Measurement of the photoelectron-collection efficiency in noble gases and methane

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Abstract

The photoelectron-collection efficiency from photocathodes in noble gases and methane is experimentally investigated. The ratio between the number of transmitted photoelectrons in the gas media and in vacuum is determined as a function of the applied reduced electric field E/p, where p is the gas pressure. Results are presented for He, Ne, Ar, Xe, Kr and CH_4.
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1. Introduction

Radiation detectors are often based on the production of scintillation, and a photosensor device is used where photoelectrons are extracted from a photocathode and collected at an anode to produce a pulse. Applications of Cherenkov detectors, gas scintillation counters, gas photo-multipliers and other VUV photosensors have been implemented. In most cases, the photocathodes are in contact with a gaseous atmosphere, allowing for back-scattering of photoelectrons to the photocathode and reducing the effective quantum efficiency.

Several studies have been performed, either by simula-tion or experimentally, to determine the photoelectron-collection efficiency in different gases, when compared to vacuum [1–9]. The photoelectron-collection efficiency depends on the gas, the electric field intensity at the photocathode surface and the photon energy incident on the photocathode.

In the case of noble gas filled photosensors, a particu-larly significant reduction in the collected charge is observed due to the backscattering of the photoelectrons by the gas atoms [2–5,7–9]. Pure noble gases are important for its large scintillation, easy handling and purification and the use of solid photocathodes in pure rare gas is being implemented [5,10–12]. Up to now, the photoelectron-collection efficiency has been studied experimentally only for pure Ar [2,3,5], while simulation studies have been performed for Ar [2,4,7,8] and for Ne and Xe [7,8].

In the present work, the backscattering effects in pure He, Ne, Ar, Kr, Xe, and CH_4 are investigated. For that purpose, a 500 nm thick reflective CsI photocathode is used. The photoelectron emission is induced by a Hg lamp (185 nm centered, 5 nm FWHM). The photoelectron-collection efficiency is determined as a function of the applied reduced electric field E/p, where p is the gas pressure.

2. Experimental set up and procedure

The experimental set up used for this work is depicted in Fig. 1. A small vacuum chamber was assembled with the

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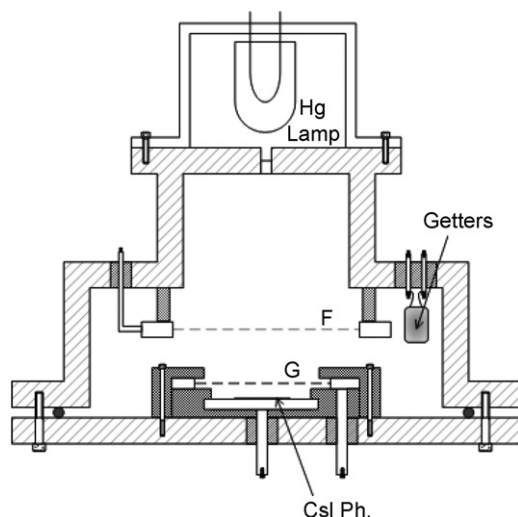
Fig. 1. Experimental set-up for the measurement of the photoelectron-collection efficiency in a gaseous atmosphere.

Fig. 2. Photoelectron-collection efficiency in Ar and CH_4 as function of the electric field applied in the gas when the CsI phocathode is irradiated with a Hg(Ar) lamp. The symbols correspond to experimental values while the solid lines represent Monte Carlo simulation results.

CsI photocathode deposited on a gold plated stainless steel plate, placed at a distance of 4 mm from the photoelectron-collecting grid G. A second grid F is placed above grid G so that an electric field can be established between the two grids to guarantee full photoelectron collection when operating under vacuum. The chamber is made of stainless steel except for the Macor ceramic used for electrical insulation of the stainless steel plate, the grids and the feedthroughs. The grids are made of stainless steel wire with 80 μm diameter and 900 μm pitch.

The chamber is filled with the gas under test, at atmospheric pressure, and is sealed during the measurements. Small getter units with a built-in resistor (SAES ST172/HI/7) are used to keep a high level of gas purity. The CsI photocathode is irradiated with the VUV photons and the photocurrent is measured in the photocathode as a function of the grid G voltage, using a Keithley Instruments 610C electrometer. The photocathode plate was operated at ground potential. To check for any possible photocathode degradation during measurements, the photocurrent under vacuum is measured before and after the measurements in gaseous atmosphere.

For each gas, the photoelectron-collection efficiency was measured as the ratio between the photocurrent values obtained while operating the photocathode in the gas and vacuum for the same applied field. For each gas, measurements were performed in different gas fillings in order to obtain an average value for the photoelectron-collection efficiency and the corresponding error.

3. Experimental results and discussion

Experimental results for the photoelectron-collection efficiency in Ar and CH_4 as a function of the electric field above the photocathode surface are shown in Fig. 2, together with other results presented in the literature.
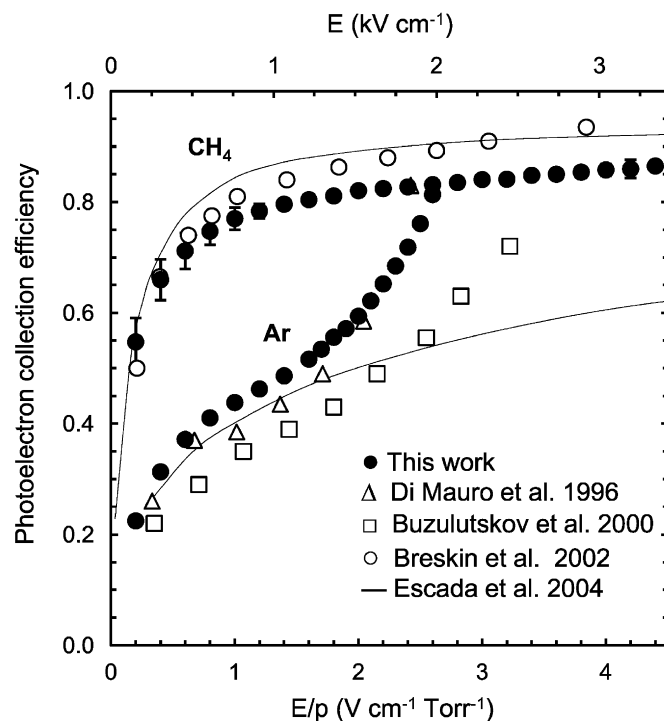
The collecting effect of the field is observed for both gases. The results obtained in this work are in agreement with those presented in the literature. The more noticeable differences between the experimental values for argon could be attributed to different levels of gas impurities. For Ar, the onset of gas excitation ($E/p > 1$ V cm^{-1} Torr^{-1}) and photon feedback effects prevent the observation of the slow increase in photoelectron collection with increasing field as observed for methane. Instead, a fast increase of the photoelectron collection with the electric field is observed above that threshold.

In Fig. 3 we present the experimental results obtained for the electron-collection efficiencies in He, Ne, Ar, Kr and Xe as a function of the electric field above the CsI photocathode. Except for He, all the other gases present a fast increase in the photon-collection efficiency due to photon feedback, for reduced electric fields above the gas excitation threshold: ~ 0.5 V cm^{-1} Torr^{-1} for Ne, ~ 1 V cm^{-1} Torr^{-1} for Ar, Kr and Xe and ~ 2 V cm^{-1} Torr^{-1} for He [13]. The broken lines represent a logarithmic function fitted to the experimental data below the gas scintillation threshold. This logarithmic trend is observed in Monte Carlo simulation results of photoelectron-collection efficiencies calculated for any gaseous atmosphere [7–9]. Assuming that this trend presents a typical behavior for the photoelectron-collection efficiency dependence on the electric field above the photocathode surface, the dashed curves of Fig. 3 present
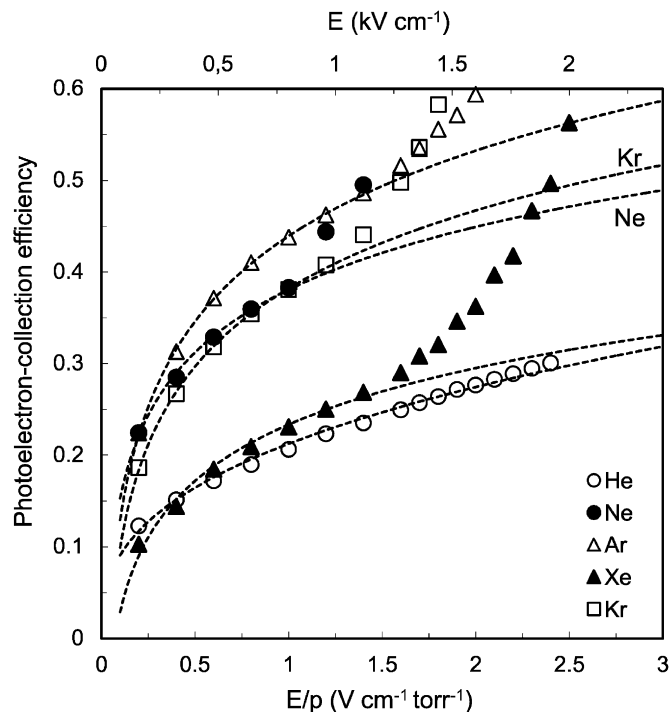
Fig. 3. Photoelectron-collection efficiencies in He, Ne, Ar, Xe and Kr as a function of the pressure reduced applied electric field.

a good estimation for the real photoelectron-collection efficiency in noble gases without the presence of photon feedback, even at high electric fields. This situation can occur whenever the path travelled by photoelectrons in the region above the photocathode is of the order of few tens of μm so that photoelectrons produce only a few scintillation photons in that path, e.g. as in micro pattern-based photosensors operating with reflective photo-cathodes. As an example, about five photons are produced at $4 \, V \, cm^{-1} \, Torr^{-1}$ for paths $\sim 100 \, \mu m$ in Xe at atmospheric pressure.

Fig. 3 shows that the photoelectron-collection efficiency for He and Xe only reaches values about 30% at reduced electric fields of $4 \, V \, cm^{-1} \, Torr^{-1}$, a factor of two lower than that obtained for Ar, Kr or Ne, and about a factor of three lower than that for the molecular gas CH_4. This fact has to be taken into account in the operation of solid photocathodes in xenon (e.g. in applications to Xe dual-phase detectors for dark matter search), since the effective quantum efficiency of a CsI photocathode operated in a xenon atmosphere will be well below 10% for the distribution of the Hg lamp, centered at 185 nm. Fig. 3 also shows that the photoelec-tron-collection efficiency in Ne is lower than that for Ar. If the same relative effect is observed for xenon scintillation light, centered at 172 nm, then this could be one of the reasons for the poorer performance obtained with a microstrip-based photosensor operating in Ne–Xe atmo-spheres [10] when comparing with those obtained in Ar–Xe mixtures [14].

4. Conclusions

We have measured the photoelectron-collection effi-ciency of a CsI photocathode operating in noble gas atmospheres and methane, when irradiated with a Hg lamp. Our results confirm the low photoelectron-collection efficiencies that are achieved in noble gases. He and Xe present the worst cases with the photoelectron-collection efficiency achieving values around 30% for reduced electric fields about $4 \, V \, cm^{-1} \, Torr^{-1}$; the values for Ne and Kr are around 50%, while for Ar, the most favorable case, the achieved values are about 60%. This is a drawback for the operation of solid photocathodes in noble gas atmosphere, when comparing with the values around 90% that are achieved in molecular gases such as CH_4. The effective quantum efficiency of a CsI photocathode operating in xenon atmosphere is well below 10% for this spectral distribution.

For reduced electric fields above the gas excitation threshold, secondary scintillation photons are produced in the gas by photoelectrons in their path above the photocathode, and photon feedback effects will occur. However, if this path length is short enough, so that the number of secondary photons that are produced is small, these effects will become negligible.

References

[1] A. Breskin, A. Buzulutskov, R. Chechik, A. Di Mauro, E. Nappi, G. Paic, F. Piuz, Nucl. Instr. and Meth. A 367 (1995) 342.
[2] A. Di Mauro, E. Nappi, F. Posa, A. Breskin, A. Buzulutskov, R. Chechik, S.F. Biagi, G. Paic, F. Piuz, Nucl. Instr. and Meth. A 371 (1996) 137.
[3] A. Buzulutskov, L. Shekhtman, A. Bressan, A. Di Mauro, L. Ropelewski, F. Sauli, S. Biagi, Nucl. Instr. and Meth. A 433 (1999) 471.
[4] A.V. Phelps, Z.L. Petrovic, Plasma Sources Sci. Technol. 8 (1999) 21.
[5] A. Buzulutskov, A. Breskin, R. Chechik, G. Garty, F. Sauli, L. Shekhtman, Nucl. Instr. and Meth. A 443 (2000) 164.
[6] A. Breskin, A. Buzulutskov, R. Chechik, Nucl. Instr. and Meth. A 483 (2002) 670.
[7] P.J.B.M. Rachinhas, J.A.M. Lopes, T.H.V.T. Dias, F.P. Santos, A.D. Stauffer, C.A.N. Conde, in: Proceedings of MC2000 International Conference on Advanced Monte Carlo for Radiation Physics, Particle Simulation and Applications, Springer, Heidelberg, 2001, p. 535.
[8] T.H.V.T. Dias, P.J.B.M. Rachinhas, J.A.M. Lopes, F.P. Santos, L.M.N. Távora, C.A.N. Conde, A.D. Stauffer, J. Phys. D 37 (2004) 540.
[9] J.M.D. Escada, P.J.B.M. Rachinhas, T.H.V.T. Dias, J.A.M. Lopes, F.P. Santos, C.A.N. Conde, A.D. Stauffer, in: J.A. Seibert (Ed.), 2004 IEEE Nuclear Science Symposium & Medical Imaging

Conference, 16–22 October, Roma, Italy. Conference Record, vol. 1, 2004, pp. 559–563.

[10] D.S.A.P. Freitas, J.F.C.A. Veloso, C.M.B. Monteiro, J.M.F. dos Santos, C.A.N. Conde, Nucl. Instr. and Meth. A 505 (2003) 228 (and references therein).

[11] L. Periale, V. Peskov, P. Carlson, C. Iacobeause, T. Francke, N. Pavlopoulos, F. Pietropaolo, T. Sokolova, P. Picchi, Nucl. Instr. and Meth. A 497 (2003) 242.

[12] T. Meinschad, L. Ropelewski, F. Sauli, Nucl. Instr. and Meth. A 547 (2005) 342.

[13] M.A. Feio, A.J.P.L. Policarpo, M.A.F. Alves, Jpn. J. Appl. Phys. 8 (1982) 1184.

[14] L.M.P. Fernandes, D.S.A.P. Freitas, A.M.F. Trindade, J.F.C.A. Veloso, C.M.B. Monteiro, L.F. Requicha Ferreira, J.M.F. dos Santos, IEEE Trans. Nucl. Sci. NS-51 (2004) 1509.