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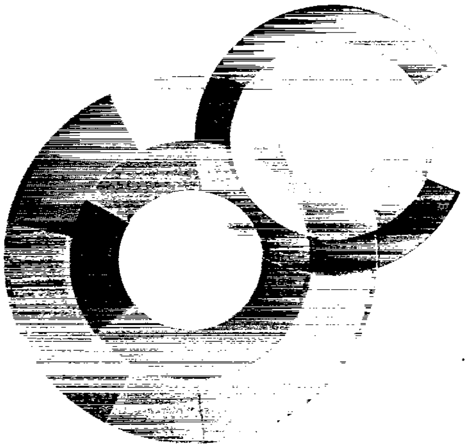

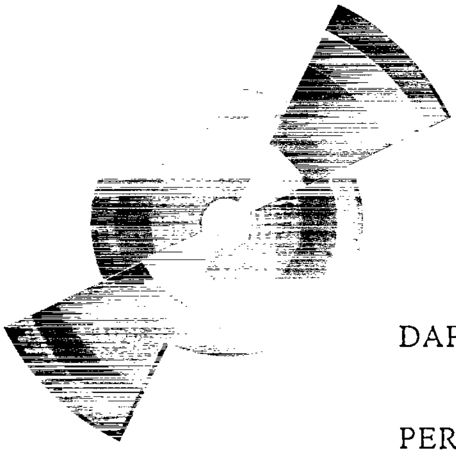

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Ceramic electron multipliers with real metal dynodes and independent channels were constructed using multilayer ceramic technology. Tests of these prototypes show their capability to form sensitive detectors such as photomultipliers or light intensifiers. Here, we present results for the photocathode sensitivity, dynode activation, gain, linearity range and dynamic characteristics as well as the effect of 3-year aging of the main operational functions. The advantages provided by the ceramic components are discussed. These results motivate the development of a compact 256 pixel ceramic photomultiplier.

1-INTRODUCTION:

The multi-channel photomultipliers that have appeared in the last 10 years have provided new solutions to fast imaging problems at very low luminosities. To adapt these photodetectors to such applications by optimizing their geometry and dimensions, simplifying their operation and facilitating their production, we proposed using multi-layer ceramic technology for manufacturing these new components (1). In (2), we reported the main results of a feasibility study which showed good conformity with all the PM dynamic operating functions and gave an optimistic forecast for the performance of an industrially-developed detector.

This article extends these data and gives the first values for the analog and temporal characteristics of these ceramic PMs.

2-CERAMIC PHOTOMULTIPLIER PROTOTYPE DESIGN (CMP)

2.1-*Ceramic electron multiplier block (CEM)*

We have described the structure and the fabrication procedure for ceramic photomultipliers (1), (2). The production of the new CEM has again made it possible to test the techniques used in multilayer ceramic technology both for obtaining new cavity shapes and sizes as well as precision and reproducibility of conductive layers to form real metallic dynodes.

Improved understanding of the problems involved has allowed NTK TECHNICAL CERAMICS (3) better selection and scheduling of the basic fabrication procedures. The results are interstage insulation values consistently above 200 Gohms at 200 volts and more uniform gains for the gold-plated dynode channels.

To increase the stage gains to usable levels, we deposited an (Sb-Cs) type layer, known to have high emmisivity and widely used industrially, on the walls of each cavity. Antimony deposition on the dynodes was done by electroplating using DALIC industrial products (4). This procedure does not change the operating characteristics evaluated above.

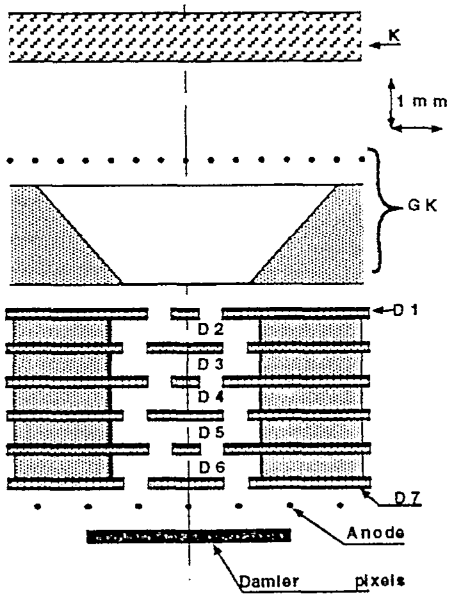

Fig.1. Schematic of CPM electrode and dynode arrangement

2.2- *Activation of antimony-plated CEMs*

To provide simple, autonomous mountings that facilitate repeated measurements for determining aging characteristics, and to benefit from specialized industrial photoelectric techniques, we decided to construct photomultipliers. Thus, our results go beyond the simple objective of dynode activation. Antimony-plated CEMs with measured gains were sent to

PHILIPS PHOTONIQUE (5) where they were incorporated in standard PM XP4722 structures to evaporate a photocathode and activate the multiplier.

A schematic electrode arrangement is shown in Figure 1. The input stage consists of the photocathode K and the GK electrode. The multiplier is made up of dynodes 1 to 6. The electrode 7, the grid-anode and the damier-pixels form the output stage. The 4 damier-pixels are antimony vacuum-deposited; their emissivity serves to estimate the efficiency of the activation process.

3-CPM CHARACTERIZATION

3.1- *Photocathode*

The CPM fabrication steps, i.e., photocathode production and multiplier activation, are now carried out simultaneously in the glass envelope. Experience has shown that both material characteristics and electrode geometry can affect photocathode sensitivity. The sensitivities at 407 nm of bialkali (Sb-K-Cs) photocathodes with both compact mountings and new materials are given in Table T1. Although they have not been optimized, these values establish the compatibility of the multiplier components (ceramic and electro-metal plating) with those of tube activation (alkali metals and photocathode). This compatibility is strengthened by the practically complete stability of a SbCs-type photocathode of PMC 3 over 42 months.

Table 1:PHOTOCATHODE SENSITIVITY AT 407 nm (mA/W)

PMC 7	PMC 11	PMC 12	PMC13	PMC 16	PMC 17	PMC 18
45	58	41	40	47	61	68

3.2 *Dynode gain*

The gain, Gi of each dynode-cavity is given by: $Gi(v) = C_{(i-1)i}(v) * S_i(v)$, where $C_{(i-1)i}(v)$ is the electron collection factor between stages (i-1) and i and $S_i(v)$ is the secondary emission factor of dynode i. The ratio T(i-1)i(v)=C(i-1)i(v)/C(i-1)i(200) represents the electron transfer efficiency relatively to operating conditions for an interdynode voltage Vid = 200 volts. The T(i-1)i(v) values of each dynode for the same CPM are given in Figure 2. There is a plateau with a slight slope which indicates an efficient transfer of secondary electrons (>90%) for Vid < 200 V. The small scatter in the parameters can be interpreted as due to good geometric reproducibility of the channel structure. The average curve T(v) specifies the electron propagation in this structure. Table T2 gives, for each of the 5 CPMs, the electrode type, the antimony plating technique used: (VD) for vacuum deposition, (EP) for electroplating, and the corresponding gains for an interstage voltage, Vid, = 200 V.

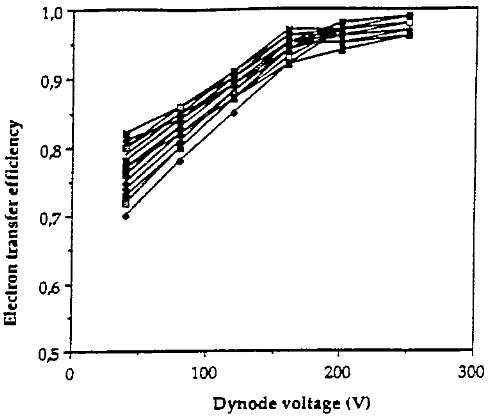

fig.2. channel electron transfer efficiency

PMC Label	ELECTRODE METAL	GK STEEL	DYN1 GOLD	DYN2 GOLD	DYN3 GOLD	DYN4 GOLD	DYN5 GOLD	DYN6 GOLD	DAMIER ALUMINIUM
13	Sb layer		EP	EP	EP	EP	EP	EP	VD
	Gain		4,25	2,1	1,6	1,4	1,6	1,9	10
14	Sb layer		EP	EP	EP	EP	EP	EP	VD
	Gain		6,7	1,8	1,8	1,5	1,5	1,8	6
15	Sb layer	EP	EP	EP	EP	EP	EP	EP	VD
	Gain	2,2	1	2,2	1,4	1,5	1,2	1,3	7
16	Sb layer	VD	EP	EP	EP	EP	EP	EP	VD
	Gain	1,8	1	2	1,3	1,6	1,5	1,4	12
17	Sb layer	EP	EP	EP	EP	EP	EP	EP	VD
	Gain			2	1,7	1,7	1,6	2,2	5

The vacuum depositions give the best efficiency, in particular those for the CMP13 and 14 damier-pixels. Nevertheless, the yield from the EP-Sb layer on the D1 dynode (CPM14) reaches the same values as those of the associated VD-Sb damier-dynode. The very different emissivities of the VD type layers of the GK electrode and damier (CPM16) show the influence of the sublayer. The low gains observed for the innermost dynodes indicate poor diffusion of the products coupled with insufficient preparation of the metal surfaces.

Although these results are limited, it can be stated that there are physical-chemical conditions providing an electrolytic antimony deposit with a usable emission yield. These conditions are also closely related to electrode type and geometry and thus require a specific process. This designates the transfer technique - which is widely used for producing microchannel image intensifiers - for activating and assembling the CPMs freed of a glass envelope studied here .The gain dependence of the 4 channels on the voltage Vm applied to the multiplier is shown in Figure 3. At this stage we have true photomultiplier with stable operation. Although the gains are limited due to non-optimization of the production steps and the reduced number of stages, we can evaluate the main analog and dynamic characteristics of these new components.

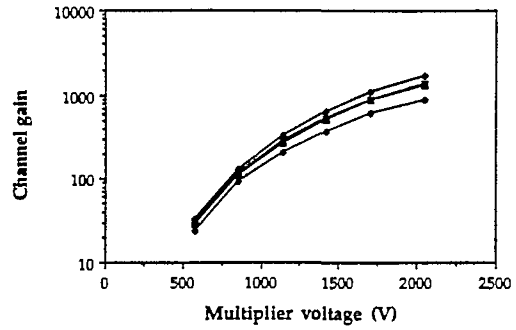

fig.3. Gain of the 4 channels vs multiplier voltage

3.3 *Dynamic parameters*

To explore the dynamic characteristics we used a test bench including a LED emitting very short light flashes at 450 nm directed by optical fibers to the studied CPM and a standard Philips XP2020 PM. This was used as a reference as its specifications and performances are well known. The anode pulses of these 2 PMs observed under 50 ohms by means a Hewlett-Packard oscilloscope (6) for cathode voltages of -1500 and -1900 volts, respectively, are shown in Figure 4. From the similarity of these pulses, we derive a CPM rise time very close to that of the XP2020 and below 2 ns.

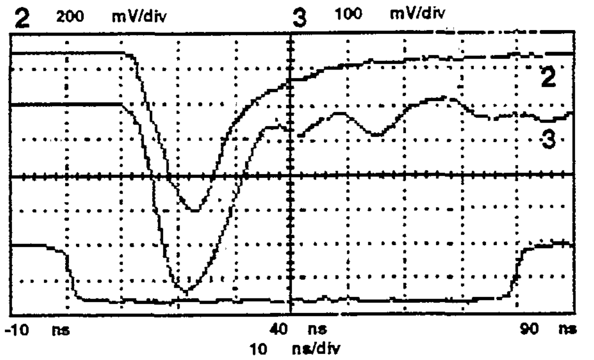

fig.4. Anodic pulses of (2) XP2020, (3) CPM, on 50 ohms load

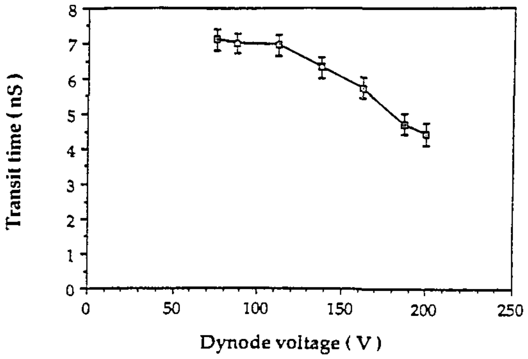

fig.5. CPM transit time versus dynode voltage

The variation of the CPM transit time with the voltage Vid applied to all the stages is shown in Figure 5.The tight dynode spacings (0.25 mm) establish strong electric fields which fast collect the electrons to generate short latency-times: from 7 to 4.5 ns depending of the dynode voltage.

3.4 *Linearity*

It might be thought that the small dynode area (2-3 mm^2/cavity) involved in the electron multiplication would restrict the linearity range of these multipliers. Thanks to the light sources performances, which allow adjusting the flash intensities with practically no degradation of the time characteristics we can establish the correlation between the main light power measured using a semiconductor detector (7) and the corresponding charge of the anodic pulses. The results reported figure 6 for a dynode voltage Vid= 200 volts show a linear dependance until 260 pC per pulse. The absence of any saturation index indicates a higher limit.

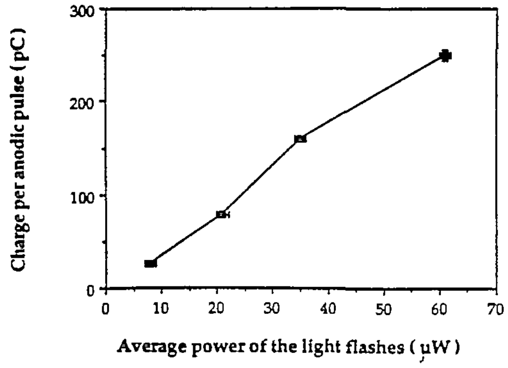

fig.6. Anodic pulse charge versus the mean power of the light flashes

4-CEM POTENTIALITIES

One of the initial motivations in this development was to produce multiplier blocks that were autonomous with respect to vacuum, dynode interconnection and detector mechanical assembly problems.This autonomy allows designing various components that do not require a vacuum envelope and can be placed side by side to provide large detection surfaces or even volumes. The suggestion made on completion of this study that a feasibility study be made for constructing a 256 channel CPM is in this direction (2).

But the use of this ceramic multiplier largely goes beyond the photosensor field (PMs and light intensifiers) and is applicable to all the fields where electrons are the indicators of a physical event (calorimetry (8), ion analysis, vacuum-sensors, etc.)

The constituents of these components ensure that they are highly resistant, with ultra-high vacuum properties and suitable for integration in advanced technology equipment.

5-CONCLUSION

These results complete and reinforce the conclusion of the preceding studies. Analysis of the main analog and dynamic characteristic shows that the behavior of these CPMs is identical to that standard metal dynode PMs. In particular, these CEM allow to built fast detectors with transit time of 5ns, a high dynamic rate and a linear range greater than 250 pC/pulse. Issuing from a masse production technique, these components enable to facilitate the detector manufacture and, then, to cut down the production cost.

To make these multipliers completely operational, the activation conditions, which are now well known, must be extended to the innermost dynodes. This fabrication process development phase exceeds the capabilities of a simple research laboratory. It requires the competence and motivation of the photoelectric industry .

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