

Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 2001

Experimental results of Gas Avalanche Devices Made by LIGA Process

Il Jin Park, Nam Ho Lee, Hyun Kyu Jung, Seung Ho Kim
J. Kadyk*, and V. Perez-Mendez*

Korea Atomic Energy Research Institute
Yusong, Taejon, Korea 305-600

*Lawrence Berkeley National Lab.
Berkeley, CA94720, USA

Abstract

The characteristics of GEM-like gas avalanche devices made by using a deep X-ray lithography technique (LIGA process) have been investigated. The devices described here consist of thin polymethylmethacrylate (PMMA) sheets ($10^{14} \Omega/\square$ surface resistivity), with thin metal surface layers, top and bottom, to serve as electrodes. The sheets are perforated with a grid array of small closely spaced holes. The performance is measured in terms of absolute gain and gain stability as a function of the uniformity of PMMA sheet and as a function of radiation intensity. The short-term gain stability is found to be constant to $\sim 2\%$, and the rate capability extends to more than 10^5 Hz/mm². Potential advantages of devices made using the LIGA technique will be discussed.

I. Introduction

The radiation detector development field have been explosively extended with increasing the potential applications in medical imaging, astrophysics, nuclear physics experiments, biological diagnostics and many other field demanding radiation detection and measurement. One type of commonly being used radiation detector is gas avalanche detector. Since G.Charpak[1] had successfully developed the multiwire proportional chamber (MWPC) in 1968, which is large sensitive position detector, the utilization of gaseous detector has been convinced because of the wide active area and economic gain. But they have reached their limits in spatial resolution and rate capability in many of the proposed experiments.

New model for proportional counter which is based upon the microelectronics technology had been developed, for example microstrip gas chamber (MSGC), invented by A.Oed[2] in 1987, to improve the spatial resolution and rate capability of the previous version. The invention has been promoted the development of various type of gas avalanche microdetectors such as microgap gas chamber (MGC) and microdot gas chamber (MDOT). However, the gains of such detectors are typically limited to 10^4 by the one set of electrical breakdown. More significant problem is that the detectors are totally damaged after electrical breakdown, so that they can not operate any more.

In recent years, there has been a major breakthrough in the development of gas avalanche detector, such as CAT and the the Gas Electron Multiplier (GEM), using the concept of electrodes separated by an insulator between them, resulting in intense electric field across a hole defined through the insulator. The GEM is basically a multi layer foil with many high precision holes. The conventional GEM consists of a thin Kapton foil covered on both sides with a metal layer and is perforated by chemical etching after photo lithographic patterning. Due to the manufacturing process, the shape of a hole is double conical. In case of this structure, a gain degradation with time is reported[1]. This gain shift is due to surface charging by avalanche ions of the GEM Kapton insulator. In other to prevent the surface charging effect, a laser drilled GEM which has straight holes have been suggested by University of Louisville. However, the cost of manufacturing is too expensive.

A new technique for making gas avalanche devices by means of a deep x-ray lithography (the LIGA process) was initialized by Lawrence Berkeley Lab.[2] It is a microfabrication technique, which, in this case, uses polymethylmethacrylate (PMMA) as the basic material, and is ideally suited for building a microstructure having a large aspect ratio. The acronym LIGA originates from the German expressions for the major process steps: lithography (Lithographie), electroplating (Galvanofornung), and molding (Abformung). Our devices consist of thin polymethylmethacrylate (PMMA) sheets (~100 μm – 300 μm thick) with arrays of cylindrical holes having steep wall sides. Copper electrodes of about 0.5 μm thickness were electroplated on both sides of the PMMA layer. These gas avalanche devices provide an alternative technology for fabrication of a gas electron multiplier (GEM).

I. Structure of GEM made by LIGA Process

Figure 1 shows a procedure of fabrication to make a LIGA device. A patterned gold mask having 25 μm thickness was placed on the thin PMMA sheet, and X-rays from the LBNL electron storage ring, the Advanced Light Source, were used for this lithography step.

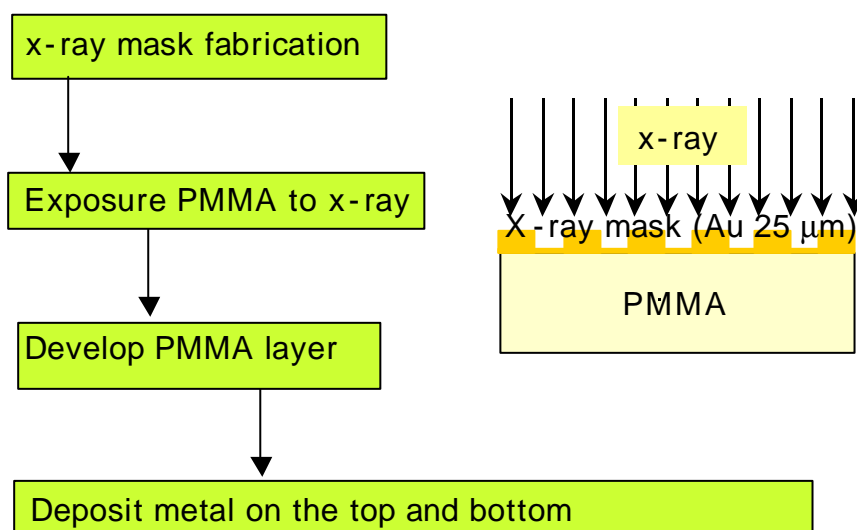


Figure 1: The procedure of LIGA process to make GEM-like gas avalanche device.

It should be noted that the PMMA should have a narrow distribution of high molecular weight, so that the material can have a sufficiently good etch selectivity after the x-ray exposure. A minimum exposure dose is 4 kJ/cm^3 and the damage threshold of PMMA is around 15 kJ/cm^3 . After exposure the PMMA is developed using a mixture of 2-2 butoxyethanol, morpholine, ethoamine and deionized water. After development of PMMA exposed parts are rinsed in deionized water and dried. Figure 2 shows a scanning electron microscope photograph of the developed PMMA with a thickness of $300 \text{ }\mu\text{m}$. $150 \times 150 \text{ }\mu\text{m}^2$ rectangular holes with a pitch of $300 \text{ }\mu\text{m}$ are patterned on the layer. Copper electrodes of about $0.5 \text{ }\mu\text{m}$ thickness were electroplated on both sides of the PMMA layer, to be used as electrodes.

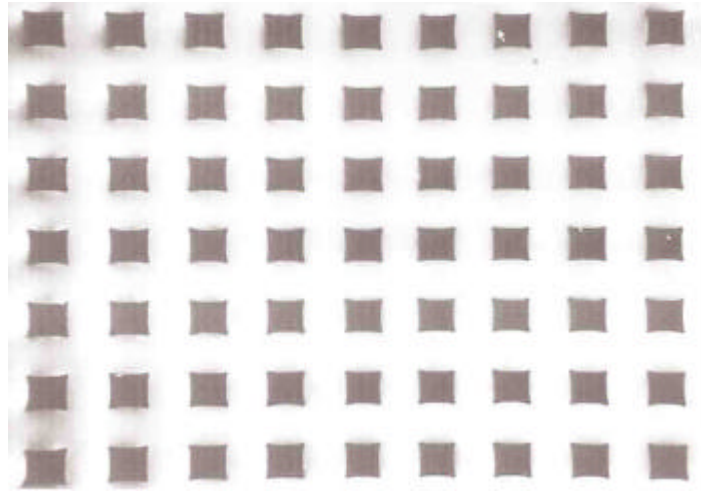
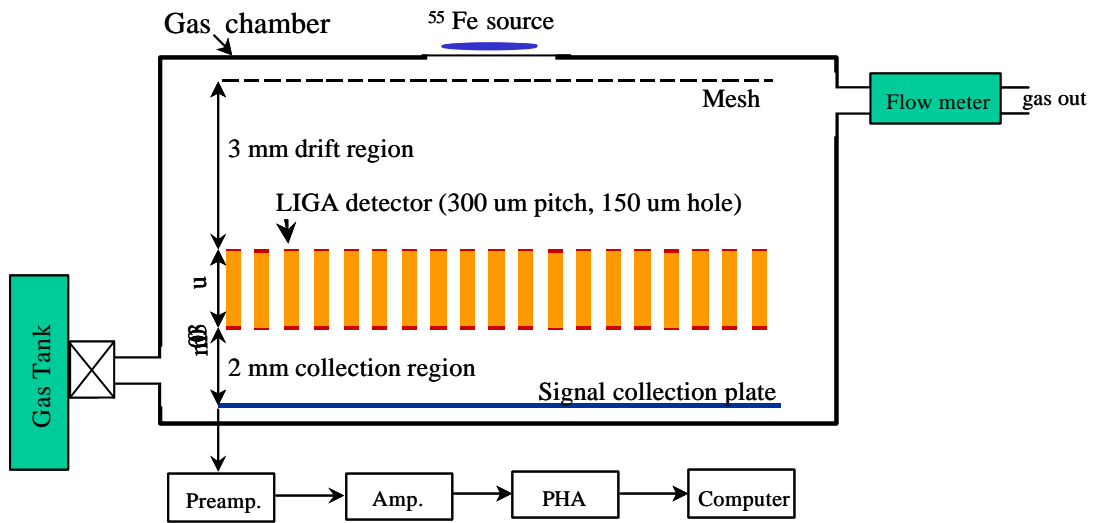


Figure 2: Scanning electron microscope photograph of GEM made by LIGA process. The hole in PMMA has very steep wall sides. Black parts show the holes in PMMA layer.

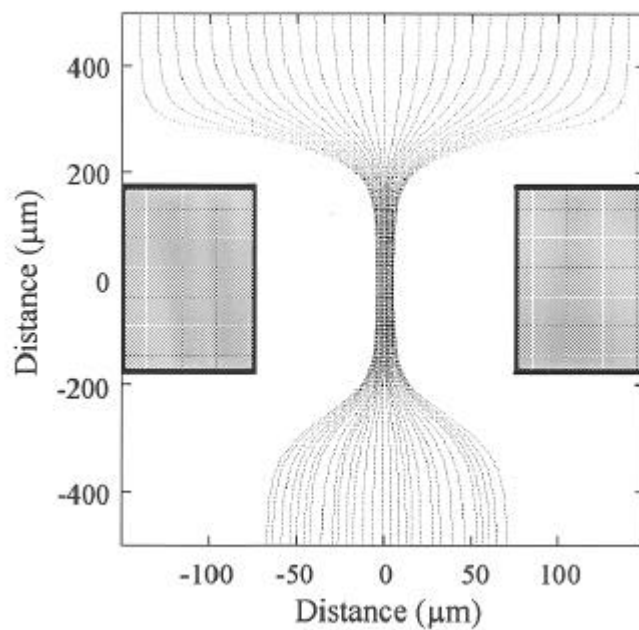
II. Tests and Discussion

The structure of our measurement system consists of three distinct parts: (1) a 3 mm drift region between the top surface of the LIGA device and the drift plane; (2) the gas avalanche region in the PMMA holes; (3) a 2 mm collection region between the bottom of the LIGA device and the charge collection pad. Figure 3(a) shows a schematic diagram of the measurement system. The drift field intensity (E_d) was fixed at 2 kV/cm and the collection field intensity (E_c) was fixed at 5 kV/cm . The applied voltage on the GEM is defined as the voltage difference between top and bottom electrode. Both P10 and Ar/CO₂ (70/30) gas mixtures were used for these measurements. The source of primary ionization was ⁵⁵Fe source for the effective gain measurement. An x-ray generator having a copper target was used for the tests of rate capability.

To understand the electron migration and electric field shape in the GEM device, simulation of electron trajectory along the drift and collection field has been carried out using MAXWELL code[2,3]. The electron trajectories are plotted in figure 3(b). In this simulation, the electric field at the center of the hole was 100 kV/cm . Field lines terminating on the top and bottom electrodes are not shown in this plot. As can be seen, all of the field lines are concentrated in the hole center in which the gas avalanche can be occurred.



(a)



(b)

Figure 3: (a) Schematic diagram of the effective gain measurement system. 200 μm pitch metal strips patterned on glass were used as a collection electrodes. (b) electron trajectory along the drift and collection fields. Field lines terminating on the top and bottom conductors were not considered in this plot.[2]

The gas avalanche gain was measured as a function of applied voltage on the PMMA layer for two different gas media. The operating voltage of GEM in P10 gas is lower than that in Ar/CO₂ (70/30), for the amount of Ar gas is large. We achieved the maximum gain around 6,000 $\bar{\epsilon}$ which

was limited by micro-breakdown on the device, causing fluctuations in the collected current. These results are shown in figure 4. We also measured a pulse height spectrum from ^{55}Fe source using the LIGA-GEM, and it is shown in figure 5.

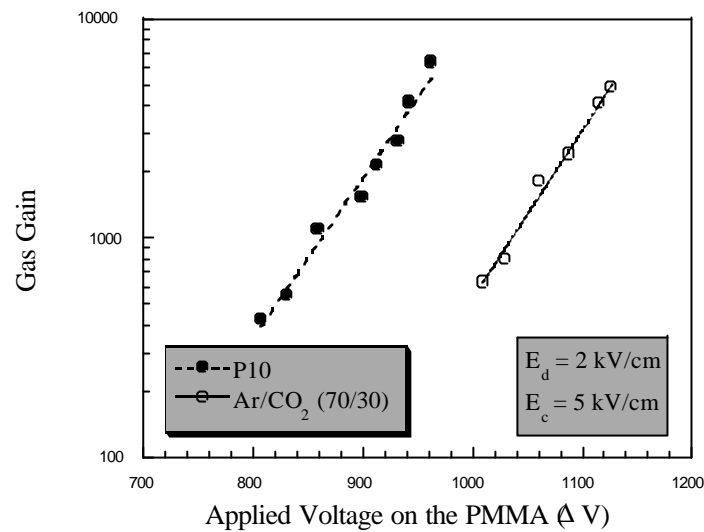


Figure 4: Measurements of avalanche gain as a function of an applied voltage (ΔV) across a LIGA device of $300\ \mu\text{m}$ thickness, using P10 and Ar/CO₂ (70/30) gas mixtures. E_d is defined as the drift field strength and E_c is defined as the collection field strength.

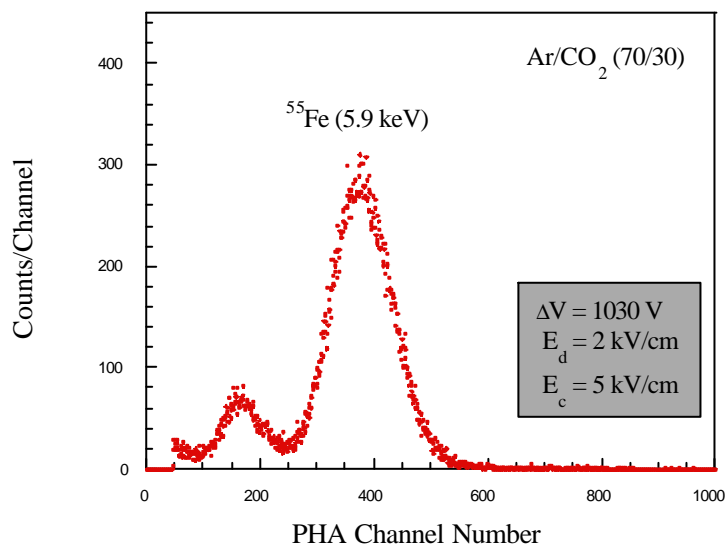


Figure 5: Pulse height spectrum for ^{55}Fe source obtained from the LIGA device of $300\ \mu\text{m}$ thickness, $300\ \mu\text{m}$ pitch and $150\ \mu\text{m}$ hole diameter. $5.9\ \text{keV}$ energy peak from ^{55}Fe source and $3.0\ \text{keV}$ Ar escape peak are shown in the spectrum.

The thin PMMA sheets were prepared at LBNL by compression under heat, from initial thicknesses of 1 mm. We investigated the gain variation arising from a thickness non-uniformity over the effective area of $4 \times 4 \text{ cm}^2$. Figure 6 shows the gain and corresponding thickness variations according to the position. Our future devices will be made from PMMA sheets obtained commercially from the Goodfellow company [3], having a smaller thickness variation ($\sim 5\%$). LIGA devices using Goodfellow PMMA are currently being produced by us, and performance results will be presented for various thicknesses and pitches.

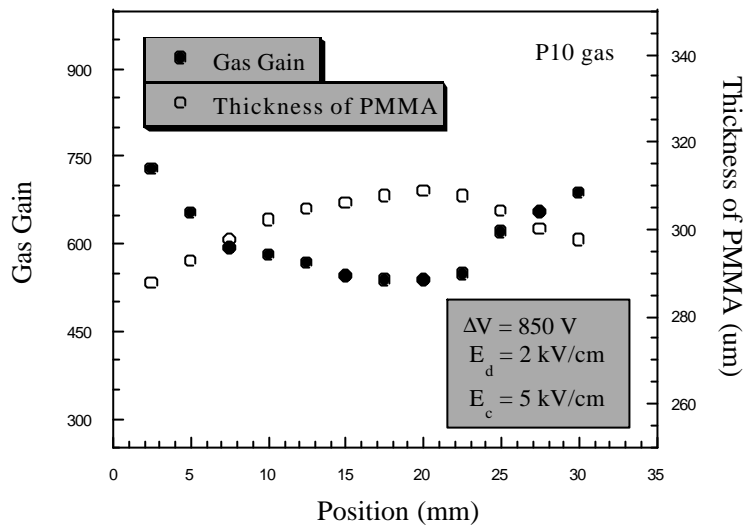


Figure 6: Gain variation vs. position on the surface of the LIGA device, resulting from thickness non-uniformity.

For future experiments which have to work in the environment of very high luminosity, high rate detectors are needed. Using an x-ray generator, we measured the relative gain of the LIGA device as a function of rate for three different gains. As shown in figure 7, the gain is rate dependent for rates greater than about 10^5 Hz/mm^2 .

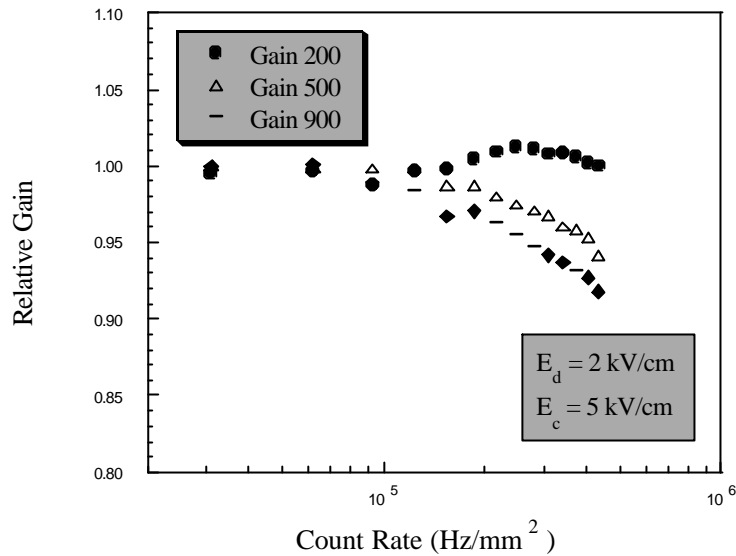


Figure 7: Relative gain as a function of count rate for LIGA device.

III. Conclusions

A GEM made by LIGA process has been tested in terms of a maximum gain and a rate capability. The LIGA technology allows flexibility in design parameters, such as in thickness and pitch, and in increased path length for gas avalanche development relative to the conventional GEM design; also, the holes are nearly cylindrical, minimizing hole charging effects on gain. This design flexibility permits arrays of holes having large high aspect ratio and small pitch, providing high gain and good spatial resolution. With LIGA-GEM having 300 μm PMMA thickness, a maximum gain of $\sim 6,000 e^-$ was obtained. A rate capability of 10^5 Hz/mm^2 was measured by using a conventional x-ray generator. Further studies for optimizing the LIGA device are in progress now. This gas avalanche detector can be used in various application fields in radiation detection.

II. References

- [1] F. Sauli, "GEM: A new concept for electron amplification in gas detector," Nucl. Instr. Meth., A386, pp.531-534, 1997.
- [2] H.K. Kim, K. Jackson, W.S. Hong, I.J. Park, S.H. Han, J.Kadyk, V. Perez-Mendez, W. Wenzel and G. Cho, "Application of the LIGA Process for Fabrication of Gas Avalanche Devices," IEEE Trans. Nucl. Sci., vol. 47, no. 3, pp 923-927, 2000.
- [3] MAXWELL Electric Field Simulator, Ansoft Corporation, Pittsburgh, PA 15219, USA.
- [4] Goodfellow Co., Cambridge Science Park, Cambridge CB44DJ, England.