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Substrate-less, spark-free micro-strip gas counters

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Abstract

We review recent work involving micro-strip gas counters with "advanced passivated" cathode strips. We present results from tests of a new variation of the MSGC, the planar micro-gap counter (PMGC), with very small ($\sim 10\,\mu m$) anode–cathode gap. Gains of up to 3×10^4 were achieved and gain variations due to charging effects were less than 10% using an ordinary (uncoated) boro-silicate glass substrate. The PMGC showed no reduction in gain when subjected to an X-ray flux of 4×10^5 Hz/mm^2 and survived exposure to alpha particles equivalent to 75 days' running at LHC with no signs of strip damage.

1. Introduction

The trend in the design and construction of modern gas detectors is the use of micro-electronics or advanced printed-circuit technology to define micro-structures for charge collection. Examples of such devices include the micro-strip gas counter (MSGC) [1,2], the micro-gap counter (MGC) [3], micro-dots [4], micro-mesh [5] and the gas electron multiplier (GEM) [6]. Compared with classical gas counters, these detectors have the advantages of very high granularity (100–200 μm pitch), very good position resolution ($\sim 30\,\mu m$) and two-track resolution ($\sim 400\,\mu m$), obtained in very short time (25–50 ns). In addition, micro-detectors generally have much higher rate capability (fine pitch and short collection time for positive ions) and better energy resolution ($\sim 12\%$ FWHM at 6 keV) due to their extremely high definition ($\sim 0.1\mu m$) and high field strength.

Micro-detectors do however suffer from some disadvantages. These include the fact that the area of a single detector is relatively small ($\sim 30\,cm \times 30\,cm$) and limited gas gain ($< 10^4$). In the case of MSGCs, the main problem is that the device is built on a resistive substrate, which is prone to charging effects.

2. Comparison of four types of micro-detectors

Four variations of micro-detector, manufactured using photolithographic techniques, are compared in Fig. 1. The figure shows cross-sections through a standard MSGC, an MGC, an MSGC with a coated substrate and advanced passivation, and a planar micro-gap counter (PMGC). The standard

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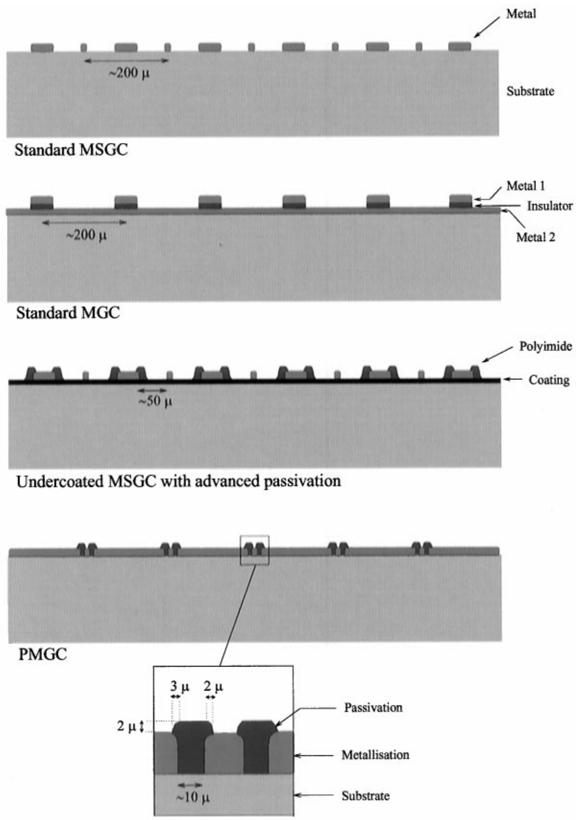

Fig. 1. Comparison of various types of micro-detectors.

MSGC is a one-dimensional device in terms of physical construction, the metal layer being essentially confined to one plane. In contrast, the MGC is two-dimensional because insulating layers must be deposited between the cathode plane and the anode strips. The alignment between the anodes and the strips of insulator must be very good, resulting in comparatively high production costs. On the other hand, the MSGC suffers from the fact that over 50% of the substrate is exposed, resulting in charging and substrate polarisation effects. The MGC is "substrate-less" and its performance is largely free of these unwanted effects.

Substrate effects in MSGCs may be minimised by careful optimisation of the substrate surface resistivity. This may be achieved using conductive coatings such as diamond-like carbon [7] or Pestov glass [8]. The surface resistivity must not be too low, however, as this results in streamer development [9] and excessive leakage currents. The optimum surface resistivity range has been identified as 10^{15}–$10^{16}\ \Omega/\Box$. A further improvement on the performance of the standard MSGC may be achieved using "advanced passivation", i.e. covering of all of the cathode edges with a thin ($\sim 2\,\mu$m) layer of polyimide. This technique prevents extraction of electrons from the cathode edges and therefore extends the working voltage range of the detector.

A natural extension of advanced passivation is to design a detector with increased cathode width and very small anode–cathode gap (typically 10 μm), the gap and both electrode edges being passivated with polyimide. Such a device combines the favourable properties of being one-dimensional, and therefore relatively inexpensive to produce, and exposing only a very small (less than 10%) area of the substrate surface. In this configuration the detector is practically "substrate-less" and therefore free of unwanted substrate effects and the need for coatings. We call this detector a planar micro-gap counter (PMGC). Detectors of similar design, built without the polyimide passivation lines [10] or on a silicon substrate [11] were recently proposed by other groups. PMGCs without the passivation lines have limited gain ($\sim 3\times10^3$), while the use of a silicon substrate of very low resistivity implies significant parasitic capacitance of the anode strips towards the substrate itself.

The electric field structure of the PMGC is very similar to that of the MGC, see Fig. 2. It is thought that this configuration, in which the region of high field strength is contained within a very small volume, is resistant to the development of streamers into sparks.

An unwanted consequence of the reduced anode–cathode gap width in PMGCs is that the strip capacitance of the device is increased to 0.63 pF/cm (compared to 0.32 pF/cm for an MSGC), leading to an increase in noise. However, the signal-to-noise ratio is not reduced because the charge collection time for the PMGC is shorter than for the MSGC, and a higher percentage of the charge is therefore collected by the pre-amplifiers in the same time interval, see Fig. 3. The plots, obtained from a simulation program [12], show that in 50 ns (the approximate integration time for the PREMUX amplifiers to be used in CMS) over 80% of the

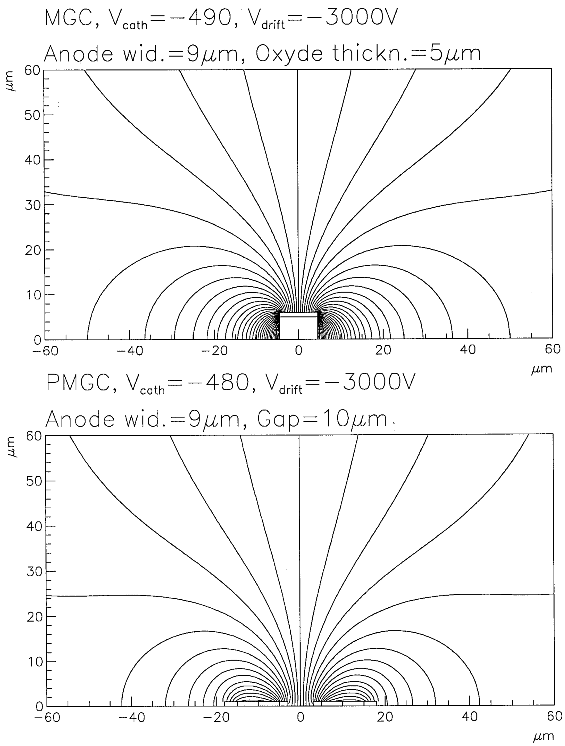

Fig. 2. Electric field maps for an MGC and for a PMGC.

signal charge is collected by the PMGC electrodes compared with only about 65% for the MSGC. Assuming a primary charge of 40 electrons and a gain of 2000, we calculate from these values that the S/N for a PMGC should be 77, compared to 75 for an MSGC.

3. Experimental observations

3.1. *MSGCs with advanced passivation*

Experimental results for MSGCs with advanced passivation have been presented at this conference [13] and have been reported also in Ref. [14]. It was shown that the working voltage range of an MSGC may be extended by more than 100 V using this improved detector design.

3.2. *Planar micro-gap counter*

The gain curves for two PMGCs built on *glass* substrates, one with an anode–cathode gap of 10 μm and the other with a gap of 20 μm, are displayed in Fig. 4. The gains were calculated from the pulse amplitudes observed when the chambers were irradiated with an ^{55}Fe source, using a Ne(33)/DME(67) gas mixture. For both chambers, the cathode voltage was increased until a single very large pulse, characteristic of a micro-discharge, was observed. It is clear from the curves that saturation of the read-out electronics occurred

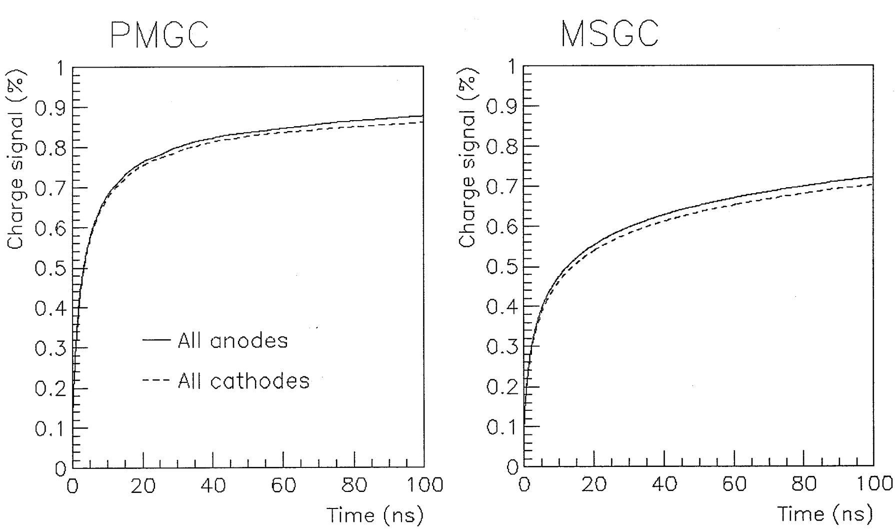

Fig. 3. Percentage of signal charge collected as a function of time for (a) a PMGC and (b) an MSGC.

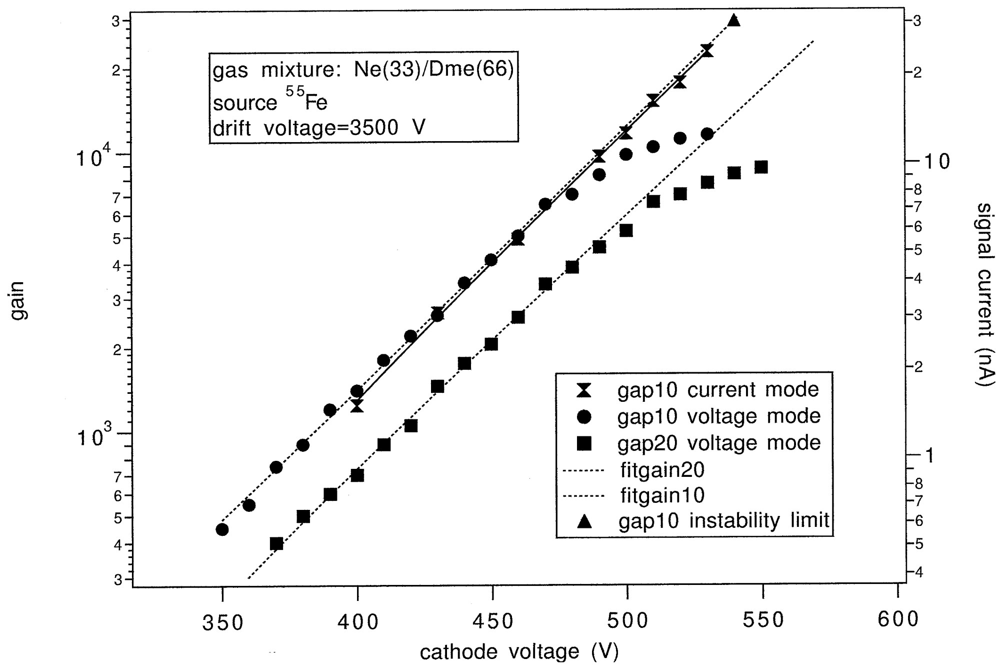

Fig. 4. Gain curves for PMGCs with two different gap widths.

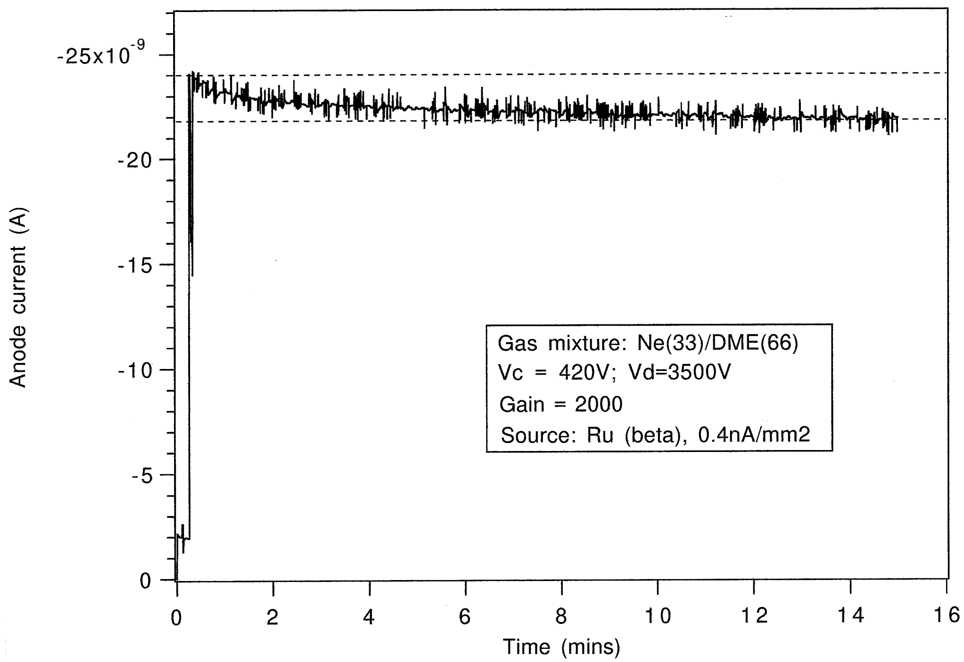

Fig. 5. Time development of charging effect for a PMGC with gap 10 μm.

before this point in both cases. Exponential fits could be made through the reliable data to estimate the gain at the maximum cathode voltage. These maximum gain values were 3×10^4 for the PMGC with the 10 μm gap and 2×10^4 for the 20 μm gap chamber. The signal current was measured for the 10 μm chamber using a pico-ammeter, for various cathode voltages (see Fig. 4). These measurements, which showed no saturation, confirmed that the behaviour observed in the pulse height data at high cathode voltages was due to electronics effects.

Charging of the substrate of the 10 μm gap chamber was investigated by monitoring the anode current while exposing the PMGC to beta particles from a ^{106}Ru source, see Fig. 5. The current was at its maximum value immediately after the source was placed in front of the chamber, and fell to a stable value after about 15 min. The overall drop in the current from its maximum value was less than 10%.

The rate capability of the 10 μm gap chamber was also studied. The signal current was monitored as the chamber was irradiated with collimated X-rays from a tube with a Cr target. The results of this test are summarised in Fig. 6. Fig. 6a displays the anode current as a function of X-ray tube current (proportional to X-ray intensity). Fig. 6b shows the anode current, normalised to the X-ray tube current, as a function of X-ray rate. The results show that the PMGC withstood X-ray rates higher than 4×10^5 Hz/mm^2 with no measurable drop in gain.

Finally, the 10 μm gap chamber was subjected to high-intensity alpha irradiation from an ^{241}Am source to study its resistance to sparking in the presence of heavily ionising particles (hips). The source profiles before and after irradiation are compared in Fig. 7. The integrated alpha exposure was 3×10^6 particles/mm^2, equivalent to more than 75 days' running at CMS. No sign of damage to any of the strips by this irradiation was observed in the profiles or in the subsequent optical inspection.

4. Conclusions

The MSGC with coated substrate and advanced passivation is a robust baseline solution for the central tracker of CMS. It has been demonstrated

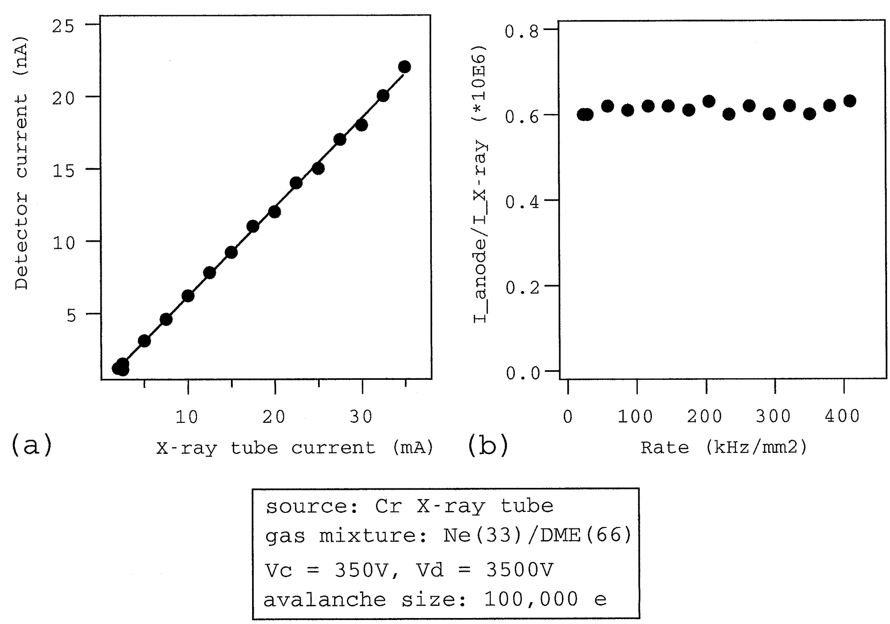

Fig. 6. Rate capability of a PMGC with 10 μm gap.

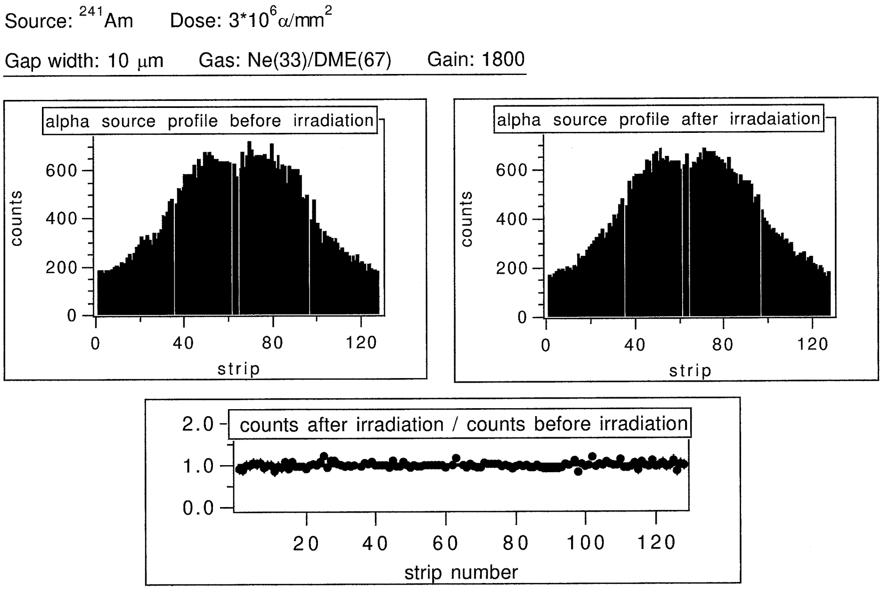

Fig. 7. Source profiles for a PMGC before and after alpha particle irradiation.

that the use of advanced passivation on the cathode strips increases the working voltage range of the detector by more than 100 V.

The planar micro-gap counter (PMGC) has been developed to exploit the cost-beneficial one-dimensional construction of the MSGC and the "substrate-less" properties of the MGC. The anode–cathode gap is reduced to 10 μm and filled with polyimide, which is also used to passivate the anode and cathode edges. In our tests, gains of up to 3×10^4 were achieved, while substrate charging effects produced gain drops no greater than 10%. No reduction in gain was observed when a PMGC was subjected to an X-ray flux of 4×10^5 Hz/mm^2. No sign of strip damage was seen when the chamber was irradiated with a dose of alpha particles equivalent to over 75 days' running at LHC.

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