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FGLD: a novel and compact micro-pattern gas detector

Louis Dick*, Rui De Oliveira, David Watts

CERN, CH 1211 Geneva 23, Switzerland

Abstract

A new gas detector which combines in the same structure the gas amplification mechanism and the position sensitive readout, named the field gradient lattice detector (FGLD), is being developed at CERN. The detector, reminiscent in geometry of a multi-wire proportional chamber but with a different field configuration can be fabricated as two or more layers of micro-patterned parallel tracks on a variety of substrate materials.

Two preliminary proof-of-concept designs without position sensitivity have been fabricated as copper tracks of 50 μm width and 150 μm pitch on polyimide in a 3D geometry and on epoxy in a 2D geometry. They have been shown to detect the 5.9 keV X-rays of an ^{55}Fe source with a stable gain ranging from 500 to 5000 in a 3 mm drift chamber containing an argon carbon-dioxide gas mixture.

The elegance and compactness of the FGLD design make it a very attractive gas detector solution both economically and mechanically. Most interestingly, the 3D FGLD design on flexible polyimide should greatly simplify the mechanical challenges of gas chamber assembly in planar and cylindrical detector designs.

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1. Introduction

A new type of gas detector, the field gradient lattice detector (FGLD), has been invented and developed at CERN. The detector geometry consists of two or more layers of parallel tracks which are electrically isolated, have uniform spacing and are aligned in a periodic lattice such that the tracks of each layer are at an angle with respect to the tracks of each other layer. This low-capacitance design provides a region of strong electric field gradient in the cross-over regions between the tracks of each layer (Fig. 1) when a cascading voltage configuration is applied. This electric field gradient is capable of producing an electron avalanche in gas and thus charge amplification of primary ionization electrons measurable by a charge-sensitive preamplifier coupled to each track of each layer. In this way, the FGLD provides the gas amplification mechanism and the position-sensitive readout in a single compact structure, offering a mechanically simple solution for gas detector systems.

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*Corresponding author.
E-mail address: louis.dick@cern.ch (L. Dick).

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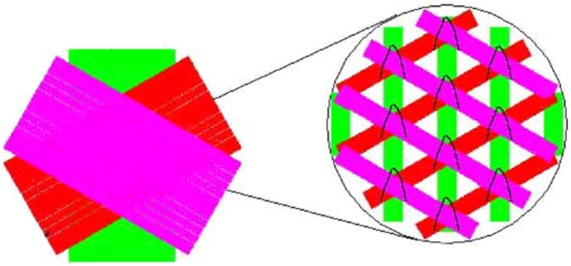

Fig. 1. Schematic of the 3D FGLD geometry with a close-up of the active area and indication of the high-field gradient at the cross-over regions between the layers.

2. Fabrication

The FGLD design has been realized in both 2D (2-coordinates) and 3D (3-coordinates) geometries as a micro-pattern device using proprietary photolithographic processes developed in CERN's printed-circuit workshop.

2.1. 2D FGLD in epoxy

A rigid epoxy substrate provides the mechanical support for the 2D FGLD micro-structure. Using both standard and new techniques of photolithography, copper tracks forming the lower layer are patterned into the epoxy substrate and glue spacers, located at regular intervals throughout the structure, provide support for the upper layer of copper tracks that are patterned above. The resultant matrix (Fig. 2) is a unique micro-pattern detector design: parallel tracks suspended above another layer of such tracks with only space (or gas) in between them.

2D epoxy detectors with active areas of about 3 cm diameter and a track-width ranging from 30 to 150 μm, a pitch of 100 μm, and a spacing between the layers of 50 μm, were fabricated for experiment. Detectors were accepted under the condition that they held at least 600 V between layers with less than 1 nA leakage current.

2.2. 3D FGLD in polyimide

Flexible polyimide provides the mechanical support in the 3D FGLD micro-structure. Three layers of copper tracks are patterned onto polyimide films (the middle layer being encapsulated between the two layers of polyimide) and then the polyimide between the tracks of the active area removed by chemical etching. The resultant matrix (Fig. 3) is about 30% or 40% optically transparent depending on the width of the tracks.

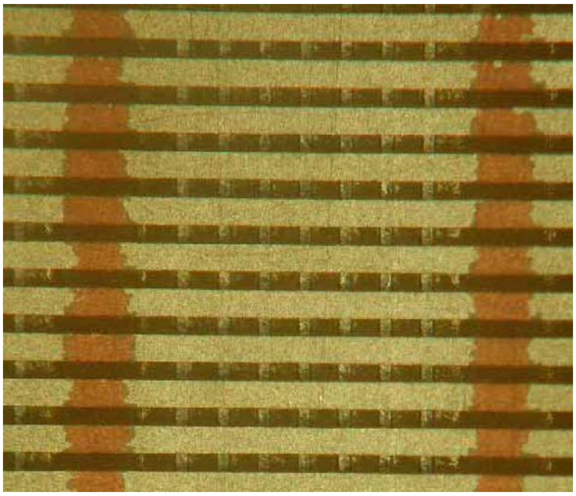

Fig. 2. Close-up of the active area of a 2D FGLD in epoxy. The lower tracks are 50 μm wide, the upper tracks 100 μm wide, the pitch 150 μm, and the separation between layers 50 μm.

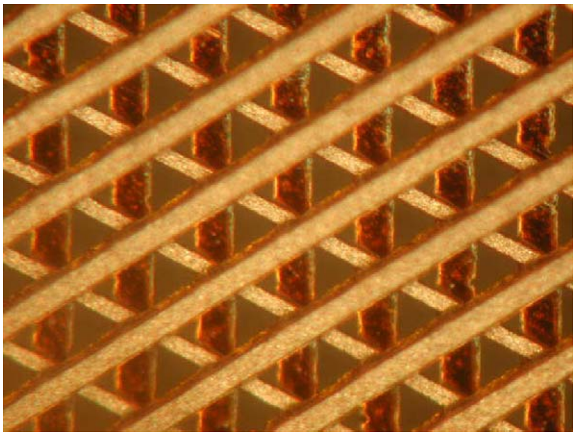

Fig. 3. Close-up of the active area of a 3D FGLD in polyimide. The middle tracks are 30 μm wide, the upper and lower tracks 50 μm wide, the pitch is 150 μm, and the separation between layers is 50 μm.

Unlike the 2D epoxy design, narrow strips of polyimide are present beneath all the tracks of the 3D structure maintaining the spacing between layers and providing the support upon which the tracks rest. The presence of polyimide near the high-field gradient avalanche region could adversely influence the field character or produce charging-up effects as discussed in literature concerning instabilities in micro-pattern gas detectors [1,2]. Furthermore, the build-up of conductive discharge products on the polyimide could be a source of deterioration over long operation times with significant discharge probability. This is not the case for the 2D design however, which we expect to have a more stable performance than the 3D design under strenuous operating conditions.

3D designs with active areas of about 3 cm diameter and a track-width ranging from 30 to 50 μm, a pitch of 150 μm, and a spacing between the layers of 50 μm, were fabricated for experiment. Accepted detectors held at least 600 V between adjacent layers and 900 V between the top and bottom layers, with less than 1 nA leakage current under both conditions.

2.3. Other fabrication methods

The FGLD concept is not limited, in theory, to micro-pattern technology. One idea that may be advantageous for producing large detector sizes involves using a semi-conductive wire mesh as each layer of the FGLD structure. If the mesh were created such that one axis was of insulating strands and the other axis of conducting strands, it would be possible to bring two or more such semi-conductive meshes within a close distance to form the FGLD structure. Furthermore, if the strands of the conductive axis were alternated with insulating ones, the distance between conductive strands forming the cross-over points between two layers could be kept constant. This idea is illustrated in Fig. 4, however, it is still unclear as to whether such a construction would create a working device useful for particle detection.

3. Experimental setup

Detectors of two types, 2D in epoxy and 3D in polyimide with 3 cm active areas, were each tested in a small gas chamber filled with an argon–carbon-dioxide gas mixture at atmospheric pressure. An anode plane and an ^{55}Fe source were placed at 3 mm above the detector and a voltage (V_1) of between −1500 and −2000 V was applied in order to drift the primary ionization electrons towards the detector biased with working voltages,

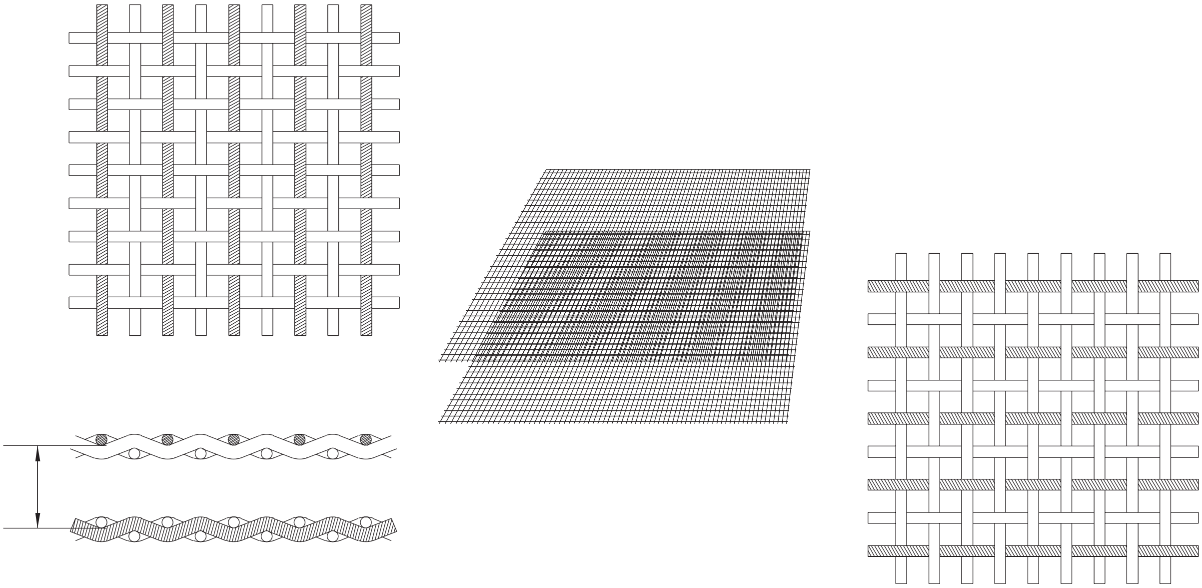

Fig. 4. The semi-conductive mesh idea used to create a 2D FGLD structure.

V_2 (upper layer) and V_3 (lower layer) with the lower layer as the anode. In the 3D detector the middle layer was connected to ground.

All the tracks of each layer were electrically connected and only one charge-sensitive preamplifier per layer was used to detect the charge pulses induced on each set of tracks. In this way we were unable to make any tests involving position but were able to greatly simplify the electronics needed. An electronics chain capable of digitizing the signal pulses was used to record the pulse height spectrum from the ^{55}Fe source and to display it on an oscilloscope.

4. Results

For the 2D detector, we observed the first charge pulses on the oscilloscope above working voltages across the detector of ±200 V. We measured a gain of ~500 in argon (15% CO_2) at working voltages of ±240 V. The pulse height spectrum, recorded by the electronics chain from either the top or bottom layer, shows the 5.9 keV peak and the argon escape peak at 3 eV (Fig. 5).

For the 3D polyimide detector, we observed pulses at working voltages above ±300 V. At working voltages of ±350 V we obtained a gain of ~1000 in argon (12% CO_2), which apart from effects caused by normal daily pressure changes, remained stable over nearly ten weeks of continuous operation with no observable discharges. The pulse height spectrum, recorded from any of the three layers, clearly shows the 5.9 keV peak and the argon escape peak (Fig. 6) with an energy resolution of about 25%. A gain of 5000 was obtainable at voltages of ±380 V, near the limit before inducing discharges. A gain of 10 000 was obtained with voltages above ±400 V, but with observable and frequent discharges.

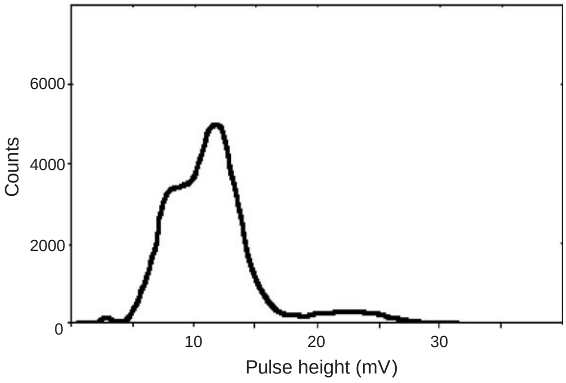

Fig. 5. The pulse height spectrum of ^{55}Fe as detected by a 2D FGLD in epoxy in a drift chamber containing argon (15% CO_2) gas.

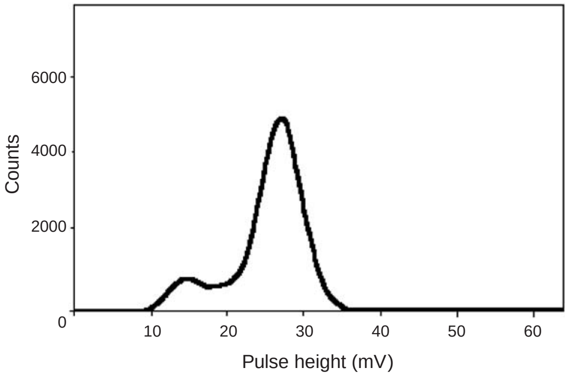

Fig. 6. The pulse height spectrum of ^{55}Fe as detected by a 3D FGLD in polyimide in a drift chamber containing argon (12% CO_2) gas.

5. Conclusions and future work

Both the 2D epoxy and 3D polyimide FGL detectors have been shown to provide reasonable gas amplification of primary ionization electrons from 5.9 keV X-rays in an argon carbon-dioxide gas mixture. The 2D epoxy detector showed stable operation with gains between 500 and 1000, while the 3D polyimide detector showed stable operation at gains of 1000–5000. In addition, the 3D polyimide detector performed stably at a gain of 1000 without any observable deterioration during ten weeks of continuous operation.

Much detailed study of the FGLD remains to be done, including a thorough analysis of the FGLD gain and discharge characteristics. In particular, a position-sensitive FGLD with larger active area is essential in order to make measurements of the spatial resolution and operation stability in a real beam with high particle rates. Work is currently underway to develop such a detector, which would incorporate a thick-film hybrid of polarization resistors, decoupling capacitors, and current limiting diodes on the detector itself.

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