GEM Operation in Negative Ion Drift Gas Mixtures

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Abstract

The first operation of GEM gas gain elements in negative ion gas mixtures is reported. Gains up to several thousand were obtained from single-stage GEMs in CS_2 vapor at low pressure, and in mixtures of CS_2 with Argon and Helium, some near 1 bar total pressure.

1   Introduction

Microstructured detectors such as GEMs [1, 2] and Micromegas [3, 4] are seeing rapidly increasing application to physics experiments and applied problems[5]. These detectors offer a number of advantages over other gas gain structures, including ruggedness, mass manufacture-ability, high speed, and greatly reduced positive ion backstreaming in TPC applications.

Negative ion drift gases (NI-gases) are another innovation in gas detector technology which are just beginning to become known[6, 8, 7, 9]. Certain electronegative gases allow the primary ionization in a drift or TPC device to be transported to the gain elements in the form of negative molecular ions[10]. Mainly due to the mass matching of the drifting ions with respect to the gas molecules, the ions are much more tightly thermally coupled to the gas than are drifting electrons. As a result, the drift-diffusion, *both longitudinal and transverse*, remains at the thermal (lower) limit up to extraordinarily high drift fields, several tens of V/cm·Torr at least. This can give a dramatic advantage in space-point resolution, particularly in long drift geometries and/or where imposing the usual magnetic field along the drift direction would be impractical or undesirable. Of course, ions of mass m_I will drift approximately $\sqrt{m_I/m_e} \sim$

500 times slower than electrons at the same reduced field. This is usually a disadvantage but in low rate experiments with high channel count, it may actually be a significant advantage. The spatial resolution (particularly in the drift direction) can still be quite high, even using very low-bandwidth and hence low-noise electronics.

The present work demonstrates the compatibility of GEM gas amplification with negative ion drift. Furthermore it describes for the first time some results for GEM gain in NI-gas mixtures near 1 bar total pressure. Such mixtures will considerably ease the construction of large NI-gas detectors by removing the need for operation at reduced pressure in a vacuum vessel. Drift velocities and longitudinal diffusion have also been measured for these NI-gas mixtures, and will be reported on separately. However the measured drift velocities in all the mixtures reported on here, do show pure NI-gas behavior under the conditions of these measurements.

2 Apparatus

The apparatus used in the present work is shown schematically in Figure 1. A single 50 mm diameter GEM manufactured by 3M Corporation[11] was mounted 7.5 mm below a transparent (mesh) electrode, within a stainless steel bell jar vacuum system used as a gas envelope. Drift voltages of up to -500 Volts were applied to the mesh in the measurements reported below. The top electrode of the GEM was operated at ground potential, and the bottom electrode at variable positive voltages ranging up to 580 V. The GEM amplification signal was read directly from the bottom electrode through an Ortec 142PC preamp and an Ortec 572 shaping amplifier. Shaper gains from 20-200 and shaping times from 6 to 10 μs were used. The detector was irradiated by a collimated ^{55}Fe x-ray source a few cm above the mesh. The x-rays were directed downward along the drift direction near the center of the GEM area. The source was opened and closed remotely. Pulse height spectra were obtained using an ORTEC ADCAM Analyst MCA.

To operate, the bell jar was closed and evacuated, backfilled with the desired gas mixture (minor component first), and data were taken with the system sealed. The rate of pressure rise was less than 50 mTorr/hour at the base pressure of 80 mTorr. It should be noted that with negative ion gases the influence of air contamination is minimal, since capture by oxygen is a comparatively weak, three body process[12], and negative molecular ions of water are promptly stripped by drift fields of just a few tens of V/cm[13].
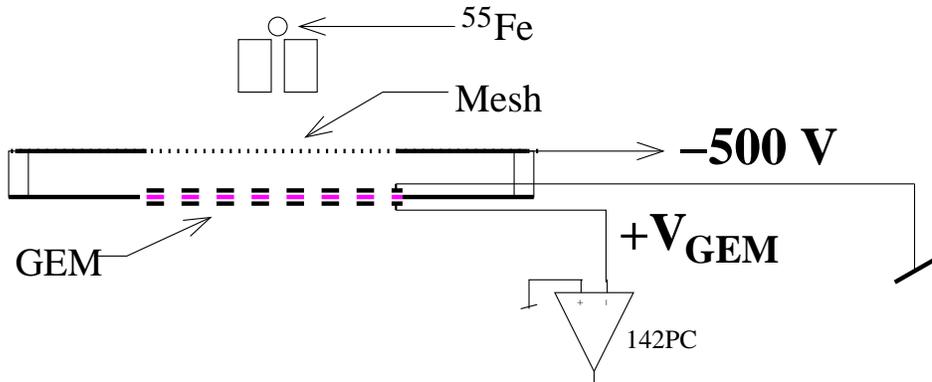
Figure 1: GEM apparatus including drift mesh grid, GEM foil, collimated ^{55}Fe source, and bias voltages.

3 Results

The results are summarized in Table 1 and Figure 2. Several gas mixtures were tested, A single measurement was also made with Argon-Isobutane (a conventional "e-gas"). These are shown in Table 1 along with the gas gain achieved when each measurement was terminated, the logarithmic slope of the gain vs. V_{GEM} curve, and the last (highest) value of V_{GEM} which was tried. Each measurement was terminated somewhat arbitrarily at a V_{GEM} that gave a satisfactorily high gain. While no sparking or breakdown was observed in the Ni-gas mixtures at any applied voltage, no attempt was made to find the maximum sustainable value of V_{GEM} for the different gases.

Pulse height spectra for two of the NI-gas mixtures are shown in Figure 3. Note the enhanced Sulfur fluorescence-escape peak in the Helium mixture due to the low x-ray attenuation of this mixture compared to the dimensions of the drift gap. The pulse height resolution in the argon mixture is about 35% FWHM. Electronic noise sets in at different levels in the two spectra mainly because of the different shaping amplifier gain settings used.

4 Discussion

GEM's in NI-gas mixtures show stable operation at moderately high gain. GEM voltages up to 580 Volts were explored without any evidence of sparking or instability.

The near 1-bar Helium mixtures are of particular interest for gas-based

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Gas Mixture	$V_{GEM,max}$	Max Gas Gain	k
Ar 70 T+Iso 630T	270 V	162	-
CS_2 40 T	400	729	.019
CS_2 40 T+Ar 660T	400	1540	.032
CS_2 70 T+He 340 T	500	2450	.021
CS_2 120 T+He 580 T	580	2460	.025

Table 1: Gas gains obtained with 3M-GEM in various gas mixtures. Only one point (270 V) was taken for the e-gas Ar/Iso. The curves were terminated once a satisfactory gain was achieved; no attempt was made to determine the maximum voltage the GEM would take. No instability or sparking was observed at any voltage with any gas mixture. The last column gives the fitted logarithmic slope of the gas gain vs. GEM voltage curves (Gain = $A \exp k V_{GEM}$).

direction-sensitive Dark Matter searches. Note that the Helium component of the 1-bar CS_2-Helium mixture only increases the total electron density by 25% over that of the CS_2 component alone. Thus a detector could be constructed with low total gas density (hence reasonably long tracks from low energy recoils, for direction determination), but operating at or near 1 bar total pressure. This would permit such experiments to be operated without a vacuum vessel, with its attendant expense and radioactivity. Other advantages of such a scheme would include the excellent spatial resolution in all three dimensions afforded by negative ion drift, greatly reduced sensitivity to electronegative contaminants, and a significant and variable content of medium-mass nuclei to kinematically match the favored range of WIMP masses.

References

[1] F. Sauli Nucl. Instr. Meth. A **388**, 531 (1997); F. Sauli, US Patent #6, 011, 265, granted January 4, 2000.

[2] P.S. Barbeau *et al.*, hep-ex/0304013, accepted for publication in Nucl. Instrum. Meth.

[3] Y. Giomataris *et al*, Nucl. Instr. Meth. A **376**, 29 (1996).

[4] S. Kane *et al*, IEEE Nuclear Science Conference Record, 2002, ISBN: 0-7803-7324-3 (softbound) or 0-7803-7326-X (CD ROM).

[5] F. Sauli Nucl. Instr. Meth. A **461** (2001).

[6] C. J. Martoff, D. P. Snowden-Ifft, T. Ohnuki, N. Spooner, M. Lehner Nucl. Inst. Meth. A **440**, 355 (2000); T. Ohnuki, D. P. Snowden-Ifft and C.J. Martoff, Nucl. Instrum. Meth. A **463**, (2001) 142.

[7] D.P. Snowden-Ifft *et al.*, Nucl. Instrum. Meth. A **498**, (2003) 164.

[8] A. Schreiner *et al*, Proposal to the University Consortium for a Linear Collider, see `www.lns.cornell.edu/public/LC/UCLC/ projdesc/ trk/WayneState_Bonvicini_1022.pdf`

[9] C. J. Martoff, invited talk at Berkeley Symposium on the TPC, LBNL, October, 2003

[10] H. R. Crane, Rev. Sci. Inst.**32**, 953 (1961)

[11] P.S. Barbeau *et al*, IEEE Trans. on Nuc. Sci. **50**, 4 1285-1289 (2003) (hep-ex/0212034).

[12] J. L. Pack and A. V. Phelps, J. Chem. Phys. **45**, 4316(1966)

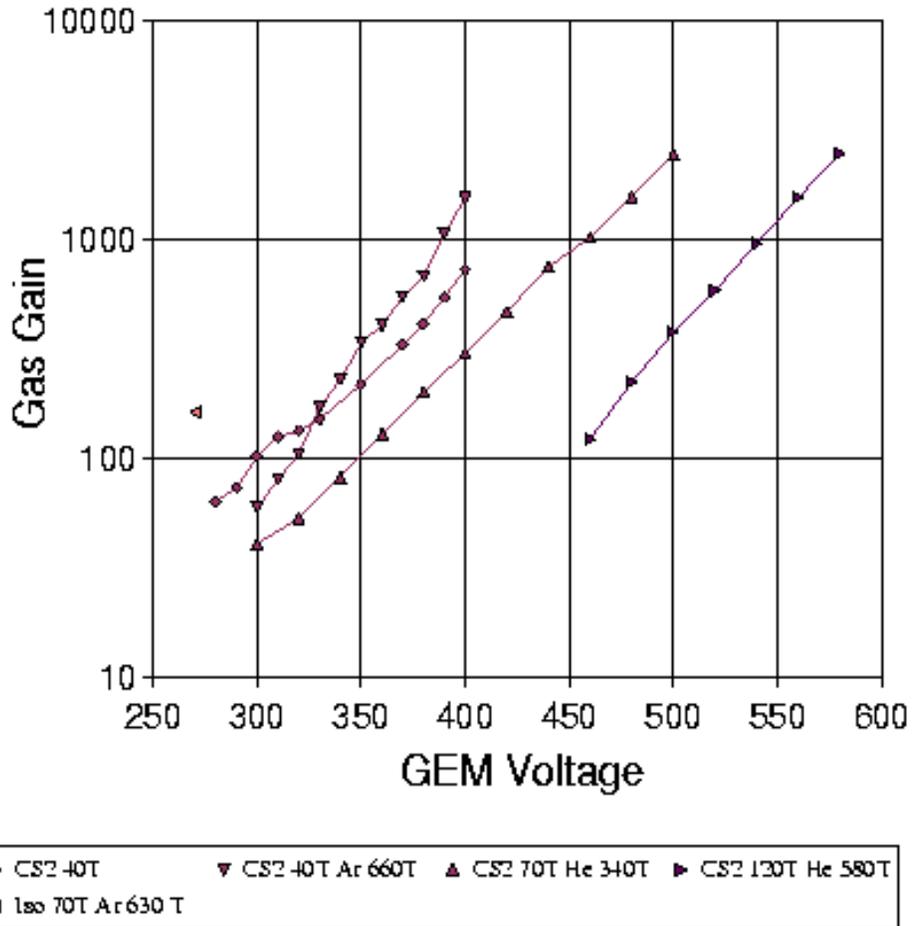[13] P. Rice-Evans,Spark, Streamer, Proportional and Drift Chambers, Richelieu, London (1974).

Figure 2: Gain vs. V_{GEM} curves for 3M-GEMs exposed to collimated ^{55}Fe source. The single point at 270 V is for the e-gas Ar-Isobutane.
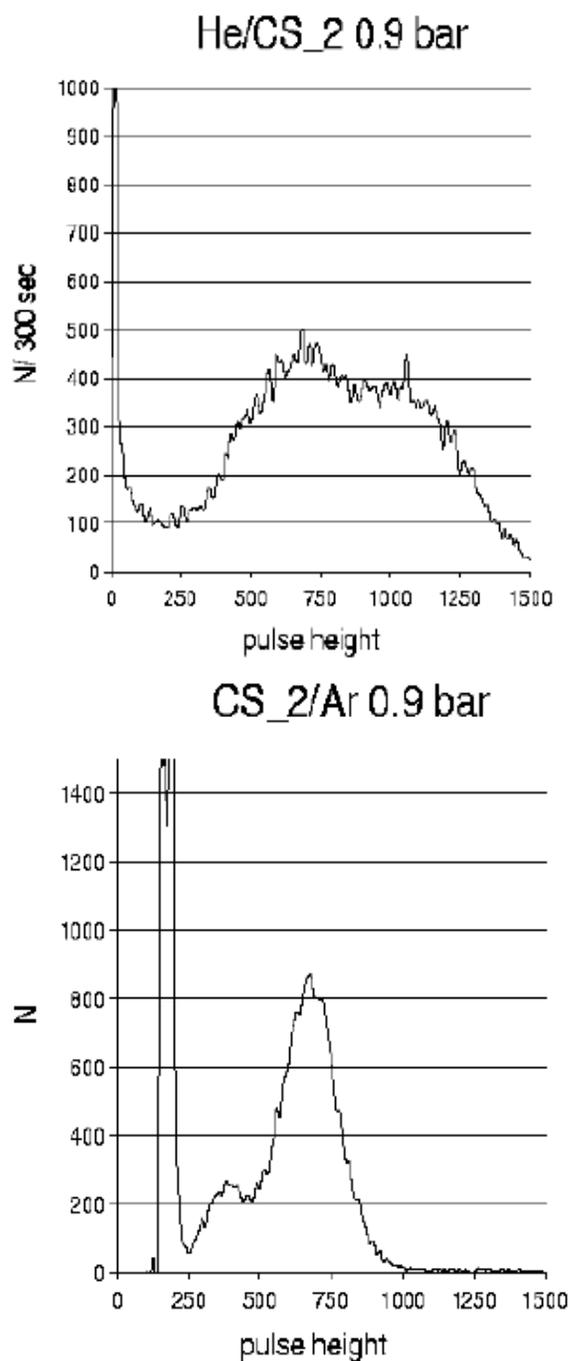
Figure 3: Pulse height spectra for 3M-GEMs exposed to collimated ^{55}Fe source. Upper panel shows 0.9 bar Helium mixture from Table 1, V_{GEM}=500 V, V_D= 375 V, shaper gain 20. Lower panel shows 0.9 bar Argon-Isobutane mixture from Table 1, V_{GEM}=375 V, V_D=500 V, shaper gain 200.