

# CMS Internal Note

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## **VPTs with “anomalous” gain**

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### **Abstract**

The new results on the design and characteristics of VPT's with a gain of 30÷50 are described. These VPT's were designed and produced at IHEP and MELZ in the last years. This year MELZ has started to product VPT's with radiation hardness Ce-doped photocathode window and such gain.

## Introduction

Energy resolution of the CMS endcup of the ECAL along with other factors is defined by the VPT gain, which determines the equivalent noise value [1].

The desirable value of required gain is around of 10 in 4 T axial magnetic field. In the same time the mean gain value of tested VPT's with bialkali dynodes is not more than 12-16 [1,2] and goes down by factor of 2 in the magnetic field of 4 T.

Two years ago at IHEP, in collaboration with MELZ the first samples of VPT's with a gain more than 30 were designed and successfully tested. This year MELZ started to produce the fine-mesh VPT's with the gain of 30-50.

At first, the data on secondary emission gain of bialkali  $K_2CsSb$  and multialkali  $Na_2KCsSb$  dynodes were obtained by A.M.Sommer [3] and these gain values were around 25 and 30 correspondingly under electron energy of 800V. Therefore in the tested VPT's [1,2] the all possibilities of bialkali dynodes were not realized. Our results on the same type of dynode differ from data [4] by factor of two but in the side of gain up.

### 1. Parameters of VPT's with “anomalous” gain.

Schematic views of the IHEP and MELZ VPT's with gain up to 50 are shown on Fig.1a and Fig.1b correspondingly.

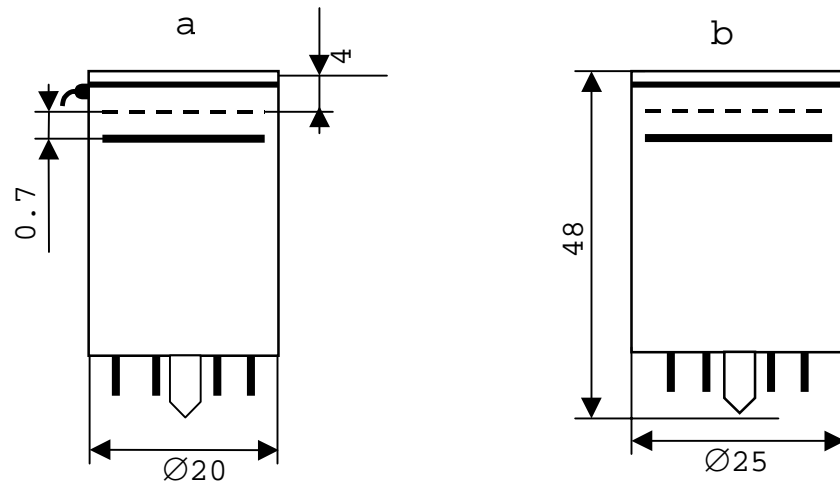


Fig. 1. Construction of IHEP VPT (a) and MELZ VPT (b).

The construction illustrated on the Fig. 1a has a distance between a photocathode and dynode on internal VPT glass surface more in 1.5 times than Fig. 1b construction case. As a result the maximum value of cathode-dynode high voltage for Fig 1a construction is on a few hundreds volts more in comparison with Fig. 1b construction and attains 3000V.

The measurements of VPT gain were carried out under the pulse illumination of photocathode with a help of LED's. The width of a light pulse was around 100 ns. Output pulse photocathode current under VPT gain measurement was  $10 \div 20$  mA.

Fig. 2 demonstrates power supply and measurements scheme.

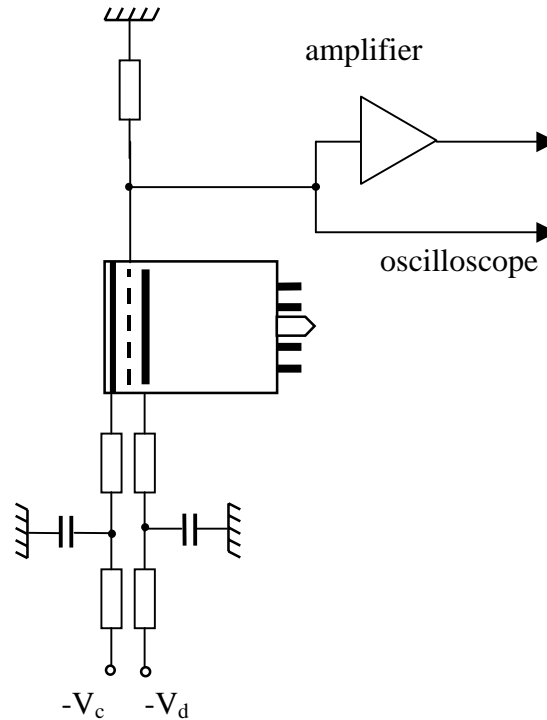


Fig. 2. Scheme of measurement.

Typical dependencies of IHEP VPT's gain from dynode-anode electric field under optimization of thickness of Sb layer evaporated on dynode bases and optimization of a dynode activation regime. These VPT's have the mesh anode  $20 \frac{1}{\text{mm}}$  and different photoelectron energy values are shown on Fig. 3. The dependencies of a gain from photoelectron energy are presented on Fig. 4. These results came from an nonradiation hard photocathode window. The blue sensitivity of photocathode attains  $50 \text{ mA/W}$  ( $\lambda=410 \text{ nm}$ ).

Having got the “anomalous” gain the main problems are to design radiation hard VPT's with fine mesh anodes (to operate in 4 T axial magnetic field).

A few tens of VPT's with C-95-1 glass (Ce-doped) photocathode window were produced at MELZ. The main characteristics of designed VPT's are presented in Table 1. For IHEP VPT's the dependencies are very similar to the ones showed on Fig. 3, Fig.4 for MELZ VPT's.

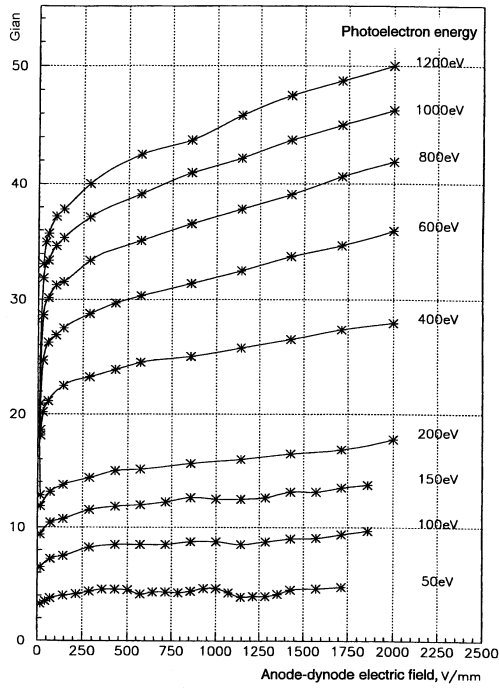


Fig. 3.

Dependencies of a VPT gain from anode-dynode electric field under different photoelectron energy values

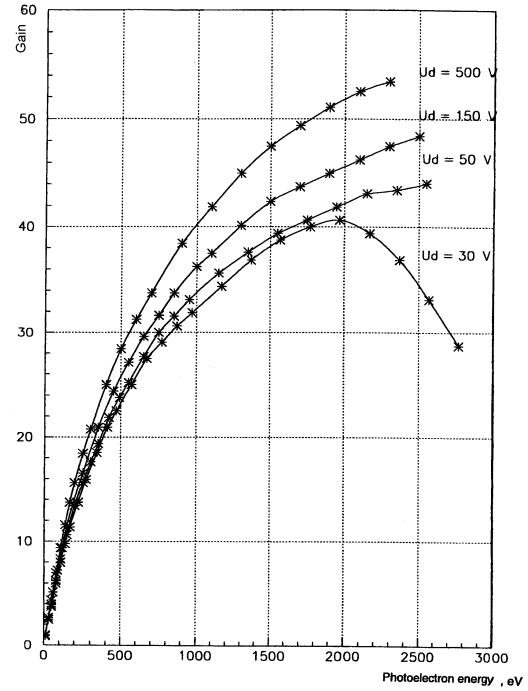


Fig. 4.

Dependencies of a VPT gain from photoelectron energy under dynode voltage values

Table 1

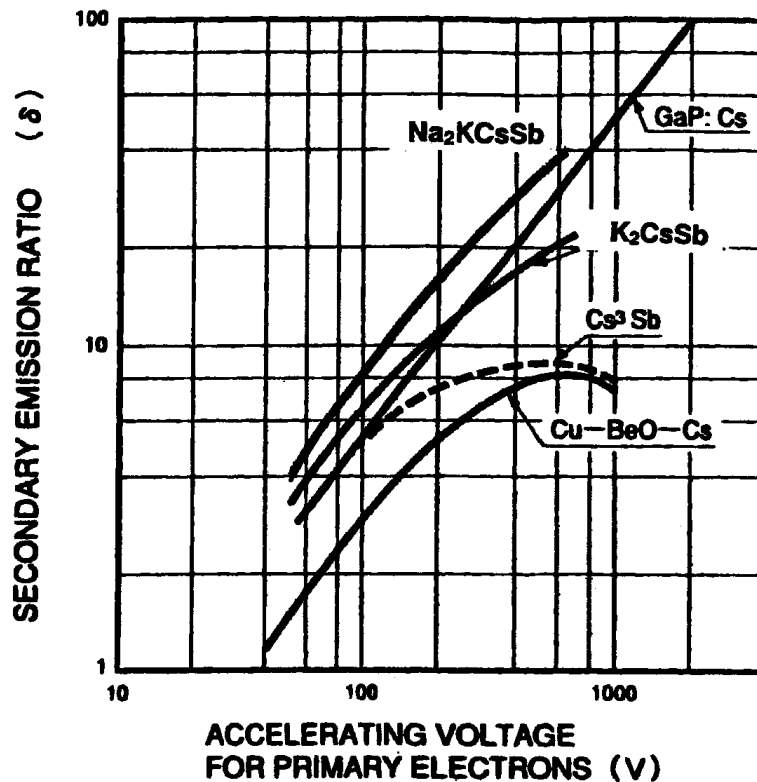
### Main characteristics of MELZ VPT's

• , producer	$S_{ph.cath}$ 410 nm, mA/W	Gain .	HV nom., kV	HV max., kV	Anode signal ampl. from LED $\lambda_{max}=430$ nm	Photocathode signal ampl. From LED $\lambda_{max}=430$ nm	Type of mesh
1, Hamamatsu	80	9	1	1	1	1	
48, MELZ	54	47	1.85	2.4	2.34	0.3	Cu, 60 l/mm
50, MELZ	50	39	1.85	2.4	2.2	0.34	Cu, 60 l/mm
54, MELZ	51	46	1.85	2.05	3.1	0.42	Cu, 60 l/mm
57, MELZ	62	20	1.85	2.4	2	0.64	Cu, 100 l/mm
59, MELZ	47	44	1.85	2.4	2.6	0.38	Cu, 100 l/mm
61, MELZ	62	35	1.85	2.85	2.65	0.47	Si, 100 l/mm
63, MELZ	51	35	1.85	2.45	2.5	0.44	Cu, 100 l/mm
64, MELZ	44	37	1.85	2.45	2.2	0.36	Si, 100 l/mm
65, MELZ	40	36	1.85	2.4	1.8	0.3	Si, 100 l/mm
66, MELZ	49	35	1.85	2.05	2.2	0.38	Si, 100 l/mm
69, MELZ	52	41	1.85	2.45	2.5	0.38	Cu, 60 l/mm
71, MELZ	53	52	1.85	2.45	2.24	0.24	Cu, 60 l/mm
72, MELZ	52	80	1.85	2.0	3.3	0.54	Cu, 60 l/mm
74, MELZ	40	49	1.85	1.9	1.7	0.45	Cu, 60 l/mm
79, MELZ	48	69	1.85	2.0	3.9	0.72	Cu, 60 l/mm
88, MELZ	55	75	1.85	2.0	4	0.72	Cu, 60 l/mm
Mean, MELZ	50.6	46	1.85	2.3	2.6	0.44	

As we see from Table 1 the gain of MELZ VPT in a few times more than Hamamatsu VPT (R2148) case, but their mean blue photocathode sensitivity at least two times less so, there is a room to improve the output signal from MELZ VPT.

## 2. Possible nature of process for “anomalous” gain.

The known results of secondary emission coefficient ( $\delta$ ) measurements for  $K_2CsSb$ ,  $Na_2KCsSb$  and  $CsSb$  dynodes are shown on Fig.5 [4,5]. For bialkali and multialkali dynode cases from this data it's not seen the significant saturation of  $\delta$



from photoelectron energy. That is  $\delta$  can increase under energy more than 1000V. Besides that, it is unknown what were the values of electric fields “collected” secondary electrons from a dynode for the case of Fig. 5 data. At the same time curves presented on Fig. 3, Fig. 4 shows, that the dependence  $\delta$  (gain in the case of Fig. 4) can be sufficiently strong.

Fig. 5.

It seems to be the explanation [5] of the high emission coefficient value of these dynodes only due to the effective Negative Electron Affinity (NEA) similar to that of  $GaP(Cs)$  is not sufficient for the case of the  $K_2CsSb$  dynode. Indeed, the dependencies of Fig. 3 show that gain of the VPT increases with stepping up of electric field in the dynode-anode gap and a gain saturation takes place for small photoelectron energy only. It means, that electric field penetrates to the dynode material on the depth of photoelectron range in  $K_2CsSb$  dynode at least. It can be

real, as  $K_2CsSb$  matter is the semiconductor with very high resistivity of  $6 \cdot 10^9$  Ohm/cm and number of carriers can be insufficient to compensate outside electric field.

The following qualitative model seems to be more real:

1.  $K_2CsSb$  layer has relatively small value of the surface potential barrier.
2. Electric field inside  $K_2CsSb$  dynode "warms up" and transports secondary electrons to the surface, but doesn't lower the value of potential barrier on the surface of dynode as there is the plateau of the gain in the region of the small value of photoelectron energy (Fig. 4.).

### 3. Conclusions

1. Received VPT gain values of  $40 \div 50$  is not more anomalous than gain of around 10, received for Hamamatsu and RIE VPT's.
2. The technology designed at IHEP and MELZ permits to product VPT's with a gain of  $40 \div 50$  among with radiation hard photocathode window.
3. Mean value of MELZ VPT's signals (430 nm LED) exceeds Hamamatsu R-2148 one about 2 times and the R&D to improve the photocathode sensitivity are still in progress.

### References

- [1] "The Electromagnetic Calorimeter Project. TDR" CERN/LHCC 97-33 CMS TDR4, p. 128-138.
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- [3] A.H. Sommer J.Appl. Phys., Vol 43, N 5 , 1973
- [4] "Photomultiplier tube. Principle to application, Photonics our business" Hamamatsu, March 1994
- [5] RCA "Photomultiplier handbook theory. Design. Application", p. 23