Study of Scintillation Light from Microstructure Based Detectors

M. M. Fraga[1], S. T. G. Fetal[1], F. A. F. Fraga[1], E. Antunes[1], J. Gonçalves[2], C.C. Bueno[2], R. Ferreira Marques[1] and A. J. P. L. Policarpo[1]

[1]LIP - Coimbra and Departamento de Física da Universidade de Coimbra, 3000 Coimbra, Portugal

[2]IPEN and Departamento de Física da Pontífica Universidade Católica de São Paulo, 01303-050 São Paulo, Brasil

Abstract

In a previous work it has been pointed out that a CCD readout system associated to a microstructure based gaseous detector (microstrip, microgap, GEM, etc.) can be used for non destructive testing of these detectors. The choice of the gas mixture is an important issue, in so far as its emission spectrum should overlap efficiently the sensitivity region of the CCD (400-1100 nm). In the present work we report on a systematic study for several gas mixtures which includes measurements of the total light yields as a function of the electric field and of the spectrometric distribution of the light emitted, in the wavelength region between 250 and 930 nm. Results are presented for pure argon and argon and xenon based gas mixtures. A comparison is made between the results obtained with the CCD coupled to a GEM detector and with a gaseous scintillation proportional counter.

I. Introduction

It has been shown in previous works [1], [2], that scintillation light emitted in microstructure based gaseous detectors (microstrips, microgaps, GEMs, etc.) can be used for non destructive testing of these detectors when they are associated to a CCD readout system. On the other hand, the readout of the GEM detector scintillation by means of an appropriate CCD constitutes, thanks to the fine structure of the GEM holes, a simple high-resolution position sensitive detector [3] convenient, for example, for imaging. In both cases, the choice of the gas mixture is an important issue to assure not only that its emission spectrum overlaps efficiently the sensitivity region of the CCD but also that a comfortable number of photons is emitted per drifting electron. For imaging purposes other requirements must be met, namely in what concerns efficiency and electron diffusion.

Gas scintillation proportional counters have been thoroughly investigated for the last 20 years, in particular for low energy X-ray detection. Most studies concentrate on the UV and VUV emissions of rare gases (Ar, Kr, Xe) and some mixtures, namely Ar/N_2, in low electric fields (either below the threshold for charge multiplication or low charge gains, 10-100). Thiess and Miley [4] extended the measurements up to the near infrared region (< 850 nm) with a detailed study of the emissions from both atomic and molecular states in a cylindrical gas proportional scintillation counter as a function of the applied electric field and total pressure, for pure He, Ne and Ar, as well as for mixtures with N_2, O_2, H_2, CO, Kr and Xe as additives. The main features in their near infrared spectra were the atomic lines of the rare gases and oxygen. Lindblom and Solin [5] have also investigated the optical spectra of direct and proportional scintillation of pure rare gases covering the range between 350 and 930 nm. Other studies, concerning the electroluminescence of rare gas based mixtures, have been reported in view of their application for optical readout purposes, either in parallel plate chambers or in wire chambers [6], [7], [8], [9], [10], [11]. Most of these studies concern UV and visible light emissions and only a few extend their measurements up to the near infrared region [11]. It was found that rare gas mixtures containing TEA (triethylamine) exhibit high light yields but their emission spectra lie in the region between 280 and 290 nm which is out of the sensitivity region of our CCD (see Figure 1). TMAE (tetrakis[dimethylamino]ethylene) is also known as an efficient photosensitive vapor, with its emission spectrum peaking at 480 nm, but it is troublesome to handle.

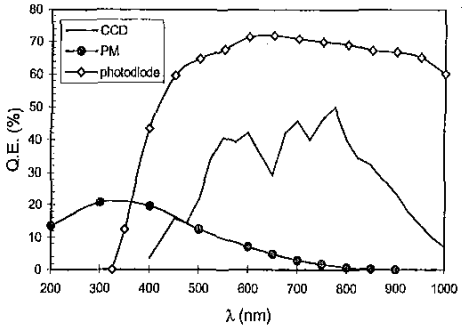

Figure 1: Comparison of the quantum efficiencies of the photodetectors used in the present work.

The former light yield measurements in MSGCs or GEM detectors need further clarification concerning the influence of the electric fields and of impurities both on the total light yields and on the spectral distribution of the scintillation. In the present work a systematic study of light emissions in the wavelength region between 250 and 1000 nm is undertaken. In parallel with the experimental measurements, calculations were performed and the results were compared.

II. Experimental Set-Up

The experimental results presented in this work were performed for three different electric field configurations: a GEM detector, a parallel plane chamber and a scintillation counter with a spherical anode.

0018-9499/00$10.00 © 2000 IEEE

A. Light measurements with the GEM detector

The experimental set-up is described in detail in [2]. A Quantix 1400 camera, manufactured by Photometrics Ltd, was used for the readout of the scintillation emitted from the GEM. The chamber was irradiated by an X-ray generator with a molybdenum target and the gases, high purity research grade, are supplied to the chamber through stainless steel pipes without any additional purification.

B. Light measurements with the PPC

The parallel plate chamber consists of two parallel grids 0.35 cm apart. X-ray photons from an X-ray generator are used as excitation source. The tube is operated at about 10 kV, with a copper target. The light emitted is collected through a mylar window and detected by a UDT planar-diffused silicon photodiode (PIN-25DP). Long-pass colour glass filters are used to select the wavelength cut off. Current in the chamber was measured with a 610R Keithley electrometer and the photodiode was fed to an amplifier. The gases flow continuously, at atmospheric pressure, through calibrated flowmeters and the detector.

C. Light studies with the GSPC

This experimental set-up is represented schematically in Figure 2. The scintillation detector has a 3 mm diameter stainless steel spherical anode and is described in detail elsewhere [12]. The gas chamber is coupled, through Spectrosil A windows (without wavelength shifter), from one side to a 56 TUVP photomultiplier, having a S20 response (see Fig. 1), and from the other side to an Applied Photophysics monochromator, mod. 7300, equipped with a 1200 g/mm grating, blazed at 500 nm. The light analysed by the monochromator is detected by a second photomultiplier, an RCA C31034A, with a GaAs:CsO photocathode which covers the region between 185 and 930 nm. This photomultiplier is

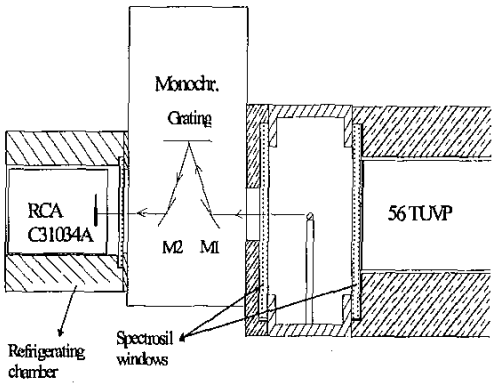

Figure 2: Experimental set-up used associated with the scintillation counter with the spherical anode.

cooled to -20°C and is operated in the single photon counting mode.

The 56 TUVP photomultiplier was calibrated using the scintillation of a NaI (Tl) crystal when irradiated with ^{60}Co, ^{137}Cs and ^{22}Na gamma sources. As excitation sources, we used X-ray photons from a collimated ^{55}Fe source (5.9 keV) and alpha particles from ^{241}Am. Radiation is admitted into the chamber through a 12.5 μm aluminized mylar window. The energy of the α particles lost in the gas is about 3 MeV. Light and charge signals are fed into standard electronic units. All the xenon containing mixtures were kept in a closed gas circuit, at a pressure slightly above atmospheric pressure, and were allowed to circulate by convection through a purifier containing calcium turnings heated at about 450°C [12]. Before filling, the system was evacuated with a diffusion pump. The other mixtures flow continuously, at atmospheric pressure, through calibrated flowmeters and the detector.

III. Ar, Ar-CO_2 and Ar-N_2 Mixtures

A. Total light yields

The first studies concerning the use of the scintillation light emitted by avalanches in GEM channels for checking defects in foils, were performed with argon and Ar/CO_2 mixtures [2], at normal pressure. The chamber was operated in a closed system mode, the gas or gases being admitted without any additional purification. It was shown that, in general, the ratio between the light intensity and the current does not depend on the applied voltage. It was also shown that, with argon, the light emission decreases with time, but the addition of CO_2, although reducing the total light yield (see Figure 3), makes

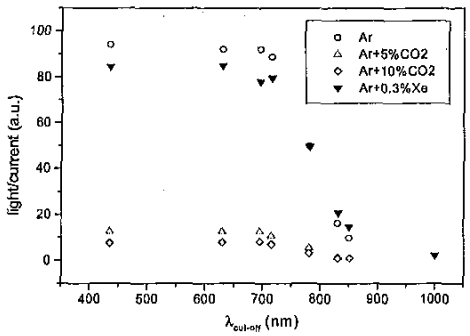

Figure 3: Light, normalised to the current, emitted in the GEM detector for several gas fillings, as a function of the wavelength cut-off (specified at 50% internal transmittance) of the longpass glass filters. (P ~ 760 - 800 torr)

the operation of the detector more stable. The decrease of the scintillation yield with time is most probably due to an impurity quenching mechanism (much less efficient than the one responsible for the quenching of VUV argon emissions), suggesting that the light seen by the CCD is due to argon and not to the impurities themselves. As seen from Figure 3, most of that light is emitted in the near-infrared region (NIR).

Measurements of the total number of photons emitted per drifting electron were also performed for pure argon and some

argon based gas mixtures, as a function of the charge gain for two other electric field configurations. Results are shown in Figure 4. Corrections to the experimental data were made to take into account the solid angle of detection, transmission of windows or grids and the response of the photon detectors.

As shown, the total light yield, normalised to the current, slightly decreases with the increase of the gain, and it is reduced by about a factor of ten when 5% of CO_2 is added to argon. Although the curves represented in Figures 4a and 4b show similar behaviours, the number of photons emitted per electron cannot be directly compared. This is due not only to

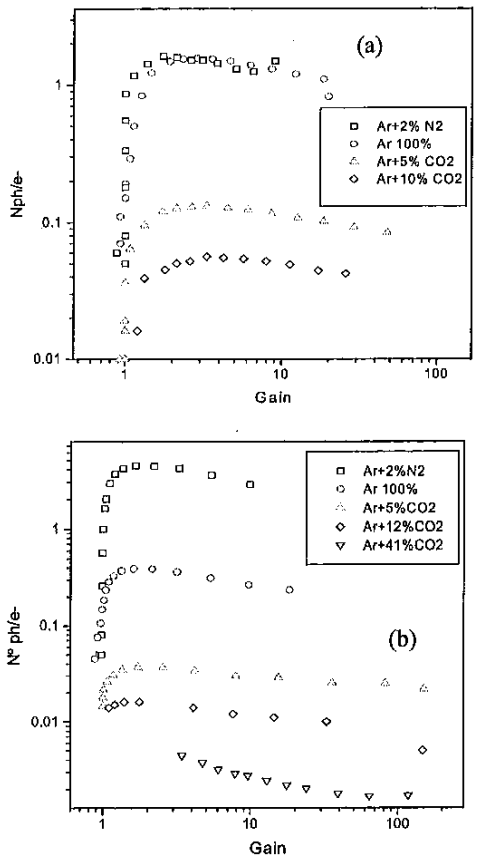

Figure 4: Total number of photons emitted per electron as a function of the charge gain, for several gas mixtures: a) between 450 and 1000 nm (PPC); b) between 200 and 850 nm (spherical geometry).

the different electric field geometries involved but also to the fact that the photodetectors do not cover the same wavelength region. Moreover, the photomultiplier (56 TUVP) was calibrated by using the scintillation light of a NaI (Tl) crystal whose emission spectrum peaks at around 415 nm while most of the light emitted in Ar and Ar/CO_2 mixtures lie in the NIR region (above 700 nm), a region where the sensitivity of the photocathode of the photomultiplier is already decreasing (Figure 1). On the other hand, in $Ar+2\%N_2$, a strong emission in the UV region is observed and this explains why the number of photons emitted per electron in this mixture is about ten times higher than in pure argon when measured with the 56 TUVP photomultiplier. In the NIR region, the total light yield is about the same (Figure 4a). In spite of its low quantum efficiency below 400 nm, the photodiode is also sensitive to the UV emission of $Ar+2\%N_2$, as shown from Figure 5. Similar data are represented in Figure 5, for pure argon, for comparison.

B. Emission spectra

The emission spectrum of pure argon was measured using the scintillation counter with the spherical anode. The data are not corrected for the transmission of the mirrors and diffraction grid of the monochromator. The sensitivity of the photocathode of the photomultiplier is almost constant for the wavelength region between 200 and 900 nm. As shown in Figure 6, the most important emissions, essentially the atomic lines due to transitions between the atomic states of the Ar ($3p^5$ 4p) and Ar ($3p^5$ 4s) configurations, lie in the near infrared region, in agreement with the data shown in Figure 3. An

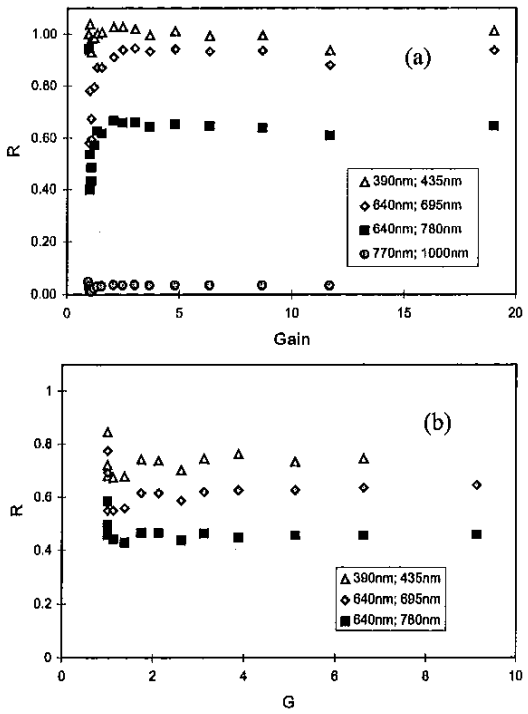

Figure 5: Ratio between the total light yield with and without longpass color filter for: a) Ar and b) $Ar+2\%N_2$. For each filter, the limit of stopband (specified at 0.001% internal transmittance) and the cut-off position (specified at 50% internal transmittance) are indicated.

important band, centred at 310 nm, is also observed together with the corresponding second-order diffraction, peaking at 620 nm. This band has been observed by other groups [8], [13], and it is probably due to the presence of water vapour as an impurity. In fact, this emission is present even at gas flows

of about 2.5 vol./min, but its intensity almost doubles when the gas flow is reduced to about 0.25 vol./min.. This increase is followed by a decrease of the intensity of the Ar I atomic lines of about 1/3.

It was also shown that small air leaks into the system produce a considerable increase of the amount of light emitted below 400 nm and a slight decrease of the NIR emissions. This is due to a very efficient energy transfer mechanism between the first excited states of argon and the C $^3\Pi_u$ (v=1,0)

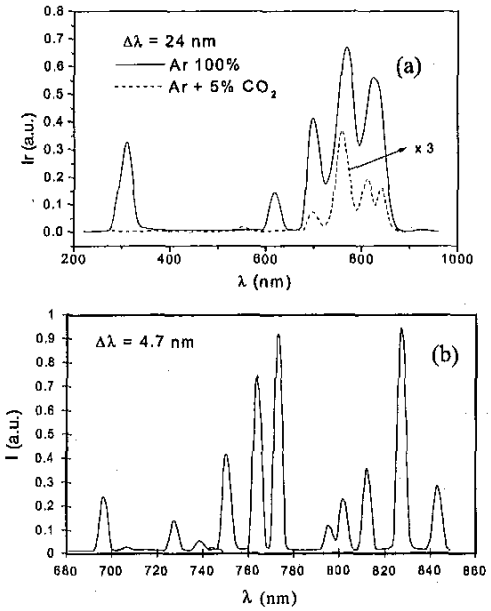

Figure 6: (a) Comparison of the emission spectra of pure Ar and Ar+5%CO_2, measured under α particle excitation, for a charge gain G ~ 30 (P~750 torr; slit widths = 5 mm); (b) NIR emission spectrum of pure Ar measured with slit widths of 1mm.

molecular states of N_2 [14], which de-excite to a lower molecular state giving rise to an intense molecular system, the 2nd positive molecular system of N_2, between 300 and 400 nm, whose intensity is maximum for a concentration of N_2 of 1-3% [15]. However, the CCD is not sensitive in this wavelength region and it only sees the decrease of the NIR emissions.

The addition of a small amount of a quencher gas like CO_2 does not change significantly the emission spectra in the visible and near-infrared regions. In fact, the emission spectra of Ar+CO_2 mixtures are very similar to that of pure argon, consisting essentially of the Ar I atomic lines (Figure 6). However, the line intensities (normalised to the current) are considerably reduced. No emissions are detected in the UV region.

C. Modelling of NIR emissions

We calculated the number of photons emitted per electron, in argon, resulting from the Ar I ($3p^5$ 4p)→($3p^5$ 4s) transitions. The electron excitation and ionization coefficients were obtained using the Boltzmann code developed by P. Ségur and his group [16] together with their set of electron impact cross sections. The excitation coefficients for the 4p levels include both direct excitation by electron impact and their population by cascades from upper states. All the ($3p^5$ 4p) levels were considered as one level with mean lifetime of 30 ns [15] and mean two-body rate constant for intermultiplet transfer to the 4s manifold of 10^6 $torr^{-1}.s^{-1}$.

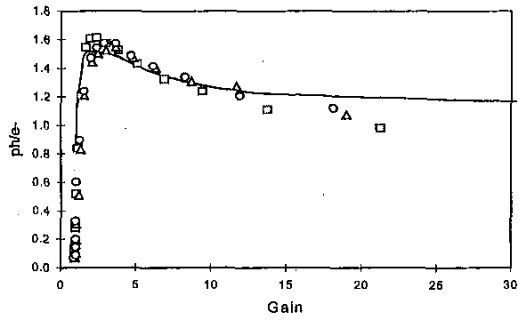

Figure 7: Total number of NIR photons (650-1000 nm) emitted per electron as a function of charge gain, in a PPC with a 0.35 cm gap (P ~ 750 torr). The solid curve represents the calculated values and the symbols represent experimental data taken at different days. (σ<20%)

Both experimental and theoretical data are represented in Figure 7, for the parallel plate chamber, showing that a good agreement is obtained for argon. Calculations take into account the absorption of X-rays within the amplification gap, the transmission of the anode grid and the sensitivity of the photodiode for the wavelength region between 650 and 950 nm.

IV. Ar-Xe Mixtures

A. Total light yields

Experimental evidence has shown [1], that rare gas mixtures exhibit large scintillation yields in the visible and/or

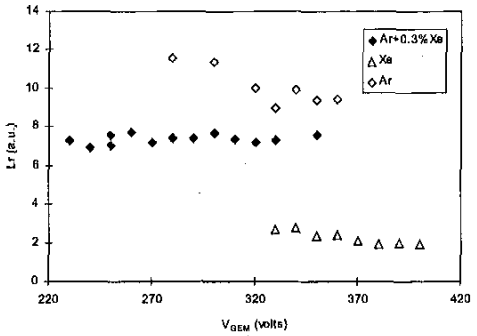

Figure 8: Ratio of emitted light and electron current versus V_{GEM} for several gas fillings. The gases are admitted into the chamber and are kept in a closed circuit, slightly above atmospheric pressure, without any additional purification.

near-infrared regions when used in microstrip gaseous chambers. Tests performed with the GEM detector filled with Ar/Xe mixtures showed that the scintillation yield is lower than in pure argon (Figure 8). Similar results were obtained with the scintillation detector with the spherical anode (Figure 9), with the scintillation yield decreasing with increasing concentration of xenon. Data shown in Figure 3 also indicate that most of the scintillation light seen by the CCD lies in the NIR region.

B. Emission spectra

The emission spectra in Ar-Xe mixtures are compared in Figure 10. These spectra were further studied with improved resolution, allowing an identification of most of the emissions. For concentrations of Xe above 1.5% , the main emissions are the atomic Xe I lines, in the near infrared region, and a molecular emission centred at 290 nm which is attributed to a xenon molecular emission. For lower Xe concentrations, the Ar I atomic lines become more intense. For the Ar+0.10% Xe mixture a strong band system between 300 and 400 nm arises. This band system was identified as the 2nd positive system of N_2 (present as an impurity). For this low concentration of xenon, the energy transfer from the $^3P_2$ and $^3P_1$ states of argon to the C $^3\Pi_u$ (v=1,0) molecular states of N_2 is more efficient than the energy transfer mechanism to the atomic excited states of xenon.

The influence of charge gain on the structure of the emission spectrum was also studied for an Ar+0.3%Xe mixture. In Figure 11 two emission spectra are compared. One was measured at a low charge gain, under α particle excitation whereas the other was measured at a higher charge gain, using

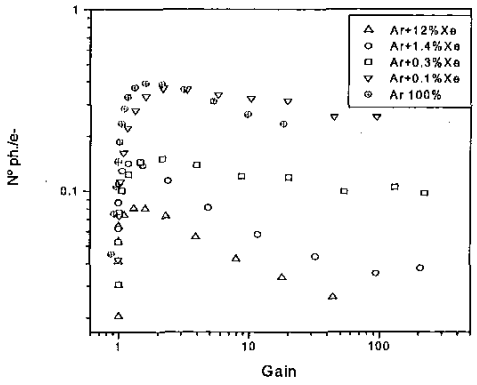

Figure 9: Total number of photons emitted per electron, between 200 and 850 nm, as a function of the charge gain, for several gas mixtures (spherical geometry).

the Fe-55 X-ray source. No differences were found in the structure of the spectra. The impurity contents is expected to be low as a continuous purification gas system is used.

Measurements of total lights yields with longpass glass filters interposed between the CCD and the GEM detector (Figure 3) show similar variations of the total light yield emitted in Ar+0.3%Xe and in pure argon, as a function of the wavelength cut-off, implying that Xe I lines above 930 nm should not be very important in the present detection conditions.

V. Conclusion

Among the gases and gas mixtures investigated, argon is the one which features the highest number of photons emitted per drifting electron in the region of sensitivity of our CCD.

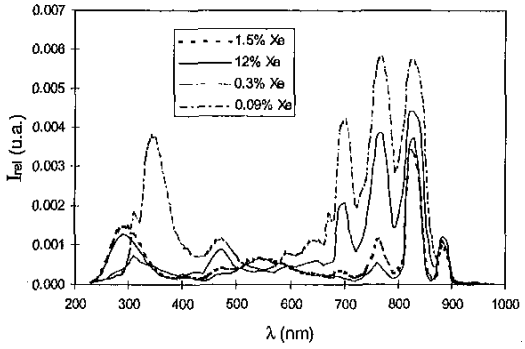

Figure 10: Emission spectra for several argon/xenon mixtures (P=980 torr), measured at low charge gains (G ~ 30-60).

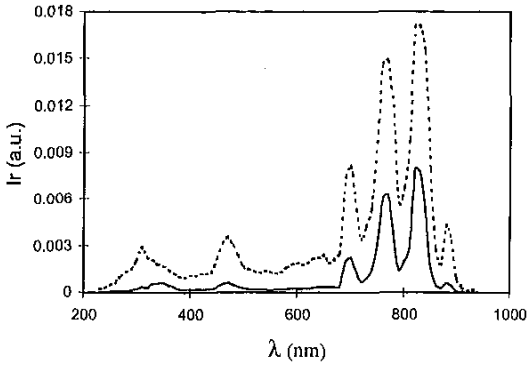

Figure 11: Light intensity per electron as a function of wavelength, for an Ar+0.3%Xe mixture (P ~ 980 torr) for two charge gains: solid curve-G = 2×10^4 (X-ray excitation); dashed curve - G = 40 (α–particle excitation).

Argon is a cheap gas and it can be kept flowing through the chamber in order to minimize the influence of impurities on the light yield. However, the operation of the detector is limited to low charge gains. On the other hand, the electron diffusion coefficients are high in argon which makes it inadequate for imaging purposes. The addition of a small amount of CO_2 reduces considerably the electron diffusion coefficients but at the expense of a reduction of the total scintillation output. However, even with this reduction, a comfortable number of photons emitted per electron is obtained which makes the Ar/CO_2 mixtures suitable for optical read-out.

The addition of 2% of N_2 increases the scintillation yield but in a wavelength region where our CCD is not sensitive. Studies of other rare gas mixtures are in progress.

The processes leading to NIR light emissions are well understood and a good agreement is obtained, for argon, between experimental and theoretical data. Modelling studies of light emissions in a GEM detector are also in progress.

VI. Acknowledgements

Acknowledgements are due to Dr. P. Ségur, from the Centre de Physique Atomique, Université Paul Sabatier, Toulouse, for providing us with the Boltzmann code and electron impact cross section data. This work was supported by contract CERN/P/FIS/1198/98 with the Portuguese FCT.

VII. References

[1] F.A.F. Fraga, M.M. Fraga, R. Ferreira Marques, J.R. Gonçalo, E. Antunes, C. Bueno and A.J.P.L. Policarpo, "Towards a Method for Quality Control of Microstructures for Gaseous Detectors Based on Scintillation Light", to be published in NIM A.

[2] F.A.F. Fraga, S.T.G. Fetal, R. Ferreira Marques and A.J. P.L. Policarpo, "Quality Control of GEM Detectors Using Scintillation Techniques", 2nd Conf. On New Developments in Photodetection, June 21-25, 1999, Beaune, France; to be published in NIM A.

[3] F.A.F. Fraga, S.T.G. Fetal, R. Ferreira Marques and A.J.P.L Policarpo, "The use of scintillation light for quality control of microstructures", Int. Work. on Micro-Pattern Gas Detectors, Orsay, France, June 28-30, 1999.

[4] P.E. Thiess and G.H. Miley, "New Near-Infrared and Ultraviolet Gas-Proportional Scintillation Counters", IEEE Trans. Nucl. Sci. NS 21, pp. 125-145, 1974.

[5] P. Lindblom and O. Solin, "Atomic Near-Infrared Noble Gas Scintillations I", Nucl. Instr. and Meth. A268, pp. 204-208, 1998.

[6] G. Charpak, W. Dominik, J.-P. Fabre, J. Gaudaen, F. Sauli, and M. Susuki, "Studies of Light emission by Continuously Sensitive Avalanche Chambers", Nucl. Instr. and Meth. A269, pp. 142-148, 1988.

[7] D. Sauvage, A. Breskin and R. Chechik, "A Systematic Study of the Emission of Light from Electron Avalanches in Low-Pressure TEA and TMAE Gas Mixtures", Nucl. Instr. and Meth. A 275, pp. 351-363, 1989.

[8] V. Peskov, G. Charpak, W. Dominik and F. Sauli, "Investigation of Light Emission from a Parallel-Plate Avalanche Chamber Filled with Noble Gases and with TEA, TMAE, and H_2O Vapors at Atmospheric Pressure", Nucl. Instr. and Meth. A 277, pp. 547-556, 1989.

[9] V. A. Polyakov, V.I. Rykalin and E.G. Tskhadadze, "Use of Electroluminescence of Gas Mixtures for Optical Data Acquisition from Wire Chambers", Instr. and Exp. Techn. 31, pp. 33-38, 1988.

[10] M. Susuki, P. Strock, F. Sauli and G. Charpak, "The Emission Spectra of Ar, Kr or Xe+TEA", Nucl. Instr. and Meth. A 254, pp. 556-560, 1987.

[11] O. Siegmund, P. Sanford, I. Mason, L. Culhane, S. Kellock and R. Cockshott, "A Parallel Plate Imaging Proportional Counter with High Background Rejection Capability", IEEE Trans. Nucl. Sci., Vol. NS-28, pp. 478-482, 1981.

[12] A.J.P.L. Policarpo, M.A.F. Alves, M. Salete S.C.P. Leite and M.C.M. dos Santos, "Detection of Soft X-Rays with a Xenon Proportional Scintillation Counter", Nucl. Instr. and Meth., vol. 118, pp. 221-226, 1974.

[13] J.-L. Teyssier, D. Blanc et J.-P. Boutot, "Les Spectres d'Emission des Gaz Rares Excités par des Particules α en Présence d'un Champ Électrique Constant", Le Journal de Physique, T. 28, pp. 427-432, 1967.

[14] A.J.P.L. Policarpo, "Light Production and Gaseous Detectors", Physica Scripta, Vol. 23, pp. 539-549, 1981.

[15] A.J.P.L. Policarpo, M. A. F. Alves and C.A.N. Conde, "The Argon-Nitrogen Proportional Scintillation Counter", Nucl. Instr. and Meth., Vol. 55, pp. 105-119, 1967.

[16] P. Ségur, M. Yousfi, M.H. Kadri and M.C. Bordage, "A Survey of the Numerical Methods Currently in Use to Describe the Motion of an Electron Swarm in a Weakly Ionized Gas", Transp. Theor. and Stat. Phys., Vol. 15, pp. 705-757, 1986.

[17] R.S.F. Chang and D. W. Setser, "Radiative Lifetimes and Two-Body Deactivation Rate Constants for Ar ($3p^5$,4p) and Ar ($3p^5$,4p') States", J. Chem. Phys., Vol. 69, pp. 3885-3897, 1978.