The development of MICROMEGAS for high particle-flux environments

Y. Giomataris, Ph. Mangeot, Ph. Rebourgeard and J.P. Robert

DSM/DAPNIA/SED-C.E-Saclay
Paris, France

1 Introduction

A great effort has been invested the last 8 years to develop gaseous detectors capable to operate in high rate environements, with particle flux beyond 10^4 particles/mm^2/s, which is the limit of operation of conventional MWPCs. The motivation is great for both future high energy physics projects or contamporary medical radiography.

Recently a new promising technique, called MICROMEGAS, has been proposed and experimental results obtained using a small prototype have been published. It consists of a two-stage parallel-plate avalanche chamber of small amplification gap (100 μm) combined with a conversion–drift space. Encouraging results obtained with the small prototype are described in reference [1].

In this paper we present results obtained with large area detectors. The main advantages of this type of detector are the following :

1. High granularity can be obtained in a straight forward fashion. Strips of several tenths of microns are printed using conventional low-cost lithography on a epoxy or thin kapton substrate.

2. Low material : there is not any obstacle to reduce the total material of the detector at the level of the MWPC radiation lenght. Our goal is to have a total material not exceeding 10% of the radiation length of a typical silicon detector.

3. High counting rate : the positive ion signal has a duration of 100 ns. The fast evacuation of positive ions combined with the high granularity of the detector provide a high rate capability. First results indicate that a counting rate superiour to 10^6 particles/mm^2/s can be obtained.

4. Stable operation and excellent aging behaviour of the detector has been observed

5. Low cost : the construction of the detector is achieved using known-low-cost technology. So the total cost is inferiour to the silicon and the MSGC detector.

2 Description of MICROMEGAS and experimental results

The amplification occurs between the mesh plane and the microstrip plane. A small gap, of about 100 μs, between the anode and cathode plane is kept by precise insulating spacers. The device operates as a two-stage parallel plate avalanche chamber and it is called MICROMEGAS (MICRO-MEsh-GAseous Structure). It is a miniaturized version of a very asymmetric two-stage parallel plate detector. A micromesh separates the conversion space, of about 3 mm, from a small amplification gap that can be as small as 100 μm . This configuration allows us to obtain, by applying reasonable voltages in the three electrodes, a very high electric field in the amplification region (about 100 kV/cm) and a quite low electric field in the drift region. Therefore, the ratio between the electric field in the amplification gap and that in the conversion gap can be tuned to large values, as is required for an optimal functioning of the device. Such a high ratio is also required in order to catch the ions in the small amplification gap: under the action of the high electric field, the ion cloud is quickly collected on the micromesh and only a small part of it, inversely proportional to the electric field ratio, escapes to the conversion region. Figure 1 shows a schematic representation of a typical detector. It consists of the following components:

1. Anode electrode. Copper strips of 150 μm , with 200 μm pitch, are printed on a 1 mm substrate. The thickness of the copper strip was 5 μm . Thinner strips were easily obtained by vacuum deposition. These allow a substantial reduction of the interstrip capacitance. Both metal-deposition techniques can be applied on a 25 μm thick Kapton substrate, whenever a reduction of the material of the detector is required. The strips were grounded through low-noise charge preamplifiers of high gain (4 V/pC).

2. Quartz fibres of 100 μm , with 4 mm pitch, were stretched and glued on a G10 frame or a kapton foil. The quartz frame was then mounted on the strip surface, defining a precise (2%) gap. Thicker (145 and 230 μm) quartz spacers were also utilized during our tests.

3. The micromesh. It is a metallic grid, 3 μm thick, with 17 μm openings every 25 μm . It is made of nickel, using the electroforming technique. The use of the photographic process and especially high-resolution emulsions, enssures a high precision, better than 1 μm . The transparency was measured to be 45%.

4. The conversion-drift electric field was defined by applying negative voltages on the micromesh (HV2) and a slightly higher voltage on a second electrode (HV1), spaced by 3 mm in order to define a conversion–drift space. This second electrode was made by a 2 micron aluminized mylar.

5. The gas volume. The various elements of the parallel-plate structure were placed in a tight stainless steel vessel flushed by a standard gas mixture of Ar + 6% Iso-butane at atmospheric pressure. Simmilar results were obtained by flushing with an Argon and DME gas mixture.

Ionization electrons, created by the energy deposition of an incident charged particle in the conversion gap, drift and can be transferred through the cathode micromesh;

they are amplified in the small gap, between anode and cathode, under the action of the electric field, which is high in this region. The electron cloud is finally collected by the anode microstrips, while the positive ions are drifting in the opposite direction and are collected on the micromesh. The electric field must be uniform in both conversion and amplification spaces. This is easily obtained by using the micromesh as the middle electrode. The electric-field shape is, however, disturbed close to the holes of the micromesh. The knowledge of the shape of the field lines close to the micromesh is a fundamental issue for the operation of our detector, and especially for the efficiency of the passage of electrons through the micromesh, as well as, for the fast evacuation of the positive-ion build-up.

A simmulation program, based on the CASTEM2000 software, has been invested. A special set-up has been used to check the validity of those calculations. Details of the structure of that program, as well as the experiment which was pefrormed , are given in reference [1]. Figure 2 shows the transmission of the micromesh, as a function of the ratio ξ=E2/E1, E1 is the electric field in the conversion space and E2 in the amplification space. There is a fast rise up to a ratio of about 10; then a slower rise up to a ratio 40; finally a plateau when the full elect ron cloud is transmitted through the micromesh. This is a particular behaviour, which characterizes the micromesh, and it is different from the measurements obtained with conventional wiremeshes having larger holes. At a first order, the agreement with our simulation model is satisfactory.

Several prototypes, with a dimension of 15*15 cm**2, have been recently constructed and tested. Most of the measurements were performed by using an amplification gap of 140 μm . Since anode strips were grounded, a negative voltage was applied on the anode grid HV2 and a slightly more negative voltage on the drift electrode HV1. Under these conditions electrons produced by the radioactive source in the conversion gap were easily transferred to the amplification gap through the fine grid. Comfortable signals were obtained by irradiating the detector with ^{241}Am or ^{55}Fe radioactive source. The rise-time of the signal was about 200 ns, corresponding to the drift of the ion cloud produced during the avalanche process. With a smaller gap of 75 ns, the rise-time was inferior to 100 ns as is shown in Figure 3. Obviously after that lapse of time, ions produced in the avalanche, which can disturb the electric field, are fully evacuated from the detector; it is therefore possible to detect a second particle entering the same area. It gives a substantial improvement in terms of rate capability over conventional gaseous detectors. We were able to observe fast signals due to the collection of the electron cloud in the anode. Figure 4 shows such a signal taken through a fast current preamplifier. The rise-time is 4 ns and it is a convolution of the physical effect itself, the rise of the amplifier and the capacitance of the channel.

We must point out that gains supperior to 10^4, using a standard gas mixture of Ar + 10% CH_4 at atmospheric pressure, could be safely reached. Notice that, using more adequate quenchers, superior gains must be achieved. At those gain values single electron detection is possible and therefore it could be possible to reduce the conversion gap to 2 mm or even to 1 mm, using a heavier gas. Reducing the conversion gap one can reduce the parallax error for inclined tracks and improve the spatial resolution.

The energy resolution of the detector was measured using the ^{55}Fe radioactive source. The obtained pulse-height distribution is shown in Figure 5. One can easily separate the 5.9 keV peak and the Ar escape peak at 3.5 keV. The energy resolution

obtained, 13% (FWHM), is more than satisfactory. It shows that the detector can achieve a reasonable homogeneity of the gain, in spite of possible fluctuations due to mechanical misalignments inside the micro-amplification gap. Systematic long-term gain-stability measurements have not yet been performed. But we can point out that observed no notable effect of charge-up or drop of the gain during our tests after many days of operation at high fluxes. Stability of gain and simple low-cost construction of the detector could be a considerable advantage of this detector compared to the MSGC [2, 3, 4, 5] or the microgap [6] gaseous detector. Compared to the assymetric multiwire chamber [7], its construction is simpler and the minimum required material is lower.

3 Conclusion - Outlook

These results indicate that our detector combines most of the qualities required for a high-rate position-sensitive particle detector: excellent spatial resolution can be obtained with fine strips printed on a thin G10 substrate or a thin kapton foil. High gain in steady operation has been achieved. At such gain, high efficiency can be obtained for minimum-ionizing particles with excellent signal-to-noise ratio. Reduction of the conversion gap to 2 mm or to 1 mm can be envisaged in order to reduce electron diffusion and the parallax error induced by inclined charged particles. This would also improve the spatial resolution. The fast evacuation of the ion space charge and the high granularity of the detector open the way to the achievement of very high counting rates, beyond 10^6 particles/mm^2/s. Using conventional charge preamplifiers with long picking time, the total rise-time is of the order of 100 ns, which corresponds to the total ion drift time, without any shaping of the signal. In some applications it can be envisaged to use fast current preamplifiers with time constants of the order of 1 ns to catch the electron signal. The device is simple, easy to operate, and cost-effective. The excellent energy resolution obtained with MICROMEGAS show that the mechanical precision of the various elements of the detector is under control.

4 Figure captions

Figure 1. A schematic view of Micromegas: the 3 mm conversion gap and the amplification gap separated by the micromesh and the anode strip electrode.

Figure 2. Measured electron transmission through the micromesh for various values of the ξ ratio

Figure 3. Signal seen on the anode by a charge preamplifier. The rise-time reflects the ion cloud collection.

Figure 4. Fast signal measured on the anode using a fast-current preamplifier.

Figure 5. Pulse-height distribution from an ^{55}Fe source. The position of the 5.9 keV peak corresponds to a gas gain of 2000.

References

[1] Y. Giomataris, Ph. Rebourgeard, J.P. Robert and G. Charpak, C.E. Saclay-DAPNIA/SED 95-04, submitted to Nuclear Instruments and Methods

[2] A. Oed, Nucl. Instr. Meth. A263(1988)351

[3] F. Angelini, R. Bellazzini, A. Brez, M.M. Massai, G. Spandre and M.R. Torquati, Nucl. Instr. Meth. A283(1989)69

[4] R. Bouclier, J.J. Florent, J. Gauden, G. Million, A. Pasta, L. Ropelewski, F. Sauli and L. I Shekhtman, Nucl. Instr. Meth. A323(1992)236.

[5] S.F. Biagi, J.N. Jackson, T.J Jones and S. Taylor, Nucl. Instr. Meth. A323(1992)258

[6] F. Angelini, R. Bellazzini, A. Brez, M.M. Massai, R. Raffo, G. Spandre and M.A. Spezzina, Nucl. Instr. Meth. A335(1993)69

[7] G. Charpak, I. Crotty, Y. Giomataris, L. Roppelewski and C. Williams, Nucl. Instr. Meth. A346(1994)506