Performance of a Tracking Device Based on the GEM Scintillation

F.A.F. Fraga, L.M.S. Margato, S.T.G. Fetal, R. Ferreira Marques and A.J.P.L Policarpo

***Abstract*--A tracking device based on the GEM (gas electron multiplier) scintillation using a high-resolution cooled CCD camera was developed. The CCD is sensitive to the 400-1000nm band and standard glass photographic lenses are used. The active gas is an Ar-CF_4 mixture. The prototype detector is described and images of single alpha tracks are presented. The light yield and detector performance for several other gaseous mixtures, such as ^{4}He-CF_4 have also been investigated.**

I. Introduction

The use of gaseous tracking chambers for trajectory imaging is well established in scientific fields such as radiochemistry, radiobiology and microdosimetry. For this purpose the optical readout of gaseous avalanche detectors with CCD cameras has been done in the past, but associated with VUV or UV emitting mixtures, expensive lenses or optical systems and photocathodes with image intensifiers [1,2].

In a recent work [3], we considered the possibility of using the GEM as an active scintillator for X-ray detection, using visible light optics and a standard high resolution CCD camera for the readout, and a two-dimensional, large area, low granularity gaseous position sensitive detector for X-rays was developed. The results obtained with a 10 x 10 cm^2 GEM foil demonstrated that the position resolution with 8 keV X-rays using a Xe-CO_2 mixture is better than 100 μm (RMS) and that operation is possible at count rates up to 10^5 mm^{-2} s^{-1}. In order to increase the sensitivity of the detector two stacked GEMs were also used, resulting in an improved gain and higher light emission per detected photon.

Our previous work on the scintillation in the 400-1000nm band has shown that the very high electric field in the GEM channels, needed for electron multiplication, is not the optimum electric field for light emission [4]. Although careful optimization of the two GEMs operation improved its sensitivity, an enlarged collecting gap at the end of the detector improved the light emission by an order of magnitude, with a small deterioration in the spatial resolution. This improvement of the detector sensitivity is enough for recording single small energy deposits and made possible track imaging using a standard CCD camera.

Recently, after some research was done in scintillation properties, a gaseous mixture yielding high luminosity was found [5]. In this paper we describe a gaseous tracking detector that we built using a standard CCD and glass optical system operating in the 400-1000nm band and its performance.

II. The Gain and Scintillation of Ar-CF_4

Our first studies of the scintillation of avalanches in microstructures were done with Ar-CO_2 mixtures.

Although it was found that the addition of CO_2 to Ar decreased the light emission, the amount of emitted light in Ar has a strong dependence on the purity of the gas and a few percent of quencher should be added to stabilize its operation [6].

Gas mixtures based on CF_4 have been widely used in detectors, mainly due to its high drift velocity, optical and scintillation properties. Although the most studied photon emissions are in the far UV, CF_4 also emits visible and near infrared photons [7]. Replacing the CO_2 with CF_4 should result in a detector with good counting and localization properties but higher scintillation yields. It is known that CF_4 is transparent to its own photons, resulting in maximum gain limitations due to photon feedback in wire detectors, but the GEM geometry is intrinsically free from photon feedback [8]. Cascading GEMs even improves this shielding effect.

In order to study the operation of the GEM with Ar-CF_4 mixtures we made measurements of charge and scintillation using our setup.

As the experimental system and detector that were used to obtain these results is similar to the one described in [3], we will only refer the more relevant aspects. The entrance window of the test chamber was made from 12.5 μm aluminium foil and a 10×10 cm^2 GEM foil was used for the measurements. The GEM and the drift grids were supported by fiber glass frames. The GEM, supplied by the CERN Gas Detector Development Group, was manufactured from a 50

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µm thickness copper coated kapton foil by a chemical etching process that produces holes with a double conical shape (standard shape) [9]. The diameters of metal and kapton holes were 80 µm and 50 µm, respectively. The pitch was 140 µm and the optical transparency ≈12%. The GEM front electrode was grounded, the back one was operated at negative voltage. A drift plane was placed 4 mm before the GEM. No collecting electrode was used on these experiments, the avalanche electrons were collected by the GEM outer electrode. The light window, placed 5mm behind the GEM was made with a 75 µm mylar foil.

The ratio between the secondary and the primary currents, measured at the GEM back electrode and operating the chamber in ionization mode, respectively, were used to calculate the GEM gains. A Quantix 1400 camera, manufactured by Photometrics Ltd, was used to readout the light emitted from the GEM. It uses a Peltier cooled, low noise CCD, KAF 1400 from Kodak, with 1317 × 1035 pixels of 6.8 × 6.8 µm^2 and the spectral response goes from 400 to 1000 nm. All the pictures presented in this work were taken with the CCD cooled to -30ºC. A standard 50 mm f:1.8 photographic lens was used and the camera was placed at the minimum allowable focusing distance, about 30 cm away from the chamber mylar window.

Fig. 1 shows the gain-voltage characteristic of the GEM in Ar-CF_4 for several quencher concentrations. As expected, GEMs have to be operated with higher V_{GEM} when using CF_4 and the maximum gain is smaller than with CO_2 mixtures.

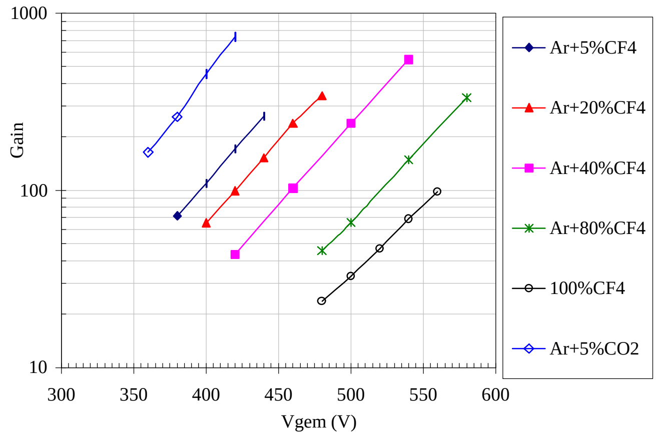

Fig. 1 GEM gains measured in Ar-CF_4 as a function of V_{GEM}. Ar-5%CO_2 values are shown for comparison.

The variation of the detected light divided by the secondary current versus V_{GEM} for several quencher concentrations of the Ar-CF_4 gas filling is shown in fig. 2. This figure, in arbitrary units, is a good parameter to compare relative scintillation yields of gas mixtures if the geometry of the system is kept unchanged. The data on Ar-5% CO_2 is shown for comparison. Ar-5%CF_4 has a much greater light emission than Ar-5%CO_2, almost 20 times larger, and considerable light emission for higher percentage of quencher, contrary to what was observed in Ar-CO_2.

The very high scintillation yield of Ar-5%CF_4 opens new areas of research in GEM imaging, resulting in detectors of much increased sensitivity.

III. Development of a Tracking Chamber

We presented the possibility of using the double GEM chamber as a tracking detector in [10]. Since then we built a

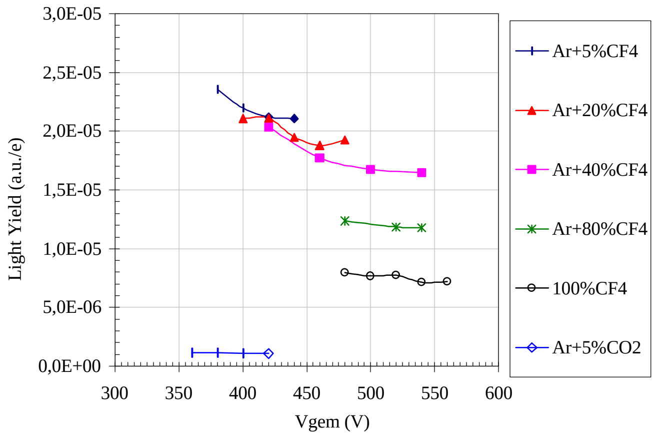

Fig. 2 Ratio of emitted light over secondary electron current versus V_{GEM} for several quencher concentrations of the Ar-CF_4 mixture. Ar-5%CO_2 values are shown for comparison.

tracking chamber with a sensitive volume of ~250 cm^3, that can image track lenghts up to 8cm. The schematic drawing of the chamber is shown in fig. 3. The chamber is fitted with

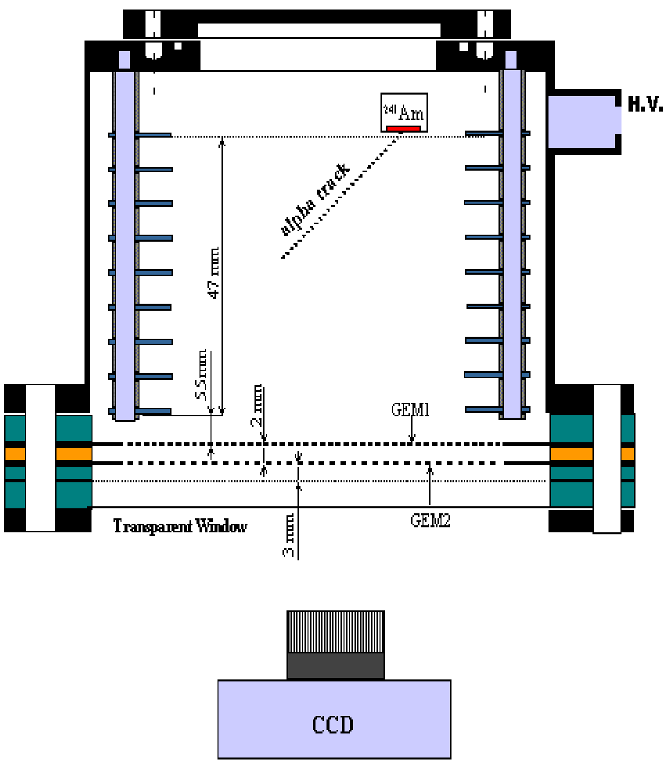

Fig. 3 Schematic cross-section of the tracking chamber used in this work. The CCD (not drawn to scale) was placed 30 cm away from the mylar window

two 10×10 cm^2 cascaded GEMs, separated by 2 mm, and a collecting / multiplying electrode placed 3 mm away from the outer GEM. The GEM pitch was 140 μm, the copper and kapton holes diameters were 80 and 60 μm. Two views of the chamber are presented in fig. 4, showing the drift zone with the field rings and a detail of GEM assembly.

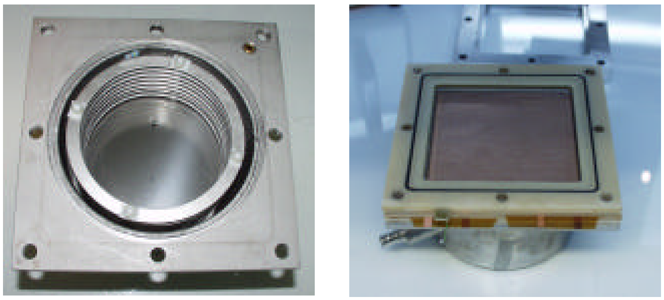

Fig. 4 Photographs of the tracking chamber drift zone and of the chamber with the mylar window removed, showing the outer GEM.

The chamber was filled with Ar-5%CF_4 and the CCD camera was again placed at 30 cm from the chamber transparent mylar window. A low counting rate ^{241}Am alpha source was placed in the chamber, just over the drift electrode. The 5.48 MeV particles have a range of 4.5 cm in Ar.

In this paper we will call E_D, E_T and E_C, respectively, the drift field, the transfer field between GEMs and the collection field between the outer GEM and the collecting electrode. When using CF_4 mixtures, needing higher V_{GEM} voltage, the transfer field was found to be critical and was carefully optimized by simulation and experimental measurements.

The images of tracks obtained with several values of GEM gain and collection electric field are shown in Fig. 5. Images

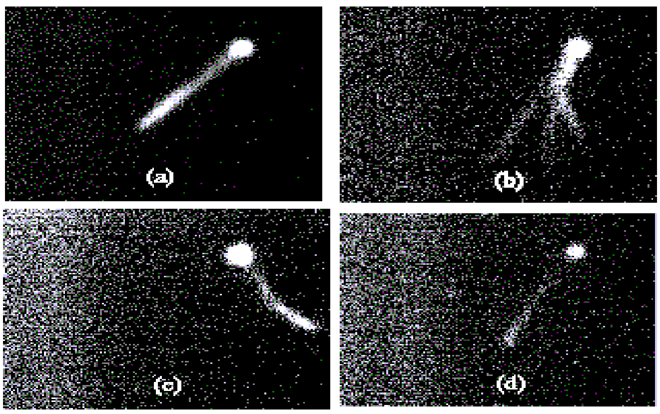

Fig. 5 Images of alpha tracks taken using the tracking chamber with Ar-5%CF_4.: (a,b) V_{GEM1}=V_{GEM2}=400V (Gain~140), E_T=5.45KV/cm, E_C=5.86KV/cm, CCD Binning 4x4, Texp.=10ms; (c,d) V_{GEM1}=V_{GEM2}=430V (Gain~300), E_T=5.45KV/cm, E_C=0, CCD Binning 7x7, T=10ms.

(a) and (b) were obtained with a collecting field of 5.9 kV/cm, that increases gain and scintillation. Increasing the GEM gain and the CCD pixel binning, that improves the CCD signal to noise ratio, we could also operate the chamber without collection field, as seen in (c) and (d). From these data we estimated that 200 photons were detected by the CCD per deposited keV in the gas.

Fig. 6 shows in more detail an image of a single track and the distribution of the scintillation light along the longitudinal CCD pixels of the track. The familiar Bragg curve is revealed.

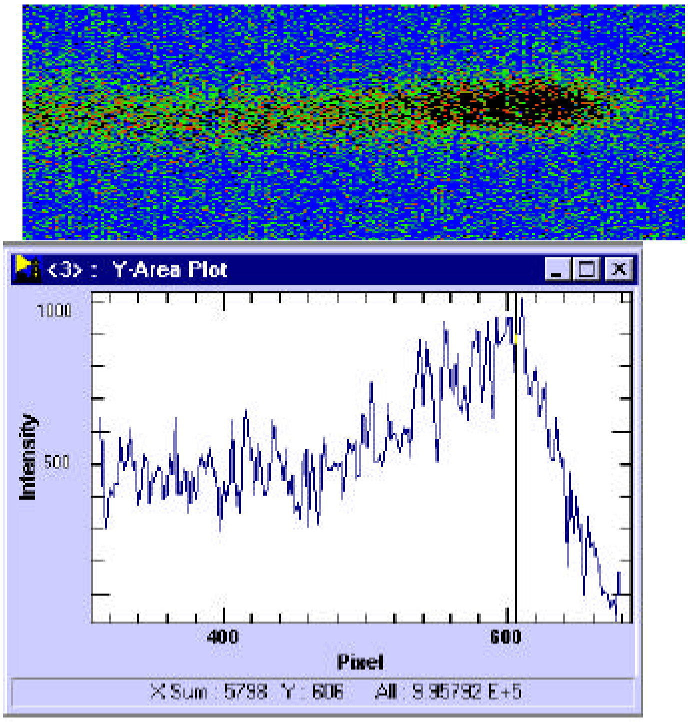

Fig. 6 Distribution of measured scintillation along an alpha track. The Bragg curve is revealed.

IV. He-CF4 RESULTS

^{3}He-CF_4 is commonly used in gaseous neutron detectors [11]. The ^{3}He is used for neutron conversion (^{3}He + n ⇒ p + ^{3}H + 770 keV) and the CF_4 is needed to decrease the range of the proton and the triton. Considering that the proton and the triton ranges in CF_4 are 4.4 mm and 1.6mm, respectively, and that the mean energy deposit of alpha particles per mm in the preceding section (~120 keV/mm) is similar to the energy density of the track resulting from the neutron absorption, we decided to perform some preliminary measurements in ^{4}He-CF_4 mixtures.

The experimental setup and operating mode was the same of section II.

The gain as a function of the GEM voltage for different CF_4 concentrations is shown in Fig. 7. The data for Ar-5%CO_2 is added for comparison. As already reported by several authors for other type of microstructures, the He mixtures have higher maximum gain before breakdown than the Ar ones. The variation of the light over secondary current ratio versus V_{GEM} for several quencher concentrations of the He-CF_4 gas filling is shown in fig. 8. Despite the fact that the luminosity of He-CF_4 is lower than Ar-CF_4 it is still five times higher than Ar-CO_2.

These preliminary measurements show that integrating position detectors for neutrons could be developed using scintillation readouts.

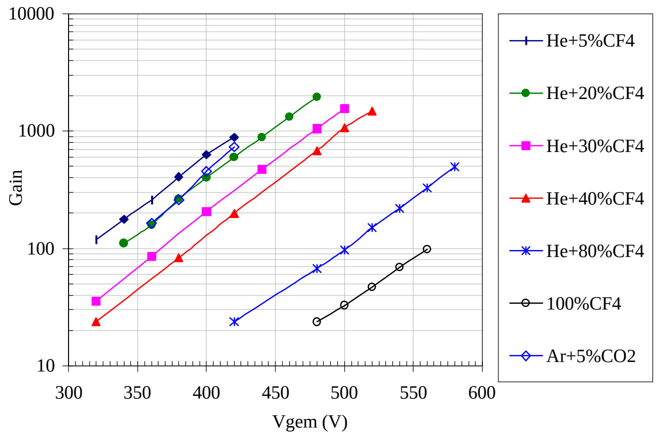

Fig. 7 GEM gains measured in He-CF_4 as a function of V_{GEM}. Ar-5%CO_2 values are shown for comparison.

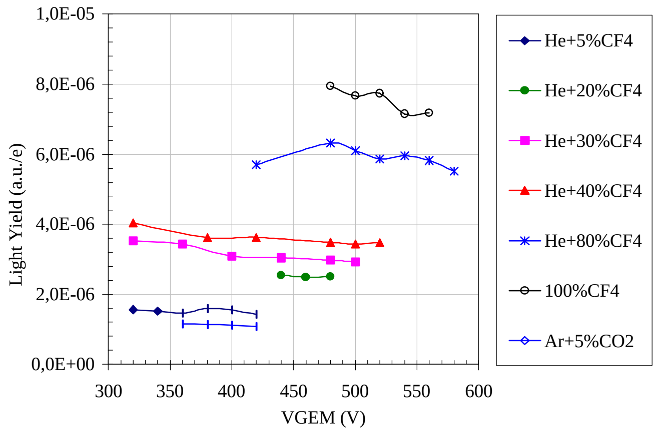

Fig. 8 Ratio of emitted light over secondary electron current versus V_{GEM} for several quencher concentrations of the He-CF_4 mixture. Ar-5%CO_2 values are shown for comparison.

V. Conclusions

Our findings that Ar-CF_4 mixtures have much higher luminosity than Ar-CO_2 made possible the development of an imaging chamber for single events using GEM scintillation readout by common CCD systems. The detector is currently being improved with an additional third GEM and studies on the dependence of the scintillation versus pressure and GEM hole dimension have been started.

The optical readout of ^{3}He neutron detectors was shown to be feasible. We will soon perform tests in a neutron beam.

VI. Acknowledgment

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VII. References

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