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Performance of a low-pressure Micromegas-like gaseous detector

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ABSTRACT

We studied the properties of low-pressure Micromegas detectors in which the length of the amplification gap was slightly increased to improve the attainable gas gain. Two detectors with amplification gaps of 200 and 400 μm were constructed and operated at gas pressures below 60 Torr. Large gas gains (10^4–10^5) and fast signals (100–200 ns duration) were observed and the possibility of obtaining an ion backflow as low as 10^{-4} was demonstrated. These properties, combined with the simple and robust structure of the detector which result from the increased length of amplification gap, make it an attractive choice for applications which benefit from low-pressure operation.

1. Introduction

The Micromegas detector [1] has emerged as an outstanding gaseous detector due to its excellent counting rate, high spatial and time resolution, as well as its simplicity, low-cost and radiation resistance [2–4]. The performance of this detector has been studied with a large variety of gas mixtures with regard to different applications ranging from particle physics experiments to medical imaging (see e.g. Refs. [5–7]). However, most of these studies have been performed at normal pressures, while there are applications which could benefit from the operation at low gas pressures. For example, a low-pressure Micromegas detector in combination with an appropriate solid neutron converter would be an excellent candidate to meet the considerable demand which now exists for high-rate neutron detectors with extreme insensitivity to γ-rays [8]. A low-pressure Micromegas also has potential advantages in the detection of heavily ionizing particles with low penetration.

The use of a narrow amplification gap, in the range of 50–100 μm, is the key element in the operation of normal-pressure Micromegas detectors because it leads to a very fast evacuation of positive ions, thus permitting high counting rates. Moreover, this range of amplification gap corresponds to the optimum thickness for charge multiplication at normal pressure of many types of gas fillings [2,9]. However, at low gas pressures, due to the large ionization mean free path of electrons, such amplification gaps are insufficient for attaining a satisfactory level of gas gain, which is of the utmost importance in most applications.

In the present work, we present the characteristics of a Micromegas-like gaseous detector in which the amplification gap is chosen according to operation at gas pressures below 60 Torr. The detector is operated with pure isobutane (iC_4H_{10}), which is a suitable choice for the operation at low gas pressure. The fast signal waveform, gas gain and details of operation modes are presented and some potential applications of the detector are briefly discussed.

2. Choice of gap thickness

The optimum thickness of an amplification gap corresponding to operation at a given gas pressure can be estimated by the gas gain formula. In a thin parallel-plate chamber, the gas gain associated with a single electron is given by

$$M = e^{\alpha d} \tag{1}$$

where α is the first Townsend coefficient and d is the length of the amplification gap. A good approximation of the α-coefficient is given by the Rose and Korff formula:

$$\alpha = A \cdot P \cdot e^{-BP/E} \tag{2}$$

where P is the gas pressure, E is the electric field strength and A and B are the constants for the filling gas. Replacing E by V/d (V being the voltage) and using Eq. (1) leads to

$$M = e^{A.P.d.e^{-B.P.d/V}} \tag{3}$$

Using Eq. (3), we calculated the variation of gas gain versus the gap length (d) for isobutane gas at several pressures ranging from 20 to 60 Torr and two typical operating voltages of 300 and 400 V. The A and B values of isobutane were taken from Ref. [10]. The

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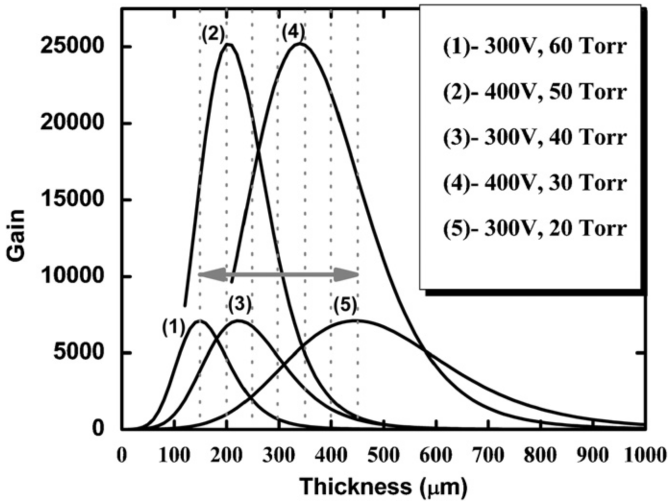

Fig. 1. The expected gas gain as a function of the amplification gap for several gas pressures and two operating voltages of 300 and 400 V. The calculations show that for a given gas pressure and voltage, there is an optimum choice of gap thickness. Nevertheless, it should be noted that these calculations do not necessarily reflect the maximum achievable gains of each gap working at a given pressure because the calculation is done at constant voltage and therefore it does not take into account that the larger gaps allow applying larger voltages which lead to larger gas gains.

results of the calculations, shown in Fig. 1, indicate that at the gas pressure range of 20–60 Torr, the optimum thickness of the amplification gap lies in the range of 150–450 μm, which is somewhat larger than that of conventional Micromegas detectors having amplification gaps of 50–100 μm. This might be deemed to be detrimental to the fast evacuation of the avalanche charge from the amplification gap. Nevertheless, as shown later, operation at low gas pressures leads to a considerable rise in the mobility of positive ions that keeps the signal duration as short as that of conventional Micromegas detectors.

3. Description of the detector and test setup

Tests were performed using two detectors with amplification gap sizes of 200 and 400 μm that are, in accordance with the results of Fig. 1, suitable for operation in the gas pressure range of 20–60 Torr. The active area of the detectors is $6 \times 6\,cm^2$. The structure of the detector with the 200 μm amplification gap is schematically presented in Fig. 2. The amplification gap is defined by stretching nylon fishing lines with a diameter of 200 μm every 5 mm on the anode plane made of a 1.6 mm thick Printed Circuit Board (PCB). To ensure the flatness of the anode electrode, the PCB is glued onto a 1 cm thick acrylic plate. In the detector with the 400 μm amplification gap, the gap is maintained by means of a simple side spacer and no support exists in the active area of the detector.

In both the detectors, woven wire mesh made of 20 μm stainless steel wire with 500 LPI (lines per inch) was used to delimit the amplification and conversion gaps. The woven wire mesh is used instead of electroformed micromesh foil, employed in the initial Micromegas detectors. This significantly reduces the cost and greatly increases the mechanical strength with regard to stretching and handling [11]. The drift electrode is realized with an aluminized Mylar foil (6 μm thick), well stretched over a glass/epoxy frame. The conversion gap, defined by the distance between the drift electrode and the wire mesh, is maintained by a 3 mm thick glass/epoxy spacer.

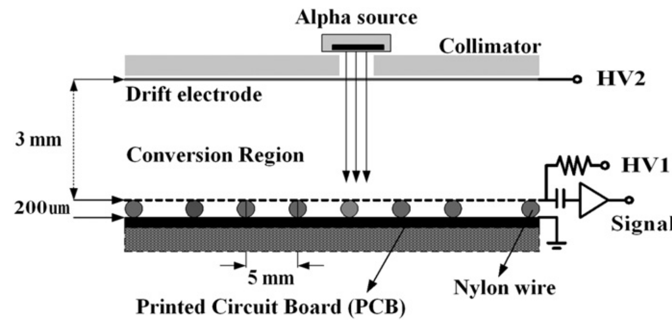

Fig. 2. Schematic view of the counter with 200 μm amplification gap. The detector with the 400 μm amplification gap has the same structure but no support exists in the detector active area.

Tests were performed using a ^{241}Am α-source. It was positioned in such a way that a collimated beam of α-particles enters the conversion gap (Fig. 2). The detector and source were enclosed in a vacuum vessel and the system was operated in a gas flow mode using a mass flow controller, a two-stage mechanical pump and a pressure gauge with a precision of better than 5%.

Negative potentials were applied to both the drift electrode and wire mesh. The anode of the detector was grounded and the readout signal of the detector was taken from the wire mesh through a decoupling capacitance. In order to investigate details of the charge multiplication process, the signals from the drift electrode were also obtained through a decoupling capacitance. The detectors were operated in conjunction with different types of preamplifiers, including charge-sensitive preamplifiers (Ortec 142 PC and Ortec 142 IH) as well as a fast preamplifier with a risetime of 1 ns.

4. Experimental results and discussion

The first tests of the detector were performed to study the behavior of electron transmission from the conversion volume to the amplification gap. For this purpose, in the detector with the 200 μm amplification gap, a negative voltage between 200 and 450 V was applied to the wire mesh (HV_1) and then the voltage of the drift electrode (HV_2) was slowly increased. Observation showed that as soon as the HV_2 exceeds the HV_1, fast signals are induced on the wire mesh indicating an efficient transfer of the primary electrons from the conversion volume into the amplification gap. In fact, owing to operation at low gas pressures, the electron transfer takes place with very small potential differences between the drift electrode and wire mesh, making it practically sufficient to set the HV_2 only a few volts above the HV_1. However, the electric field intensity in the conversion gap can affect the time which is required to collect the electrons from the conversion gap and consequently the detector response. In iC_4H_{10}, a reduced electric field of ~4 V/cm. Torr is sufficient to reach the maximum electron drift velocity of ~5 cm/μs [12]. In such operation conditions, the typical values of the electric fields in the conversion region and amplification gaps are on the order of 0.1 kV/cm and 20 kV/cm, respectively. The same electron transfer behavior was observed for the detector with the 400 μm amplification gap over the pressure range examined in our study (20–60 Torr).

Fig. 3 depicts the typical charge signals obtained for the 200 and 400 μm amplification gaps. The signals were taken using a fast charge-sensitive preamplifier (Ortec 142 IH) whose minimal risetime is 20 ns. The detectors were operated at a gas pressure of 30 Torr, and the voltage of the drift electrode was set 10 V above