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Development of GEM detectors and their applications to Imaging

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Abstract. The Gas Electron Multiplier (GEM) Detector is being used extensively to handle a reasonably large flux environment in high energy and other related experiments. Due to the ease of operation with environment friendly gases, this detector can be deployed for a wider range of experiments as well as in applications to developing the instruments for humanitarian aid purposes. In this talk, we will present results from one such effort. We collaborated with the industry to produce the GEM foils of various specifications and then made an effort to use GEMs as an imaging detector for medical as well as security purposes. The key component of a GEM detector is the GEM foil which has very dense go-through holes on a 50 μm highly insulating foil (Kapton/Apical) coated on both sides with 5 μm layers of copper. Before these GEM foils can be used for assembling the GEM detector, the foil's electrical and optical properties have to be tested to find defects and correct them. We report on the development of techniques used to study the GEM foils electrically and optically. The polarisation and charging up effects of these foils will also be discussed, along with the ways to better handle these effects. A feasibility study to utilize GEM detectors for imaging objects with varying densities with x-rays was carried out. The reconstructed images show a good distinction between materials of different densities, which opens the possibility to further explore the applications of GEM detectors to medical imaging or cargo imaging.

1. Introduction

F. Sauli presented a new concept in gaseous detectors with micro pattern foil called Gas Electron Multiplier (GEM) in 1997 [1]. GEM foils are made of a 50 μm thin polyimide (Kapton/PI) foil that is coated on both sides with a thin layer (5 μm) of copper. Bi-conical holes with inner diameters of 50 – 60 μm and outside diameters of 70 – 80 μm are chemically etched in the foil at a pitch of around 140 μm using either a double mask or a single mask process. Photolithographic methods (used in PCB manufacture) are used to transfer hole patterns to the copper-clad polyamide substrate utilizing thin masks positioned on the top and bottom of the substrate. UV-light exposure and other chemical etching techniques are used to carve holes on the foil [2]. These tiny geometries of the holes build up a very high electric field under comparative low voltage than traditional gaseous detectors for the charge multiplication and particle identification.

2. GEM foil inspection

The stable and uniform performance of GEM foil is highly influenced by the polyamide quality, copper coating, hole geometry, and their pattern [3]. Any imperfection or flaw in the foil can have a significant impact on their performance. As a consequence, we extensively examined the foils both visually and electrically and found consistent findings, as shown in Figure 2. Because foils are manufactured utilizing single mask technology, we discovered asymmetry in the top and bottom hole diameters on the foils. Optical studies revealed an inner and outer top (bottom) diameter of 50.07 ± 0.946 and 76.42 ± 2.47 (65.41 ± 1.76), respectively, with few of imperfect holes in shape [4]. The leakage current of the foils is shown below 1nA under a potential difference of 600 V. An extensive examination of the leakage current under various humidity and temperature is shown in left Figure 2. The stable and best performance a GEM foil gives when there is a very small leakage current and small fluctuation in leakage current. The left figure in Figure 2 concludes the best operating condition in the labeled region I.

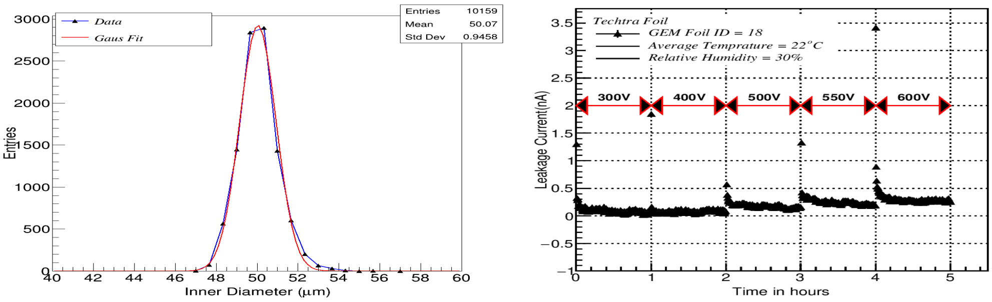

Figure 1. Left: Hole diameter distribution of the inner hole in the foil. Right: The leakage current of the foil at various voltages.

3. GEM detector and calibration

A prototype 10 cm × 10 cm triple-layer GEM detector with 3/1/2/1 [5] gaps in mm was assembled and inspected its nature under high voltage up to 5000 V in pure CO_2 to see ohmic behavior and the fake signal coming from the detector. The detector has shown linear behavior and at a threshold of 100 mV fake signal rate below 5 Hz at a maximum applied voltage of 5 kV. Gain [6] of the detector was measured in Ar:CO_2 (60:40) gas mixture flushing at 3 ℓ/h for detector current 650 μA to 730 μA. We observe stable and linear behavior of gain on a logarithmic scale. The right figure in Figure 2 shows the gain curve and rate with detector's divider current. Apart from this, stability and discharges were also monitored to see the behavior in the long term and found convening results.

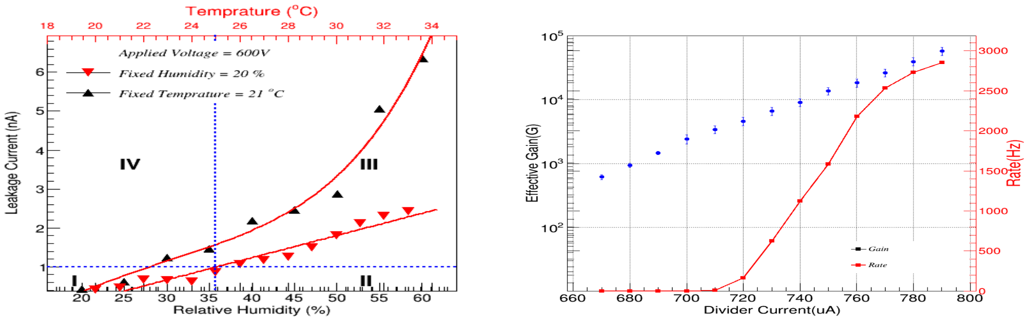

Figure 2. Left: Leakage current of the foil in a well-controlled environment, keeping one parameter fixed and another varying. Right: Rate and gain curve of the detector with divider current.

4. Imaging

For imaging, we have used a 2D (128 X 128 channel) readout board to collect the charge from the detector using four DDC24 20 bit 64 channels current input analog to digital converter (ADC) chip and used an FPGA-based data acquisition system capable of taking data at a sampling frequency of 6 kHz [7]. The detector was flushed with $Ar : CO_2$ (60:40) gas mixture at 2 (ℓ/h) and irradiated with a silver target X-ray of 22.8 keV source [8] at the detector gain of ~4k. The data is saved in raw format, which requires further data processing to construct the image. The algorithm finds the consecutive hit channel called a cluster and then finds the peak position in the cluster to make the hit position in each event which can be seen on the left of Figure 3. The 2D hit position is then used to construct the final image of the object. The right figure of Figure 3 shows the image constructed. Hit density of the reconstructed objects distinguishes the nature of materials. Depending on mass thickness material of each object can be identified up to some extent as metallic, nonmetallic, or organic. Metallic or nonmetallic objects are easy to reconstruct using high-energy X-rays; however, for biological samples, high-energy X-ray appears to be transparent and are less significant in image reconstruction. Low energy x-ray or beta source appears to be a good source for imaging using GEM. Efforts are going on to reconstruct the image of biological samples at very low flux and low levels of irradiation with an alternate source.

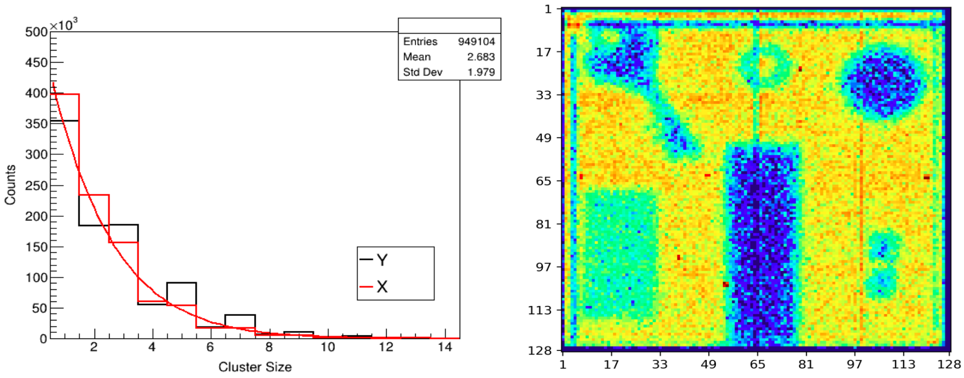

Figure 3. Left: Histogram of the cluster size. Right: Reconstructed image of the objects. Objects & thickness of the materials used in imaging: Stainless steel key (2.5 mm), copper (6 mm), coin (2 mm), Nut (7mm), FR4(4 mm), and SS pullout (4 mm)

5. Conclusions

GEM foils 10 cm ×10 cm in size have been examined optically and electrically for use in future imaging investigations. The optical test confirms that the hole pattern is homogeneous and that there are no apparent flaws. The detector performance using these foils improved in terms of gain, stability, and uniformity. The GEM detector has been used to photograph a variety of items. The preliminary imaging results are promising. In contrast, all of the items of varied densities may be readily identified. For the majority of the items, the dimensions of reconstructed pictures correspond with actual dimensions within 1% of the fluctuation.

6. Acknowledgments

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[7] *Techtra technology transfer agency, Techtra GEM board*.

[8] AMETEK Mini-X X-Ray Tube, *Mini-X2 X-Ray Tube*.