Operation of GEM in ^{4}He gas for fast neutron detection

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1. Introduction

The gas electron multiplier (GEM) has been introduced by Fabio Sauli as an amplification stage for micro-strip gas chamber (MSGC) to boost their gain and improve the reliability of the combined detector.[1] The GEM consists of a thin, metal-clad polymer foil chemically perforated by a high density of holes which can act as multiplication channel. Since GEM foils can achieve large gains and operate reliably in severe operation condition, GEM detectors have been used in wide field. These fields include hard X-ray detection applications such as digital radiography, synchrotron radiation studies, crystallography and astrophysics and GEM-based gas photomultipliers for a UV and visible photon imaging.[2] Especially applications to neutron detection have been investigated by many researchers up to now. Our group has developed a cascade GEM for a neutron detector by using the drift plate coated with boron compound.[3] But this detector can measure thermal neutron only because it used drift plate coated with boron as neutron converter. Since the fast neutrons are to be widely used not only in the field of fundamental science such as the structure analysis of a material and atom but also in the industrial and medical fields, the fast neutrons detection technique is essential for the applications. A more effective fast neutron measurement technique is needed.[4] The ^{4}He gas detector is used mainly for fast neutron detection. ^{4}He gas can be used suitably in fast neutron detector around MeV energy range, because the ^{4}He proportional counter's detection mechanism is the elastic scattering and the ^{4}He gas has large scattering cross section at fast neutron region.(Fig.1)[5]

$$^4_2He + ^1_0n \rightarrow ^4_2He(recoil) + ^1_0n^*$$

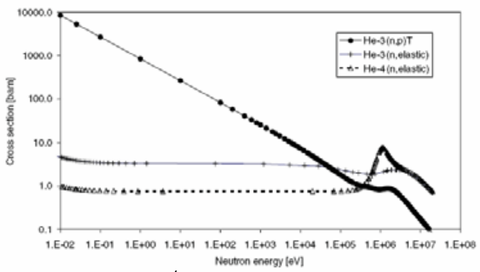


Fig. 1. Cross section of ^{4}He reaction with neutrons

The major aim of our study is to develop a fast neutron detector by using single-GEM filled with ^{4}He gas. When ^{4}He is filled in a gas chamber with GEM, the fast neutron can be measured. In this paper, we studied the performance of a single-GEM detector operating in ^{4}He- CO_2 gas mixture. The gas gains which can be obtained to the GEM are investigated by changing structure of detector. And to achieve an optimized response of GEM detector to neutron, we simulated the response of the detector according to drift gap and collection gap sizes.

2. Methods and Results

2.1. Experimental setup and method

A gas chamber equipped with a GEM was designed and fabricated. The GEM foils with a 5x5 cm^2 active area, which were mounted in a cascade inside the stainless-steel chamber. The GEM foils were purchased from the CERN GDD group. The schematic diagram of the single-GEM detector used in this study is shown in Fig. 2. The drift plate, which was made of aluminized Mylar, was placed above the GEM foils. The gaps between the drift plate and GEM and between GEM and electrode were variable to obtain optimized structure. The avalanche electrons are extracted out of the holes and are collected in induction mesh. The experimental setup was similar to our previous research [3]. Each electrode was connected to an individual power supply of CAEN N471A. Highly pure ^{4}He (99.999% purity) and CO_2 (99.99% purity) with a mixing ratio of 80:20 flowed through the chamber. And gases to observe operation of GEM detector were Ar (99.999% purity) and CO_2 (99.99% purity) with a mixing ratio of 70:30. The signal from the collecting electrode mesh was passed through the ORTEC 113 pre-amplifier, amplified and shaped in the ORTEC 572 amplifier. The spectrum was obtained by ORTEC 919E MCA and the currents which was amplified by GEM at the electrode were measured by a Keithley 6517A electrometer. We used ^{252}Cf source with 6 μCi to measure the neutron response of the chamber. ^{252}Cf is the most common spontaneous fission neutron source. The neutron energy spectrum of the neutron source has a peak between 0.5 MeV and 1 MeV, and a significant yield of the neutrons extends to as high as 8 or 10 MeV.

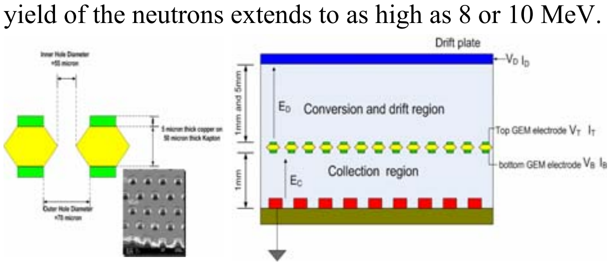


Fig. 2 schematic diagram of the single-GEM detector in this study

2.2. Results and Discussion

To examine operation of the gas chamber, X-ray (5.9 keV) from ^{55}Fe was used through a 0.5-mm-thick Be window. The flux from the Fe source was 580 mm^{-2} s^{-1}. The gas chamber was filled with Ar and CO_2 mixing gas. The energy spectrum was measured and is shown in Fig. 3.

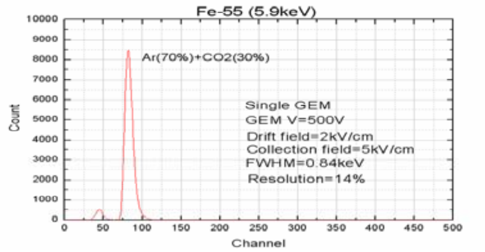
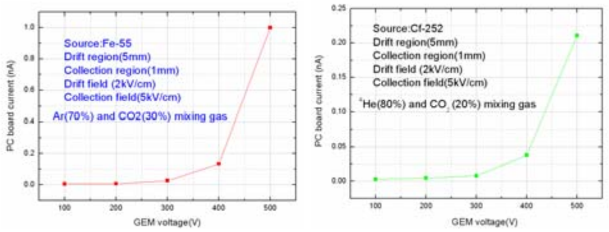


Fig. 3 Measured spectrum of X-ray from ^{55}Fe

And we studied the gain and efficiency of the GEM detector under the change of structure. The drift region which was placed between drift plate and GEM was changed from 1 mm to 5 mm. The effect of collection and drift electric fields to the avalanche of GEM was evaluated. Because the drift electric field has a small effect on the avalanche of GEM, current of electrode mesh generated by avalanched electrons nearly didn't change as the drift electric field increases from 1 to 10 kV/cm for Ar-based gas mixture. But the change of collection electric field affected avalanche of GEM, therefore current at electrode mesh was increased as about 10 times as the collection electric field increases from 1 to 10kV/cm. The effect of GEM voltage to gain was compared with 1 mm and 5 mm drift gaps. The current of electrode mesh for GEM chamber with 5 mm drift gap was larger about 3 times than that of 1 mm drift gap at the same conditions.

In Fig. 4, we compared the total gain of GEM chamber filled with pure Ar and CO_2 mixing gas, ^{4}He and CO_2 mixing gas, as function of voltage difference across the holes, ΔV_{GEM}, when each GEM chamber was irradiated with X-ray from ^{55}Fe and ^{252}Cf fast neutron source. During measurements, ΔV_{GEM} was gradually increased from 100 to 500V. The GEM total gain was measured by interconnecting the electrode mesh. The curve shows the characteristic exponential avalanche growth. As in this study, Fig. 4 shows different trend of the dependence of current by avalanche on X-ray detection and neutron detection: while for neutron detection, the maximum achievable current presents a smaller value than those of X-ray detection. The maximum current which we could obtain in ^{4}He for fast neutron detection was around 0.2 nA. This value is smaller as about 5 times than the current for X-ray detection. This result was caused by neutron interaction probability with ^{4}He. Because of the small drift region as interaction area, neutron could get low probability of interaction with gas. Even though the GEM chamber with ^{4}He makes small signals, we confirmed that ^{4}He gas can be used for neutron detection with GEM.



(a) (b)

Fig. 4 GEM total gain as a function of ΔV_{GEM} for X-ray (a) and fast neutron detection (b)

3. Summary

We have investigated the characteristics of a single-GEM detector operated in ^{4}He and CO_2 mixing gas at atmospheric pressure. To examine operation of the gas chamber, the chamber filled with Ar and CO_2 mixing gas was irradiated with X-ray from Fe. The gas gains were achieved in Ar mixing gas under change of structure for GEM detector. The current of electrode mesh for GEM chamber with 5 mm drift region was larger about 3 times than that of 1 mm drift region at the same conditions. And the effect of collection and drift electric field to avalanche of GEM was evaluated and collection field affects largely to gas gain of GEM chamber.

The GEM total gain was obtained as a function of ΔV_{GEM} in ^{4}He gas when chamber was irradiated with ^{252}Cf fast neutron source and compared this result with gain of chamber filled with Ar and CO_2 mixing gas for X-ray detection. The gain of GEM exhibits the characteristic exponential avalanche growth. Accordingly we confirmed that ^{4}He gas can be used for neutron detection with GEM. We will perform further studies on characteristics of GEM at various gas compositions and structures of detector.

Acknowledgements

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Reference

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