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Modern micropattern gas detectors

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Abstract. In all measurement systems of radiation, the detector is the most important part. We can say that it is the heart of these systems. Gas detectors are still the most popular type of detector. Modern technologies allow manufacturing gas detectors having a very good energy and position (2D) resolution, high efficiency, large effective area, small count rate effect, radiation hardness, good signal-to-noise ratio and not complicated structure. These detectors are very fast and can stably work for a long period of time. One advantage of gas detectors is the possibility to read not only charge, but also UV light generated in the detector. In this paper we want to make a review of construction, mechanical properties, performance and possible applications of the following so-called micropattern gas detectors (MPGD): microstrip gas chamber (MSGC), gas electron multiplier (GEM), MICRO-MEsh GAseous Structure (MICROMEGAS) and capillary plate detector (CP).

Key words: microstructure detector • microstrip • GEM • MICROMEGAS • capillary plate

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Introduction

Position sensitive gas proportional counters have been widely used in such fields as high energy physics, X-ray astronomy, medical science and industry. The recently developed micropattern gaseous detectors (MPGD) have demonstrated excellent performance. Various types of MPGD have recently emerged as very promising tools for several applications in many fields. A hole type gaseous multiplier represented by gas electron multiplier (GEM), capillary plate gas proportional counter (CGPC, CP) and MICROMEGAS is one of the most interesting and useful MPGD. The microstrip gas chamber (MSGC) was the first of the microstructure gas detectors. Recent achievements in the technologies have encouraged MPGD applications in a wide range of experiments and offer a great potential for the future.

In this paper, we presented a short review of the MPGD with a focus on design principles, performance and operational experience.

Microstrip gas chamber (MSGC)

The MSGC [8, 9] is an upgrade of multi-wire proportional chamber in which the anode plate is replaced by an insulating or a semi-insulating substratum plate on which very thin metallic strips are engraved. The strips are alternatively connected as anodes and cathodes. The MSGC is historically the first of the microstruc-

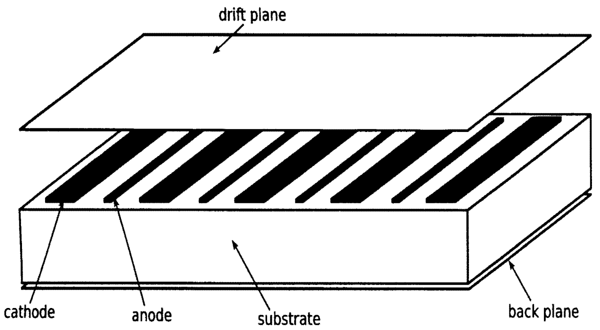

Fig. 1. Experimental set-up of MSGC.

ture gas detectors. The typical pitch of the structure is 200 μm, width of the anode and cathode are (10–30) μm and (60–90) μm, respectively. The depth of drift and absorptions region is a few millimetres. The detector set-up is shown in Fig. 1.

MSGC detector operates in the following way:

- electrons are produced in the gas volume in the absorption and drift region between drift cathode plane and microstrip structure plane,
- produced electrons reach the electric field between the anode and cathode strips,
- gas multiplication takes place at the sufficiently high field strength closed to anode strips.

The general characteristics of the MSGC may be summed up as follows [2, 6]:

- high value of gas gain up to 7×10^3,
- very high count rate capability $\sim 10^6$ count/mm^2·s,
- high position resolution ~ 50 μm,
- good energy resolution ~ 16% FWHM for X-ray of 5.9 keV,
- moderate cost and moderate applied high voltage,
- structure is sensitive to humidity and temperature,
- insulating substratum material should have surface resistance $\sim 10^{12}$ Ω/□, in an other way the insulating part of the surface is charged up by ions,
- the structure can be easily damaged by discharges.

Finally, one can conclude that it is possible to manufacture a single detector having excellent properties, but mass production of this detector type is unrealistic. Currently, MSGC is not used in any high energy physics experiment.

Gas electron multiplier (GEM)

A thin polymer foil, metal coated on both sides, is chemically etched by a high density of holes. By applying a suitable voltage difference 400–500 V between the two metal sides, an electric field with an intensity as high as 100 kV/cm is produced inside the holes. The holes act as electron multiplication channels for electrons released on the top side in drift region by ionizing radiation. The maximum gain reachable with a single GEM foil is of the order of 10^3 in most commonly used gases [10, 13]. Typical geometry is 5 μm Cu foils on 50 μm kapton foil, 40–50 μm holes at 100 μm pitch (Fig. 2). In multiple structures, see Fig. 3 (double GEM or triple GEM) gas gain as high as 10^5 is reachable for low applied high voltage. The performance of a counter at low value of high voltage strongly decreases the probability of spurious discharges, for instance in the triple GEM

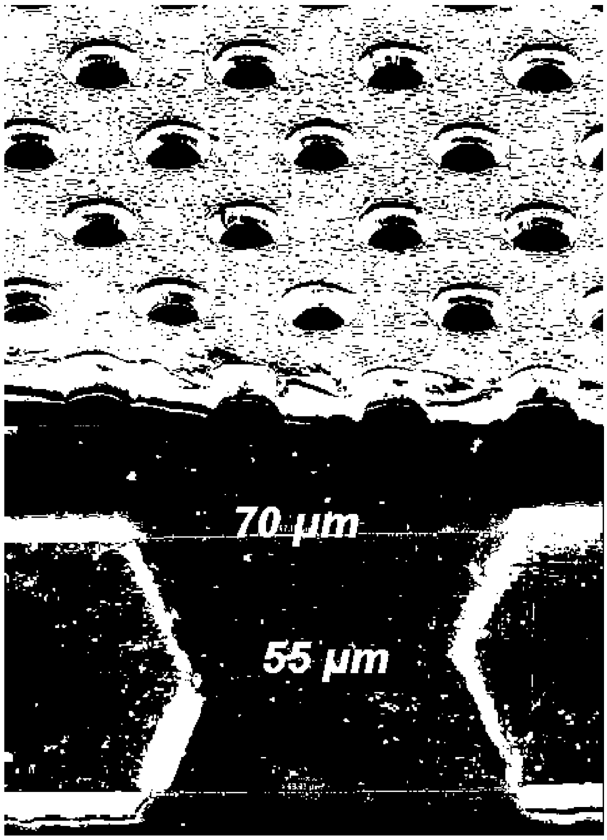

Fig. 2. Structure of GEM foil.

the discharge probability is not measurable. Due to the slight bi-conical shape of the holes, charge can deposit on the insulator and dynamically modify the gain. The equilibrium state is reached when any lines of electric field enter the dielectric. The charging depends on irradiation rate, but the gain saturates at the same value.

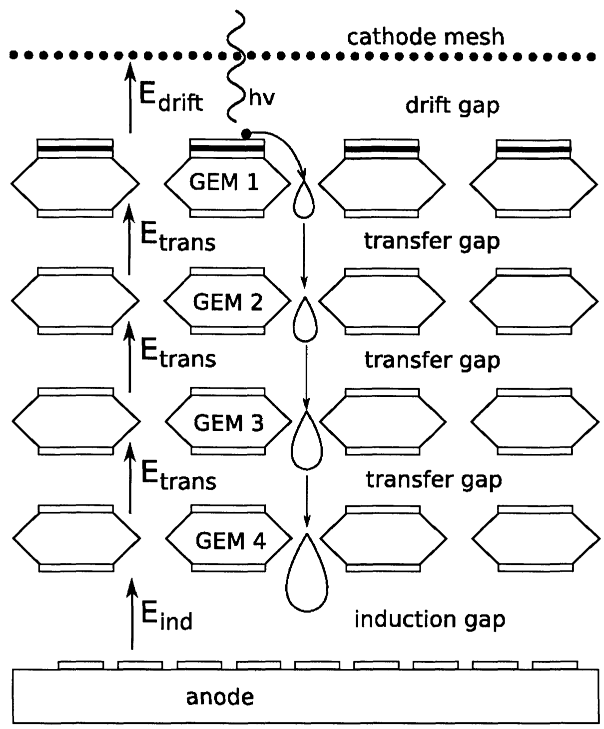

Fig. 3. Schematic drawing of multistage GEM set-up.

GEM detectors are hard radiation resistance. There is a large area available for polymer deposits and the radicals are produced mostly in the centre of the hole, in a big distance from Cu electrodes. A unique property of the GEM detector is the complete decoupling of the amplification stage (GEM) and the readout electrode, which operates at the unity gain and serves only as a charge collector. This offers freedom in the selection of the anode readout structure, which can be made of pads, strip or directly electronic chips. GEM's can be also easily bent to form cylindrically curved detectors. In contrast to wire, GEM shows no preferred direction, thus any magnetic field effect is isotropic. Relative ion feedback of 0.5% is achieved, and by optimizing the geometry and the operation voltage of the GEM it can be further reduced [1]. This kind of detector is used in contemporary high energy physics experiments and fulfils all the requirements in terms of the rate capability, efficiency, radiation hardness and time and position resolutions.

MICRO-MEsh GAseous Structure (MICROMEGAS)

MICROMEGAS [7] is a double stage parallel plate avalanche counter. It consist of a few mm conversion region, electric field ~ 1 kV/cm, and a narrow electron multiplication gap, 25–150 μm, 50–70 kV/cm, located between the thin metal grid (micromesh) and the readout electrode plate, Fig. 4. The mash is mounted on a kapton or quartz spacer, which kept the parallelism between the micromesh and the anode. The mesh itself is a very thin, 3–5 μm, metallic micromesh, with the pitch of 25 to 50 μm and a regular array of square holes mostly 39 × 39 μm^2.

The field applied to the amplification gap is about 40 times higher than the conversion field resulting in a working gain of a few thousand [4].

Primary electrons coming from the drift space cross the micromesh, which is fully transport and are multiplied in the small gap.

Advantages of MICROMEGAS [5, 14]:
- fast signal, time resolution of ~ 10 ns,
- maximum safe gas gain is close to 10^5,
- very good energy resolution, ~ 12% at 6 keV,
- possibility of industrial manufacturing of large-size detectors,
- very small ion feedback of the order of 10^{-3},
- detector is radiation and spark resistant and mechanically robust,
- no sensitivity to magnetic field,
- excellent detector uniformity over the whole surface (few percentage),

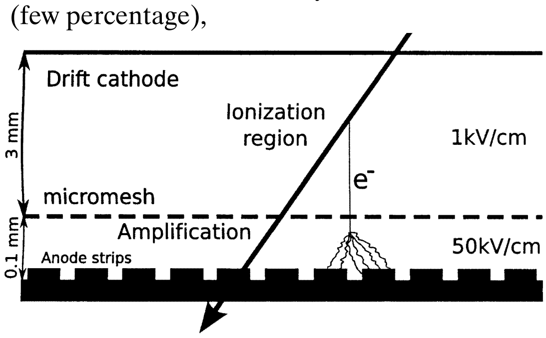

Fig. 4. Schematic drawing of MICROMEGAS detector.

- non-sensitivity to small variations of the amplification gap,
- no gas gain saturation with rate up to fluxes of $10^9/mm^2 \cdot s$,
- anode plane can be easily segmented into strips or pads to give two dimensional read-out,
- detection efficiency of single electrons is closed to 100%,
- signal-to-noise ratio > 100.

Summarising, the MICROMEGAS is suitable for many applications in physics or for a high rate imaging device.

Capillary plate gas proportional counter (CGPC, CP) [II]

Capillary plate gas proportional counter (Fig. 5) is composed of an absorption and drift region and a capillary plate where gas multiplication occurs. Capillary plate is a bundle of fine glass capillaries with electrode on both sides. The capillaries are 1–1000 μm in inner diameter and 0.2–2 mm in length and are made of high resistance lead glass.

The characteristic of CGPC [12, 15, 16]:
- gas gain up to 10^4 without the breakdown,
- energy resolution 26% at 5.9 keV,
- detection efficiency comparable to the standard proportional counter,
- gas multiplication occurs in each capillary and hence each part of the electron cloud is identified in a very small domain,

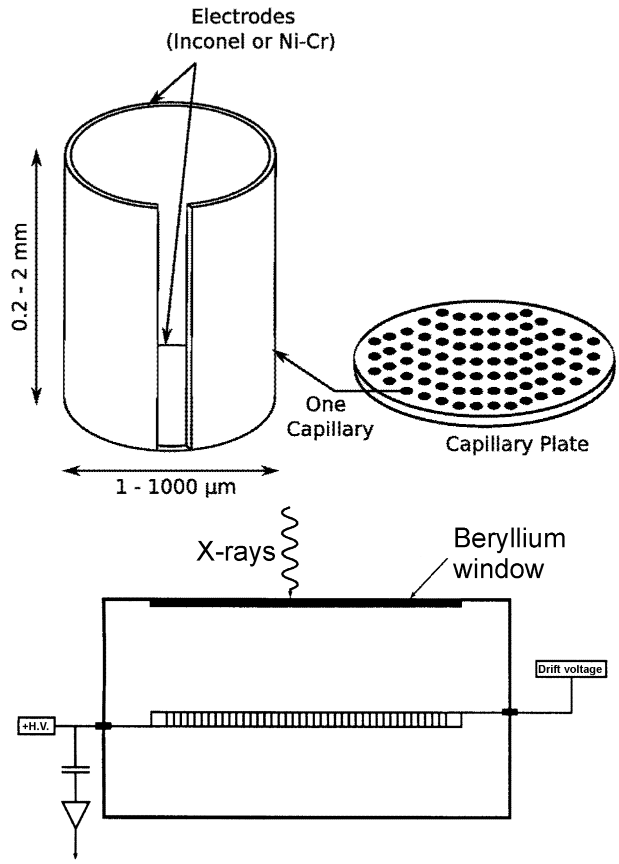

Fig. 5. Schematic view of capillary plate and set-up of CGPC.

- capillary charging is observed after switching on the high voltage,
- detector is not fast, the observed pulse rise time is about 800 ns,
- CGPC stacking is possible,
- the scintillation light emitted during the development of electron avalanches and the charge can be readout,
- open area ratio ~ 57% (ratio of active surface to total surface),
- position resolution ~ 50 μm with optical readout,
- excellent optical imaging capability.

Conclusions

Modern photo-lithographic technology has enabled a series of inventions of novel MPGD concepts.

MPGD are presenting the required high counting rate, good spatial and time resolution, low magnetic field effect, low ion backflow, fast signal, radiation hardness, long term performance stability, good signal-to-noise ratio, high single photoelectron detection efficiency and industrial production of large surfaces detectors. The works to optimize the MPGD properties are still in progress [3].

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