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### Title

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# GEM-type Detectors Using LIGA and Etchable Glass Technologies

S. K. Ahn, J. G. Kim, V. Perez-Mendez, S. Chang, K. H. Jackson, J. A. Kadyk, W. A. Wenzel and G. Cho

**Abstract**—Gas electron multipliers (GEMS) have been made by a deep X-ray lithography technique (LIGA process) using synchrotron radiation on polymethylmethacrylate (PMMA) and by UV processes using a UV etchable glass. Gain, stability and rate capability for these detectors are described.

The LIGA detectors described consist of PMMA sheets of various thicknesses, 125  $\mu\text{m}$  to 350  $\mu\text{m}$ , and have 150  $\mu\text{m}$   $\times$  150  $\mu\text{m}$  square holes spaced with a pitch of 300  $\mu\text{m}$ . Thin copper electrodes are plated on the top and bottom surfaces using a Damascene method, followed by electroless plating of the copper onto a palladium-tin base layer. For various thicknesses of PMMA measurements have been made of absolute gain vs. voltage, time stability of gain, and rate capability. The operating gas mixture was usually Ar/CO<sub>2</sub> (70/30) gas, but some tests were also done using P10 gas. We also made GEM-like detectors using the UV etchable glass called Foturan, patterned by exposure to UV light and subsequent etching. A few measurements using these detectors will be reported, including avalanche gain and time stability.

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## I. INTRODUCTION

SINCE the group of Sauli introduced in 1996 the gas Electron multiplier (GEM) [1] as a pre-amplification foil, there has been a considerable effort devoted to the investigation of its characteristics, and to the improvement of its performance. Other methods of fabrication have been investigated, including dry etching and laser drilling [2]. Here we present results based upon new and different fabrication technologies.

We have made GEM-like detectors by two methods: (a) by the LIGA process [3], [4], using the ALS electron synchrotron at LBNL to expose the PMMA to X-rays, and (b) by exposing Foturan glass to UV light [5], [6], and subsequent etching [7]. In this paper, we describe fabrication techniques and a new method for placing copper electrodes on the top and bottom GEM surfaces. We also present new measurements of GEM-like detectors made by the LIGA process, including absolute gain, time stability and rate capability, and preliminary results from the Foturan glass detectors.

## II. TECHNICAL DESCRIPTION

We have previously described detectors [3] made by the LIGA method [4], in which low-energy X-rays are used to expose patterns on polymethylmethacrylate (PMMA) sheets. Our LIGA-fabricated detectors described here consist of thin PMMA sheets (125  $\mu\text{m}$  – 350  $\mu\text{m}$  thickness) with arrays of 150  $\mu\text{m}$   $\times$  150  $\mu\text{m}$  square holes having steep wall sides and a pitch of 300  $\mu\text{m}$ . These patterns are made on PMMA sheets exposed to X-rays of about 10 keV energy through patterned gold masks. GEM-like detectors have also been made using Foturan glass of 300  $\mu\text{m}$  thickness. These have arrays of 130  $\mu\text{m}$   $\times$  130  $\mu\text{m}$  square holes, and also have steep wall sides and a pitch of 250  $\mu\text{m}$ . The cross sectional dimensions of the detector sensitive region are approximately 30 mm  $\times$  30 mm for the PMMA and 10 mm  $\times$  10 mm for the Foturan.

### A. Fabrication of LIGA Detectors

The fabrication process begins with the creation of a chromium-on-quartz photomask using a Nanowriter [8], which uses a fine electron beam to produce the desired pattern. The photomask is then used as a template to generate a LIGA mask: a 20  $\mu\text{m}$  thick gold pattern on a silicon wafer using photolithography of a spin-cast photoresist layer. The

function of the LIGA mask is to produce a high differential absorption ratio at X-ray wavelengths. The two major performance considerations in masking are to ensure the proper exposure ratio between the absorbing and the transmitting regions of the mask, and profile dimensional accuracy. The LIGA mask is used as a pattern for X-ray exposure of a PMMA wafer, which will become the GEM-like device after development and plating. The X-ray source used for LIGA exposures is a beam line at the Advanced Light Source (ALS) at the Lawrence Berkeley National Laboratory (LBNL). During exposure, X-ray radiation performs chain scission on the long-chain molecules of PMMA. This effectively reduces the molecular weight in the exposed regions from  $\sim 10^6$  to  $\sim 10^3$  AMU's. The PMMA is then exposed to a developer (a mixture of 2-2 butoxyethoxyethanol, morpholine, 2-aminoethanol and de-ionized water), which selectively dissolves the lower molecular weight material. The unexposed PMMA remains and defines the GEM grid.

### B. Fabrication of Foturan Detectors

The Institute of Microtechnology in Mainz (IMM), Germany [5], has developed a photo-etchable glass, with the trade name Foturan, which is one of the products of the Schott glass Co. [6]. It is an alkali-alumosilicate-glass, whose photosensitive characteristics arise from additions of  $\text{Ce}_2\text{O}_3$  and  $\text{Ag}_2\text{O}$ . This photosensitivity allows it to be structured by UV photolithography for a variety of purposes. Foturan has mechanical, thermal and electrical properties similar to conventional glass, and has a bulk resistivity  $\rho = 8.1 \times 10^{12} \Omega\text{cm}$  at 25 °C. For our Foturan detectors, we used a mask of 20  $\mu\text{m}$ -thick nickel mesh with  $125 \mu\text{m} \times 125 \mu\text{m}$  square holes and a pitch of 250  $\mu\text{m}$ . The exposure was made with light of 300 nm wavelength. The exposed glass is etched using 10% hydrofluoric acid; the etching rate of exposed regions is about 10-15 times faster than that of the unexposed regions. The sides of holes etched into the material are nearly perpendicular to the surfaces. After this process of etching, the final hole size is  $130 \mu\text{m} \times 130 \mu\text{m}$  and the thickness is 300  $\mu\text{m}$ . We contracted with Mikroglas in Mainz, Germany [7] to do the lithography and etching that produced the detectors reported in this paper. The microscopic picture of patterned Foturan wafer is shown in Fig. 1.

### C. Electrode Plating

For both these fabrication techniques, we deposited copper plate electrodes on the top and bottom surfaces of the detectors. The electrodes have a thickness of 1  $\mu\text{m}$ , and are made in the following way. The surface plating begins with a step known as the Damascene method [9]: this prevents copper being plated on the walls of the holes. At first, a colloidal suspension of sub-micron size titanium oxide is used to cover both surfaces of the device as well as filling in the volume of the holes. The necessary qualities for this purpose are available in a commercial product used as a typing correction fluid [10]. It is used here for the Damascene

step. The dried layer is removed from the top and bottom surfaces, but still remains in the holes. Next, a thin coating of palladium-tin [11], an initiator for the copper plate, is deposited on the top and bottom surfaces of the device. Finally, the filler is removed from the holes by ultrasonic agitation in an isopropyl alcohol, and copper is electroless-plated [11] onto the palladium-tin layer to the desired 1  $\mu\text{m}$  thickness.

### D. Experimental Setup

The detector was placed between two electrode planes, the drift (cathode) and collection planes (anode), which were spaced by 3.2 mm and 1.2 mm (or no spacing), respectively from the wafer (see Fig. 2). The drift plane was a thin stainless steel wire grid. A copper plated ceramic layer was used as the collection plane, and was connected to a pulse height analyzer through a calibrated amplifier. In this study, the drift field was fixed at 1.2 kV/cm, or at 40 V/cm for some tests. The applied voltage on the detectors is defined as the voltage difference between the top and bottom electrodes. In order to provide high voltage on detectors safely with no spark damage, a network of voltage dividers and protective series resistances was used, as described in detail in [12]. As is well known, some of the electrons from the GEM avalanche are lost during the collection step by going to the bottom electrode of detector rather than to the collection plane [13]. So we investigated this effect by setting the collection gap to zero in several measurements, i. e. by placing in contact the collection plane and the bottom surface of the GEM-type detector. This also helped to avoid using the voltage-dividing network, which can be a source of noise.

The gas mixture used was either  $\text{Ar}/\text{CO}_2$  (70/30), or P10,  $\text{Ar}/\text{CH}_4$  (90/10), and the source of primary ionization was either an  $^{55}\text{Fe}$  (5.9 keV) source ( $\sim 40 \mu\text{Ci}$ ) or vanadium-filtered X-rays from an X-ray tube having a copper target, and operated with an anode voltage of 6 kV. Gains were measured using the pulse height of the principal 55Fe peak, which was calibrated independently using the known current and rate in an operating MSGC.

## III. RESULTS AND DISCUSSION

We give below the results of a number of detectors made by the LIGA and etchable glass techniques. The leakage resistance of each detector was determined by measuring the current as a function of applied voltage between the top and bottom conducting surfaces. This resistance is more than  $10^{14} \Omega$  for the LIGA detectors, and about  $10^{11} \Omega$  for the Foturan glass detectors. The volume resistivities specified by the manufacturers are  $2 - 14 \times 10^{15} \Omega\text{cm}$  and  $8.1 \times 10^{12} \Omega\text{cm}$ , for the PMMA and Foturan glass, respectively.

### A. Results from LIGA Detectors

Fig. 3 shows gain for several LIGA detectors of different thicknesses. The maximum gains were limited by the onset of fluctuations in the collected currents, thought to be due to electrical micro-discharges on the devices, although no

obvious sparking was observed. From the measurements of avalanche gain vs. drift field, our LIGA detectors obtain the best gain performance with a drift field of about 1.2 – 1.5 kV/cm. The gains were also measured in the P10 gas with zero collection gap, as shown in Fig. 4. In this case, however, we set the drift field at 40 V/cm because avalanche gain was not much smaller than for higher fields, and we obtained better energy resolution. It should be noted that no attempt has been made to optimize the relative sizes of the holes, thickness, and pitch: such optimization is expected to result in a considerable gain increase.

Gain stabilities for various detectors were measured in Ar/CO<sub>2</sub> (70/30) gas (Fig. 5). We used a collimated <sup>55</sup>Fe source at a count rate of 50-100 Hz/mm<sup>2</sup> in all measurements. Observed gain changes are thought to be due to a combination of surface charging and polarization of the substrate. The gain decreased about 15% within about 1.5 hours and then stabilized for thicknesses of 125 – 150 μm, when the collection gap was zero. However, in the case of 1.2 mm-collection gap and 5 kV/cm collection field, the gain drop was less than 10%. We obtained similar results from the thicker (300 and 350 μm) detectors. We believe that because of the longer path through holes of the thicker detectors, there is an increased surface charging and a larger gain drop.

A pulse height spectrum from an <sup>55</sup>Fe source is shown in Fig. 6; the principal peak and the escape peak are clearly seen. The FWHM of the principal peak (5.9 keV) is typically about 30%, and the best result obtained is 20% FWHM. We believe that the square hole geometry contributes to a somewhat poorer resolution than would be obtained with circular holes.

For future experiments, which have to work in the environment of very high luminosity, high rate detectors are needed. Using our X-ray generator, we measured the relative gain of the LIGA detectors as a function of rate for three different gains. As shown in Fig. 7, the gain decrease in detectors running at a gain of about 400 occurs at counting rates exceeding 10<sup>5</sup> Hz/mm<sup>2</sup>. At the higher gain of G=560, however, the gain decrease begins at a few tens of kHz/mm<sup>2</sup>. Comparing Fig. 7 (a) and (b), the rate capability is only slightly worse, if at all, for the thicker detectors, but it depends sensitively on the operating gain.

### B. Results from Foturan Glass Detectors

We have measured the gain and time stability of Foturan glass detectors. Fig. 8 shows the avalanche gain for these detectors in Ar/CO<sub>2</sub> (70/30) gas. As stated in section A above, the maximum gains were limited by the onset of fluctuations in the collected currents. No obvious sparking was observed. With the wafers of 300 μm thickness, we obtained the same avalanche gains at a smaller applied voltage than for LIGA detectors of similar thickness. This result perhaps can be partially explained by the different hole size and pitch. For the Foturan and LIGA detectors of similar thickness (~300 μm), the pitch and hole size are: (pitch/hole) = (300/150)<sub>LIGA</sub> and (250/130)<sub>Foturan</sub>. A change of GEM

geometry can result in very different gain properties. We determined the gain from the principal peak of the measured <sup>55</sup>Fe pulse height spectrum, but the energy resolution was poor, as shown in Fig. 9. These results represent the first measurements of GEM-like detectors using an etchable glass. Further investigations should help determine the potential of this method as the alternative form of GEM detector fabrication. The time stability, which is shown Fig. 10, is quite similar to that of the PMMA detector made by the LIGA process.

## IV. CONCLUSION

GEM-type detectors were made by the LIGA technique of exposing PMMA to low energy X-rays, and by UV light exposure of the etchable glass, Foturan. Both techniques are shown to make functioning GEM-type detectors. Using detectors of several thicknesses, we measured reasonable performance with regard to gain, time stability and rate capability. We also introduced a new method for placing copper electrodes on the top and bottom GEM surfaces. The results from detectors using Foturan glass indicate the possibility of using this alternative technique for GEM manufacturing. Compared with previously used techniques, the different properties of this glass substrate (e.g. thickness, robustness) might provide an extended range of application of GEM-type devices.

Another possibility under investigation is to use either of these techniques to make copper molds, by electroplating copper into the hole patterns, following the original meaning of LIGA: lithography, electroforming and molding. These copper molds could then be used for making GEM-like detectors from molded plastic wafers.

## V. ACKNOWLEDGMENT

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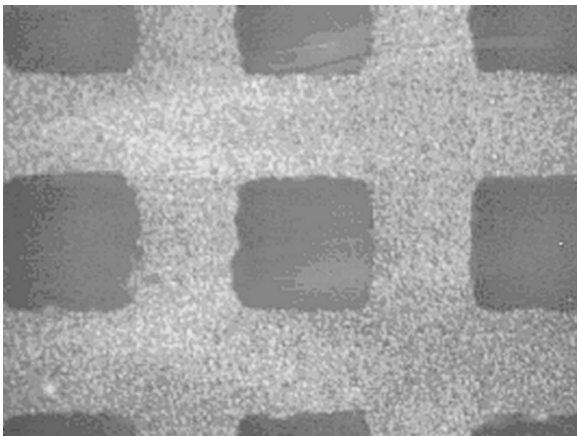


Fig. 1. Hole pattern produced with UV exposure and etching of a 300 μm-thick Foturan wafer. The hole size is 130 μm × 130 μm and the pitch is 250 μm.

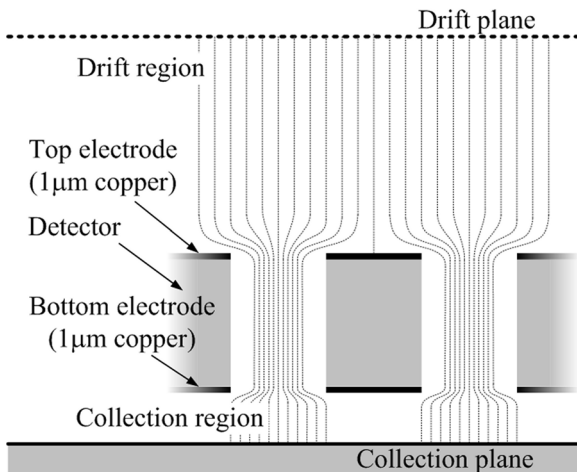


Fig. 2. Schematic representation of the structure of the GEM-type detector, coupled with drift and collection planes. The drift gap was 3.2 mm and the collection gap was either 1.2 mm or zero.

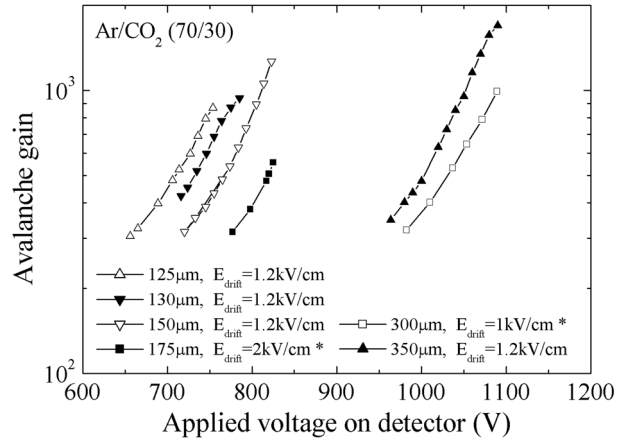


Fig. 3. Measurements of avalanche gain as a function of applied voltage across LIGA detectors of 125 – 350 μm thickness, as indicated on the graph, in Ar/CO<sub>2</sub> (70/30) gas. All measurements have been performed with an <sup>55</sup>Fe source, and up to voltages at which fluctuation of current become prominent. The drift gap was 3.2 mm, and E<sub>drift</sub> was 1.2 kV/cm or 2 kV/cm. The collection gap was zero except for tests marked with \*, where the collection gap was 1.2 mm and E<sub>collect</sub> was 5 kV/cm.

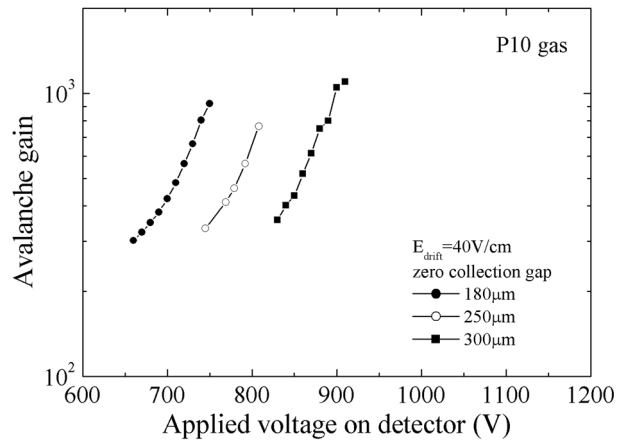


Fig. 4. Measurements of avalanche gain as a function of applied voltage across LIGA detectors of 180, 250 and 300 μm thickness in P10 gas. E<sub>drift</sub> = 40 V/cm and the collection gap was zero.

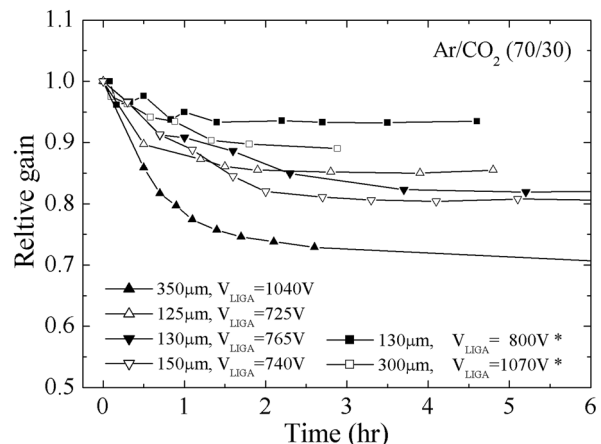


Fig. 5. Gain variation with time of several detectors of different thicknesses. For the thinner detectors, ~130 μm thick, there was a gain

decrease of about 15% after about 1.5 hours, and then the gain stabilized. The drift gap was 3.2 mm, and  $E_{\text{drift}}$  was 1.2 kV/cm. The collection gap was zero, except for those marked as \*, where this gap was 1.2 mm, and the fields were  $E_{\text{drift}}=2$  kV/cm,  $E_{\text{collect}}=5$  kV/cm.

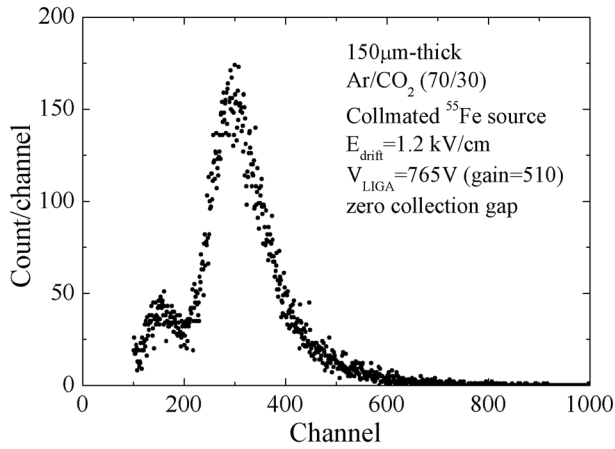


Fig. 6. Pulse height spectrum obtained using a LIGA detector of 150  $\mu\text{m}$  thickness and an  $^{55}\text{Fe}$  source. The FWHM is 30% (see text).

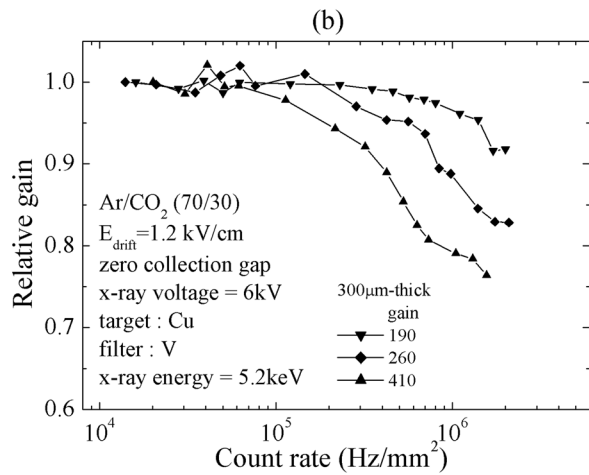
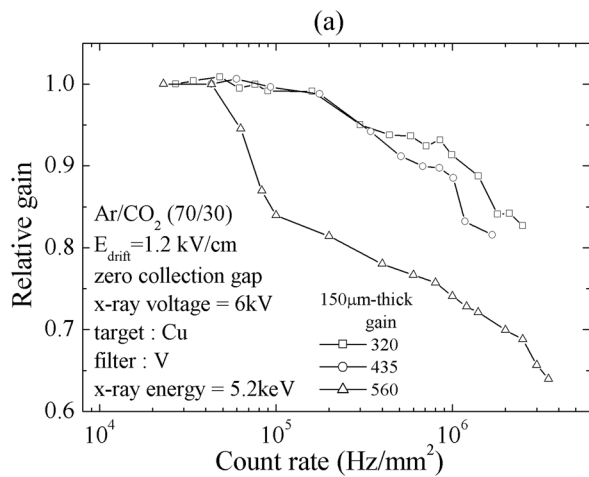


Fig. 7. Relative gain as a function of count rate for the 150  $\mu\text{m}$  (a) and 300  $\mu\text{m}$  (b) -thick LIGA detectors. X-rays of about 5.2 keV were used as a source of primary ionization.

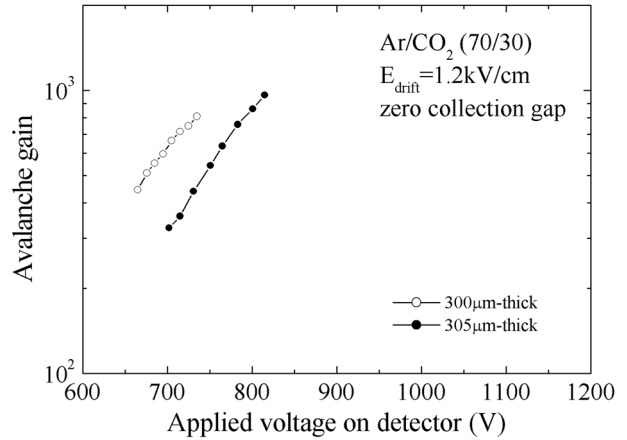


Fig. 8. Measurements of avalanche gain as a function of an applied voltage across Foturan detectors of two 300  $\mu\text{m}$  thickness in  $\text{Ar}/\text{CO}_2$  (70/30) gas.  $E_{\text{drift}}$  was 1.2 kV/cm and the collection gap was zero.

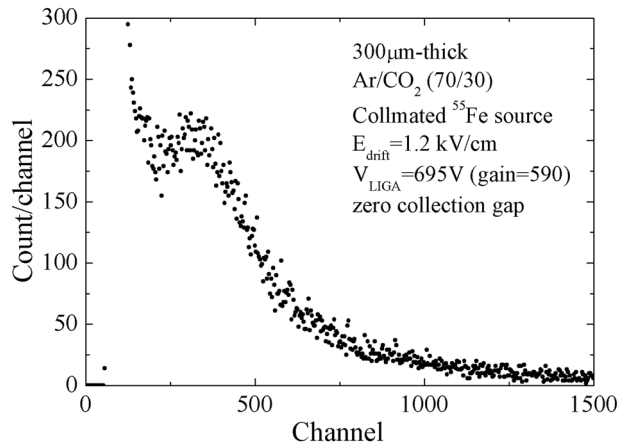


Fig. 9. Pulse height spectrum for an  $^{55}\text{Fe}$  source obtained using a Foturan glass detector of 300  $\mu\text{m}$  thickness (see text).

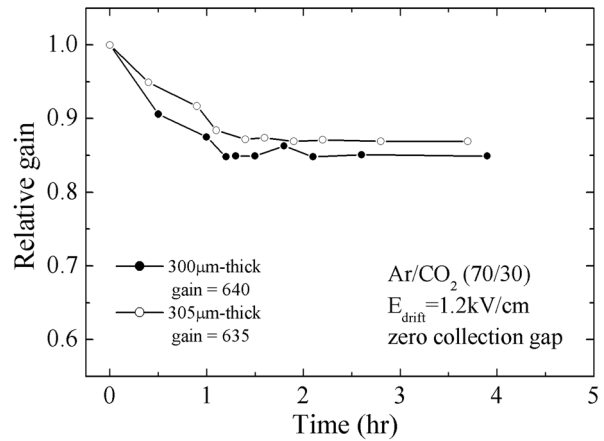


Fig. 10. Gain variation vs. time of Foturan detectors of 300  $\mu\text{m}$  thickness using a 40  $\mu\text{Ci}$   $^{55}\text{Fe}$  source. About 15% decrease of gain is observed after 1.5 hours.