High-Pressure GEM Operation Aiming at Thermal Neutron Detection

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Abstract—Experiments at the anticipated intense spallation neutron sources require neutron detection with typically millimeter position resolution. We are investigating the possibility of applying the gas electron multiplier (GEM) for this purpose. For efficient detection, ^3He gas at up to 10 bar is required with some stopping gas at a differential pressure of 3–5 bar, i.e., high enough to sufficiently reduce the range of the neutron capture reaction products to achieve the required resolution.

Due to the large initial charge deposition in the gas, only a small gain (10–100) is necessary. However, at the high pressures involved, it is not clear if even this can be achieved.

We present first results of experiments using a range of gases, pressures, and, in this case, GEM hole sizes of 60 and 80 μm to investigate this question. We observed the highest gain in an Ar/DME mixture, but this mixture does not meet the resolution criterion. The use of Xe (an effective stopping gas) in a Xe/DME mixture is ruled out, as no signal can be detected at pressures above 2 bar.

Index Terms—Gas electron multiplier, thermal neutron detection.

I. INTRODUCTION

A. Application of the GEM at New Spallation Sources

INTRODUCED by Sauli [1], the gas electron multiplier (GEM) consists of a thin polyimide foil, typically 50 μm thick, metal plated on both sides, and pierced with a regular matrix of holes. The holes are etched with a diameter of 50–100 μm and a pitch of 100–200 μm using a photolithographic process. The GEM relies on gas multiplication inside the holes, where the electric field is strong.

The new spallation neutron sources, currently already under construction in various places around the world, call for a next generation of position-sensitive thermal neutron detectors.

Several applications require millimeter position resolution in at least one dimension and operation in fluxes of sometimes up to $10^7 \text{ mm}^{-2}\text{s}^{-1}$. In 4π detector systems, position resolution can in some cases be relaxed, but time resolution of a microsecond is required.

To provide some kind of unified approach to these challenges, the GEM's flexibility might well prove indispensable. Due to the circumstance that the gas multiplication stage can be separated from the signal pickup stage, there is great freedom for the detector designer in choosing the anode layout.

B. Gaseous Thermal Neutron Detectors

In principle, a gaseous neutron detector, such as the GEM, can use either ^3He or $^{10}\text{BF}_3$ as a detection medium. When a large efficiency is required, the pressure of the detection medium must be increased. Gas multiplication in $^{10}\text{BF}_3$ at high pressure is somewhat problematic due to electron attachment to the molecule. This leaves ^3He as the only viable choice for thermal neutron detection.

The ^3He thermal neutron capture reaction is as follows:

Position resolution based on ^3He capture is limited due to the fact that the reaction products deposit their energy in the gas in an asymmetrical manner. This implies that the interaction position can only be determined with a precision directly proportional to the range of the reaction products in the gas.

Mixing ^3He with a stopping gas can reduce this range. The molecules of the stopping gas must have a high collision cross section for fast charged particles, such as the proton or triton. Good candidates are CF_4 and Xe, though the latter is less attractive because it results in relatively high gamma-ray sensitivity. Adding a stopping gas also affects the gas gain and the lateral electron diffusion, which in turn influences charging up of the insulator in the GEM holes and the electrical transparency of the GEM.

C. Influence of Pressure and GEM Hole Diameter on Gain

Previous research has been reported on the subject of GEM behavior under high pressure in some gases [2], e.g., Xe/ CO_2 up to 5 bar.

Xe is a good stopping gas. However, from [2], we learn that the prospects for achieving a high gain at 10 bar are not good, as a maximum gain of ~ 6 was attained at 5 bar.

The electric field threshold for gas multiplication increases with higher pressure. To have any chance for finding an effective gain greater than ten, we may be forced to use small-hole GEMs [3].

The higher electric field along the axis in the holes naturally leads to a higher gain. Why the effective (i.e., observed) gain does not increase any further below a hole size approximately equal to the GEM thickness [3] can be explained from the electron losses to the lower electrode of the GEM.

Reduced lateral diffusion at higher pressure will result in a narrower charge cloud where it exits the GEM hole. This may lead to a smaller fraction of the electrons' being collected at the lower GEM electrode.

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Fig. 1. Schematic of the constructed test setups for the GEMs. Pressure can be increased up to 10 bar absolute. Beryllium windows are required for use of X-rays, the glass window for observation of light emission.

II. EXPERIMENTAL SETUP

In cooperation with LIP Coimbra, two test vessels have been constructed to provide a high-pressure gas volume for the GEMs.

Standard Conflat flanges were used, with copper gaskets to ensure gas tightness. The beryllium entrance window (for initial measurements it is convenient to use X-rays) can also serve as a drift cathode. Several GEMs can be mounted: the gaps between them and the electrodes can be tuned between 1 and 5 mm.

Fig. 1(a) and (b) shows the setups. They differ mainly in the presence of the glass window, visible in Fig. 1(b), which serves to enable investigation of the light produced in the electron transport/amplification process.

The GEMs to be used in the experiments are available in three varieties: hole sizes of 80, 60, and 45 μm . They were purchased from the CERN workshop and are made on standard 50 μm Kapton at 140- μm pitch. The usable area of the GEMs is $5 \times 5 \text{ cm}^2$.

The signal caused by electrons' moving from the GEM to the pickup electrode is fed into a hybrid charge preamplifier of the type PAC-LP 87, resulting in a rise time of 10 ns and a fall time of 50 μs .

Next the signal is amplified in an Ortec 572 spectroscopy amplifier. An Ortec Quad 8k analog-to-digital converter of type AD413A converts the signals to digital format, which are then processed by a computer.

The electronic chain is calibrated by injection of known charge pulses via a test capacitor at the preamplifier input. For

Fig. 2. Gain versus drift field for several values of transfer (T) and induction (I) fields in Ar/DME 90/10 at 1 bar, irradiated by an X-ray tube with a chromium anode (5.4 keV), and two GEMs with hole size 60 μm .

Fig. 3. Gain curves as a function of the voltage across two GEMs in Ar/DME 90/10, irradiated by an X-ray tube with a chromium anode (5.4 keV) at various pressures (p) and GEM hole diameters (d).

known X-ray energy, the gain can then be determined from the peak position.

The terminology of the gaps used here is that introduced by Sauli. The gap where radiation interacts with the gas is the drift gap. The electrons are transferred from the first to the second GEM through the transfer gap, and the space next to the pickup electrode is called the induction gap.

III. RESULTS

A. Electric Transparency

A GEM with 140- μm pitch and 60- μm hole size has relatively low "optical transparency," which is defined as the ratio of the surface of the holes over the total surface. A related concept is "electrical transparency," which means the number of electrons that will enter the hole (and not be collected at the top of the GEM) divided by the total number of approaching electrons.

In [3], it is shown that the electrical transparency can always be made to approach 100% by lowering the drift field strength.

Fig. 4. Gain curves as a function of the voltage across two GEMs (hole size $60\ \mu\text{m}$) in Ar/CH₄ 90/10, irradiated by an X-ray tube with a chromium anode (5.4 keV) for gas pressures ranging from 1–2 bar.

Fig. 5. Gain curves as a function of the voltage across two GEMs (hole size $80\ \mu\text{m}$) in Xe/DME 80/20, irradiated by an X-ray tube with a chromium anode (5.4 keV) for two gas pressures, $p = 1 - 2$ bar.

A GEM with high optical transparency will easily reach 100% even with a relatively strong drift field.

Our GEMs with hole size $60\ \mu\text{m}$ turned out to require a very low drift field to achieve high electrical transparency; see Fig. 2. In some gases, even at 1 bar no signal could be perceived at all, such as in pure argon, a gas with very “hot” electrons.

When mounting two GEMs in cascade, the field between the two (the transfer field) must be high to satisfy the needs of the first GEM and low for those of the second GEM [4]. At a pitch of $140\ \mu\text{m}$, no reasonable compromise could be found for the

$60\text{-}\mu\text{m}$ hole GEMs. As a result, very few measurement series have been recorded with these GEMs.

B. Measurements at High Pressure

We decided to start with a gas that has already shown high gains in the past. First, we present results of measurements with two GEMs in an argon mixture.

Using $80\text{-}\mu\text{m}$ holes, in Ar/DME 90/10 gains of ~ 105 could be achieved at 1 bar, descending to ~ 100 at 7 bar (see Fig. 3). For $60\text{-}\mu\text{m}$ GEMs, we measured so far only at 1 bar in this gas.

Using $60\text{-}\mu\text{m}$ GEMs and Ar/CH₄ 90/10 in the range 1–2 bar, only relatively low gains could be reached. The maximum gain does not seem to decrease at all; see Fig. 4. The pressure range could not be extended to higher values due to the absence of an appropriate reduction valve.

Next we turned to a stopping gas candidate, Xe/DME 80/20. Using two $80\text{-}\mu\text{m}$ GEMs, we obtained the results shown in Fig. 5. The general trend is analogous to that of Ar/DME (Fig. 3). However, above 2 bar, the gain was already too small to observe a signal. With $60\text{-}\mu\text{m}$ GEMs we could not obtain any signal, not even at 1 bar.

IV. CONCLUSION AND OUTLOOK

Experiments with Ar/DME have shown that gains of $\sim 10\text{--}100$ can be achieved with pressures approaching 10 bar. However, Ar has insufficient stopping power for neutron detection.

Measurements on Xe/DME gas have demonstrated that only very small gains can be obtained using GEMs with $80\text{-}\mu\text{m}$ hole size. With $60\text{-}\mu\text{m}$ hole size, no response is observed.

We will continue our experiments using a “GEM60” followed by a “GEM80” to avoid problems with electrical transparency, and we will try to obtain GEMs with higher optical transparency.

Furthermore, we will focus on a He/CF₄ mixture. Although the latter has aggressive chemical properties, it has the best stopping power.

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