Sealed GEM photomultiplier with a CsI photocathode: ion feedback and ageing

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Abstract

We present the performance of a sealed gaseous photomultiplier consisting of a cascade of 3 or 4 GEM (Gas Electron Multiplier) elements coupled to a semitransparent CsI photocathode, in Ar/CH_4 (95/5). A few-month stability study of the photocathode in a sealed mode is presented. Increasing the number of GEMs in cascade substantially reduces the ageing of the detector under strong irradiation. The ion feedback to the photocathode has probably a minor effect on the ageing rate.

1.Introduction

The GEM [1] (Gas Electron Multiplier) photomultiplier (GPM), recently introduced [2], might have a number of advantages over vacuum photomultipliers: insensitivity to magnetic fields, large active area, excellent localization response, flat-panel geometry and low cost. In addition, the multi-GEM amplification structure considerably reduces photon [3] and ion [4] feedback to the photocathode. Such devices can operate in non-ageing mixtures of pure noble gases at high gains [2]. However, in order to become a practical device, the GPM should be operated in a sealed mode, nonstandard for gaseous devices. This may result in fast detector ageing, which should be carefully studied. It has been recently shown that a sealed GPM with a CsI

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photocathode and multi-GEM multiplier can successfully operate at high gains for single-photon counting [5]. In this paper we further study the performance of a sealed GPM and the ion feedback to the photocathode. We show that employing the multi-GEM structure may considerably reduce the ageing rate.

2. Results

A schematic view of the GPM is shown in Fig.1. 4 GEM foils (50 μm thick kapton, 80 μm diameter and 140 μm pitch holes), mounted in cascade with 1.2 mm gaps, were installed within a Kovar package and then baked for a few days. After baking, the package was sealed to a quartz window coated with a 30Å Cr conductive layer and a semitransparent 150Å CsI photocathode. The sealing was done with a hot indium alloy, under 1 atm Ar/CH_4 (95/5). As a result of non-optimized evaporation procedure, the quantum efficiency (QE) of the photocathode was only 2% at 170 nm, which is about 5 fold smaller than the QE of an optimized semitransparent CsI photocathode. The distance between the photocathode and the 1st GEM was 6.6 mm. The GEM electrodes were connected to a resistive high-voltage divider, as shown in Fig.1. Typically electric fields were E_D = 0.6 kV/cm in the drift gap, E_T = 2 kV/cm in the transfer gaps and E_I = 4 kV/cm in the induction gap. A photograph of the GPM is presented in Fig.2. More details are given elsewhere [5].

We used 3 modes of anode signal readout: from the lower electrode of GEM3, lower electrode of GEM4 and upper electrode of GEM4. Following reference 5 these are designated 3GEM, 4GEM and 3GEM+PCB operation modes, respectively. In the last mode (depicted in Fig.1), the detected gain is only a fraction (typically ½) of the "real" gain due to the avalanche charge sharing between the readout electrode and bottom face of GEM3. In contrast, in 3GEM and 4GEM modes the whole avalanche charge is detected. In all cases either pulse-counting or current readout modes were applied. The ratio of the cathode-to-anode currents provides the ion feedback fraction to the photocathode: $F = I_C / I_A$.

Rather high GPM gains were obtained, around 10^6, both in 4GEM and 3GEM+PCB configurations (Fig.3), allowing for the effective detection of single photons [5].

In sealed detectors two avenues of ageing exist: the ageing induced by an operation under strong irradiation and the self-ageing under storage (without voltage). The ageing under irradiation could be caused by the degradation of the photocathode by impact of avalanche-induced ions and by its contamination with gas derivates created in the avalanche process.

To estimate the contribution of ion impact and find conditions for its minimization, we measured the ion feedback fraction to the photocathode as a function of several parameters: the drift field (E_D), the ratio between the transfer field (E_T) and the field inside the GEM hole (which is proportional to the voltage ratio $\Delta V_T/\Delta V_{GEM}$), the detectable GPM gain (G) and the number of GEMs in cascade. We found that the ion feedback is most sensitive to E_D (Fig.4) and increases linearly with it. In particular, operation at drift fields of the order of 100 V/cm reduces the ion feedback to values below 1%. The other parameters have minor effect. For example, adding the 4th GEM to the cascade reduces the ion feedback by a factor of 2 at larger gains (Fig.5). Also, the ion feedback depends weakly on the total gain for gains above 10^3 (Fig.5).

In the second mechanism, the ageing depends on the production rate of active radicals in the avalanche plasma, which is related to both the overall gain and the electron temperature in the avalanche, the latter being determined by the electric field inside the GEM hole (i.e. by ΔV_{GEM}). All three variables, which might affect the ageing rate, were under control during the ageing measurements: ion feedback, total gain and voltage drop across the GEM.

The ageing characteristics were obtained by measuring both the anode current and the relative QE as a function of the accumulated anode charge, under high photon flux (3×10^4 ph.e./mm^2 s) and large anode currents. Fig.6 shows the evolution of the anode current density with accumulated anode charge, for 3 aging runs. The corresponding ion feedback, total gain and single-GEM voltage-drop values are indicated. Note that when increasing the gain by 40% (run 2 to run 3), the anode current increased by a larger factor. This is indicative of charging-up effects at large anode currents [2,5] and implies that the anode current variations during the ageing test do not always reflect the true photocathode ageing [6].

At a gain of 1×10^4 the relative anode current did not vary after 2 μC/mm^2, while at a gain of 7×10^4 it was reduced by a factor of 2 after accumulating about the same charge. The corresponding ageing rate is comparable to that measured in unsealed detectors [6]. On the other hand, in the 4GEM mode the ageing rate is by far lower as compared to the 3GEM mode, despite of the higher gain. This difference is even more pronounced in the QE decay characteristic (Fig.7). Note that the ion feedback fraction in all the measurements was about the same, varying from 3 to 8%.

Combining the data of Figs. 6 and 7 leads to the conclusion that neither the anode current density nor the overall gain and the ion feedback fraction correlate with the ageing rate. The parameter mostly affecting the ageing seems to be the voltage drop across a single GEM, which determines the electron temperature and thus the production rate of active molecules in the avalanche. A direct consequence is that an increase of the number of GEMs in a cascade may considerably reduce the ageing rate at a given total gain, due to the reduction of ΔV_{GEM} .

Regarding the long-term stability of the GPM, Fig.8 shows the evolution of the QE with time. The self-ageing is reflected in a gradual decay of the QE over a few months scale. The approximate 30% degradation of the QE over 5 months was obviously due to modification of the gas composition inside the GPM, since it was accompanied by a constant increase of the operation voltage. We cannot say at the moment whether the self-ageing is due to an air leak through the seal or an outgassing of the Kapton substrate.

3. Conclusions

In conclusion, we have manufactured for the first time a sealed GEM photomultiplier (GPM) with a CsI semitransparent photocathode, 3 or 4 GEMs in cascade and Ar/CH_4 (95/5) gas filling. It can operate in a single-photon-counting mode at high gains reaching 10^6.

The ageing rate of the sealed GPM under irradiation is similar to that reported for unsealed detectors with CsI photocathodes, which are not based on GEM. Decreasing the voltage across a single GEM, i.e. by increasing the number of GEMs in cascade, might considerably reduce it. The ion feedback to the photocathode is by no means the only ageing mechanism. The feedback can be reduced below 1% by operating at low drift and high transfer fields and/or by increasing the number of GEMs in cascade. Sealing experiments with noble-gas mixtures and optimal photocathodes are in course.

Finally, we should remark that the efficient operation of a GPM crucially depends on an efficient photoelectron extraction from the photocathode and its transfer into the GEM apertures. These subjects have been systematically investigated both for semitransparent photocathodes and for reflective ones, deposited on the top of the first GEM [7,8].

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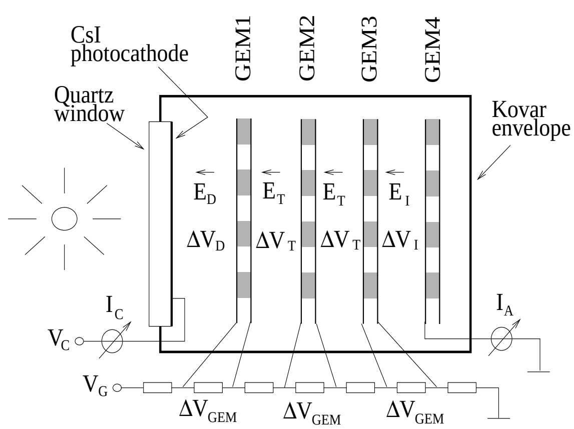

Fig.1 A schematic view of the sealed GEM photomultiplier (GPM).

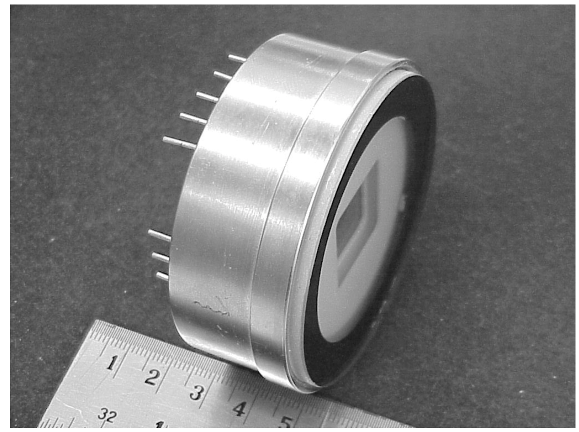

Fig.2 A photograph of the sealed GPM.

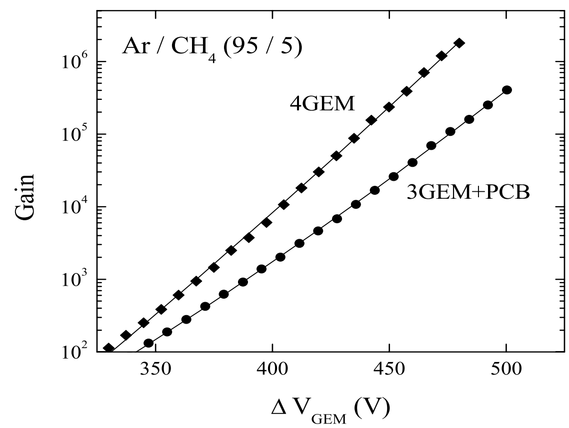

Fig.3 GPM gain as a function of the voltage drop across a single GEM, in 3GEM+PCB and 4GEM modes.

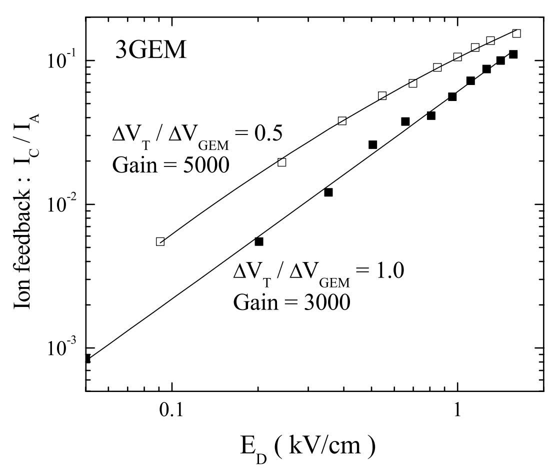

Fig.4 Ion feedback fraction to the photocathode as a function of the drift field, in 3GEM mode.

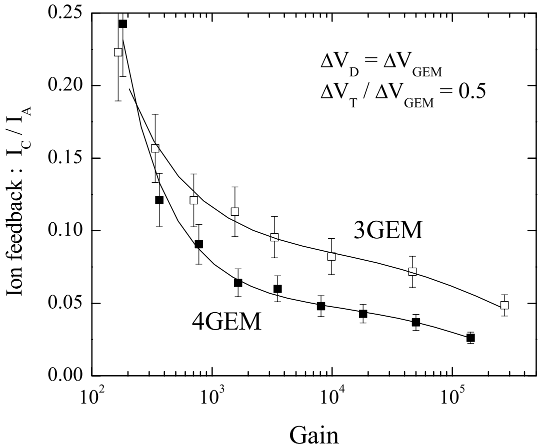

Fig.5 Ion feedback fraction to the photocathode as a function of the gain, in 3GEM and 4GEM modes.

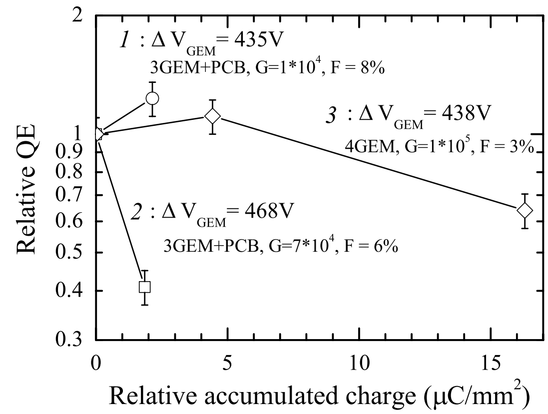

Fig.7 Induced ageing under irradiation in 3 ageing runs. Shown is the relative QE, normalized to the QE value at the beginning of each run, as a function of the accumulated anode charge in that particular run.

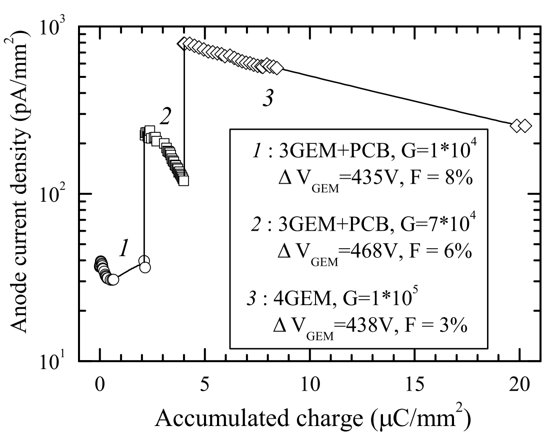

Fig.6 Induced ageing under irradiation. Shown is the evolution of the anode current density with the accumulated anode charge, in 3 ageing runs with different gains (G), voltage drops across a single GEM (ΔV_{GEM}) and operation modes. The ion feedback fraction to the photocathode (F) is indicated as well.

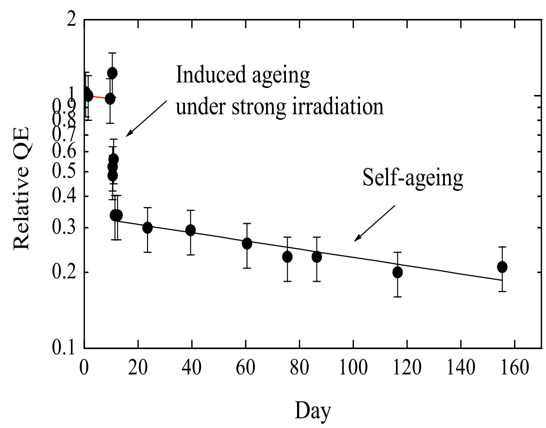

Fig.8 Long-term stability of the GPM. Shown is the evolution of the relative QE with time.