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A large area avalanche photodiode as the VUV photosensor for gas proportional scintillation counters

J.A.M. Lopes, J.M.F. Dos Santos*, C.A.N. Conde

Departamento de Física, Universidade de Coimbra, P3004-516 Coimbra, Portugal

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Abstract

The feasibility of using UV-sensitive Large Area Avalanche Photodiodes (LAAPD) as the photosensor in xenon Gas Proportional Scintillation Counters (GPSC) is investigated. It is shown that the LAAPD can successfully replace the photomultiplier tube as the UV photosensor of GPSCs without degradation of the detector energy resolution, enabling the development of compact GPSCs. Energy resolutions of 7.9% and 4.4% are obtained with a xenon-filled GPSC for 5.9 and 22.1 keV X-rays, respectively. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Gas scintillation detectors; UV-photosensors; X-ray spectrometry

Gas Proportional Scintillation Counters (GPSC) are mostly used for X-ray spectrometry in a variety of applications including astrophysics, high-energy physics and medical instrumentation [1–4], where room-temperature operation with large detection areas and high counting rate capability are required.

Since its introduction [5], GPSCs have been largely investigated and its technology is now well established. Photomultiplier Tubes (PMT) are the most used photosensors for the GPSC scintillation readout and xenon is the preferred absorption medium for X-ray detection. However, while PMTs provide low-noise gain with large active areas, they increase the bulk, cost, power consumption, complexity and fragility of the otherwise simple and robust detector. Additionally, they require high-purity quartz windows, which partially absorb the scintillation light, especially the thick windows required for high-pressure applications.

Alternatives to replace the PMT by a more convenient photosensor have been investigated [6–15]. These included multiwire or microstrip proportional chambers with either UV-sensitive filling gases or CsI photocathodes. Typically, these have been independent devices coupled to the GPSC through an intervening VUV window. Also, photosensors integrated in the GPSC envelope, in direct contact with the scintillation gas, have been investigated [11–13,15]. However, the best performance achieved with such integrated photosensors [15] is worse than the one achieved with a PMT-based GPSC, although better than the one achieved with proportional counters.

The use of photodiodes as the scintillation readout for GPSCs was also formerly investigated

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* Corresponding author. Fax: 351-39-829158.
E-mail address: jmf@gian.fis.uc.pt (J.M.F. Dos Santos).

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[7,9]. Photodiodes present an attractive alternative to PMTs as the GPSC photosensor. They are simple to operate, have very low power consumption, high quantum efficiency and can be operated in high-intensity magnetic fields. However, until recently, their sensitive range excluded the VUV region and they were operated outside the detector together with a wavelength shifter placed on the inside of the scintillation window, a serious drawback for gas purity and long-term operation stability.

Recently, silicon photodiodes sensitive to VUV photons have been developed [16,17]. These can operate within the xenon envelope without the requirement of a quartz window that has less than full transmission of the VUV light. The substitution of the PMT and the elimination of the scintillation window is in itself a compelling reason for further development of integrated photosensors. Thus, the study of the potential application of VUV photodiodes to GPSC technology is demanding.

The use of a VUV photodiode as the photosensor in GPSCs was investigated [18], but the lack of an amplification stage in the photosensor resulted in very low output signal and a limited signal-to-noise ratio. The obtained results were not as good as the ones obtained with a standard proportional counter. In principle, an avalanche photodiode would provide the needed signal amplification and improve the achievable performance.

In this work we report experimental results obtained with a xenon-filled GPSC using a Large Area Avalanche Photodiode (LAAPD) as the VUV photosensor readout, in substitution of the PMT.

The schematic representation of the GPSC with the LAAPD is presented in Fig. 1. It is a uniform-field GPSC with a 2.5 cm deep drift region, a 0.8 cm deep scintillation region and filled at a pressure of 825 Torr with xenon that is continuously purified through getters. The LAAPD is placed just below the second grid, G_2. Grids G_1 and G_2 are highly transparent and are made of stainless-steel wire, 80 μm in diameter and 900 μm spacing. The detector radiation window is made of Mylar, 6 μm thick, with 2 mm in diameter. A Macor piece is used to insulate the radiation window holder and the grid G_1 holder. A low vapour pressure epoxy was used to vacuum-seal the Macor piece, the radiation

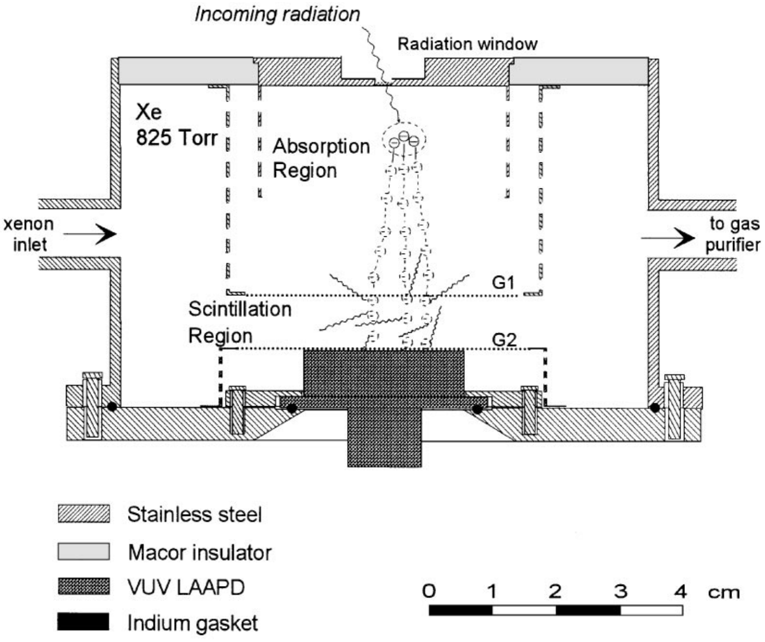

Fig. 1. Schematic of the GPSC with LAAPD photosensor.

window and holder as well as the grid G_1 voltage feedthrough. The LAAPD is vacuum-sealed by compressing the photodiode enclosure against the stainless-steel detector body using an indium wire.

The GPSC radiation window and its focusing electrode are operated at negative voltage while the grid G_2 and holder, as well as the LAAPD enclosure, are maintained at ground potential. The voltage difference in the drift region between the radiation window and the first grid, G_1, determines the reduced electric field (the electric field intensity divided by the gas pressure, E/p) in the drift region, while the G_1 voltage determines the reduced electric field in the scintillation region. Typical reduced electric fields of 0.8 and 6.5 V cm^{-1} $Torr^{-1}$ were used in the GPSC drift and scintillation region, respectively [19]. The LAAPD [20] has 105% quantum efficiency at 170 nm and an active area with a diameter of 16 mm. It was biased with a variable voltage, V_{ph}, for operation at different gains.

The LAAPD signals were fed through a low-noise 1.5 V/pC charge pre-amplifier to an amplifier with 2 μs shaping time and are pulse-height analyzed with a 1024-channel MCA. For pulse-amplitude and energy resolution measurements, the X-ray pulse-height distributions are fitted to a Gaussian function superimposed on a linear background, from which the centroid and the full-width at half-maximum (FWHM) are determined.

In Fig. 2, we depict the detector relative pulse amplitude, the energy resolution and the peak to electric-noise-tail in the low-energy-limit ratio, as a function of the LAAPD bias voltage for 5.9 keV X-rays, obtained from a ^{55}Fe radioactive source with the K_β line filtered with a chromium film. As expected, the detector relative pulse amplitude variation presents a good agreement with the exponential gain of the LAAPD, specified by the manufacturer. Energy resolutions of 7.9% are obtained, a performance similar to the one achieved with a 2″-PMT-based GPSC of similar design [19,21] and better than the one obtained with small area ($1\frac{1}{2}$”) PMTs [22,23].

Fig. 2 also shows that a good detector energy resolution is achieved even for sensor gains as low as 20, corresponding to a peak to electric-noise-tail in the low-energy-limit ratio larger than 30. The possibility of using such low photosensor gains reflects not only the high gain of the scintillation amplification process in the GPSC but also the high efficiency of the VUV light conversion into charge signal, before charge amplification, in the photosensor [18]. This behaviour shows that the

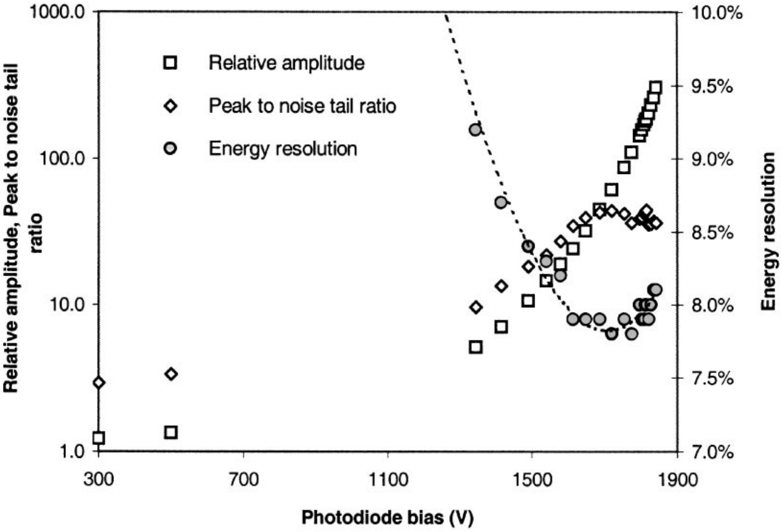

Fig. 2. Relative detector pulse amplitude, energy resolution and peak to electric-noise-tail ratio as a function of the LAAPD bias voltage for 5.9 keV X-rays.

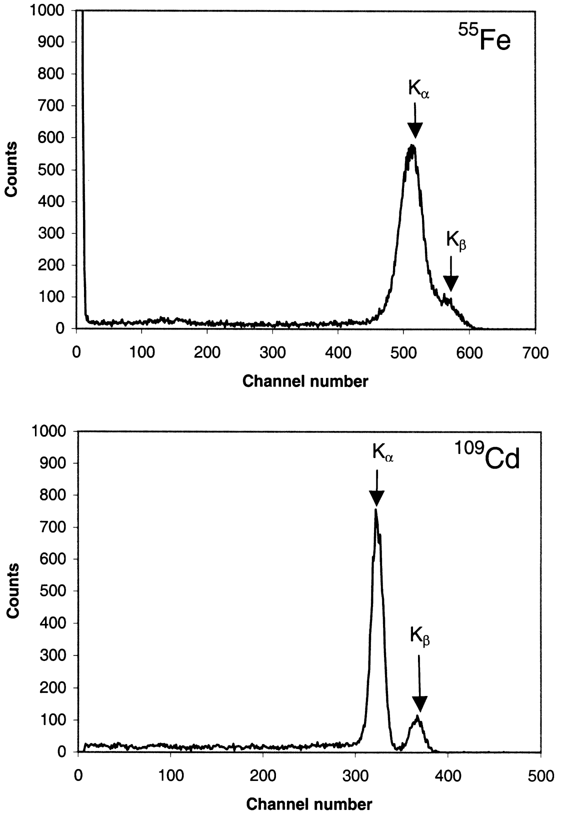

Fig. 3. Pulse-height distributions obtained with the GPSC instrumented with a LAAPD for ^{55}Fe and ^{109}Cd X-ray radioactive sources and for $V_{ph} = 1720$ V. E/p of 0.8 and 6.5 V cm^{-1} Torr^{-1} were used in the GPSC drift and scintillation region, respectively.

light-to-charge conversion efficiency is much larger for the silicon-photodiode-photosensor than for the CsI-based photosensors which, even with photoelectron charge gains of about 10^3, cannot produce that low-energy-resolution figure [14,15].

Typical pulse-height distributions for ^{55}Fe and ^{109}Cd X-ray radioactive sources and for $V_{ph} = 1720$ V are presented in Fig. 3. The spectral features include the K_α and K_β peaks and the detector electric-noise-tail in the low-energy limit, below 0.2 keV. A detector energy resolution of 4.4% is obtained for the 22.1 keV X-rays, a figure that is better than the one achieved with a 2″-PMT-based GPSC of similar design (5.2%) [24].

The present results demonstrate that UV-LAAPD can be used as the photosensor in a xenon GPSC, substituting the PMT without detector performance degradation. These results present a significant advance towards the feasibility of portable high-performance X-ray spectrometry systems based on the GPSC technology. Detailed studies of the performance characteristics and ground for improvements of such type of detectors are planned.

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References

[1] H.E.N. Ngoc, J. Jeanjean, H. Itoh, G. Charpack, Nucl. Instr. and Meth. 172 (1980) 603.
[2] A. Peacock, B.G. Taylor, N. White, T. Courvoisier, G. Manzo, IEEE Trans. Nucl. Sci. 32 (1985) 108.
[3] A. Smith, M. Bavdaz, Rev. Sci. Instrum. 63 (1992) 683.
[4] Varvaritsa, I.V. Vikulov, V.V. Ivashov, M.A. Panov, V.I. Filatov, K.I. Schekin, Instr. Exp. Tech. 35 (1992) 745.
[5] C.A.N. Conde, A.J.P.L. Policarpo, Nucl. Instr. and Meth. 53 (1967) 7.
[6] A.J.P.L. Policarpo, Nucl. Instr. and Meth. 153 (1978) 389.
[7] J.C. Van Standen, J. Foh, M. Mutterer, J. Pannicke, K.P. Schelhaas, J.P. Theobald, Nucl. Instr. and Meth. 157 (1978) 301.
[8] D.F. Anderson, Nucl. Instr. and Meth. 178 (1980) 125.
[9] A.J. de Campos, IEEE Trans. Nucl. Sci. NS-31 (1984) 133.
[10] D.G. Simons, P.A.J. de Korte, A. Peacock, A. Smith, J.A.M. Bleeker, IEEE Trans. Nucl. Sci. NS-32 (1985) 345.
[11] V. Dangendorf, A. Breskin, R. Chechik, H. Schmidt-Bocking, Nucl. Instr. and Meth. A 289 (1990) 322.
[12] J.F.C.A. Veloso, J.A.M. Lopes, J.M.F. dos Santos, C.A.N. Conde, IEEE Trans. Nucl. Sci. NS-43 (1996) 1232.
[13] J.A.M. Lopes, J.M.F. dos Santos, C.A.N. Conde, R.E. Morgado, IEEE Trans. Nucl. Sci. NS-44 (1997) 517.
[14] J.F.C.A. Veloso, J.M.F. dos Santos, C.A.N. Conde, Nucl. Instr. and Meth. A 422 (1999) 273.
[15] J.F.C.A. Veloso, J.M.F. dos Santos, C.A.N. Conde, Gas proportional scintillation counter with a CsI-covered microstrip plate UV photosensor for high resolution X-ray spectrometry, Nucl. Instr. and Meth. A., 2000, in press.
[16] E.M. Gullikson, R. Korde, L.R. Canfield, R.E. Vest, J. Electron Spectrosc. Relat. Phenom. 80 (1996) 313.

[17] L.R. Canfield, R.E. Vest, R. Korde, H. Schmidtke, R. Desor, Metrologia 35 (1998) 329.

[18] J.A.M. Lopes, L.M.P. Fernandes, J.M.F. dos Santos, C.A.N. Conde, VUV Si photodiode as the gas proportional scintillation counter readout, Presented at the 1999-IEEE Nuclear Science Symposium, October 27–30, 1999, Seattle, USA, to be published in the Conference Record.

[19] F.I.G.M. Borges, J.M.F. dos Santos, T.H.V.T. Dias, F.P. Santos, P.B.J.M. Rachinhas, C.A.N. Conde, Nucl. Instr. and Meth. A 422 (1999) 321.

[20] Produced by Advanced Photonix Inc., 1240 Avenida Acaso, Camarillo CA 93012, USA.

[21] J.M.F. dos Santos, A.C.S.S. Bento, C.A.N. Conde, X-Ray Spectrom. 22 (1993) 328.

[22] D.A. Goganov, A.A. Shultz, Nucl. Instr. and Meth. A 394 (1994) 151.

[23] J.M.F. dos Santos, A.J.V.D. Soares, C.M.B. Monteiro, R.E. Morgado, C.A.N. Conde, IEEE Trans. Nucl. Sci. NS-45 (1998) 229.

[24] J.M.F. dos Santos, J.F.C.A. Veloso, R.E. Morgado, C.A.N. Conde, Nucl. Instr. and Meth. A 353 (1994) 195.