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Operation of a single-GEM in noble gases at high pressures

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Abstract

We report the performance of a single-Gas Electron Multiplier (GEM) operating in pure Ar, Xe, and in Ar-50 mbar Xe mixtures, in the range of 1–7 bar. The maximum gain and voltage that can be applied to the GEM are investigated as a function of filling pressure and compared to the results obtained with triple-GEM and MHSP (Micro Hole and Strip Plate) multipliers. The maximum gain achieved at 1 bar Xe is about 10^3, presenting a fast decrease with pressure to values around 300, 50 and 10 at 2, 3 and 5 bar, respectively. Gains around 100 were achieved in Ar up to 4 bar, decreasing to values of few tens at 6 bar. On the other hand, gains around 500 can be achieved in Ar-50 mbar Xe mixtures up to 5 bar, presenting a fast reduction at higher pressures due to the limitations on the maximum gain imposed by the GEM discharge limit. Nevertheless, gains above 100 can be obtained for pressures between 6 and 7 bar, indicating a good potential for neutron detection.

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1. Introduction

The operations of triple-Gas Electron Multiplier (GEM) and Micro Hole and Strip Plate (MHSP) electron multipliers in high-pressure noble gases have been investigated in detail through the last 6 years [1–6]. Applications to cryogenic double-phase detectors, for neutrino physics and dark matter search [7,8], and to neutron detection [9] have been envisaged, but they also present good alternatives for hard X-ray detection applications such as digital radiography, synchrotron radiation studies, crystallography and astrophysics.

Noble gases have the important advantages of simple handling and purification procedures, and the ability of not presenting ageing under charge avalanche. This allows the design of sealed detectors with stable long-term operation. However, charge multiplication in noble gases is strongly limited by photon-mediated secondary effects, and organic quenchers have been added to pure noble gases to suppress the UV-scintillation occurring in the electron avalanches. Recently, the feasibility of high-gain operation of multi-GEM cascades in pure noble gases was demonstrated. The avalanche confinement within the microstructure holes hinders photon-mediated secondary processes, allowing high gains to be achieved even in highly UV-scintillating gases [10,11].

However, studies have revealed that the maximum gain that could be achieved in triple-GEM and MHSP electron multipliers drops with increasing gas pressure, for heavy noble gases, Xe, Kr and Ar. This is due to the less efficient charge transfer between amplification stages and to the reduction of the electron-impact ionisation yield. The reduction in the ionisation efficiency is due to the decrease of the reduced electric field in the avalanche region, limited by the total voltage that can be applied to the multipliers before discharge, as the pressure increases, cf. Ref. [6] and

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references therein. It was demonstrated that MHSPs yield higher gains for Xe, Kr and Ar at high pressures than triple-GEMs [6], presenting a much slower rate for gain reduction with increasing pressure. For dense light noble gases, Ne and He, other mechanisms such as associative ionisation and/or Penning ionisation with impurities predominate over electron-impact ionisation and triple-GEM achieves rather high gains, of the order of 10^5, which are almost pressure independent [12,13].

Single-GEM operation at high pressure was only studied in detail for Kr [3] and presents an even slower rate for gain reduction with increasing pressure than MHSPs [6]. Compared to triple-GEM, single-GEM presents higher gains for Kr pressures above 4 bar [3]. On the other hand, the gain achieved with the single-GEM in Kr operated at atmospheric pressure, ~500, is more than two orders of magnitude lower than that achieved with the MHSP, reducing this difference to about one order of magnitude at pressures of 6 bar, with charge gains around 200. However, single-GEM is a good alternative for high-pressure operation in applications where high gain is not a requirement, e.g. for neutron detection, a gain of ~100 is sufficient, and where the decoupling of the readout system from the amplification stage is an advantage for detector operation, in opposition to MHSPs.

In this work, we investigate in detail the performance of a single-GEM operating in high-pressure Xe, Ar and in Ar-50 mbar Xe mixtures (with interest for neutron detection [9]). The gain and maximum voltage that can be applied to the GEM are determined as a function of filling pressure, in the range of 1–7 bar, and compared to the results obtained with triple-GEM and MHSP multipliers.

2. Experimental set-up

The GEMs used in this work were manufactured at CERN and have standard dimensions: 50-μm Kapton with 5-μm copper clad on both sides and with bi-conical holes of 50 and 70 μm in the Kapton and copper, respectively, arranged in a hexagonal layout of 140-μm edges. The GEMs active area is $2.8 \times 2.8\,\mathrm{cm}^2$. A stainless-steel detector body was built to accommodate the GEM; the absorption/drift region and the induction region gaps are 4- and 3-mm wide, respectively, Fig. 1. Macor pieces, simply glued with low vapour-pressure epoxy (Tra-Con 2116) to the stainless-steel body, were used for insulating the feedthroughs of the detector biasing. The GEM was mounted on a Macor frame to keep it stretched and to provide the electrical contacts to the GEM surfaces. The detector window was made of aluminised Mylar foil (25-μm thick) glued to the detector body with the same epoxy.

The detector was vacuum pumped down to pressures of 10^{-5} mbar and, afterwards, filled with noble gases at different pressures without backing; it was sealed off during the measurements. The gas purity was maintained using non-evaporable getters (SAES St707), heated up to about 150 °C and placed in a small volume connected to the detector one.

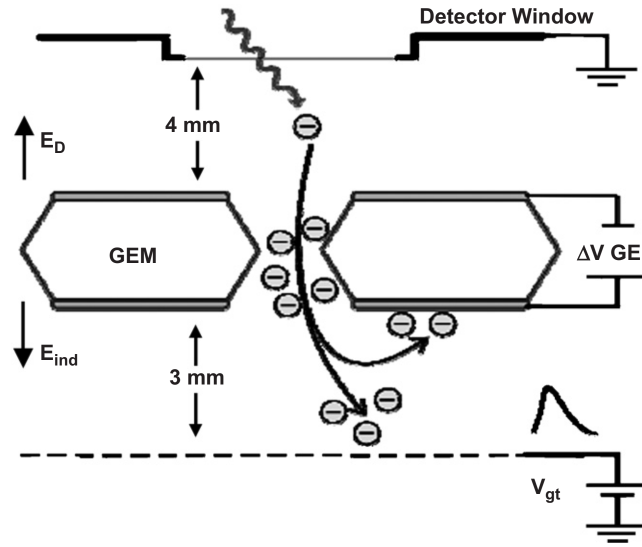

Fig. 1. Schematic diagram of the single-GEM detector used in this work.

The radiation window and the detector body are grounded, while the different electrodes, GEM top and bottom electrodes and the induction mesh, are polarised independently. The voltage in the GEM top electrode determines the drift field; the voltage difference between the GEM top and bottom electrodes, ΔV_{GEM}, determines the avalanche gain in the holes; and the voltage difference between the GEM-bottom electrode and the induction mesh determines the induction field.

The detector was irradiated with 22.1 keV X-rays from a ^{109}Cd source, allowing a clear separation of the peak distribution from the electronic noise tails for reduced detector gains. The primary electron clouds resulting from X-ray interactions in the drift region are focused into the holes where they undergo avalanche multiplication, Fig. 1; the avalanche electrons are extracted out of the holes and are collected in both the GEM-bottom surface and induction mesh. The signals from the mesh were fed through a Canberra 2006 preamplifier (sensitivity of $1.5\,\mathrm{V\,pC^{-1}}$) and a Tennelec TC243 amplifier (4 μs shaping time) to a Nucleus PCA2 1024 multichannel analyser. The electronic chain sensitivity was calibrated for absolute gain determination, using a calibrated capacitor directly connected to the preamplifier input as well as to a precision pulse generator. The gains were determined from the peak-position of the pulse-height distributions.

3. Experimental results and discussion

Throughout the measurements, the reduced drift field, determined by the GEM upper electrode voltage, was kept at values between 0.2 and $0.3\,\mathrm{kV\,cm^{-1}\,bar^{-1}}$ for pure Ar and Ar-50 mbar Xe mixtures, and $\sim 0.5\,\mathrm{kV\,cm^{-1}\,bar^{-1}}$ for pure Xe.