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In parallel-plate counters, sparks appear at rates superior to a threshold, which is gain-dependent. In multistep chambers, the gating of electrons and ions in the intermediate transfer space improves the rate capability greatly. Rates of $2 \times 10^5/\text{mm}^2 \text{ s}$ have been reached. Various characteristics of these chambers are discussed.

Introduction

The multistep avalanche chamber was introduced as an appropriate device for overcoming the space-charge limitations of multiwire proportional chambers (MWPC) for high fluxes of particles^{1,2}. It is based on the splitting of the gaseous amplification into two steps: an initial avalanche in the uniform field of a gap limited by parallel grids; and a moderate amplification in a second-step localization detector, with an appropriate gateable transfer space between the two amplifying gaps (Fig. 1).

Fig. 1 Schematics of the gated multistep avalanche chamber (GMSC). Electrodes identified by the potentials HV2, HV3, and GND are crossed wire meshes, having 50 μm wire diameter and 500 μm pitch. Electrodes HV4-HV5 and HV6 are planes of parallel wires, with diameter and pitch as before, perpendicular to each other; the particular layout of the gate electrodes makes it possible to d.c. or pulse the offset pairs of adjacent wires. Electrode HV1 is a 10 μm thick aluminium foil. By a proper choice of potentials, the charges liberated in the conversion region are preamplified and transferred to drift region 1; if the gate electrode is equipotential at the time the electron cloud approaches, the charge is transferred to the second element of amplification, equipped with read-out electronics.

Some novel features of gas amplifications were observed during the investigation of such structures, as is illustrated by several applications quite remote from our initial goals.

The study of the rate limitations inherent to these new structures has shown a gain in rate of about one order of magnitude³ over a standard MWPC with correlation between sparking and counting rates, and also some interesting features of position resolution and multiparticle separation which give to this detector a specific field of applications.

Gated Operation of a Multistep Avalanche Chamber

In a mixture of argon + acetone (98%, 2%), moderate gains up to 10^4 can be reached in a single gap without breakdown at low rates (Fig. 2).

A grid with wires placed alternatively at a potential of $\pm 70 \text{ V}$ completely blocks the transmission of

Fig. 2 The absolute gain in a 5 mm thick parallel-plate chamber, operated at atmospheric pressure in a mixture of argon-acetone (98%, 2%), as a function of the applied field.

electrons in the transfer drift space, and pulses of the order of 30 ns width bring all the wires of the grid to zero voltage and fully open the gate (Fig. 3).

With the second detector, consisting also of a parallel-plate 5 mm gap, we obtained the following characteristics:

- A time jitter of the order of 10 ns (FWHM).
- The maximum gain that can be reached in a given gas, before sparking, is larger in a multistep structure than in a single gap, even without gating of the ions. This is natural since the two dominant processes in the sparking, namely the photon feedback and the positive ion feedback, are reduced by the succession of grids, both for geometrical reasons and for electrical reasons such as the focusing of lines on the wires of a mesh.
- The maximum gain that can be reached in a multistep structure is greatly enhanced by the use of the pulsed gate. Figure 4 shows the relation between the maximum gain of the second gap, as a function of the rate of a collimated beam of 8.4 keV X-rays, without a gate and with gates triggered at a high and a low rate. While the effect of the gate opening rate is negligible, the effect of the gating itself is very important. A factor of 100 in the gain of a second gap can be obtained with a gate, at a rate of $4 \times 10^4/\text{mm}^2 \text{ s}$.
- At the rates of $10^4/\text{mm}^2 \text{ s}$ (where the space-charge limit sets in in wire chambers) it is not possible to reach a plateau with minimum ionizing particles (Fig. 5a). With gated operation, the full efficiency can be reached without sparking at $2 \times 10^5/\text{mm}^2 \text{ s}$ (Fig. 5b). This limit is dependent on the electronics sensitivity. The total gain in the chamber, at the beginning of the plateau, is about 7×10^2 in the second gap and 10^4 in the first gap, with a transmission of the order of 10% of the initial electron charge. This means a total useful gain of about 7×10^5 . Since the available initial charge with a minimum ionizing particle can be of the order of one electron only, this gives the order of magnitude of

the required electronics, which had typically a threshold of 0.01 pC on each wire. We thus see that the gain in counting rate is modest owing to the spark limitations.

However, several features make this detector advantageous with respect to wire chambers:

It is possible to trigger only a part of the grid by combining the chamber with scintillation hodoscopes of moderate spatial resolution. This limits the amplification in the second gap to those regions where a particle has been selected, with a time resolution of the order of one nanosecond. With large chambers, where the accidentals can be limiting factors because of the intrinsic high memory time ($\sim 200 \text{ ns/cm}$) of most gaseous detectors, in the case of very high rates, this combination could reduce the memory to the resolution time of the fast hodoscope.

We have found that the position resolution of these detectors is of the same order as in drift chambers³, with the advantage of being two-dimensional.

The two-particle resolution is also advantageous; this can be seen from Fig. 6, which shows the pulse height of the signals induced by two particles, only 2.5 mm apart, on the wires of the final grid.

Fig. 3 Gate transmission in the pulsed mode of operation as a function of the gate delay, relative to the migrating electron cloud and for several shaping constants. The measurement has been done irradiating the GMSC with a ^{55}Fe X-ray source and detecting the pre-amplified pulse to generate the gate pulse. The transmission efficiency is defined as the ratio of the detected pulse height in the last electrode for a gated operation to that for a d.c. open operation.

Fig. 4 The spark breakdown voltage in the second amplification element, for a fixed preamplification, as a function of the detected 8 keV X-ray flux. Measurements are shown both for the d.c. open gate condition and for the pulsed gate operation; in the last case, the small figures on the two sides of the measurement bars indicate the gate opening frequency (as a percentage of the total flux detected on the preamplification element). The gated operation allows the attainment of chamber gains that are larger by almost two orders of magnitude (see Fig. 2), also for opening frequencies approaching 100%, thus indicating that breakdown is caused by the feedback of positive ions.

Fig. 5 a) Efficiency for minimum ionizing particles, gate open. Small rates, two values of preamplification (full lines and left vertical scale), and breakdown voltage as a function of the particles' rate (broken lines and right vertical scales). Operating conditions for the GMSC: conversion off and gate d.c. open.

Fig. 5 b) The same as Fig. 5a, with a gate of 30 ns. Sparking limits at the two extremes of the gate-opening frequencies (10 kHz and zero).

Fig. 6 Double-track event; the distance between the two centres of gravity corresponds to about 2.5 mm.

The Sparking Limitations in Avalanche Gaps

In order to have a better understanding of the features controlling the appearance of sparks, we studied the correlation between the spark apparition and the counting rate, using a monochromatic beam of 8.4 keV X-rays of variable aperture in a single gap of 5 mm.

Figure 7 summarizes our observations. We see that the sparking probability is a function of the flux per unit area, much more than of the total rate. This is natural if we expect the sparks to be due to the local concentration of positive ions in the gas up to a given threshold.

Fig. 7 Rate limits in a single gap.

- Gap of 5 mm.
- Mesh electrodes of 50 μ m diameter stainless-steel wires with spacing of 500 μ m.
- Gas filling, argon + acetone (98%, 2%).
- Townsend coefficient $\alpha = x$.
- Beams of 8.4 keV X-rays.
- a, b, c - rate limits for breakdown with various beam diameters.
- d - total field at the cathode from the column of positive ions, assuming a continuous electrode.

If one computes the gradient of field produced by the column of ions drifting in the gas of the chamber after each avalanche, one observes that the sparking limit corresponds to a given value of the field at the cathode irrespective of the total rate (Fig. 7, curve d). The value of the field is moderate. However, it should be stressed that the calculation was done by assuming a uniform cathode, while the lines of force are concentrated on thin wires of 50 μm diameter where the field is higher. It is a plausible idea that the secondary electrons are extracted by the bombardment of electrons by the positive ions. This would also explain why we observe that a larger gain can be obtained, before sparking, with a structure consisting of a preamplifying gap and a wire chamber, rather than with two parallel grids. In a wire chamber, for a given gain, the field at the cathode is smaller (because of the potential drop at the wire) than in a parallel-grid gap. We have reached what seems a fundamental limitation of parallel-grid counters. For those who dreamed of replacing the wire chamber by simpler structures made of parallel meshes, the sparking conditions show the limits of the game.

However, with a large conversion gap where minimum ionizing particles can deposit enough charge transmitted to the amplifying gap, such structures can still be appealing in some cases where the rates are moderate. The fact that clouds of electrons produced in the avalanche can be transferred in a series of localization

gaps may also appear as an attractive feature, and the preamplifying gaps are partial ingredients in quite unexpected detectors for applications in surface chromatography⁴, slow-neutron imaging⁵, and new photon detectors; we report on these in other sections of the Proceedings.

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