A large-area GEM detector using a novel self-stretching technique*

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Abstract: A Gas Electron Multiplier (GEM) detector with an effective area of 300 mm×300 mm has been constructed using a novel self-stretching technique, which allows a highly flexible and efficient GEM detector assembly free of glue or spacers. This makes the re-opening and repair of the GEM detectors possible and significantly reduces the scrap rate in the mass production of large-area GEM detectors. With the technique, the assembly time can be limited to a few hours, a factor of ten improvement compared to that using gluing techniques. The details of design and assembly procedure of the 300 mm×300 mm GEM detector are described in this paper. This detector was tested with 8 keV X-rays for the effective gain, energy resolution and performance uniformity. The results show that the typical energy resolution is 20% at an effective gain of about 10^4, with fairly good uniformity.

Key words: GEM, self-stretching, effective gas gain, energy resolution, uniformity

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1 Introduction

The Gas Electron Multiplier (GEM) is a type of position sensitive gaseous detector widely used for ionizing radiation detection. The idea of GEM, based on a novel concept of charge amplification in gas, was first introduced and developed by F. Sauli in 1997 at the European organization for Nuclear Research (CERN) [1]. The general structure and working principle of GEM detectors have been described in detail in Refs. [2–4].

Soon after the advent of the GEM detectors, they found increasing applications in various fields due to their excellent performance. GEM detectors are characterized by excellent radiation hardness, high counting rate capability, good position resolution, and flexible detector shape and readout patterns. For a long period of time, the size of GEM foils was limited by the double-mask etching technique (400 mm×400 mm at the maximum) [5], and the most typically used GEM foils were 100 mm×100 mm. Small GEM detectors using these GEM foils were mainly used in laboratories for position measurement of charged particles [6, 7]. The size limitation of GEM foils had long been a major obstacle preventing GEM detectors from finding applications in large nuclear and particle physics experiments.

In 2010, a new etching method called the single-mask technique was developed at CERN [8]. It overcomes the size limitation from the double-mask technique, hence greatly increasing the maximum size (up to 2000 mm×600 mm) [5] of GEM foils that can be produced. This makes possible the fabrication of large-area GEM detectors which have great application potential in high energy physics experiments, medical imaging and radiation monitoring. For example, a set of triple-GEM detectors with an active area of 400 mm×500 mm are used as the tracking device of charged particles for the Super Bigbite apparatus experiment in Hall-A of Jefferson Lab [9]; large-area cylinder-GEM detectors are used as the inner tracker for the K LOng Experiment (KLOE) at the DAΦNEΦ-factory [10], and triple-GEM chambers with dimensions of 990 mm×(220–455) mm are proposed as a detector option for muon tracking and triggering in forward regions in the Compact Muon Solenoid (CMS) experiment [11].

Four years ago, Jefferson Lab launched their 12 GeV upgrade program in the Hall A. In the Solenoidal Large Intensity Device (SoLID) experiment, large-area GEM detectors with an effective area of 1000 mm×400 mm have been adopted as the inner-tracking device. The University of Science and Technology of China is a member of the SoLID collaboration and has been involved in the R&D of large-area GEM detectors for this experiment. As the first step, we have successfully built a 300 mm×300 mm GEM detector prototype. This is the first R&D work on the large-area GEM detector in China. To construct this GEM detector, we have compa-

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red every known technique for stretching GEM foils and chosen the self-stretching technique.

2 Construction of the 300 mm×300 mm GEM detector

2.1 Techniques for assembling large-area GEM detectors

GEM foil stretching is the most critical step in large-area GEM detector assembly. For small-area GEM detectors, GEM foils can be directly glued (with slight stretching by hand) on a small frame which can then be placed between a drift cathode and a readout anode. For large ones, the foils cannot be simply glued on the frame since they would be severely distorted by the electrostatic force between electrodes (GEM foils, cathode and anode) and the gravity. To construct large-area GEM detectors, several foil-stretching methods have been developed. One of them is a gluing technique developed jointly by CERN and the National Institute of Nuclear Physics. In this method, a stretching device with tension sensors stretches and holds a large GEM foil, and a frame is then glued onto the stretched foil [12]. Another method uses a thermal-stretching technique developed by the Florida Institute of Technology. This technique employs Plexiglas frames with a different thermal expansion coefficient than GEM foils. Large-area GEM foils are fixed on the frames and stretched when the environmental temperature increases [13].

Some GEM detector prototypes were assembled using the two techniques described above and functioned properly. However, there are some drawbacks of these techniques: 1) the assembly process takes a long time and no mistake is allowed in the assembling process; 2) a GEM detector is integrated into a whole undetachable chamber leaving no possibility of repairing the chamber by replacing any parts. This would unavoidably increase costs and the operation risk of GEM detectors.

In 2011, a new self-stretching assembling technique was developed at CERN, called "No Stretch, No Stress (NS2)" [14], as illustrated in Fig. 1. In the first step of this technique, GEM foils are mechanically fixed by a set of small inner frames located outside the active area. There are nuts embedded in the inner frames which can be fastened by the screws passing through the main frame so that the foils can be tightened. The main frame provides the mechanical tension needed for foil stretching and gas tightness for the detector. Compared with the gluing and thermal stretching techniques, the assembling process with the NS2 technique is much faster and easier. Neither use of glue nor involvement of spacers avoids dead areas and improves the gas flow uniformity inside the detector. All parts of the detector are fitted together by screws. So the major components of the detector are replaceable, which would greatly decrease the maintenance costs.

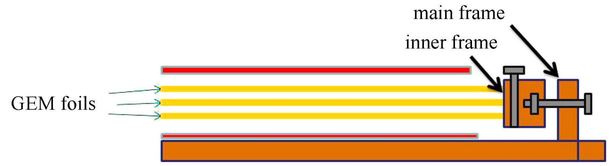

Fig. 1. NS2 self-stretching technique. GEM foils are mechanically fixed by a set of small inner frames. Stretch screws passing though the main frame can be fastened by nuts embedded in the inner frames. The main frame provides the mechanical tension and gas tightness.

2.2 Design and assembly of the 300 mm× 300 mm GEM detector

The prototype is a triple-foil GEM detector with a "3-2-2-2" structure, which denotes the gas gap thickness (mm) between "drift cathode -1st GEM foil -2nd GEM foil -3rd GEM foil - readout anode". The detector structure is shown in Fig. 2. The drift cathode and readout anode are made of printed circuit boards (PCBs). The main frame and inner frame are made of epoxy. The effective area of the GEM foils is 300 mm×300 mm. The upper copper layer on the foils is divided into 10 segments, and each segment is connected to a high voltage (HV) line via a 10 MΩ protection resistor. This design avoids possible damage to GEM foils from discharging and ensures the isolation of any shorted segments from the rest, hence maximizing the operation efficiency of the detector.

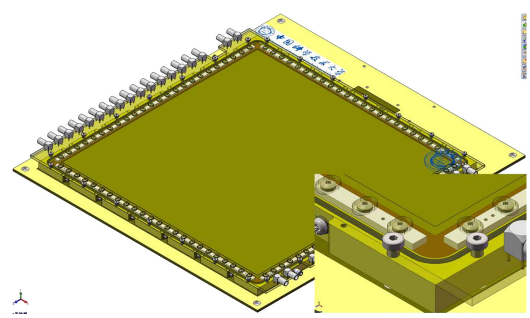

Fig. 2. Design of 300 mm×300 mm GEM detector prototype.

There are 4 main steps in the detector assembly: 1) assemble the three GEM foils to the inner frames; 2) put the main frame onto the drift PCB and fix it; 3) stretch the framed GEM foils on the inner frames by tightening the screws; 4) put the readout PCB on the main frame and fix it.

The HV divider for the detector is an 8-pin integrated resistor network with the 1st pin connected to the drift cathode, the 2nd to 7th pins connected to the 6 electrodes of the 3 GEM foils, and the last pin connected to the ground. If a very high current is passing through the HV divider, the power dissipation could heat up the metal pins and potentially damage the soldering points. To assess such a dangerous effect, a thermal sensitive camera was deployed to monitor the temperature of the pins while applying high voltage to the divider. Test results show that the temperature of the pins is below 100 ℃ even if the input high voltage is up to 4500 volts, which is higher than the normal working voltage (around 4000 volts). The pins of the HV divider are thus deemed to be safe in the presence of power dissipation.

The high voltage from a power supply is delivered to the HV divider through an RC-low-pass filter composed of 100 kΩ resistors and 2.2 nF capacitors to bypass high frequency noise. The filter is necessary to ensure a good signal to background ratio of the GEM detector.

The readout PCB was optimized for gain measurement. To make sure the charge produced in each event can be completely collected, the active area of the readout PCB is divided into 36 square sectors with relatively large size of 50 mm×50 mm. Each sector is read out independently.

3 Test setup and results

The GEM detector was tested with 8 keV X-rays generated with a Cu-target X-ray generator. The detector was mounted on an aluminum support plate and placed in a copper shielding chamber. There were 36 blind holes (diameter-25 mm) on the outer side of the drift PCB which were used as X-ray windows. The X-ray generator was fixed on a platform which could be moved flexibly. The detector was operated with a gas mixture of Ar/CO_2 (70/30) and a high voltage of 4 kV. The signals from the detector were amplified by a charge sensitive pre-amplifier with a sensitivity of 0.8 V/pC and then shaped by an Ortec 671 amplifier. The output from the Ortec 671 was fed to a Multi-Channel Analyzer (Amptek MCA8000D) for energy spectrum measurement.

Figure 3(a) shows a typical signal from the pre-amplifier. The signal has an amplitude of about 30 mV with an exponential tail spanning ∼5 μs. Fig. 3(b) shows a typical energy spectrum of the 8 keV Cu target characteristic X-ray produced by the X-ray generator, measured by the GEM detector system. Both the full energy peak and the Argon escape-peak can be seen clearly on the spectrum. The energy resolution is determined to be about 20% from the full energy peak.

If both the average current of the signals produced by the GEM detector and the rate of the incident X-rays are known, the effective gas gain of the GEM detector can be determined by the following equation

$$G=\frac{I}{R\times e\times 8\ \mathrm{keV}/26.4\ \mathrm{eV}}, \tag{1}$$

where I is the average current of the GEM output signal, R is the rate of X-ray, e is the electron charge (1.6×10^{-19} C), 8 keV is the energy of the X-ray and 26.4 eV is the average ionization energy of the gas mixture of Ar/CO_2 (70/30). We used 8 keV as the X-ray energy to calculate the gain, because the full energy peak is the dominant component of the energy spectrum, as shown in Fig. 3(b).

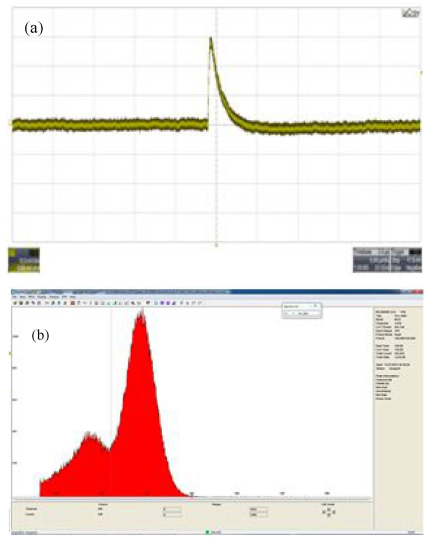

Fig. 3. (a) A typical signal from the charge sensitive pre-amplifier. (b) A typical energy spectrum of the 8 keV Cu target characteristic X-ray. Both the full energy peak and Argon escape-peak can be seen clearly. The energy resolution is about 20%.

In the X-ray test, the current collected by the readout PCB was directly measured by a Keithley6487 Picoammeter. The X-ray rate was estimated by counting the signals from the shaping amplifier with a CAEN N1145 scaler. Fig. 4 shows the effective gas gain of the detector as a function of the high voltage applied to the detector. A clear exponential relation between the gain and the high voltage can be seen. The maximum gain can reach 10^5 when the applied high voltage is 4.4 kV. The gain test was performed for the 35 individual GEM sectors. One (31st) sector behaved in an unstable manner with high voltage applied and was finally excluded from the gain test. The unstable behavior was found to be caused by the improper cleaning operation on the sector during the detector assembling process.

The gain uniformity of the GEM detector is shown in Fig. 5(a). The variation of effective gas gain is less than 31% at a working HV of 4 kV. The variation decreases down to 21% when excluding sector 25, which is at the edge of the detector. Considering the edge effect, if all the edge sectors are excluded, the variation will be less

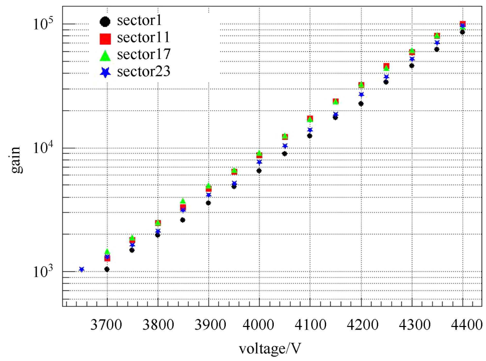

Fig. 4. Typical gain versus HV for selected sector1, 11, 17 and 23.

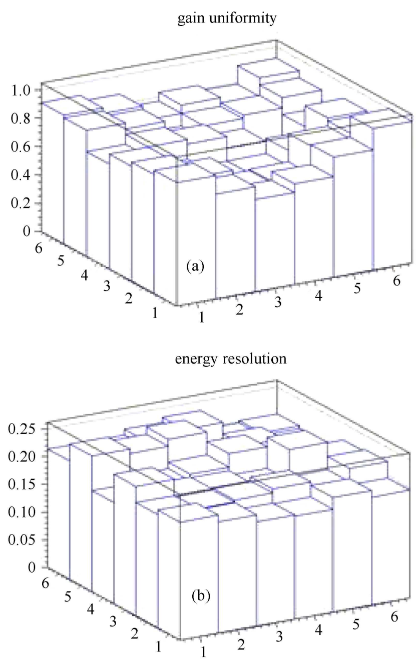

Fig. 5. (a) Uniformity of the effective gas gain at 4 kV. The gain variation is less than 31% and can be reduced down to 21% if sector 25 is excluded. (b) Uniformity of the energy resolution, which varies from 18% to 26%.

than 18% for the 16 inner sectors. The typical variation of the large-area GEM is about 10%–20% in the literatures [15, 16]. The gain uniformity of GEM (200 mm×240 mm) in LHCb is about 10%, while in CMS is about 15% (1000 mm×200–400 mm). Our GEM detector reaches this level, and we are still trying to improve the uniformity. Fig. 5(b) shows the uniformity of the energy resolution at a HV of 4 kV. The value of the energy resolution in the whole active area varies from 18% to 26%.

4 Conclusions

A 300 mm×300 mm GEM detector prototype was successfully built with the NS2 self-stretching technique. The advantages of the NS2 technique are summarized below:

1) The assembling process is easy and fast. A 300 mm×300 mm GEM detector can be assembled in 2 hours, while the traditional gluing technique or thermal-stretching technique takes at least 3–4 days;

2) All the GEM foils are self-stretched without spacers resulting in no dead area inside the active area;

3) The major components of the detector are replaceable. Thus malfunctioning GEM detectors can be repaired quickly without waste, while the GEM detectors using the gluing or thermal-stretching techniques are irreparable.

The 300 mm×300 mm GEM detector was tested for effective gas gain and energy resolution with X-rays. Good uniformity of effective gain was observed over the whole active area, and the variation is about 21%. As the first step, this large-area prototype serves as a valuable reference for the design of even larger GEM detectors. In the future, the active area of GEM detectors built with the NS2 technique is expected to reach 1000 mm×600 mm.

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