Performance of an R7110U-07 HAPD in high magnetic fields up to 4.8 Tesla

R.Scheuermann[1], A.Stoykov[1] and S. Cottrell[2]

[1]Laboratory for Muon Spin Spectroscopy,
Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

[2]ISIS Muon Facility,
Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, United Kingdom.

The dependence of the effective photosensitive area of an R7110U-07 HAPD on the magnetic field (up to 4.8 Tesla) was determined. The timing properties of this device are not affected in magnetic fields up to 4.8 Tesla.

Hybrid Avalanche Photodiodes (HAPDs) might be promising candidates for being used as photosensors in a new generation of μSR-spectrometers where high magnetic fields up to 10 Tesla will be applied.

In a μSR (Muon Spin Rotation) experiment the properties of matter are studied via the interactions of implanted muons with their surrounding [1]. The operation principle of a μSR-spectrometer is based on the measurement of the time intervals between the stopping of a muon in the sample and the registration of its decay positron. In a magnetic field $H = 10$ T the muon spin precession frequency is given by $f = \gamma_\mu H \approx 1.35$ GHz, where γ_μ is the muon gyromagnetic ratio. In order to detect such a precession signal the time resolution of the spectrometer (i.e., muon + positron scintillation counters) should be $\sigma \sim 0.1 f^{-1} \approx 70$ ps, i.e., ~ 50 ps per counter (FWHM $= 2.35 \times \sigma$). Achieving such timing properties is a difficult task by itself [2] and becomes even more challenging in a high magnetic field environment. The photomultiplier tubes (PMTs) should be placed far enough from the magnet in order not to be affected by the magnetic field. This requires the usage of long light guides which leads to deterioration of the timing properties of the counters.

Photosensors which could provide an alternative solution to PMTs for the detector system of a High Magnetic Field μSR-spectrometer should be as fast as PMTs and less sensitive to the magnetic field. In HAPD photoelectrons emitted from the photocathode are accelerated by a high electrostatic potential to hit an avalanche photodiode (APD), which serves as the anode of the device. The advantages of hybrid photodetectors over PMTs are their lower sensitivity to the magnetic field [3] and a small transit time spread of the electrons between phtocathode and anode [4]. The time resolution of an HAPD is limited by the amplifier noise and is inversely proportional to the signal amplitude [4]: $\sigma \sim 1/N_\mathrm{e}$, where N_e is the number of photoelectrons.

The R7110U-07 HAPD produced by Hamamatsu Photonics has an 8 mm diameter photocathode and a 3 mm diameter APD as anode. The electrons emitted from the photocathode are accelerated in an electric field of about 8 kV and electrostatically focused onto the anode. The maximum gain of the device is about 10^5 ($\sim 10^3$ and $\sim 10^2$ are the electron bombardment and the avalanche gain, respectively). The lowest sensitivity to the magnetic field is expected when the axis of the device is oriented parallel to the magnetic field. At some field the electrostatic focussing will be lost and the effective photocathode area will be reduced to the central part of 3 mm in diameter (i.e., only the proximity focusing will remain effective).

In this work we investigated the influence of a magnetic field on the effective photosensitive area and on the timing properties of this type of HAPD.

An R7110U-07 HAPD (S/N SA0092) with a BC418 plastic scintillator (⊘ 8.5 x 5 mm) glued by optical grease onto the photocathode was placed at the center position inside the superconducting solenoid of the ALC (Avoided Level Crossing) μSR-spectrometer [5]. The HAPD axis was oriented parallel to the solenoid axis (i.e., the magnetic field). The 4.2 MeV muons from the πE3 muon beamline [5] have a range of about 1.5 mm in the scintillator and produce a roughly uniform illumination of the photocathode by the scintillation light. The HAPD was operated at 7 kV high voltage and 155.0 V bias voltage. Its output signal was fed via a 70 pF capacitor to an ORTEC 9306 preamplifier (input impedance 50 Ohm, gain 100, bandwidth 1 GHz) placed close to the HAPD. The preamplifier output signals were analysed using a LeCroy "WavePro 960" Digital Oscilloscope connected via 40 m low-loss cable RG213U.

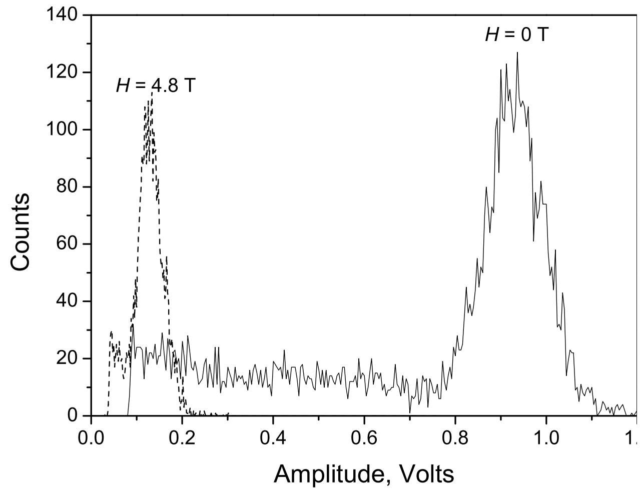

Figure 1: Amplitude distributions of the HAPD signals in zero and 4.8 Tesla magnetic field.

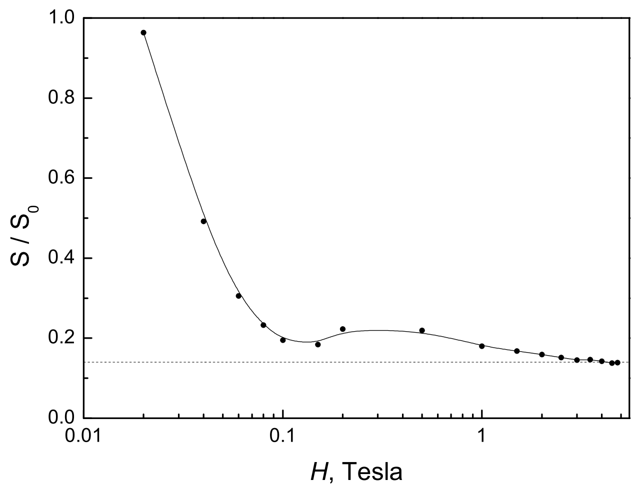

Figure 2: The change of the HAPD effective photosensitive area S with the magnetic field H (S_0 is the photocathode area). The dashed line corresponds to 0.140 – the ratio of the APD to the photocathode area. The solid line is drawn to guide the eye.

The muons stopped in the scintillator produce a signal of rather high and well defined amplitude (see Fig. 1). The amplitudes corresponding to the muon peak were obtained by fitting the gaussian function to the distributions. Figure 2 shows the dependence of the ratio $S/S_0 = A/A_0$ on the magnetic field H, where $S\,(S_0)$ and $A\,(A_0)$ are respectively the photocathode effective area and the average amplitude of the muon signal at the field H (zero field). As is seen, the effective area drops by a factor of 2 at $H \approx 400\,\mathrm{G}$ and at $\sim 1\,\mathrm{kG}$ the electrostatic focusing is practically lost. In magnetic fields above 2 Tesla we find $S/S_0 \approx 0.140$ – the value expected from the ratio of the APD to the photocathode areas. The non-monotonous decrease of S/S_0 at fields between 0.2 and 1 Tesla might be due to the focussing effect of the high magnetic field on the electrons emitted from the photocathode.

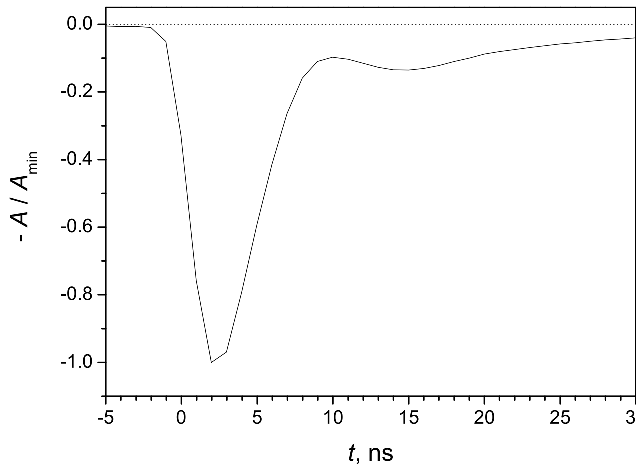

Figure 3: The averaged shape of the HAPD output pulse at $H = 4.8$ Tesla. The rise time is 2.0 ns. The pulse shape is the same as in zero field.

The timing properties of the device are not affected by the magnetic field and the averaged waveform at 4.8 Tesla (see Fig. 3) also is the same as in zero field.

Our results show that a Hybrid Avalanche Photodiode might be an alternative to a PMT in applications where fast timing in a high magnetic field environment should be achieved. **We would also like to point out that the development of proximity focussing HAPDs would be beneficial for such type of application.**

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