Fermi National Accelerator Laboratory

FERMILAB-TM-2039

Effect of Hybrid Photodiode Signal Increase in a Magnetic Field Parallel to the HPD Electric Field

J. Freeman, D. Green and A. Ronzhin

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

January 1998

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

Fermilab TM-2039
January, 1998

EFFECT OF HYBRID PHOTODIODE SIGNAL INCREASE IN A MAGNETIC FIELD PARALLEL TO THE HPD ELECTRIC FIELD

J. Freeman, D. Green, A. Ronzhin

Introduction

The results of the DEP HPD test were presented earlier[1,2,3]. The 7-pixel HPD was studied in a 5 Tesla magnet [2]. Several percents of the HPD signal increased when the magnetic field was parallel or almost parallel to the HPD electric field (see Fig. 1).

Measurements

The single channel HPD of E-type with 25 mm diameter of the photocathod (PC) was tested (Fig. 2). The PC was illuminated by a fiber connected with light emitting diode (LED) or by LED itself. The fiber diameter was 1 mm. The PC illuminated in it the geometrical center. When working with the LED the illumination area was 3 mm, also was the HPD center. Fast blue LED with less than 10 ns of full time duration was applied in the measurements. The nonuniformity of the HPD response in the area of interest can be neglected by comparison with observed effects. We used a warm magnet with a pole size of 150 mm and a distance between poles of ~100 mm. The HPD was installed in the center of the magnet. The field nonuniformity was approximately 1% in the HPD area.

First measurements were accomplished in pulse mode. Presumably the HPD electric field coincides with its axis. The accuracy of the HPD axis adjustment was better than 0.3^o. The small increase of the HPD signal (at the level of 2%) was observed for the fiber or the LED at zero angle between electric and magnetic fields (Figs. 3 and 4). The signal continues to increase with the value of the field if the angles between the HPD electric and the magnetic field increase. The oscillation of the signal observed for the non-zero angle is shown in Figs. 3 and 4. The angular dependence of the signal is shown in Fig. 5. The result was the same under different light intensity in the dynamic range which was ~30.

A more thorough investigation of the LED behavior in the magnetic field could have been done. Our data showed no big difference in the HPD behavior when illuminating the HPD by the fiber or the LED for the magnetic field up to 1 Tesla. The increase of the signal can be due to the PC or the silicon. To check this the photocurrent measurements of the HPD with the silicon turned off were done.

In the case all conditions were the same except that the LED direct current mode of operation and using the HPD like a photodiode (Fig. 2). The high voltage was as before, 7 kV. The electrode of the silicon faced to the HPD photocathode was grounded through the Keithley ampermeter.

Photocurrent measurements are sensitive to temperature so the apparatus was warming up more than 3 hours and the data was then collected at a room temperature. The photocurrent was adjusted at the level of 3uA under which the noise current, with the LED turned off, was less than 3 nA. The measurement was done with the magnetic field parallel to the HPD electric field. The value of the magnetic field changed. The very small decrease of the photocurrent with the increase of the value of the magnetic field, if it even exists, can be neglected in future consideration because we were limited by our experimental accuracy which is ~0.3% (Fig. 6).

The same order of the effects was observed when tilting the HPD by the small angles to the magnetic field. We can now conclude that the signal increase is mostly due to the silicon.

Discussion

Let us start from the simplified structure of the silicon in the initial photoelectron direction. It consists of 100 nm of the dead layer, and the rest of the 300 um are of the silicon. The initial photoelectron produces electron hole pairs in 1 um of the silicon losing the part of the energy in the dead layer.

One can consider processes in the silicon that can increase the output signal with the longitudinal magnetic field. One of the processes is a backscattered electron in the silicon. For 13 keV electrons has a backscattered fraction of 18%. This fraction deposits an average of 0.4 of their 13 keV energy with the sensitive diode volume [4]. The electrons lose more energy in the dead layer than in the photoelectrons when depositing in output signal because of incident angles due to a longer track in the silicon dead layer (Fig. 7).

The backscattered electrons compress along Z-axis by the longitudinal magnetic field in accordance with its transverse momenta (Fig. 8). The scale of the compression depends on the momenta and the value of the magnetic field. This will be estimated numerically.

The HPD has a 23 mm diameter sensitive area, 5.6 mm spacing between photocathode and silicon and applied high voltage 7 kV. The maximum distance of the backscattered electron along X (45^o of incident angle) will be 11.2 mm. Some of the electrons can leave the silicon sensitive area which is 23 mm and 3 mm for the LED. The transverse momenta of the electron are 60 keV/c. When applying the 1 Tesla field the radius of rotation around Z (B-field direction) will be 0.2 mm for the electron. Presumably all backscattered electrons collected on the silicon sensitive area by the applied field increased the signal by 1-2%. That value is consistent with estimation based on the spectra of the backscattered electrons[5].

The effect is important for the finely pixelized HPD. One can suggest less crosstalk with the longitudinal magnetic field. The magnetic field can improve the HPD properties in that sense.

For the longitudinal magnetic field, the effect is not caused by the difference in the energy losses of the backscattered electrons in the silicon dead layer. The incident angles of the electrons are the same with the magnetic field also as without it [6].

As a result the increase of the signal at zero angle can be explained due to the additionally collected backscattered electrons on the silicon sensitive area which are lost without the field. A little more signal increase for the small angles probably relates with the redistribution of the energy losses of the backscattered electrons in the silicon dead layer because of the angles of the incidence changes when electric and magnetic fields are not parallel. Oscillation of the signals caused by the photoelectrons rotation due to the magnetic field (Figs. 3 and 4).

Another good tool to check the described effects is the gain curve (Fig. 1). The gain curve threshold is sensitive to the thickness of an HPD dead layer or to the energy loss changes of the photoelectrons and backscattered electrons in the layer in presence of magnetic field. The change of the slope of the gain curve can indicate the change of the collected charge on the silicon sensitive area.

Conclusion

The plan is to use HPD in CMS. The shift of the image on photocathode in presence of 5 Tesla magnetic field was measured[2]. It follows the tangent angle dependence between HPD electric field and the external magnetic field. The CMS requirement is to align the HPD along the magnetic field with ~1^{o} of accuracy.

Another zero angle effect of the increase of the HPD signal is presented here. We explain the increase by the focussing effect of the longitudinal magnetic field of the backscattered electrons. The effect can influence the calibration of the hadronic calorimeter. The gain curve can be used as tool to study the magnetic field effect.

The obtained data can help with the fine tuning of the HPD. The smallest signal increase and no oscillation will indicate the good alignment of the HPD along the magnetic field.

References

1. A. Baumbaugh, M. Binkley, J. Elias, et al., Test of DEP Hybrid Photodiode, Fermilab-TM-2013, 1997.
2. J. Freeman, D. Green, A. Ronzhin, et al., Test of the DEP Hybrid Photodiode in 5 Tesla Magnet, Fermilab-TM-2027.
3. J. Freeman, D. Green, A. Ronzhin, Test of HPD, SciFi97, Indiana, Notre Dame, USA, Nov. 2-6, 1997. To be published in proceedings from conference.
4. C.D. Ambrosio, T. Gys, H. Leutz, et al., Further Results on Photoelectron Counting with Small Diameter Scintillating Fibres, NIM, A 345 (1994), p. 279-283.
5. E.H. Darlington, Backscattering of 10-100 keV Electrons from Thick Targets, J. Phys. D, Appl. Phys. Vol 8, 1975, p. 85-93.
6. D. Green, Backscattering in Hybrid Photodetector Devices, Fermilab FN-662, 1997.

7 pixel HPD DEP, central pixel

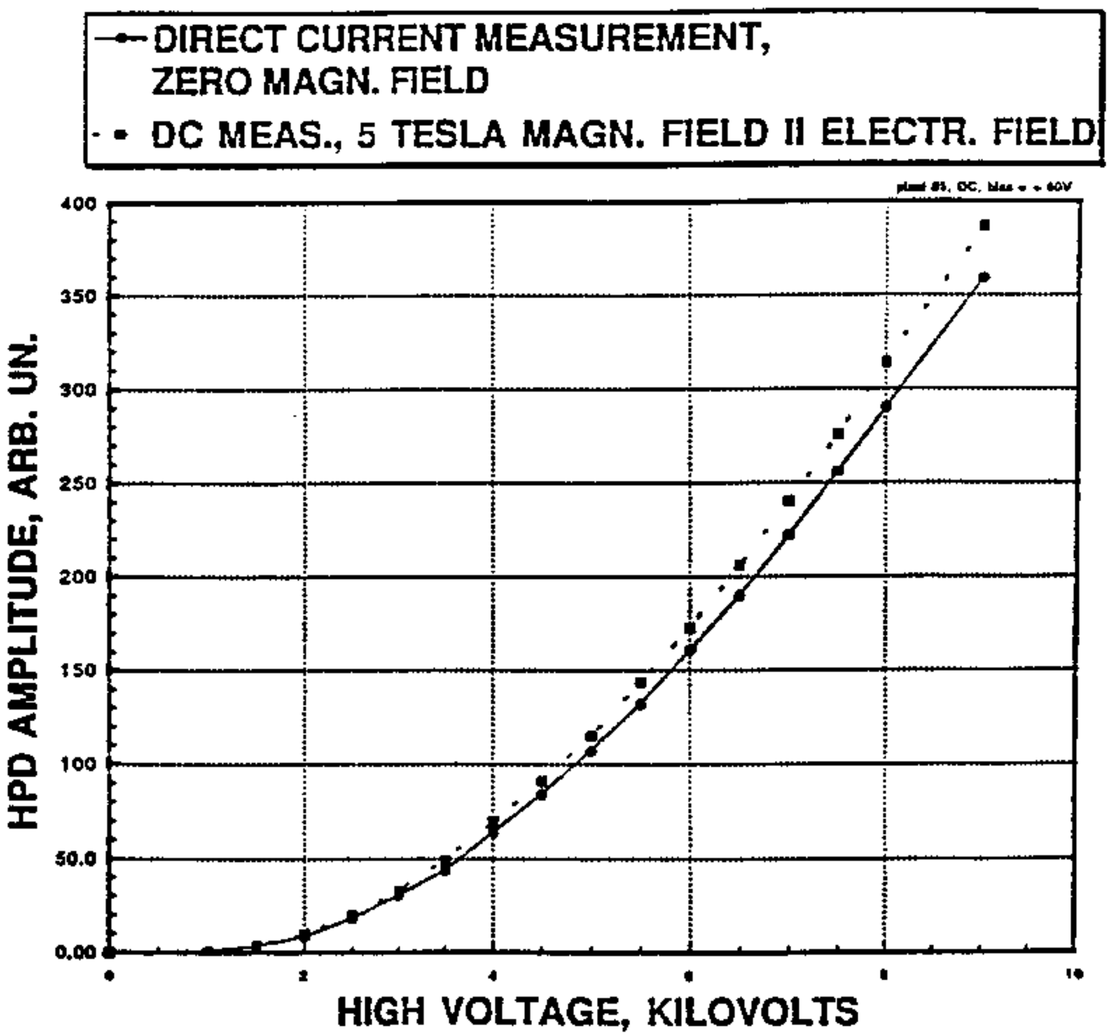

Fig. 1: The dependence of the HPD’s signal on photocathode high voltage with 5 Tesla longitudinal magnetic field and without.

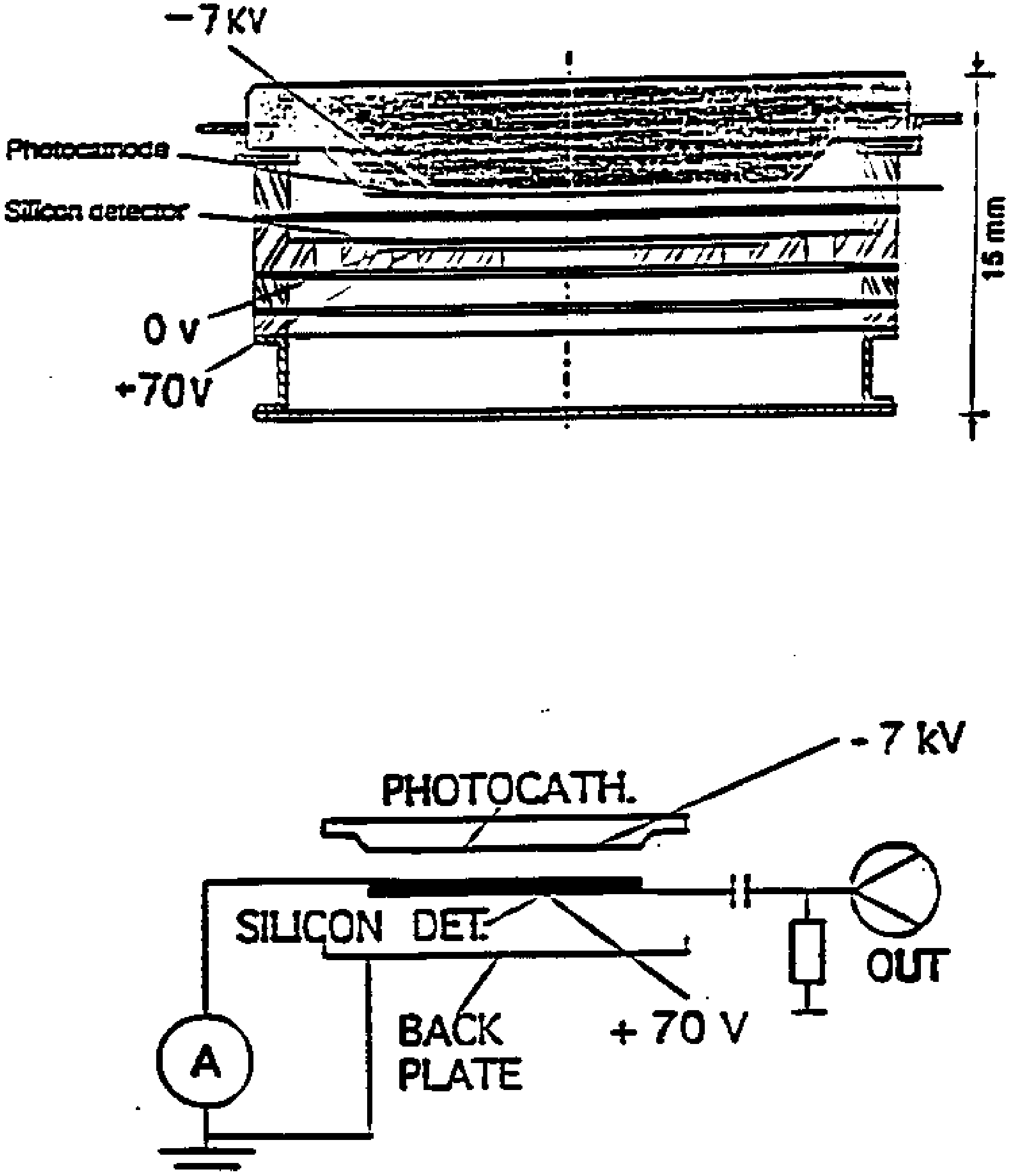

Fig. 2: Schematic view of the single channel HPD.

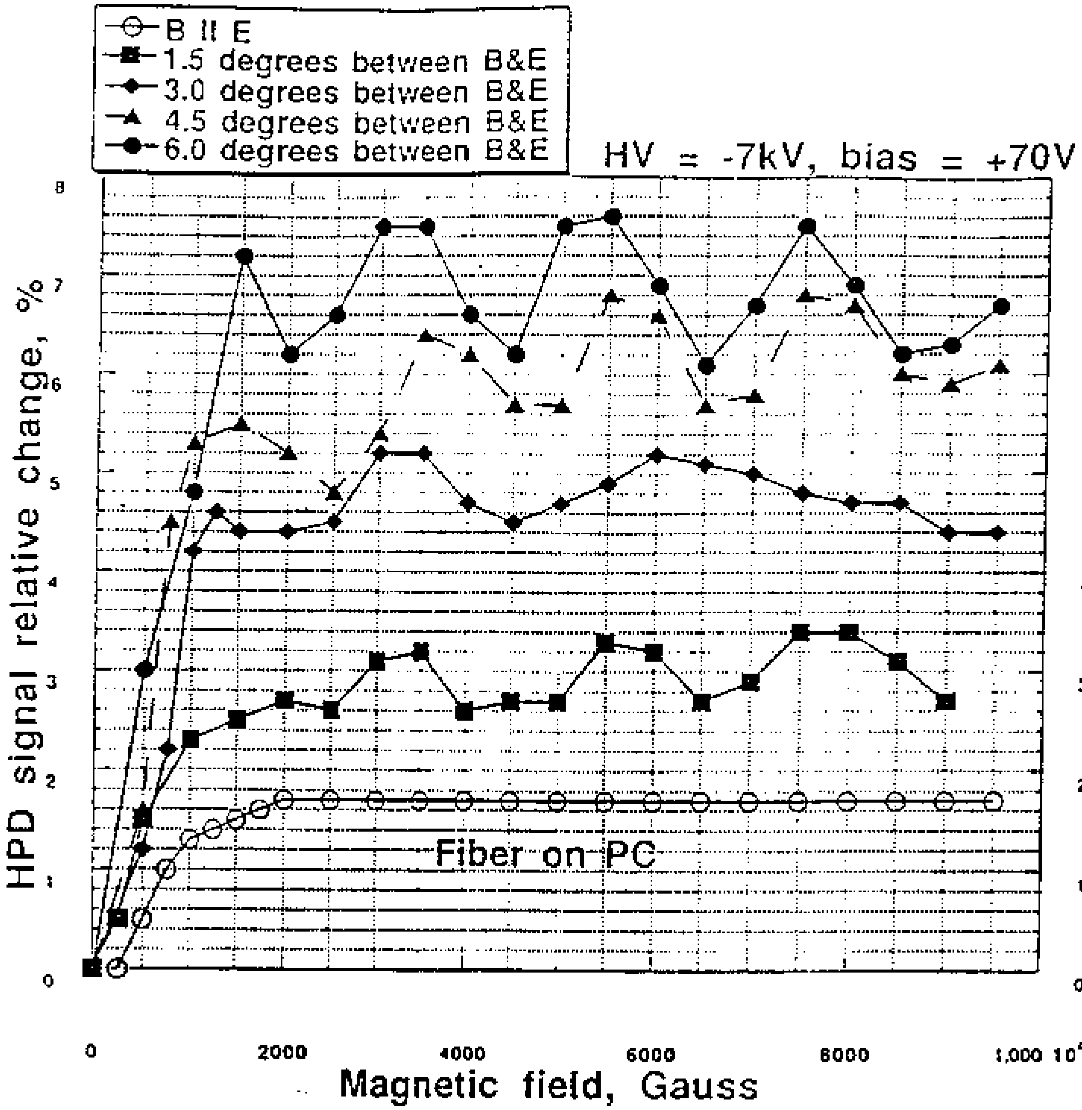

Fig. 3: The HPD signal relative change in magnetic field in dependence on the value of the field for zero angle and small angles between electric and magnetic fields. The PC illuminated by 1 mm diameter fiber at PC geometrical center.

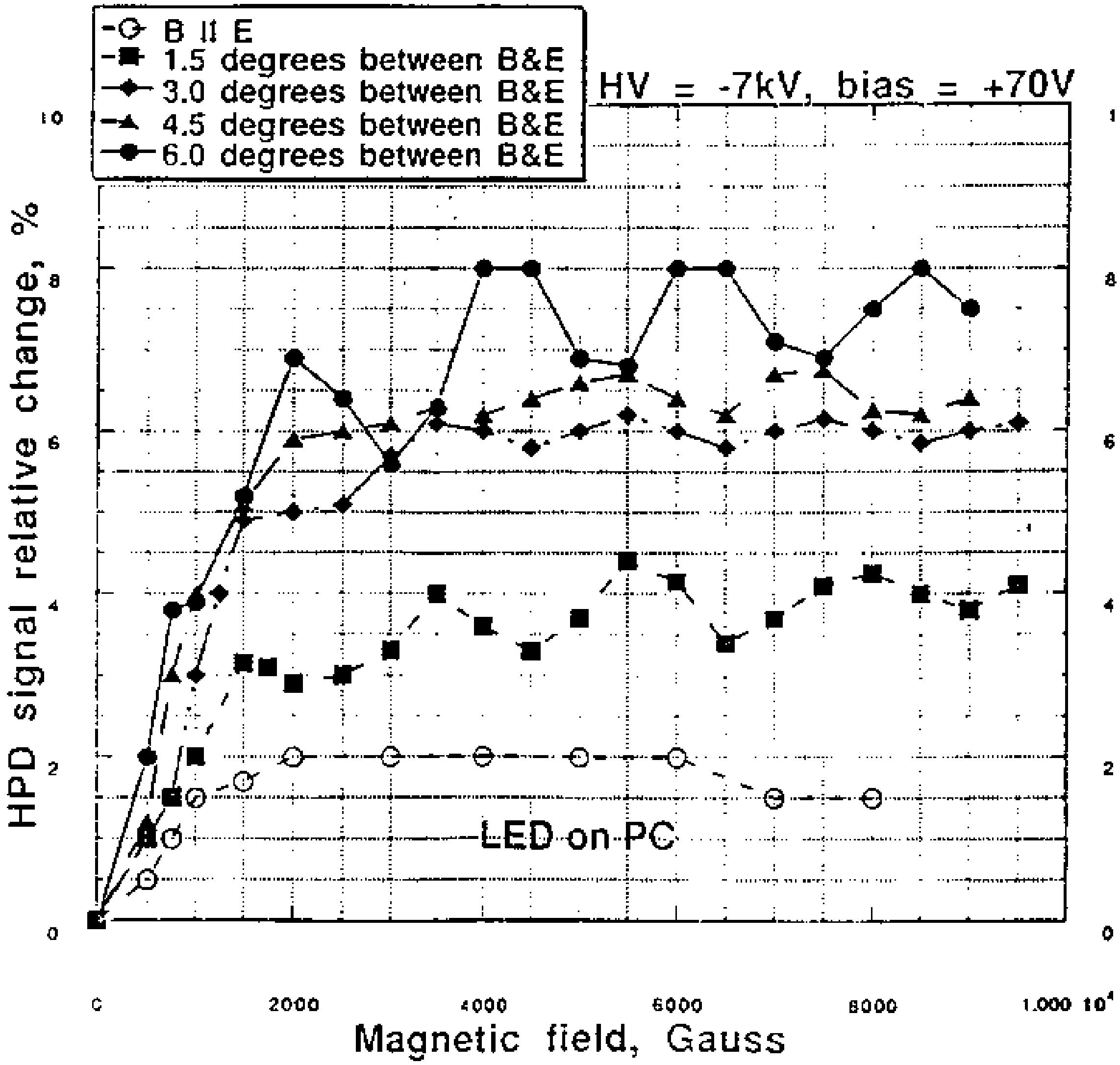

Fig. 4: The HPD signal relative change in magnetic field in dependence on the value of the field for zero angle and small angles between electric and magnetic fields. The PC illuminated by 3 mm diameter light spot of the LED at PC geometrical center.

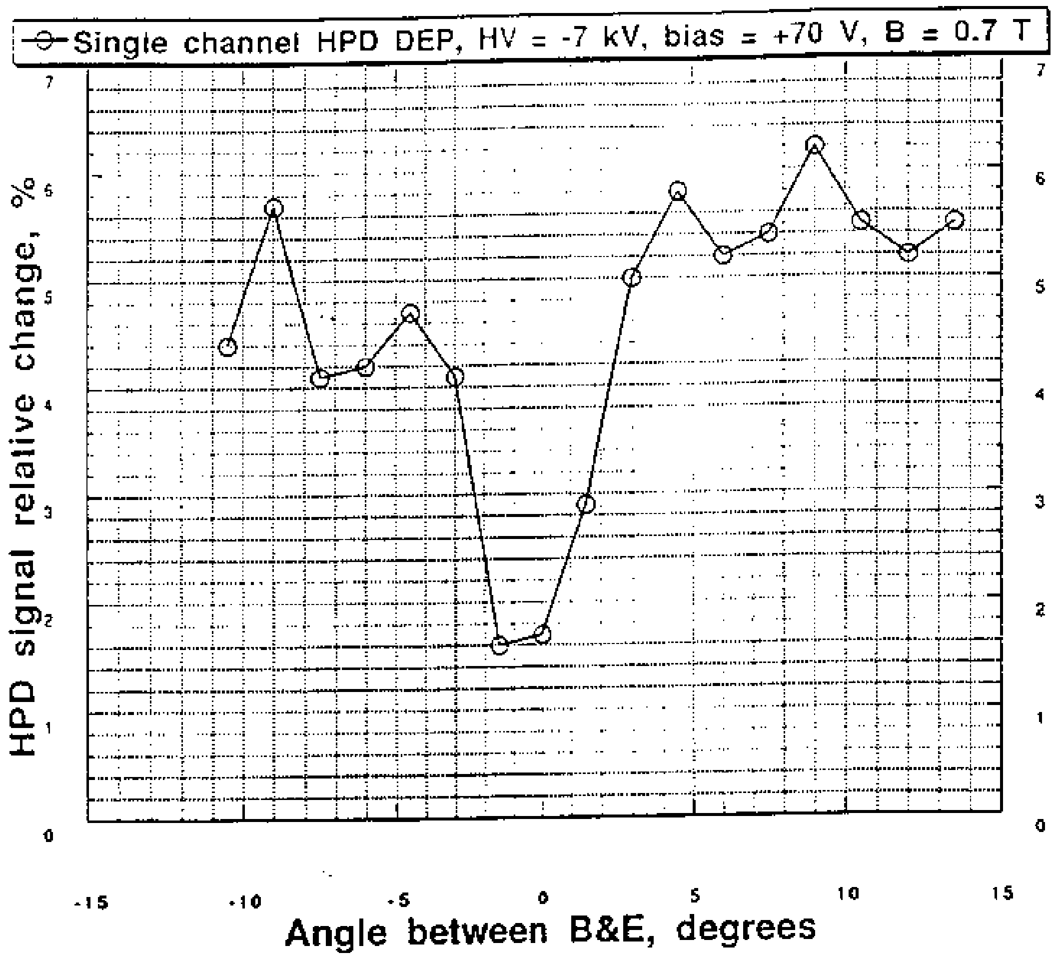

Fig. 5: The HPD signal relative change in dependence on the angle between the HPD electric field and magnetic field. The value of the magnetic field is 0.7 Telsa.

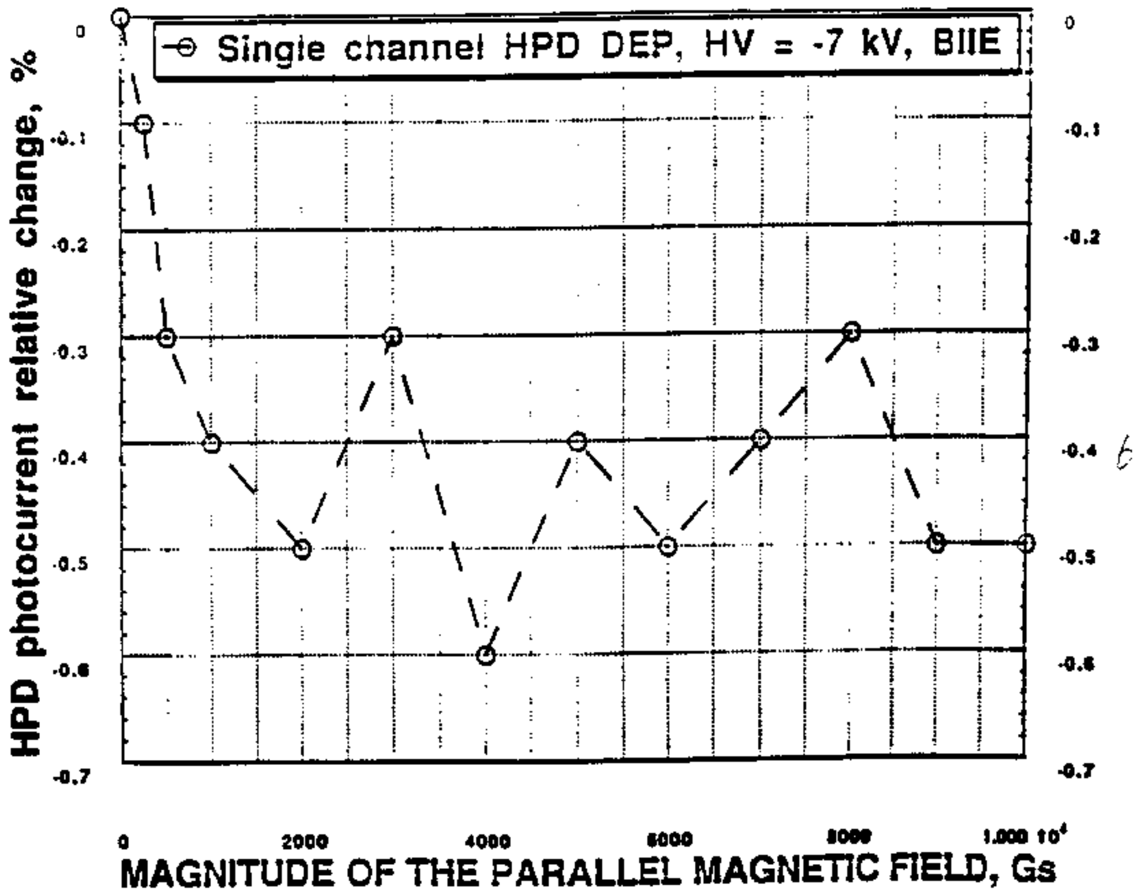

Fig. 6: The HPD photocurrent relative change in magnetic field parallel to the HPD electric field in dependence on the value of the magnetic field.

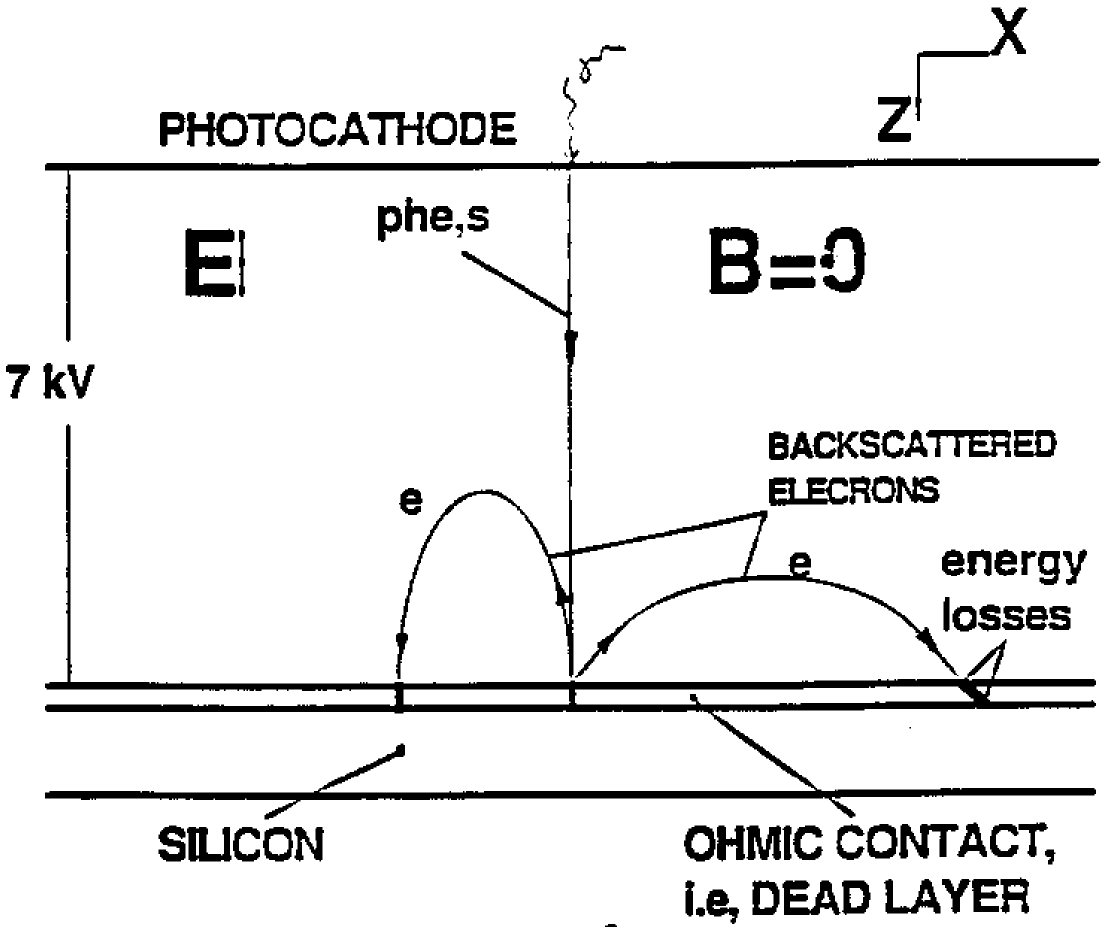

Fig 7. The illustration shows the tracks of the backscattered electrons without magnetic field.

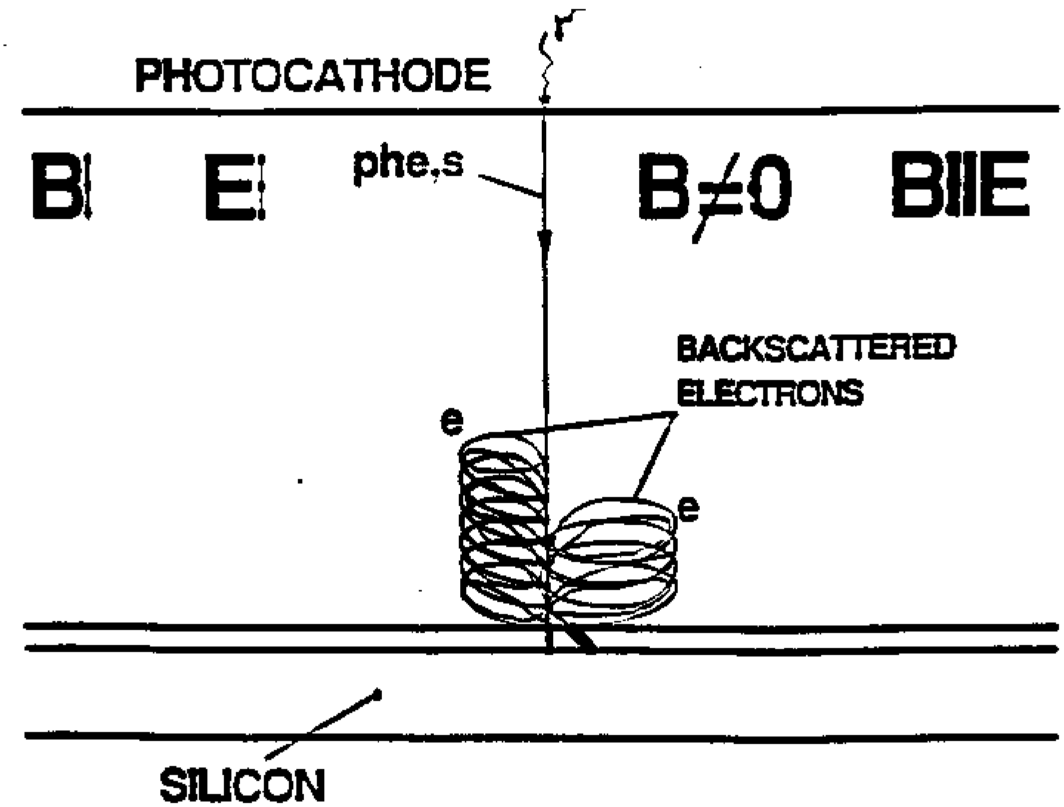

Fig. 8: The illustration of the compression of the backscattered electrons by the magnetic field parallel to the HPD electric field. The backscattered electrons returning back into the silicon sensitive area cause the increase of the HPD output signal by the magnetic field.