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| Titel | Study of Avalanche Microchannel/Micropixel Photodiodes (AMPDs) as Photodetectors for µSR Spectrometers | Ersetzt |
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**Zusammenfassung:**

This report summarizes the results of measurements of the characteristic parameters of novel high-gain avalanche microchannel/micropixel photodiodes relevant to their application as photodetectors in a high magnetic field µSR spectrometer. These results suggest a new concept for a compact scintillation detector based on an array of such AMPDs.



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The development of a 10 Tesla $\mu$SR-spectrometer sets strict requirements to its detector system, which should have a time resolution better than 300 ps (FWHM). This requires a novel approach in the design of the detector system.

Within the collaboration agreement between JINR and PSI on joint research in the field of "Development of scintillation detectors on the base of new microchannel avalanche photodiodes" we investigate the applicability of AMPDs as photodetectors for $\mu$SR-spectrometers. In 2005 a novel type of high-gain AMPDs (type ZS-2mp) was developed. These devices have a $1 \times 1$ mm$^2$ active area on a $2 \times 2$ mm$^2$ silicon substrate. Their basic parameters, such as gain, timing properties, and photon detection efficiency ($PDE$) were measured in the present work. A $1 \times 1 \times 0.2$ mm$^3$ plastic scintillator EJ-230 was glued onto the sensitive area of an AMPD using optical grease BC-630. To ensure the maximum possible ($\sim 80 - 100\,\%$) efficiency in light collection the scintillator was covered with a mylar reflector. This scintillation detector was tested by registering either 29 MeV/$c$ muons or positrons (selected by the separator setting) in area $\pi$E3. The signals from the AMPD were sent directly (i.e., without additional amplifier) to a digital oscilloscope (LeCroy WavePro 960 DSO). The amplitude distributions of the signals from positrons and muons, and also of "dark" (one-photoelectron, 1phe) signals are shown in Figure 1.

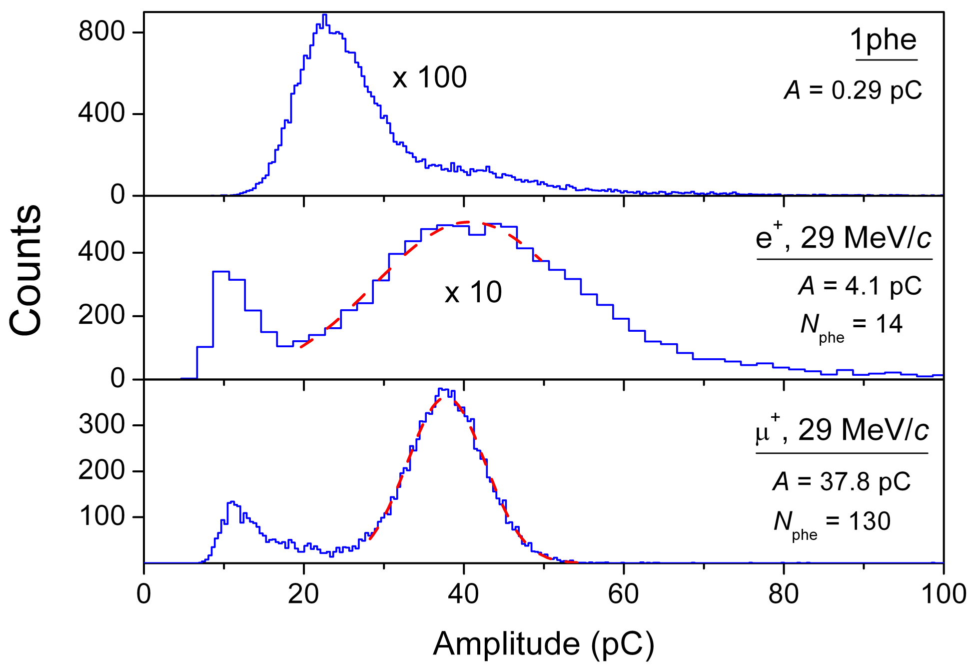


Figure 1: Charge distributions of signals from a detector based on a $1 \times 1$ mm$^2$ ZS-2mp AMPD with a $1 \times 1 \times 0.2$ mm$^3$ EJ-230 scintillator. The distributions for 29 MeV/$c$ positron and muon signals are compared with that for the "dark" (1phe) signals. The values of $A$ given in the plots are the mean amplitude for 1phe signals, and the most probable amplitudes for $e^+$ and $\mu^+$ signals.

From the mean amplitude of the 1phe signals ($A_{\rm 1phe} = 0.29$ pC) we determine the AMPD gain as $\sim 2 \cdot 10^6$. The most probable amplitude $A_e$ for positrons (minimum ionizing particles at this energy) corresponds to $\approx 14$ primary photoelectrons ($N_{\rm phe} =$

$A_e/A_{1\mathrm{phe}}$), and for muons it is about 9 times higher ($A_\mu/A_{1\mathrm{phe}} \approx 130$). An estimate for the $PDE$ of AMPD was obtained from:

$$\frac{A_e}{A_{1\mathrm{phe}}} = (dE/dx)_{\mathrm{MIP}} \cdot \rho \cdot d \cdot LE \cdot CE \cdot PDE \ ,$$

where $(dE/dx)_{\mathrm{MIP}} = 2$ MeV/(g/cm$^2$), $\rho = 1$ g/cm$^3$, and $d = 0.2$ mm are the stopping power of a plastic scintillator for minimum ionizing particles (MIP), its density and thickness, respectively; $LE$ is the light yield of the scintillator (9700 ph/MeV [1]); $CE$ is the efficiency of light collection from the scintillator to the AMPD. Assuming $CE = (80 - 100)\,\%$ we estimate $PDE$ as $3.6 - 4.5\,\%$ for the spectrum of the EJ-230 scintillator (maximum emission at $\sim 390$ nm).

Figure 2 shows averaged waveforms for 1phe and $\mu^+$ - pulses. The time response of the AMPD is very fast – the risetime of 1phe pulses is $\tau_{\mathrm{r}} = 1.1$ ns. For the scintillation pulses from muons $\tau_{\mathrm{r}}$ increases to 1.3 ns due to the finite width (1.3 ns) of the scintillator light pulse. This excellent time response and the measured $PDE$ should lead to a rather good time resolution of the detector even for minimum ionizing particles. This was tested using a $Sr^{90}$ radioactive source. A telescope of two identical AMPD based detectors was build and set up to detect electrons from $Sr^{90}$. The signals from the detectors were amplified using a one-stage MAR-6 amplifier (bandwidth $\approx 400$ MHz, gain 10; such an amplifier is described in [2]) and sent to constant fraction discriminators type ORTEC CFD935. After amplification the height of 1phe signals was about 40 mV. The thresholds of the discriminators were set to 150 mV (i.e., above 3 phe). The detectors gave “start“ and “stop“ signals for a time-to-digital converter (TDC) of type ORTEC 9308 pTA. Figure 3 shows the time distribution of “stop“ relative to “start“ signals with a time resolution of 850 ps (FWHM).

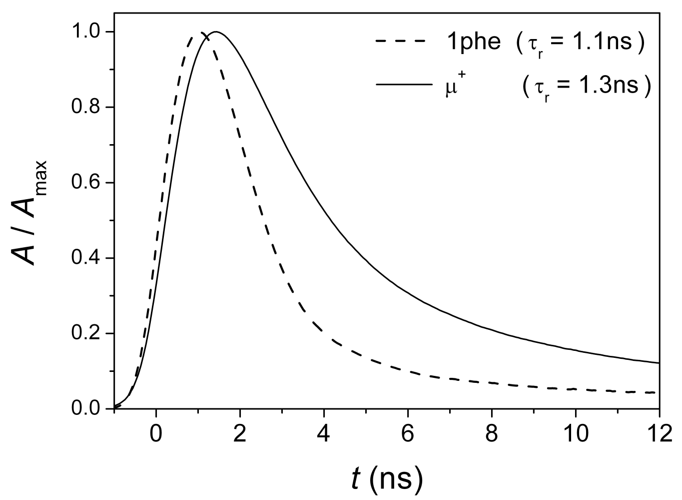


Figure 2: Averaged waveforms (typ. 1000) of 1phe and muon signals.

The tested AMPDs show promising performance in terms of time response and detection efficiency. AMPDs are also known to operate in high magnetic fields (tested up to 5 Tesla, see [2]). The only drawback at present is the small sensitive area of the device – only 1 mm$^2$. This is about a factor of 100 smaller compared to a characteristic

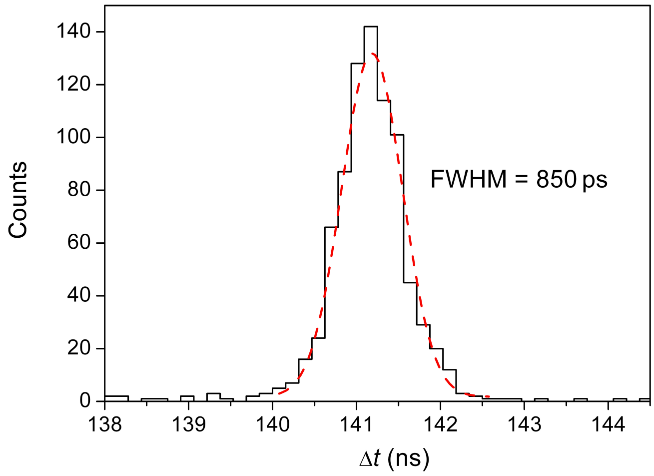


Figure 3: Time resolution of the telescope of two identical detectors (AMPD + 1 x 1 x 0.2 mm$^3$ EJ-230 scintillator) for registration of electrons from a Sr$^{90}$ source.

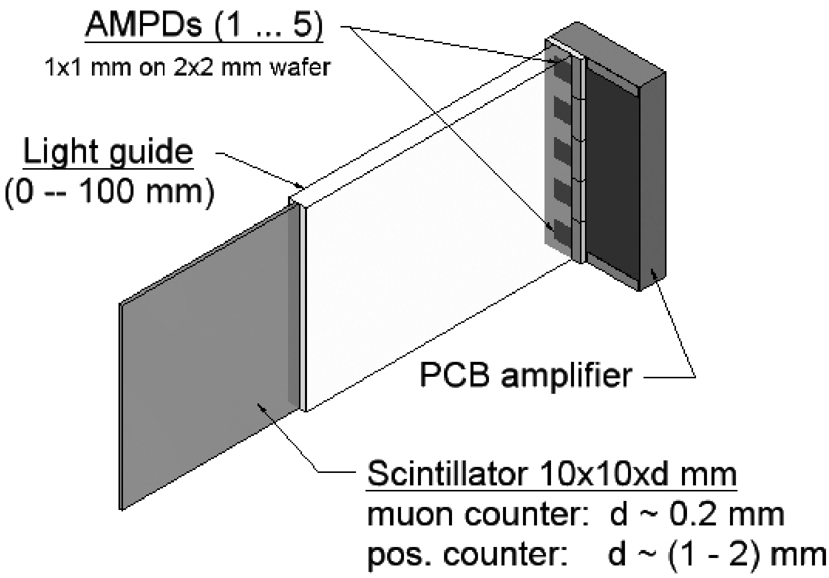


Figure 4: A design concept of a scintillation detector based on an array of AMPDs. The AMPDs are mounted directly on the printed circuit board (PCB) of an amplifier. The linear dimension of the array matches that of the scintillator.

active area required for a detector of a 10 Tesla $\mu$SR-spectrometer. In order to overcome this weak point and to take full advantage of the AMPD's best sides, we suggest a novel detector concept based on an array of AMPDs connected to a common load (in series, or in parallel; see Figure 4). By this approach the linear dimension of the photosensor is increased by a factor of $n$ (number of AMPDs in the array).

Based on the above results for the ZS-2mp AMPDs and the results on the light collection efficiency from thin plastic scintillators (see [3]), we estimate that both muon and positron detectors with dimensions $10 \times 10 \times d$ mm$^3$ ($d \approx 0.2$ mm for the muon and $(1-2)$ mm for the positron detectors) based on an array of $n = 5$ AMPDs would have a similar performance with signal amplitudes of $\sim 10$ phe, a detection efficiency close to 100 %, and a time resolution in the order of 1 ns. These parameters are encouraging for building a prototype of such detector, subject to detailed investigation and development.

# References

[1] Brochure "Scintillation Products – Organic Scintillators" (`http://www.bicron.com/`).

[2] A. Stoykov, R. Scheuermann, T. Prokscha *et al.*, NIMA **550**, 212 (2005).

[3] V.V. Zhuk, R. Scheuermann, A.V. Stoykov, PSI Technical Report TM-35-05-01.