Compact vacuum phototriodes for operation in strong magnetic field

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Abstract

The results of tests of 1" vacuum phototriodes in a magnetic field up to 4.5 T are presented. It was found that output amplitude decreases by about 6% per tesla in the magnetic field range from 2.0 to 4.0 T. For devices with an anode mesh pitch of 16μm, the output amplitude at 4.0 T is 30% lower than that at zero field.

1 Introduction

Scintillation calorimeters which are an important part of all modern elementary particle detectors are often located in harsh environment of strong magnetic field and high radiation fluxes. Photodetectors having to operate in such conditions have to satisfy special requirements.

A photodetector type satisfying these requirements is the vacuum phototriode (VPT), which is a single-dynode photomultiplier tube with proximity focusing of photoelectrons. This makes it possible to operate in a strong axial magnetic field. Use of radiation-hard glass for VPT manufacturing makes it also tolerant to high doses of ionizing radiation. VPTs are already widely used in calorimetry, for example in the detectors DELPHI [1,2] and OPAL [3] at LEP. They are also planned for use in the end-cap PbWO calorimeter of the CMS detector for LHC [4].

Another type of photodetector for calorimetry, the avalanche photodiode (APD), shows also excellent performance in strong magnetic field [5]. APDs have how-

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ever some drawbacks, such as a small active area and direct counting of charged particles which can make VPTs preferable in some cases.

Several years ago VPTs with the capability to work in magnetic fields up to 2.5 T [6] were developed in BINP; about 3500 devices of this kind operate in the electromagnetic calorimeters of the SND [7], CMD-2 [8] and KEDR [9] detectors. In 1999 a new low cost VPT was developed for operation in strong magnetic field. In this paper the results of tests of the new devices in a magnetic fields up to 4.5 T are presented, and its performance compared with that of similar photodetectors described in [10,11].

2 Phototriode parameters and experimental set-up

The VPTs were manufactured using conventional bulb technology described elsewhere in [6]. All VPT electrodes are connected to pins on its base. The semitransparent bialkali photocathode was formed on the inner surface of a window glass S52-1 or S52-2 with transparency of more than 96% in the wavelength range from 300 to 900 nm. The quantum efficiency of the photocathode in the maximum of spectral sensitivity measured with calibrated light source was about 20%.

The VPT performance in magnetic field depends on the anode mesh pitch. The smaller the pitch, the larger fraction of secondary emission electrons from the dynode is collected on the anode, but on the other hand a smaller part of accelerated photoelectrons reach the dynode. Prototypes with the anode mesh pitch s of 250, 100, 50 and 16 μm were manufactured. The devices height is 40 mm, tube diameter is 25 mm, the photocathode spectral sensitive region is from 360 to 600 nm, maximum of photocathode spectral sensitivity is $\lambda_{max} =$ 420 nm, total photocathode sensitivity is 95μA/lm, typical quantum efficiency at λ_{max} is about 20%, dark current is less than 1 nA, gain without magnetic field is 15 for $s = 50\mu$m and 10 for $s = 16$ μm, anode mesh transparency is 60% for $s = 50$ μm and 52% for $s = 16$ μm.

The layout of the test system used to check the operation in high magnetic fields is shown in Fig.1. Measurements were performed using a charge sensitive preamplifier with a sensitivity of 0.7 V/pC and a shaper with integration and differentiation time constants of 2μs. Green LED with wavelength of about 520 nm was used as a source of light signals. A magnetic field with a strength up to 4.5T was produced by a superconducting solenoid. The VPT axis could be tilted by up to 30 degrees with respect to the magnetic field direction.

The dependences of output signal on photocathode and dynode voltages at zero magnetic field are shown in Figs.2,3. For further measurements the photocathode and dynode voltages were fixed to $U_c = -1000$V and $U_d = -200$V respectively.

After absorption of high dose of radiation the input glass window may darken thus decreasing the VPT sensitivity. The dependence of transparency of VPT windows made of S52-1 and S52-2 glass on the radiation dose is shown in Fig.4. The radiation harder S52-2 glass was chosen as a material for the VPT window.

3 VPT performance in magnetic field

The dependence of VPT output amplitude on the magnetic field strength was measured both illuminating the entire photocathode area, and its central part (10mm in diameter). Fig.5 shows the dependences of the output signal on magnetic field for VPTs with different anode mesh pitches in case of illumination of entire photocathode. The amplitude drop at $B = 4.0$T varies from 70% for tubes with $s = 250\mu$m mesh to 30% for $s = 16\mu$m. The dependence for $s = 50\mu$m and $s = 16\mu$m with illumination of the central part of photocathode is shown in Fig.6. The output signal decreases by about 6% per tesla in a range of field from 2.0 to 4.0T. The difference in amplitude drops for illumination of the full photocathode area and of its central part can be explained by effective cut-off of the peripheral area of the photocathode in axial magnetic fields. Photoelectrons from this area, propagating along the magnetic field, cannot reach the dynode which due to manufacture constraints has smaller diameter.

The dependence of the output amplitude on α, the angle between the magnetic field and the tube axis, is shown in Fig.7. The initial amplitude increase by $\sim$ 15% with α can be attributed to the increase of the secondary electron emission coefficient on the dynode for larger impact angles of the photoelectrons. At larger tilt angles another effect, the decrease of anode mesh transparency for photoelectrons, apparently becomes dominant. The amplitude dependence for mesh pitch $s = 50\mu$m and $\alpha = 30°$ on the magnetic field strength is shown in Fig.8.

The tests demonstrate that the VPTs with 16μm anode mesh are the best for operation in strong magnetic field. The output signal decreases by less than 30% at 4.0 T, for a angles between the tube axis and the field up to 40°. Recently, the results of the RIE VPTs (diameter of 25 mm) tests in a magnetic field were presented in Ref.[11]. The output amplitude of the device making use of a fine mesh with 100 lines per mm decreases by about 40% at 4T and $\alpha = 0°$. As reported in Ref.[10], in commercial Hamamatsu 25 mm vacuum phototetrodes the output signal amplitude decrease by about 70% in the same conditions.

4 Conclusions

We describe the development of prototypes of compact vacuum phototriodes with quantum efficiency of $\sim 20\%$ and gain $10 \div 15$ for operation in strong magnetic field. Their performance in the fields up to 4.5 T was tested. It was found that the decrease of output amplitude is about 6% per tesla in the magnetic field range from 2.0 to 4.0 T. For VPT with anode mesh pitch of 16μm the output amplitude at 4.0 T is 30% less than that without magnetic field.

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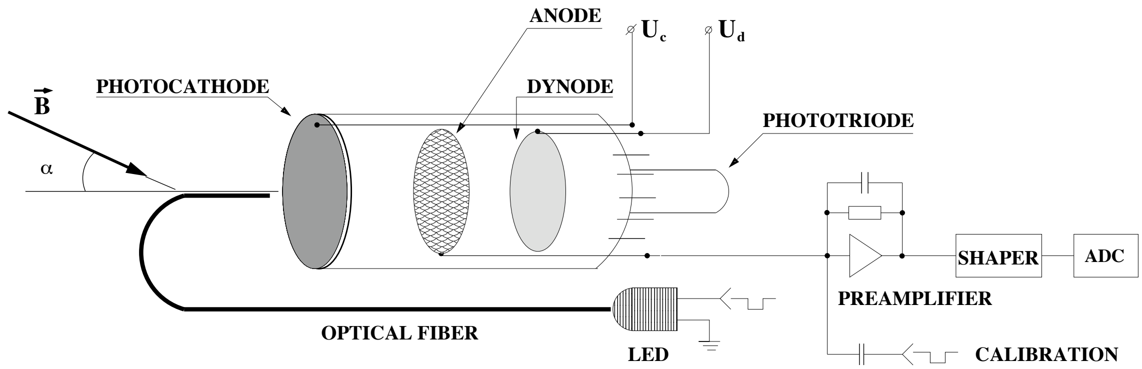

Fig. 1. Test system layout

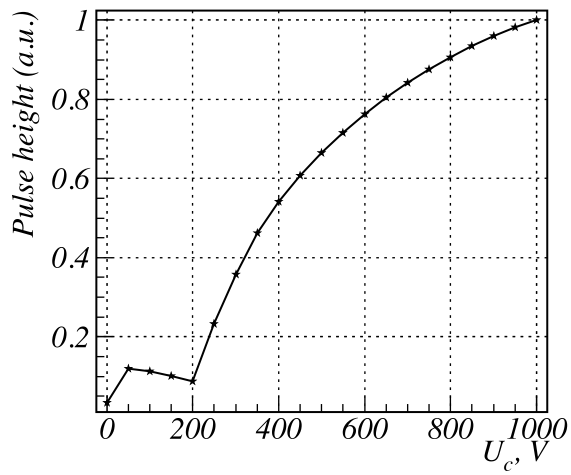

Fig. 2. The VPT output signal as a function of photocathode voltage U_c. The dynode voltage is fixed to $U_d = -200$V. The kink at $U_c = -200$ V reflects the transition from photodiode to a phototriode operation mode of the device.

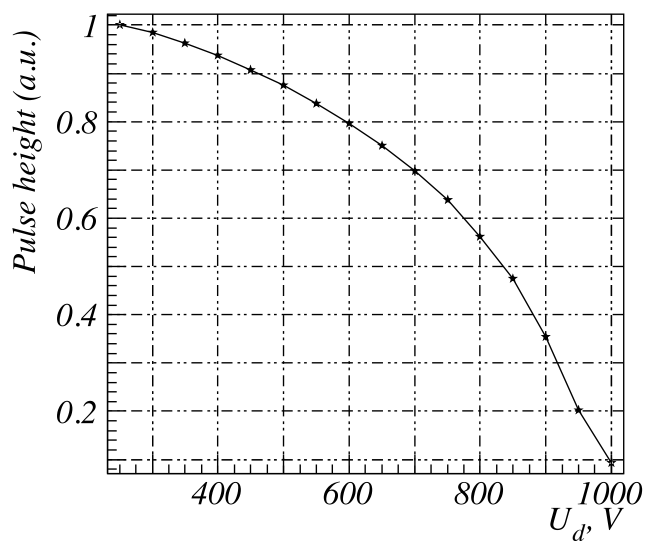

Fig. 3. The VPT output signal as a function of dynode voltage U_d. The photocathode voltage is fixed to $U_c = -1000$V

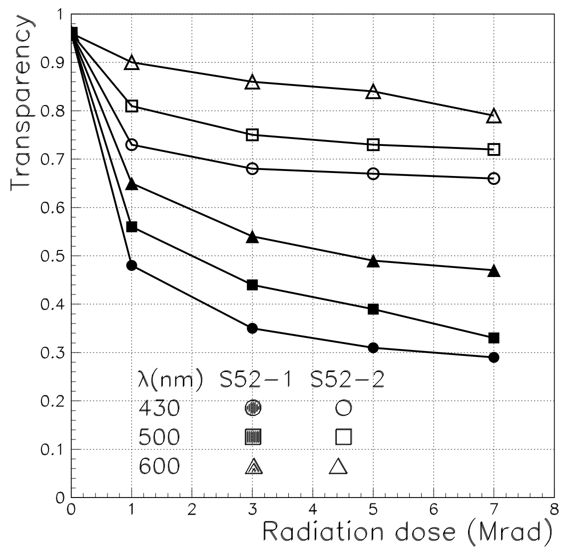

Fig. 4. Transparency of S52-1 and S52-2 glasses, 1 mm thick, as a function of absorbed radiation dose for different wavelength.

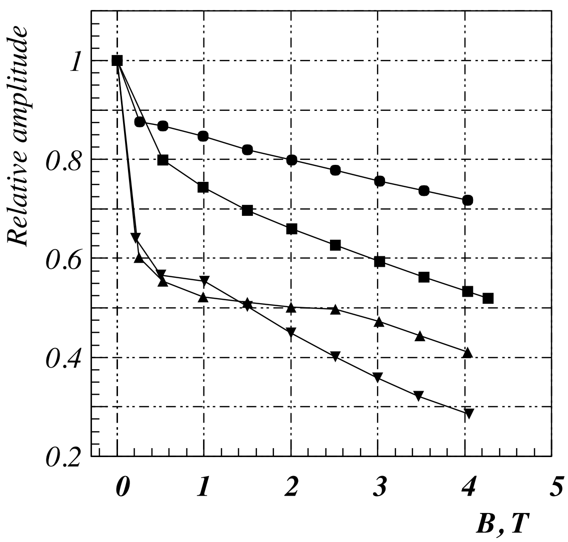

Fig. 5. Relative output amplitude as a function of magnetic field at $\alpha = 0°$ for VPTs with anode mesh spacing 16μm (●), 50μm (■), 100μm (▲), 250μm (▼). Full photocathode illumination.

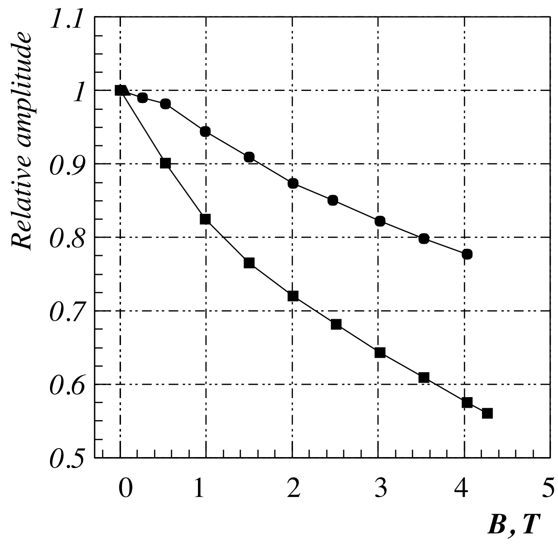

Fig. 6. Relative output amplitude as a function of magnetic field at $\alpha = 0°$ for VPTs with anode mesh spacing 16μm (●), 50μm (■). Illumination of the central part of photocathode.

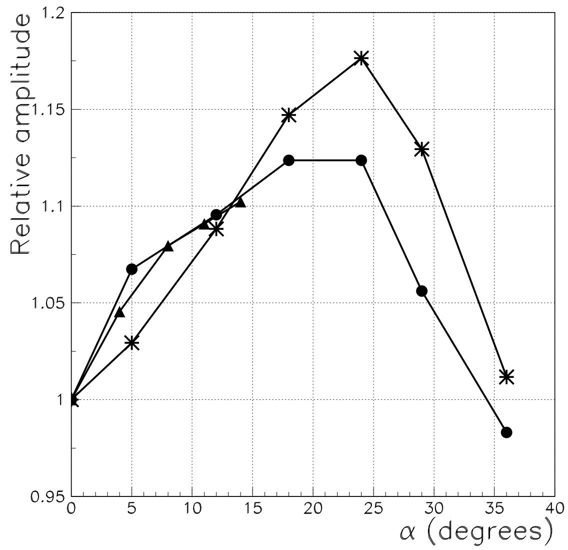

Fig. 7. Relative output amplitude as a function of tilt angle α in 4T magnetic field for VPTs with anode mesh spacing 16μm (•), 100μm (▲) in case of full photocathode illumination. The line through ($*$) corresponds to VPT with mesh spacing 16μm, when only the central part of photocathode was illuminated.

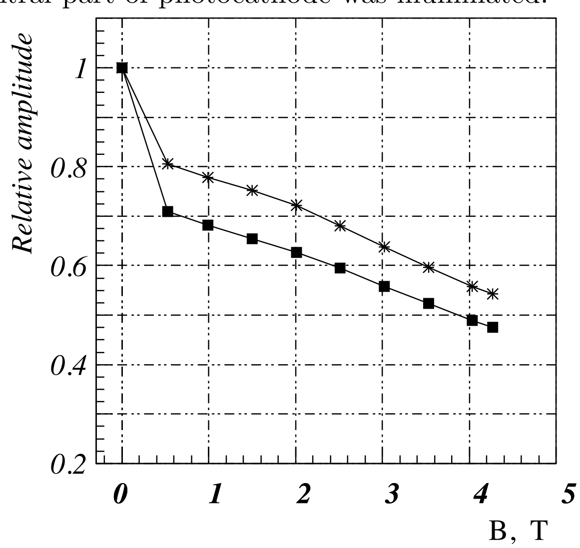

Fig. 8. Relative output amplitude as a function of magnetic field at $\alpha = 30°$ for VPT with anode mesh spacing 50μm and full photocathode illumination (■) or illumination of the central part only ($*$).