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**OPTIMIZATION OF MICROSTRIP GAS CHAMBER DESIGN
AND OPERATING CONDITIONS**

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ABSTRACT

We discuss recent experimental and theoretical work aimed at optimizing the structure and operating conditions of micro-strip gas chambers. In a systematic set of measurements we have found gas mixtures allowing high stable gains; the best results were obtained using argon-dimethylether in equal percentages (50-50), and mixtures of dimethylether and carbon dioxide. Detectors exhibit lower noise and better energy resolution when using high drift fields, i.e. above 5 kV/cm; in these conditions, stable gains in excess of 10^4 could be achieved.

We also discuss a model to characterize the breakdown depending on the combined field strength at the edges of the anode and cathode strips; using a program that computes fields and gains and applying the discharge criterion, we have estimated the optimum geometry of the detectors. The results indicate that higher gains before discharges can be obtained for wide cathodes: as an example, for 10 μm anodes we predict an increase by a factor of 4 of the maximum gain when increasing the width of the cathode strips from 80 μm to 160 μm .

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1. INTRODUCTION

Microstrip Gas Chambers (MSGCs) are an attractive choice for high-resolution, high-rate tracking detectors for the Large Hadron Collider (LHC) [1, 2], and great efforts are being made to develop the new device [3]. In many prototype MSGCs, however, discharges have been observed at relatively low gains, around or just above 10^3 ; this makes it difficult to detect minimum ionizing particle tracks with the short gas gaps dictated by the time-resolution requirements at high luminosity, and in order to get an acceptable position accuracy for inclined tracks. A high-energy charged particle produces ≈ 10 electrons/mm in the gas mixtures commonly used in MSGCs; on a 3 mm gap and with a gain of 10^3 , the total charge produced after multiplication is about 3×10^4 electrons, close to the signal generated in Si microstrip detectors. However, taking into account the longer time development of the signal in MSGCs (30 to 50 ns as compared to a few nanoseconds in silicon detectors), the signal-to-noise ratio in the gas detector is worse, particularly when using amplifiers with short time constants. An additional loss of signal occurs when tracks are inclined and the primary charge spreads over several strips.

In the present paper, we describe recent experimental work intended to investigate the influence of the gas mixture on the maximum stable value of gain that can be reached before discharge; several promising mixtures have been tested, namely argon-dimethylether (DME), CO_2 -DME and Ar- CO_2 -DME.

An attempt to characterize the gain-limiting discharge mechanism is also described. We propose a model for discharge that permits the estimation and comparison of maximum gains in chambers with different geometry (pitch, anode and cathode widths); calculations are compared with experimental results for different anode widths, and predictions are made for the behaviour of the gain as a function of the cathode width.

2. OPTIMIZATION OF THE GAS MIXTURE

The voltage dependence of gain, energy resolution and counting-rate plateaux for different gas mixtures has been measured in the laboratory on a MSGC¹ with an active area of $30 \times 38 \text{ mm}^2$ manufactured on 0.5 mm thick boro-silicate glass² having a bulk resistivity of around $10^{15} \Omega \cdot \text{cm}$ (Fig. 1). The electrodes, made from chromium 2700 Å thick, were 10 µm and 80 µm wide for the anodes and cathodes respectively, at a pitch (anode to anode centres) of 200 µm. The drift electrode was realized with a wire mesh placed 6 mm above the MSGC plate. The cathodes being at ground potential, both the anode and the drift voltage could be varied during the measurements, whereas the back-plane potential was kept fixed at +100 V. In order not to be disturbed by the well-known initial gain instabilities due to charging-up of the insulating substrate, we have allowed for a sufficient setting time after turning on the high voltage (a few tens of minutes); all measurements were realized at low rates to minimize this perturbing effect. A CERN standard gas rack was used to mix the different gases, with flow-meters individually calibrated for each component in the mixture. All measurements were made on the signals induced by avalanches on groups of twenty cathode strips and irradiating the chamber with a collimated 5.9 keV X-ray source; the number of primary electrons produced by the absorbed X-rays (around 220) was estimated from known data in the literature for each gas. Absolute gain values were obtained by comparison of the pulse height recorded using a charge amplifier and an analog-to-digital converter, with the counting rate and anode current measured using a pico-ampere meter. The counting rate was measured scaling the signals with a low threshold discriminator connected to the amplifier's output; the noise corresponds to the counting rate in the absence of radiation. The accuracy and reproducibility of the values of the gain presented here are estimated to be of the order of 10%.

¹ MSGC plates manufactured by Baumer IMT, Greinfensee, Switzerland.

² DESAG D263 produced by Schott Glass Technologies, Duryea, PE, USA.

Figure 2 shows gain and noise dependence on anode voltage for mixtures of Ar and DME in different concentrations, at a moderate value of the drift field (1000 V on the 6 mm gap). For each measurement, the voltage was increased up to the point where discharge precursors (a steep increase in noise, current instabilities in the power supply) were detected. It can be seen that DME concentrations of around 50% in argon provide the best performance in terms of maximum attainable gain, probably the result of a compensation between the higher quenching properties of DME-rich mixtures and the increase in noise due to higher anode-to-cathode potentials required. The steep increase in noise rate at a high concentration of DME suggests that at high voltages the field in the vicinity of the cathodes can be sufficiently strong to extract electrons from the metal surface and amplify them through a very high gain path, thus giving rise to large signals. This is indicative of a field-emission induced discharge mechanism, as will be discussed in the next section.

Figures 3 and 4 show the same measurements realized for CO₂-DME (40-60) and Ar-CO₂-DME (34-33-33) mixtures at the same value of drift potential. The increase of the noise rate with voltage is particularly steep for these mixtures, and as a consequence the maximum gain attainable is smaller than with Ar-DME mixtures, at least for moderate drift fields.

The dependence of gain on the voltage applied to the drift electrode is shown in Figs. 5 to 7 for different Ar-DME mixtures and at fixed anode potential; energy resolution and noise are also shown. Whereas the noise rate does not seem to change significantly with the DME concentration, the energy resolution is better for the 50-50 mixture and degrades at high drift fields for the mixture containing smaller amounts of DME. This can possibly be due to secondary effects induced by photon feedback on the electrodes in the poorly quenched mixtures. The same measurements are shown in Fig. 8 for CO₂-DME (40-60). In this case, the energy resolution improves slightly with the drift field, while the noise rate decreases.

In view of the observation that higher gains can be achieved at higher drift fields, the same quantities have been measured again as a function of the anode voltage for a higher drift potential. The results are shown in Figs. 9 to 12 for the three Ar-DME mixtures and for CO₂-DME (40-60). Except for the least quenched mixture (20% DME), gains in excess of 10^4 could be obtained before hitting the discharge limit with only a slight increase in noise rate. The effect of a high drift potential is to increase the density of the field lines going from the drift region to the anode strips thus making the gain larger and more uniform over the active region of the microstrip plate; at the same time, there is a reduction of the probability and/or of the amplitude of micro-discharges originated at the edge of the cathode strips. Under these conditions, both CO₂-DME and Ar-DME mixtures perform reasonably well.

3. OPTIMIZATION OF MSGC GEOMETRY

In order to estimate, by calculation, the optimum MSGC geometry, it is necessary on the one hand to be able to compute the gain of each structure, and on the other hand to make an assumption on the discharge mechanisms in the chamber that sets a limit on the operating voltage: neither a fixed voltage nor a fixed gain can be used as a criterion for the discharge threshold when comparing different geometries.

As suggested in earlier works [4-7] and above in the present paper, the dominant mechanisms of discharge in the MSGC is most certainly a consequence of the ejection of electrons from the cathode edges, either by field emission or by ion bombardment. Using the program MSFIELD [8] we have computed the electric field for a standard chamber geometry at normal operating potentials; as shown in Fig. 13, the field strength near the cathode edges exceeds 100 kV/cm, well above the critical field for inelastic collisions. Therefore electrons released from the cathode do undergo avalanche multiplication already from the start of their path towards the anode; since these electrons approach the anode in a region of high field they get an enhanced multiplication. With the help of the program, which includes a simplified model for the avalanche multiplication mechanism, and using values of the Townsend coefficient corresponding to an Ar-CH₄ mixture (90-10), we have computed the gain

in the MSGC as a function of position of the initial point of release of electrons, paying special attention to the region near the strips. Figure 14 shows equal-gain curves, lines connecting all points for which the total gain, integrated all the way to the anode, has the indicated values. It is clear from the figure that electrons ejected at the edge of cathodes multiply with a very short mean free path. For the same voltage settings, Fig. 15 shows the gain computed as a function of arrival point of the avalanche at the anode surface (diffusion has been switched off for this calculation). The vertical dashed line separates the region of the anode hit by avalanches coming from the drift region from those developing on field lines that originate on the cathode strips. It can be clearly seen that the “regular” and uniform gain of $2 \cdot 10^3$ is imparted to electrons produced in the drift region, while a gain orders of magnitude higher is encountered along the field lines going to the cathode edges.

Following the procedure suggested in the investigation of discharge conditions for wire chambers in different geometries [9], we assume that a discharge will be induced when the total gain for some particular region exceeds a certain value, constant for all geometries (in a given gas): by total gain we mean the result of the charge multiplication all the way from the point of ejection of an electron to the anode, taking into account the amplification near the cathode.

In order to check the soundness of the proposed discharge criterion we computed fields, voltages, and gains corresponding to a fixed discharge threshold for different anode widths and compared the results with existing measurements [6]. As the actual value of discharge gain is a priori unknown, as a point of reference for the calculations we have taken the measurements corresponding to $10 \mu\text{m}$ anode width, for which we observed a maximum gain of 2300. The voltage settings in the program were adjusted in order to obtain this value for the electrons coming from the drift region; the total gain for electrons ejected from cathode edge was then calculated and assumed to be the limit for discharge: as seen in Fig. 15, our calculation provides a value of edge-to-edge gain at discharge of $\approx 1.7 \times 10^5$. For other widths of anodes then we adjusted the anode-to-cathode voltage until reaching the same limiting value of the edge-to-edge gain, and the gain for the “normal” electrons from the drift space was then computed. The predicted limit of discharge (full curve) is compared with experimental points in Fig. 16; taking into account the reproducibility in the determination of the discharge voltage ($\approx 10 \text{ V}$), the agreement between calculations and experimental results is quite reasonable.

We then used the described model to determine the dependence of the gain before discharge on the cathode width. For each cathode width the field map was calculated and the voltages adjusted to get the same value of limiting total gain for electrons ejected at the cathode edge, the point of reference being the observed maximum gain of 2300 for a “standard” geometry ($10 \mu\text{m}$ anodes, $60 \mu\text{m}$ cathodes). The results of calculations are shown in Fig. 17 for the maximum gain, and in Fig. 18 for the corresponding values of voltage and surface field on the cathode edge at discharge, in a range of cathode widths from 60 to $180 \mu\text{m}$. It can be seen that the widening of the cathodes leads to a decrease in the discharge voltage, but also to a rapid increase of the maximum gain, due to an even faster growth of the field strength in the multiplication region. This can be understood by considering the dependence of ionization length on field strength. At around 500 kV/cm , the mean free path for multiplication is equal to about $1 \mu\text{m}$ [10]; therefore, if the gap between anode and cathode edge is close to $10 \mu\text{m}$, the electron path is too short to get enough amplification for discharge development.

The described model for the discharge mechanism is of course rather simplified, and might have to be complemented with the analysis of other gain-limiting factors, such as shape and roughness of the strip’s edges and the possibility of high-field induced surface breakdown on the insulator between strips. More experimental data should be gathered, and for that purpose we are manufacturing several MSGC plates on identical substrates in a range of cathode widths.

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FIGURE CAPTIONS

Fig. 1: Schematics of the MSGC used for the measurements.

Fig. 2: Dependence on the anode voltage of gain (full points, left scale) and noise rate (open circles, right scale), measured on a MSGC for several concentrations of DME in argon. The drift potential is -1 kV (on 6 mm).

Fig. 3: Gain and noise dependence on the voltage applied to the anode strips for CO₂-DME [40–60].

Fig. 4: Gain and noise dependence on the voltage applied to the anode strips for Ar-CO₂-DME [34–33–33].

Fig. 5: Gain, noise and energy resolution (relative FWHM at 5.9 keV) as a function of drift voltage for 20% of DME in argon and fixed anode voltage.

Fig. 6: Gain, noise, and energy resolution as a function of drift voltage for 50% DME in argon.

Fig. 7: Gain, noise, and energy resolution as a function of drift voltage for 80% DME in argon.

Fig. 8: Gain, energy resolution, and noise as a function of drift voltage for CO₂-DME [40–60].

Fig. 9: Gain dependence on the anode voltage for 20% of DME in argon, and -3 kV in the drift potential. The energy resolution degrades at the higher values of drift voltage (compare also with Fig. 4).

Fig. 10: Gain, energy resolution, and noise as a function of the anode voltage for Ar-DME [50–50] and -4 kV on the drift electrode.

Fig. 11: Gain, energy resolution and noise dependence on the anode voltage for 80% DME in argon and -4 kV on the drift electrode.

Fig. 12: Gain, energy resolution, and noise as a function of the anode voltage for CO₂-DME [40–60] and $V_d = -4$ kV.

Fig. 13: Field strength in MV/m as a function of the position, computed on a line 1 μ m from the surface of a MSGC having 200 μ m pitch, 10 μ m wide anodes and 80 μ m wide cathodes.

Fig. 14: Multiplication region in the MSGC. The line connects the points of equal gain for electrons multiplying all the way to the anode.

Fig. 15: Dependence of the gain on the position of the centre of the avalanche relative to centre of the anode. The vertical dashed line separates the region where electrons arrive from the drift volume from the one corresponding to electrons ejected from the cathodes.

Fig. 16: Dependence of the gain in the MSGC before the discharge on the width of anodes. Comparison of calculation and measurements (points with error bars).

Fig. 17: Dependence of the gain in the MSGC before the discharge on the width of the cathodes for two anode widths (10 μ m and 5 μ m).

Fig. 18: Dependence of the anode voltage before discharge and of the field strength near the cathode edge at this voltage on the cathode width.

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