An Integrated Photosensor Readout for Gas Proportional Scintillation Counters

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Abstract

A xenon gas proportional scintillation counter has been instrumented with a novel photosensor that replaces the photomultiplier tube normally used to detect the VUV secondary scintillation light. In this implementation, the collection grid of a planar gas proportional scintillation counter also functions as a multiwire proportional chamber to amplify and detect the photoelectrons emitted by a reflective CsI photocathode in direct contact with the xenon gas. This integrated concept combines greater simplicity, compactness, and ruggedness (no optical window is used) with low power consumption. An energy resolution of 12% was obtained for 59.6 keV x-rays.

I. Introduction

The photomultiplier tube (PMT) has been the photosensor of choice to read out the VUV scintillation light produced in the xenon gas proportional scintillation counter (GPSC) [1]. While PMTs provide low-noise gain over useful active areas, they are bulky, expensive, and fragile devices with relatively high power-consumption requirements. In addition, they require high-purity quartz-window interfaces which partially absorb the scintillation light, particularly in the thicker windows needed for high-pressure GPSCs. Alternatives to the PMT have been investigated during the past two decades [2-6]. These include multiwire proportional chambers with either VUV-sensitive fill gases [3] or CsI photocathodes [4]. These have typically been independent devices coupled to the GPSC through an intervening quartz window. More recently, a simple and compact alternative solution has been investigated [6] which places the photosensor, a microstrip plate coated with a layer of CsI, within the xenon envelope of the GPSC. However, the achievable gain has been limited by electrical breakdown in the photocathode coating and, to date, the performance of this device remains marginal.

II. Rationale

In the present work we studied the feasibility of an integrated photosensor in which the electrical properties of the photocathode would not be a limiting factor. In this design, the second grid of the GPSC functions both as the collector of the primary electrons produced by the ionising event and as a multiwire proportional chamber to detect and amplify the photoelectrons emitted by a reflective CsI photocathode. The entire system operates in the pure xenon atmosphere of the GPSC envelope.

III- Detector Description

A. Detector design

The GPSC and integrated photosensor design is depicted in Figure 1. The GPSC features a 4-cm thick absorption region and a 1-cm thick scintillation region, delimited by grids G1 and G2. While G1 is a highly transparent stainless steel mesh, G2 is a multiwire plane made of 25-μm diameter, 1-mm spaced, gold-plated tungsten wires. The integrated photosensor is a 500 nm thick CsI photocathode deposited on a stainless steel substrate, positioned 2-mm away from G2.

Typical values for detector biasing are -4800V on the detector window and focusing ring, -4000 V on G1 and ground level on G2. The photocathode substrate is biased at -640V.

The detector is filled with pure xenon at 1100mbar, continuously purified by convection through SAES St707 getters.

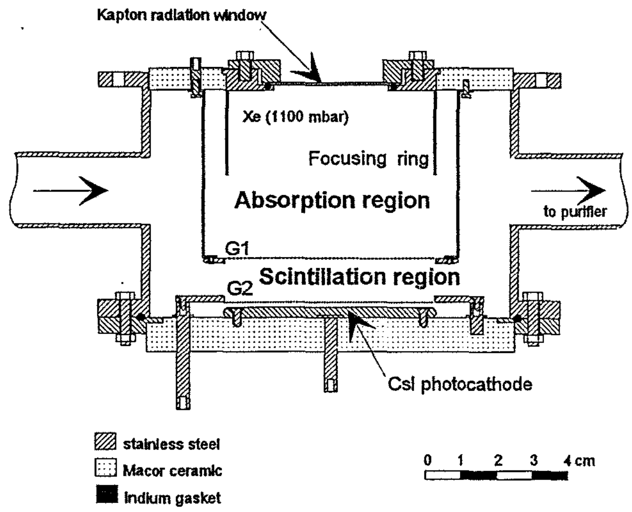

Figure 1: The GPSC with built-in scintillation sensor.

B. Principle of operation

Incoming radiation interacts preferentially in the absorption region producing a primary electron cloud which drifts under a weak electric field towards the scintillation region where the electron energy is sufficient to excite xenon atoms but is still below the gas ionisation threshold. This results in a light amplification process with high gain.

The scintillation light resulting from the xenon atoms deexcitation is detected by the CsI photocathode. The resulting photoelectrons are then multiplied in the charge avalanche around the anode wires of G2. This way G2 acts both as a grid to the scintillation region and as the charge amplification stage of the photosensor.

IV- RESULTS AND DISCUSSION

To demonstrate that the system functions as a xenon gas proportional scintillator we studied the pulse amplitude dependence on the reduced electric field E/p (the electric field E divided by the gas pressure p) in the scintillation region while maintaining constant the photosensor gain and the absorption region electric field. In Figure 2 we present the measured pulse amplitude for the 59.6 keV x-rays from ^{241}Am as a function of the reduced electric field E/p in the scintillation region.

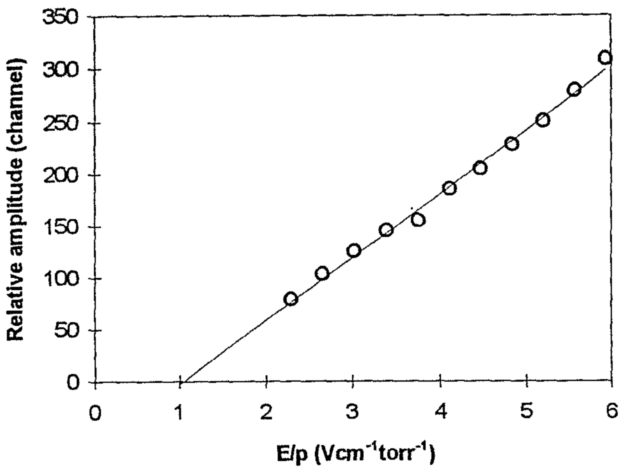

Figure 2: Relative amplitude as a function of the reduced electric field E/p in the scintillation region showing the least squares fit.

As shown it exhibits the characteristic linear dependence [7,8] with the extrapolated threshold at 1.0 V.cm^{-1}.torr^{-1}.

As the detector signal is obtained from G2, both primary electrons and photoelectrons contribute to the signal. It should then be necessary to distinguish each contribution. Since each primary electron crossing the scintillation region produces typically about 500 VUV photons, from which about 33% reach the photocathode inducing about 50 photoelectrons for a 30% photocathode quantum efficiency (see ref.6), we estimate that the primary electron contribution to the signal is only 2% of total signal amplitude. This contribution can thus be neglected.

The photosensor gain depends on the photocathode to G2 voltage difference, $V_{k\text{-}G2}$. In Fig.3 we present the detector pulse amplitude for the 59.6 keV photons from ^{241}Am as a function of $V_{k\text{-}G2}$. Together with the experimental results an exponential curve (full line) is also presented. This curve represents the typical behaviour of a pure xenon proportional (ionisation) counter gain [9]. Fig.3 also shows that the photosensor gain has a behaviour typical of a pure xenon proportional counter (full line) up to $V_{k\text{-}G2}$ of about 570V. Above this value the photosensor gain presents a faster increase, diverging from its initial behaviour. For $V_{k\text{-}G2}$ above 660V the photosensor achieves the self-sustained discharge mode. Since the photosensor charge multiplication gain is achieved close to the G2 wires and the electric field lines near the wires are typical of a proportional counter, as demonstrated with an electrostatic simulation code [10], we expected the behaviour characteristics of such a counter (the full line in Fig.3). However, unlike a proportional counter, this type of sensor has positive feedback due to the xenon scintillation light produced in its electron multiplication stage which releases more electrons from the CsI photocathode. The result is a higher gain

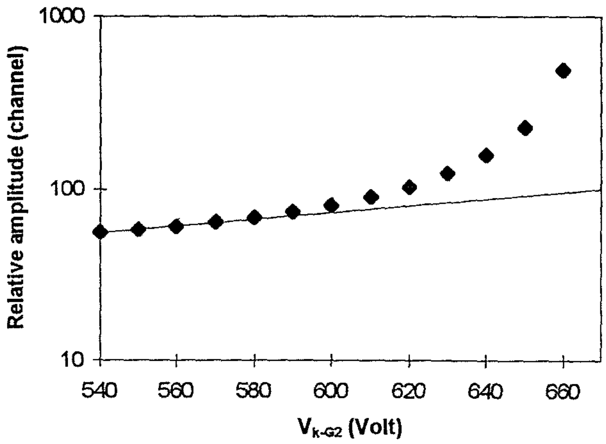

Figure.3: Detector pulse amplitude for the 59.6 keV x-rays from ^{241}Am (◆) and charge multiplication gain (full line). as a function of the photocathode to G2 voltage difference $V_{k\text{-}G2}$.

The photosensor gain G may be considered as a product of two factors, the charge multiplication gain around the wires, G_w, and the gain due to feedback, G_f. The photosensor gain G and G_w are presented in Fig.4.

In Fig.5 we present the pulse height distribution of ^{241}Am x-rays. The spectral features of ^{241}Am include the full energy peak at 59.6 keV, the K_α and K_β xenon fluorescence escape peaks, and the L x-rays from Np.

The obtained energy resolution for the 59.6 keV peak is 12%, a figure still worse than that achieved with photomultiplier based GPSC's and standard proportional (ionisation) counters [11]. However, this difference can be reduced for higher x-ray energies, where high pressure GPSC's are used and the photomultiplier will be a problem.

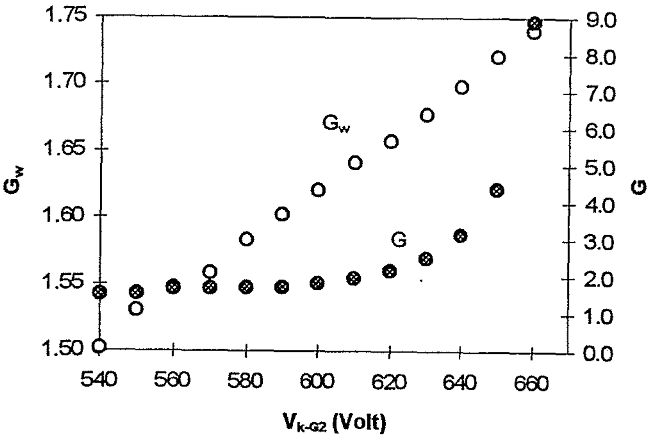

Figure 4: Photosensor gain G and charge multiplication gain G_w as a function of the photocathode to G2 voltage difference $V_{k\text{-}G2}$.

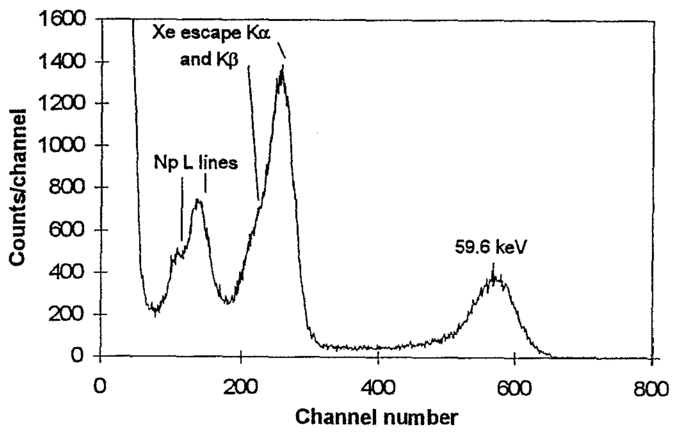

Figure 5: Pulse height spectrum of ^{241}Am.

V. Conclusions

The results demonstrate the feasibility of operating a GPSC with an integrated CsI photocathode and that the working principle of this type of detector is that of a conventional GPSC. The elimination of the quartz window is in itself a compelling reason for the further development of this type of scintillation readout. Since the detector performance is limited by feedback, alternative designs will be considered to further improve performance.

VI. Acknowledgments

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