PHOTOELECTRON COLLECTION EFFICIENCY AT HIGH PRESSURE FOR A GAMMA DETECTOR ENVISAGING MEDICAL IMAGING

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***Abstract* - Recent developments on gas avalanche detectors based on microstructures operating at high pressure allow fair detection efficiency for hard X- and gamma-rays. A hybrid system combining an assisted scintillation in a high pressure xenon gas medium and two UV photosensors based on microstructures operating face to face, having the xenon medium sandwiched between, is under investigation for imaging purposes. To evaluate the photosensor operation at high pressure, a study of the photoelectron collection efficiency (PCE) is needed. First results show no significant variation on the relative PCE from 1 to 5 bar xenon filling pressure for different applied voltages.**

I. INTRODUCTION

A new γ-ray gaseous detector for medical imaging applications is being developed at the Physics Department of the University of Aveiro, Fig.1.

The detector uses two Micro-Hole & Strip Plates (MHSP) based photosensor positioned face-to-face and stainless-steel cluster grids between them. The grids are alternating polarized with a high voltage difference. The detector was filled with Xe, acting as the gamma-rays absorption medium.

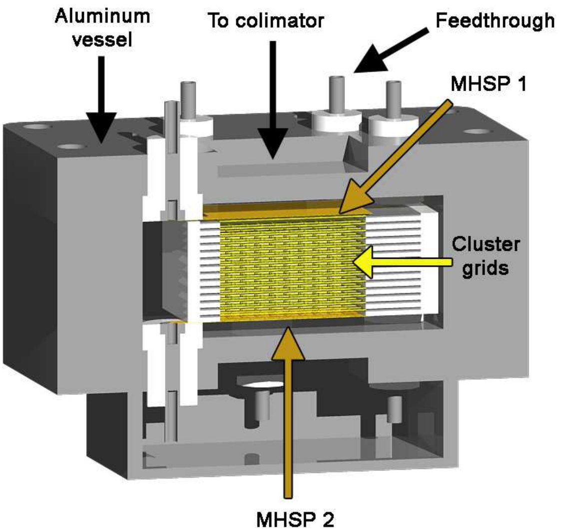

Fig.1 – Vertical slice of the new γ-ray detector

The MHSP integrates, on a single element, two successive independent charge amplification stages: a GEM-like (Gas Electron Multiplier) and a MSGC-like (Micro-Strip Gas Counter) stage. Like the GEM, the MHSP is fabricated with printed circuit board technology from a 50-µm Kapton foil, metalized with 5-µm-thick copper-layers on both sides. A GEM-like pattern of holes is etched through the foil with a continuous metal electrode on the top-side, and a standard microstrip pattern etched on the bottom side, with the holes centered on the wide cathode strips.[1,2]

II. OPERATION PRINCIPLE

The primary electron cloud, produced by radiation interaction with the gas between the intercalated grids, Fig.2, is accelerated by the strong electric field applied between consecutives grids [3], the reduce electric field:

$$E/P = \frac{\Delta V}{d \times P}(Vcm^{-1}Torr^{-1}) \qquad (1)$$

ΔV is the voltage difference between the consecutive grids, d is the distance between the grids and P is the gas pressure. the reduced electric field (E/P), is kept between the ionization threshold (6 $Vcm^{-1}Torr^{-1}$) and the excitation threshold (1 $Vcm^{-1}Torr^{-1}$) [4], each primary electron will have enough energy to excite but not to ionize the xenon atoms between collisions, producing VUV scintillation light as a result of the gas de-excitation processes.

The scintillation light intensity is proportional to ΔV and to the number of primary electrons and, thus, to the detected gamma-ray energy. The number of scintillation photons per primary electron produced is given by:

$$N_{fUV} = \frac{\Delta V}{\varepsilon_{UV}} \times Q_c \qquad (2)$$

where ε_{UV} is the mean energy of the Xe scintillation photons (7,2 eV) and Q_c is the scintillation efficiency ($Q_c \approx 0.8$ for xenon at E/p = 5 V cm-1 Torr-1) [4,5]

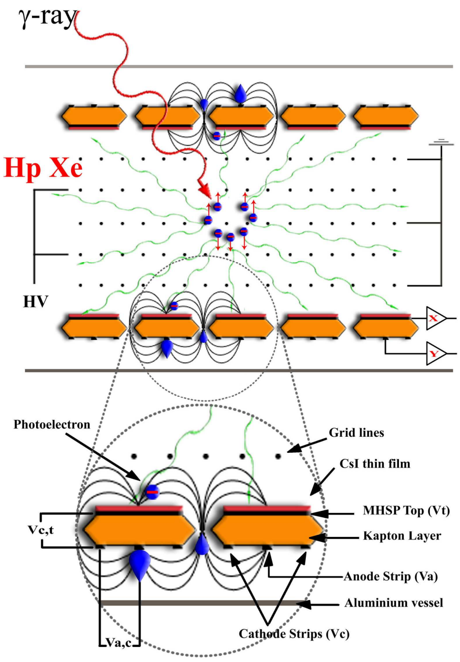

Fig.2 – Schematic diagram of the new γ-ray detector with 2 MHSPs and its operation principle

A CsI photocathode is deposited on the top of the MHSP, operating in a reflective mode. When the VUV-photons hit the CsI surface, photoelectrons can be extracted and then focused to the MHSP holes and undergo multiplication in the strong dipole electric field (V_{CT}). The avalanche electrons are then extracted from the holes towards the anode strip of the MHSP, placed on the bottom-side, where they are further multiplied in the strong electric field (V_{AC}), and collected.

One of the problems of having the CsI photosensor operating within the gas medium is the significant backscattering probability of the emitted photoelectrons from the photocathode that can return to the photocathode reducing the number of extracted photoelectrons and thus the photoelectron collection efficiency [6]. So, a study of the photoelectron collection efficiency of the detector, as a If function of pressure, is needed.

For the calculation of the photoelectron collection efficiency (number of photoelectrons detected per UV-photon produced) is necessary to calculate the *L* factor which is defined by the reason between the number of detected photoelectrons N_{fe} and the number of primary electrons N_{ep}.: [7]

$$L = N_{fe} / N_{ep} \tag{3}$$

Experimentally this value is given by the reason between the scintillation signal amplitude and the charge signal amplitude. Finally, the photoelectron collection efficiency (N_{fe}/N_{fUV}) is the ratio between Eq.3 and Eq.2. [5,6].

The CsI-coated MHSP serves simultaneously as the photosensor for the VUV scintillation and as the amplification stage for the emitted photoelectrons.

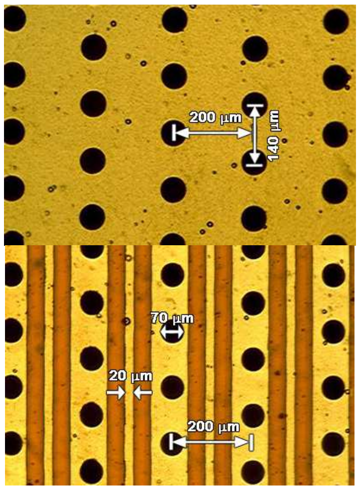

Fig.3 - Photomicrograph of the MHSP, top and bottom sides

III. EXPERIMENTAL SETUP AND DETECTOR CONFIGURATION

The present MHSP has an active area of 2.8x2.8 cm^2. The bi-conical holes, around ∅40/70 µm are implemented in a Kapton/copper film, arranged in an asymmetric hexagonal lattice of 140- and 200-µm pitch in the directions parallel and perpendicular to the strips, respectively, Fig.3. The anode and cathode strip widths are about 20 and 100 µm, respectively, with a 40-µm gap between them and a 200-µm pitch [8,9]. All the MHSP electrodes are independently polarized. The electric field in the holes is established through the voltage difference applied between the cathode strips and the top-electrode, V_{CT}, while on the bottom-side of the MHSP structure, the electric field is established through a voltage difference between the anode and the cathode strips, V_{AC}.

The detector was constructed from a 94x94x46 mm^3 aluminum block, with 60x60x25 mm^3 internal cavity and a 5 mm thick aluminum radiation entrance region (on the top and the bottom of detector).

For the present study we have used only 3 grids separated by a 1.6 mm Printed Circuit Board (PCB) frames and one MHSP placed in the bottom of the cavity. The cluster grids are 6 mm away from the top of the MHSP, where a 500 nm thickness CsI film was deposited, Fig. 4.

The grids and the MHSP electrodes were feed through stainless-steel cylinders glued to a Macor piece for electrical insulation.

Detector signals from the anode strips were feed through a Canberra 2006 charge preamplifier (sensitivity of 1.5 V/pC) and a Canberra linear-amplifier (12-µs shaping time) to a multichannel analyzer.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The detector signal amplitude was measured varying the V_{CT} and the V_{AC} voltages in three different cases: an "*ab initio*" charge amplification study, without the CsI photocathode, varying the gas pressure from 1 to 4 atm; an charge amplification and a scintillation amplification studies, with a CsI photocathode deposited on the top of the MHSP, varying the gas pressure from 1 to 6 atm.

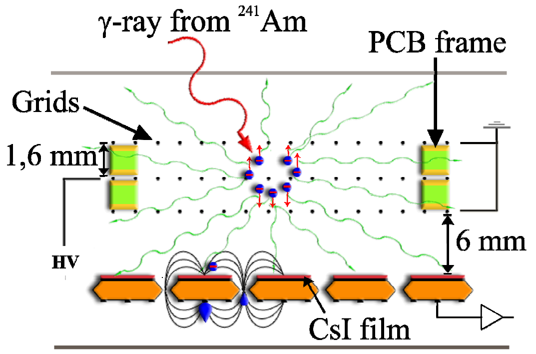

Fig.4 - Schematic design of the prototype used in this study and its operation principle.

In Fig.5 we depict the detector relative amplitude as a function of the voltage applied across the MHSP, V_{total}, where $V_{total} = V_{AC} + V_{CT}$. In Figs.5-a and Fig.6-a, V_{AC} was kept constant while varying V_{CT}. In Fig.5-b and Fig.6-b, V_{CT} was kept constant while varying V_{AC}. The full symbols represent the relative amplitude obtained with the detector working in the scintillation mode, while the circles represent the charge mode. The full circles and the open circles represent the relative amplitude obtained with and without the CsI film deposited on the MHSP, respectively.

The results show that the presence of the CsI film limits the detector achievable gain. The causes and solutions for this problem are under investigation; however, the observed ion feedback could be the main reason for this limitation. From the Fig.5 and 6 we can observe that the pulse amplitude of the detector operating in scintillation mode is always higher than the pulse amplitude observed when operating in the charge mode (with the CsI film deposited on MHSP top). This is due to the large number of emitted VUV photons that can produce a number of photoelectrons per primary electron, *L* value, higher than 1. As we can see from Eq.2, the number of produced VUV is proportional to the applied voltage across the grids, ΔV . This amplitude difference increases with the gas pressure. In this case, to maintain the same *E/p*, the ΔV should be higher and consequently the number of photons.

Figure 6.a and 6.b present the photoelectron collection efficiency (N_{ef}/N_{fUV}) as function of V_{total} across the MHSP for pressures varying from 1 to 5 atm. In general, we observe a small increase of the photoelectron collection efficiency with the increasing of V_{total} due to the increase of the electric field on the top electrode of the MHSP and in its multiplication stages[10].

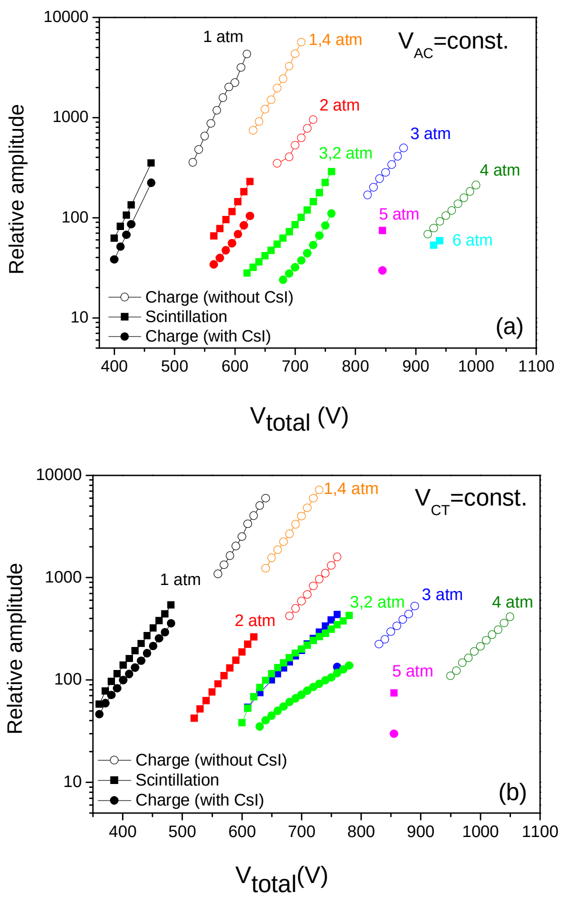

Fig.5 – Detector relative amplitude as a function of V_{total}, varying: (a)V_{CT}; and (b) V_{AC}

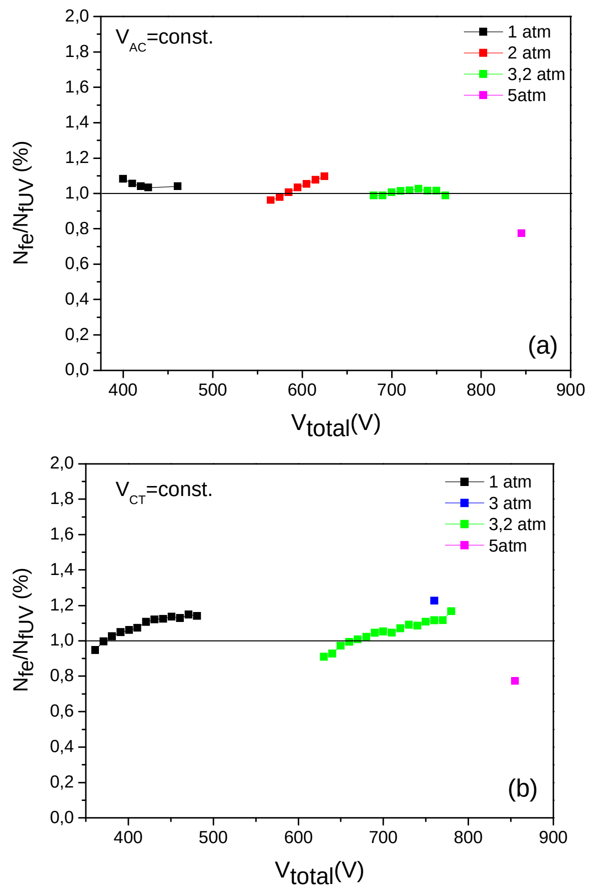

Fig.6 – Photoelectron collection efficiency, as a function of V_{total}: varying V_{CT} (a) and V_{AC} (b)

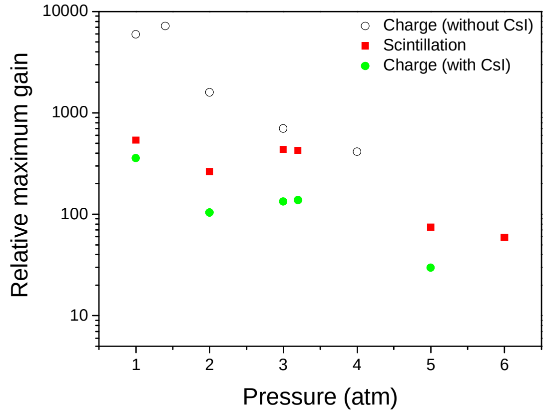

Fig.7 –Relative maximum gain achievable for the various measurements as function of the pressure.

No significant variation of the photoelectron collection efficiency was observed for the different studied pressures. This is due to the increasing of the electric field *E* on the photocathode surface, resulting in a small variation of the *E/p* with pressure (while the pressure increases, the voltages applied to the MHSP electrodes also increases), the main factor for the photoelectron extracting efficiency[5]. The value obtained for 5 atm is lower than the expected due to the low voltages applied on the electrodes limited by the discharge threshold. Further studies are in course to overcome this limitation.

The relative maximum achievable gain was also studied as a function of the gas pressure. The obtained results are plotted in Fig.7. As expected, a decrease of the maximum amplitude is observed with the increasing pressure [10]. In fact, the electron mean free path decrease with the pressure increase, resulting in a gain decrease for the same voltage. To avoid the gain decrease, it is necessary to increase the voltage applied to the MHSP. However, we can not raise the voltage indefinitely due to the discharge threshold. Again, gain limitation due to the presence of the

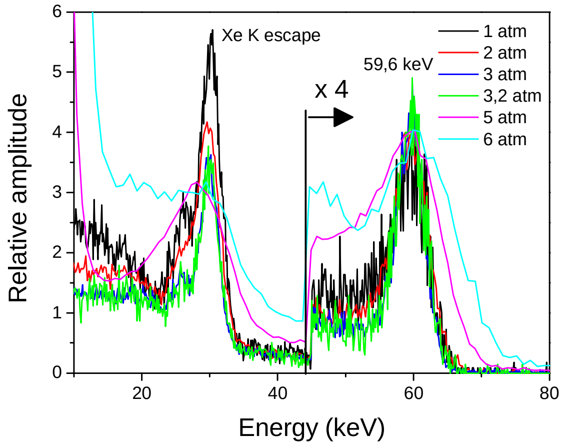

Fig.8 –Typical pulse-height distributions obtained in the scintillation mode for the γ-rays emitted from the ^{241}Am source, for the pressures reached in this study.

CsI is observed. For low pressures, the difference of the charge pulse amplitude between the operation in charge mode with and without CsI is about one order of magnitude, decreasing this difference when the pressure increases. To prevent discharges on the MHSP, moderate voltages were used at 1 and 2 atm in the case of operation with CsI in charge mode. In the scintillation mode the relative pulse amplitude is about constant until 3.2 atm, decreasing for 5 and 6 bar due to unexpected discharges. To clarify this effect, further studies will be done.

Figure 8 presents the typical pulse-height distributions obtained in the scintillation mode for the 59,6 keV γ-rays emitted from the ^{241}Am source for pressures from 1 to 6 atm. Although the detector energy resolution improves from 1 to 3.2 atm, a significant degradation is observed for 5 and 6 atm. This degradation is explained by the lower number of the recoiled electrons due to the limited applied voltages across the MHSP electrodes, which lead to a poor signal to noise ratio.

V. CONCLUSIONS:

We have investigated the photoelectron collection efficiency as function of the gas detector pressure. No significant variation of the photoelectron collection efficiency was observed with the increasing of the gas pressure, which is around 1%. This show the possibility of operation at high pressure maintaining the statistic of the number of the photoeletrons. A decreasing of the relative maximum gain with the increasing of the pressure was also observed. Further studies, operating at higher xenon pressure are in course in order to increase the detector gain.

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