HDC 81-16. Channel Multipliers and MCP's in DUMAND PMT's.

CHANNEL MULTIPLIER ARRAYS AND MICROCHANNEL PLATES IN DUMAND PMT'S.

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This note discusses the status of Channel Electron Multiplier Arrays (CEMA) and Microchannel Plate (MCP) development, and their relation to the design of DUMAND photomultiplier tubes. As pointed out in DUMAND Reports HDC 81-14 and 81-15, the channel multiplier array offers an apparently ideal mode of segmenting the dynode structure as a means of getting rid of the K^0 background. Only uncertainty concerning the degree of maturity of channel multiplier technology stands in the way of adopting the MCP for this purpose.

The DUMAND requirements are not at all concerned with the high resolution afforded by MCP plates. They could be perfectly well satisfied by a small array of channel electron multipliers (CEMA), which are single continuous-dynode multipliers equivalent to a single channel of the MCP, but larger. Each one would correspond to a single segment of the dynode structure; thus 9 to 16 assembled into a single unit, with large apertures (of order 1 cm^2 each), would also be satisfactory if its performance were equivalent.

MCP plates have been made with multiple-anode structures; such arrays are called MAMA: Multiple-Anode Microchannel Array. The DUMAND requirement is thus for MAMA, or its equivalent, CEMA. For the sake of definiteness we discuss MAMA; similar considerations will apply to CEMA.

The introduction of curved-channel MCP's has allowed the production of single high-gain high-resolution plates that preclude the necessity for two plates in a "chevron" configuration. The purpose of the latter was to suppress positive ion feedback; the curved-channel configuration serves the same purpose in a single plate.

MCP gains are generally space-charge limited; the electron charge density at the output end reaches sufficiently high values to decrease the accelerating field and thus limit the available gain. For CEM's the corresponding limit is higher, because of their greater diameter.

1.0 DESIRABLE CHARACTERISTICS OF AN MCP FOR DUMAND.

The desirable characteristics of an MCP plate for DUMAND are as follows:

1. Area: At least 1" diameter, preferably more; the size depends on how well the PMT focusing system can collect the primary photoelectrons into a narrow throat. MCP plates up to 75mm diameter, or even more, are available; the larger ones tend to be more expensive, for a fixed resolution. But DUMAND resolution requirements are minimal, and therefore large MCP arrays with lower resolution would be acceptable, if not too expensive. To date curved-channel MCP's are available with diameters up to 40mm.

2. Collection efficiency. The collection efficiency of an MCP for incident electrons is not determined simply by the ratio of open area to total area. By funneling the openings to the channels it is possible to increase the collection efficiency to values of 80% or more. This is highly desirable to avoid loss of sensitivity.

3. Overall Gain: at least 10^6, preferably 10^7.

4. Positive Ion protection: needed to eliminate positive ion bombardment of cathode. Two means of protection are available: a thin aluminum oxide film over the entrance to stop the ions, and channel curvature to prevent their reaching the opening. Probably both are desirable, since the channel curvature provides a means for getting the required gain in a single stage.

5. Capability of handling the high single-electron counting rate. The channel time constant for charge redistribution (of order 300 μsec) limits the maximum counting rate per channel. At the DUMAND counting rate, this requirement poses no problem for MCP's; it might for a CEM array. The long time constant is determined by the channel resistance and capacitance.

6. Expected lifetime of 100 years. There is simply not enough experience with large numbers of MCP's to be certain about this; but there now exist data from which rather hopeful conclusions can be drawn. These come from work by Timothy[1], who found that curved-channel MCP's, with a proper burn-in period, were capable of 10^5 counts/mm^2sec, and lifetimes exceeding 2.5×10^{11} counts/mm^2. Data on CEM lifetimes similarly indicate gain stability after a preliminary burn-in period, but the data extend only to 2×10^9 counts/channel[2].

7. Cost. The use of CEMA or MCP electron multipliers will be feasible only if they do not unduly increase the cost of the PMT. In a 16" or 20" PMT, the multiplier cost is not the only important one. It seems reasonable to set an upper limit of the order of $1000 per tube on the cost of a multiplier which allows segmentation. This might bring the total cost of the PMT to the range $2000-2500, which, although higher than originally contemplated, is not so high as to be impractical. We are assured by competent authorities in the Galileo Electro-Optical Co. that they see no difficulty in producing electron multipliers suitable for incorporation in a DUMAND PMT, in quantities of the order of 1000, at under $1000 each.

2.0 GAIN AND PULSE-HEIGHT SPECTRUM.

The maximum gain of a channel multiplier is space-charge limited; the final output pulse-height distribution is approximately gaussian, and independent of the input signal. For DUMAND purposes this is acceptable. However, the maximum gain depends upon two parameters: the ratio L/D for the channel (length/diameter), and the diameter. One-mm channels have maximum gains of 10^7 to 10^8; 25-μ channels have maximum gains near 10^6. In an MCP for DUMAND a 100-μ channel, with gain around 10^7, would be a good choice; an L/D of 100, an appropriate value, would yield a plate thickness of 1 cm.

3.0 LIFETIME

3.1 MCP Multiplier.

We can estimate the counting rate per channel and the expected lifetime as follows. Suppose we have a 40mm diameter MCP plate, with 100-μ channels on 125-μ centers. Then there are 64 channels/mm^2. The area of the plate is $\pi x 20^2 \equiv 1250$ mm^2. A total counting rate of 1.25×10^5/sec gives a mean density of 100 counts/mm^{2}sec. Since the photon density may not be uniform, we take a value arbitrarily three times as high for calculating lifetimes, or 300/sec. This yields a mean channel rate of about 5/sec., or 4.3×10^5/day. In 100 years there are 3.2×10^9 seconds, so we need a lifetime of 1.4×10^{10} counts/channel. Timothy[1] carried out tests on 25-μ channel plates up to 2.7×10^8 counts/channel, which is about the equivalent of two years of operation for us; the MCP plates did not fail at this lifetime, but were still operating stably when the test was suspended. Further life-testing is clearly desirable, but the indications are more favorable than has been the case heretofore. Timothy thinks that previous work has been insufficiently meticulous about cleanliness and baking out.

3.2 CEM Lifetimes.

In a CEMA the individual channels have both higher gain and higher counting rates than in an MCP. The available data[2] are not as extensive, but they show no indications of approaching extinction when terminated. With somewhat lower resistance per channel, counting rates of several x 10^4/sec should be tolerable, allowing the number of channels to be as low as 10-15. At a rate of 10^4/sec, we need a capability of 1.3×10^{14} counts/channel to achieve a 100-year lifetime.

In some unpublished work[3], P. Rosenbaum of the Max Planck Institute of Munich operated CEM's in an extremely clean environment, well baked out, and found, after the usual burn-in, that even after 20 coulombs had been transmitted, the CEM operation was still stable and satisfactory; at that point the test was terminated. At a gain of 10^7, we find that 20 coulombs corresponds to

$$20 \times 6 \times 10^{18}/10^7 = 1.2 \times 10^{13} \text{ counts.}$$

As noted above, this would be equivalent to ten years of operation at a singles rate of 10^4/sec. We are thus clearly within sight of the goal; 100 channels instead of 10 would reach it with no further work.

4.0 Pulse Height Discrimination.

The space-charge limitation on channel gain implies that the output pulse is independent of the input size, so that all pulse height information is lost. However, equivalent information is available in terms of the multiplicity of a coincidence between anodes. Suppose, e.g. there are 100 anodes in a 10x10 array. We need a majority logic circuit with 100 inputs to register the number of anodes struck; we require a minimum of two, but simply counting the number of coincident pulses will provide the equivalent of pulse height information (with slight corrections for multiple hits on the same anode).

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3. P. Henkel, private communication.