeV-DD neutron flux, which is no unreasonable from the point of view of the generator head operating characteristics. The above tests support the claim that use of the 2 cm lead barrier provided effective suppression of the 160 keV x-ray flux during actual measurement of the reported neutron detection efficiencies.

The repeatability of the neutron generator to provide a consistent flux level from run-to-run is another possible source of error. The flux was measured by activating foils only at the end of a sequence of experiments. Hence, an uncertainty remains about the neutron flux during actual data collection. Tests conducted on the neutron generators used for these experiments show that the flux is quite consistent from run-to-run as long as the accelerating voltage and beam current are maintained at the prescribed settings. It is expected that variations in the run-to-run flux levels as well as the tolerance involved in measuring the activated foils¹ should not exceed $\pm 20\%$, total.

VII. SUMMARY

This report has described a multi-anode microchannel plate (MCP) and various tests conducted with that MCP to characterize its behavior when excited with 600 eV electrons. From this data an optimum operating point was found for the MCP.

Experiments were conducted to determine the detection efficiency of the MCP to 14 MeV and 2.5 MeV neutrons. The MCP shows a 0.6% detection efficiency for 14 MeV neutrons and a 0.17% efficiency for 2.5 MeV neutrons. These numbers are reported to have a small but unavoidable error due to a low level of gamma contamination in the neutron flux impinging on the MCP. The gamma contamination with the 2.5 MeV neutrons is expected to be smaller than for the 14 MeV neutron due to the lower energy level.

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TABLE I

CHARACTERISTICS OF THE CHANNEL ELECTRON MULTIPLIER ARRAY

Mechanical

Pore Size: 25 μ

Channel Bias Angles: 8°/8°

Chevron Interspace: 0.002 inches

Anode Interspace: 0.015 inches

Electrical [1000 volts bias per chevron]

Gain: 1×10^7

Pulse Height FWHM: 140%

Dark Count: 1 cps/cm²Strip Current⁺: ~ 20 μ AMaximum Pulse Count Rate: 10⁶ cps random

(Per 0.4 x 1.0 cm anode pad)

⁺ Per 4.6 cm x 13 cm Plate

TABLE II
MCP RESPONSE TO NEUTRONS

Anode Group						
	TE	CC	BE	TR	CR	BR
2.5 MeV	0.19%	0.19%	0.15%	0.18%	0.14%	0.16%
14 MeV	0.60%	0.54%	0.49%	0.72%	0.78%	0.63%

TABLE III
EFFECT OF GAMMA CONTAMINATION ON MCP NEUTRON RESPONSE MEASUREMENTS

Anode Group						
	TC	CC	BE	TR	CR	BR
2.5 MeV	22%	51%	25%	42%	43%	37%
14 MeV	1.0%	0.97%	0.87%	1.2%	1.3%	1.2%

FIGURE CAPTIONS

- Fig. 1. Experimental layout for measurement of the microchannel plate sensitivity to 14 MeV-DT neutrons.
- Fig. 2. Sketch of the vacuum chamber showing major internal components. the microchannel plate and the electron gun.
- Fig. 3. Block diagram of the instrumentation used to calibrate the electronics and record the pulse height distribution.
- Fig. 4. Measured linearity of the pulse height distribution recording system.
- Fig. 5. Circuit diagram showing the microchannel plate biasing scheme and the electron gun.
- Fig. 6. Isometric assembly drawing illustrating the components of the large area chevron multianode microchannel plate detector.
- A. Assembly hardware and input electrode contact.
 - B. Front microchannel plate of the chevron MCP assembly.
 - C. Intermediate electrode and mask defining active plate area.
 - D. Rear microchannel plate of the MCP assembly.
 - E. Output (or anode) electrode.
 - F. Pattern of gold deposition defining the 75 anode pads and surrounding guard ring.
 - G. Ceramic substrate on which gold anode pad pattern is deposited. Electrical contact with the anode pads is by means of pins extending through the backside of the ceramic substrate.
 - H. Tie bars used to mount multiple chevron MCP section to form extended arrays.

- Fig. 7. Schematic showing the configuration of the anode groups used in measurement of the neutron response of the MCP array.
- Fig. 8. Effect on the MCP modal gain of the bias voltage applied to each chevron plate (A), and the acceleration voltage applied between the chevron exit face and the anode collector plane (B).
- Fig. 9. Effect of signal count rate (cps/cm^2) on the modal gain of individual MCP anodes. The data points (o,x) indicate a variation in modal gain with anode location on the MCP.
- Fig. 10. Variation of the pulse height distribution FWHM as a function of count rate per square centimeter.
- Fig. 11. Pulse height distributions (PHD) representative of measurements used to obtain the MCP response to 2.5 MeV-DD neutrons. The PHD correspond to plate excitation by: (A) electron flux (B) combined electron and neutron flux, and (C) neutron flux. Channel number 250 corresponds to a gain of 1.5×10^7 .
- Fig. 12. The 2.5 MeV neutron flux PHD is reproduced with a logarithmic count scale (ordinate).
- Fig. 13. Pulse height distributions (PHD) representative of measurements used to obtain the MCP response to 14 MeV-DT neutrons. The PHD correspond to plate excitation by: (A) electron flux, (B) combined electron and neutron flux, (C) neutron flux. Channel number 250 corresponds to a gain of 1.5×10^7 .
- Fig. 14. The 14 MeV neutron flux PHD is reproduced with a logarithmic count scale (ordinate).
- Fig. 15. Comparison of neutron detection efficiency with gamma radiation detection efficiencies reported in the literature.⁹ The gamma ray efficiency references noted on the figure are given below.

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81X0004

Fig. 1.

81X0005

Electrical
Feedthrough

Chevron Multianode
Microchannel Plate

Vacuum
Chamber

Electron
Gun

Ion Gauge

Fig. 2.

MCP
Signal
Input

81X0003

81X0028

Fig. 4.

fig. 5.

* RIKQ066

Fig. 6.

81X0023

Fig. 8.

81X0C26

Fig. 10.

Fig. 11.

#81X0025

fig. 12.

Fig. 13.

#81X0024

Fig. 14.

FIG. 15.