CHARGE CARRIER TRANSFER IN THE GAS ELECTRON MULTIPLIER AT LOW GAS GAINS

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Abstract

Connected to the Linear Collider project TESLA at DESY, studies on the readout of TPCs based on the GEM-technology are ongoing. For particle identification via dE/dx - measurement, a good energy resolution is indispensable, and therefore losses of primary electrons have to be avoided. It turned out, that in the GEM transverse diffusion inside or close to the holes is a not negligible reason for these losses. For Ar-CH_4 90:10 and TPC-like field configurations it was found, that when operated in normal amplification mode, the Standard Geometry GEM should not lose primaries, whereas for low gains, also when operated in magnetic fields up to 5T, a GEM with larger pitch and hole diameter would be necessary.

1 Introduction

The Gas Electron Multiplier (GEM) [1] is a two-side metal-clad Kapton foil, perforated with a high density of photolithographically etched holes. In the so called *Standard Geometry* holes of typically 70μm diameter are placed in a triangular pattern with a pitch of 140μm. On application of a potential difference (usually 300-500V) between upper and lower metal layer, a strong electric field is built up inside the holes. Inserted in the drift gap of a gas detector, drifting electrons are guided into these holes, where they undergo proportional gas amplification. A large fraction of the electrons then is released into the volume below the foil, where they can be collected by readout electronics or – in order to achieve even

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higher total gains – transferred to another GEM. Large size triple-GEM detectors with a two-dimensional microstrip readout are successfully operated in the small area tracker of the COMPASS experiment at CERN [2]. Among other applications, extensive R&D is ongoing on an improved readout of Time Projection Chambers (TPCs) connected to the Linear Collider project TESLA at DESY [3]. Compared to a conventional TPC readout of wires plus pads, the GEM technology offers two major advantages: higher spatial resolution and faster signals improve the multi-track resolution, and the configuration of the electric field lines intrinsically suppresses the ion feedback. For the efficient readout of a TPC, effective gains of 10^3 to 10^4 are required. For a double-GEM structure, this would mean effective gains between 30 and 100 per GEM.

2 Charge carrier transfer in the GEM

To exploit the particle identification capability of the TPC via dE/dx - measurement, a good energy resolution is indispensable, and therefore losses of primary electrons have to be kept as small as possible. At GEM voltages up to 100V, the electric field inside the holes is small enough, that no gas amplification takes place. In this regime the *transmission* of electrons (and ions) through the GEM can be measured directly and possible losses ascertained [4]. For this purpose, a single-GEM detector of $10 \times 10\text{cm}^2$ active area, with a 10mm gap to the cathode and a 2.5mm gap to the anode was built. The drift region between cathode and GEM was irradiated *sideways* [1] by a high flux of 5.9keV X-rays and all resulting currents on cathode, anode, and the two GEM electrodes were measured. Figure 1 shows the results for a Standard Geometry GEM in different gas mixtures at a field configuration, which is thinkable for the first GEM in a TPC, facing a drift field of a few hundred V/cm. It was found, that the electron transmission t depends strongly on the transverse diffusion σ_t inside and close to the GEM hole. For pure CO_2, where σ_t ranges from 150 to 165μm after 1cm, we find almost full transmission ($t = 0.98$ at $U_{GEM} = 100V$), whereas operated in Ar-CO_2 90:10 with σ_t between 240 and 290μm after 1cm, the transmission is only $t = 0.67$. In a complementary measurement, the electron transmission of two different GEM geometries in the same gas (Ar-CO_2 90:10) was compared: the Standard Geometry and a *Double-Size Geometry*. For the latter, where pitch and hole diameter are twice as big, the transmission was raised to $t = 0.95$. Nevertheless, the price to pay for the improved transmission in this geometry is a much smaller gas gain.

Recapitulating these results, we find, that in order to achieve a maximum transmission, the electron cloud must be sufficiently focused in top of the GEM hole, and the transverse diffusion has to be small compared to the diameter of the region of extracting field lines. Furthermore, it is possible to extrapolate the case without gas gain to the normal

[1] sideways means parallel to the GEM surface; the authors want to point out that an irradiation perpendicular to the GEM would create electron-ion pairs *inside* the GEM hole, therefore modify the charging up process of the Kapton, and bias the transmission behaviour [4].

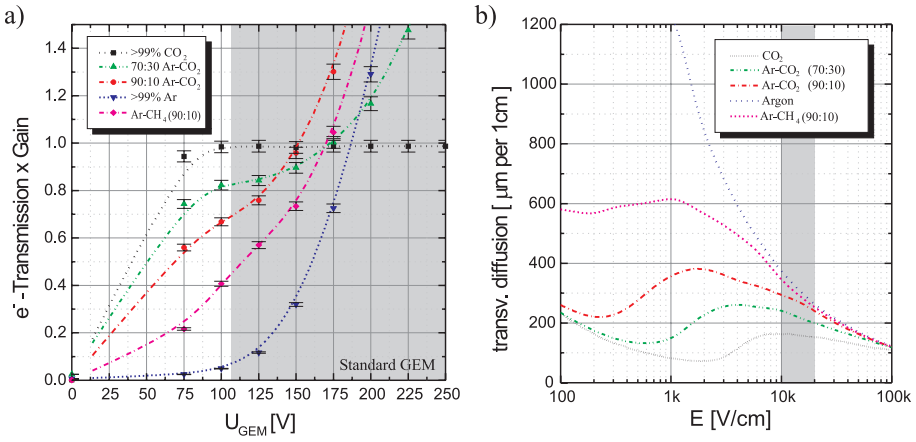

Figure 1: a) Electron transmission times gain versus GEM voltage U_{GEM} at constant drift and induction fields (E_D = 150V/cm and E_I = 2.5kV/cm) in different gas mixtures; the shaded area corresponds to the voltages where gas amplification starts to occur. b) Transverse diffusion versus electric field strength; the shaded area corresponds to field strength range inside the GEM holes at U_{GEM} = 100V. Computed with the *MAGBOLTZ* software package.

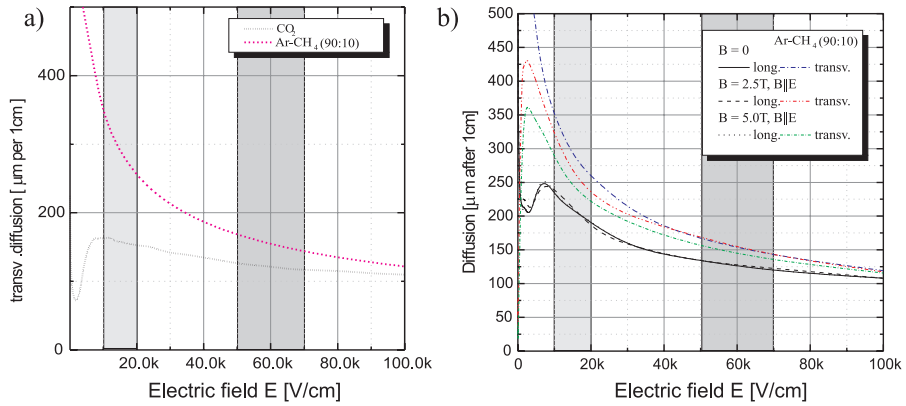

Figure 2: Diffusion versus electric field strength; the light shaded area corresponds to the field strength range inside the GEM holes at U_{GEM} = 100V, the dark shaded area to $U_{GEM} \approx$ 300V. Computed with the *MAGBOLTZ* software package. a) Comparison of the transverse diffusion of pure CO_2 and Ar-CH_4 90:10. b) Diffusion in Ar-CH_4 90:10 at different magnetic fields parallel to the electric field.

amplification mode, as illustrated in figure 2.a). For the Standard Geometry GEM at voltages $U_{GEM} \geq 300V$, the transverse diffusion in Ar-CH_4 90:10 inside the hole drops to below 170μm after 1cm. Since this is comparable to what was found for pure CO_2 at $U_{GEM} = 100V$ with almost full transmission, one can assume that no electrons should get lost before multiplication. Figure 2.b) shows, that in presence of a 5T magnetic field the transverse diffusion in Ar-CH_4 90:10 for electric fields greater than 10kV/cm is not lowered sufficiently: the reduction by 15% down to $\sigma_t \approx 250\mu$m after 1cm (for $U_{GEM} = 100$V) would not be sufficient to get full transmission. Therefore, in a scenario where the first GEM has to be operated at very low gas gain, pitch and hole diameter have to be adapted, and e.g. the Double-Size Geometry would find application.

3 Conclusion

It could be stressed, that apart from the configuration of the electric fields, which gives the essential condition for charge carrier transfer in the GEM, transverse diffusion is a dominant and not negligible reason for losses of primary electrons. Depending on the operation voltage of the first GEM, and thus its effective gain, diameter and pitch of the GEM holes might have to be optimized.

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