Gas gain stability of MSGCs operating at high rate

F.D. van den Berg a, b, C. Daum a, B. van Eijk a, F.G. Hartjes a, F. Udo a, b and V. Zhukov a, c

a NIKHEF, P.O. Box 41882, NL-1009 DB Amsterdam, The Netherlands
b IIHE, VUB, Pleinlaan 2, B-1050 Brussels, Belgium
c M.V. Lomonosov’s Moscow State University, RU-119899 Moscow, Russian Federation

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Abstract

Micro Strip Gas Counters (MSGCs) with coated and uncoated borosilicate glass substrates have been investigated on their high rate capability and long term gas gain stability. It is shown that the gain remains almost constant at count rates up to $10^8$ Hz/mm² when a semiconductive layer of S8900 glass or polydiamond is applied under or over the strips. The application of such a coating also favours the gain stability at long term operation. However, the maximum attainable gas gain for coated substrates is four to ten times smaller than for bare borosilicate glass supports. For the latter substrate type, we observe less ageing when the strips are made of nickel instead of aluminium or copper.

1 Introduction

The Micro Strip Gas Counter (MSGC) [1] has a wide range of possible applications. It may for example be used as a tracking detector in high energy physics [2, 3, 4, 5] or for X-ray or neutron detection [1, 6, 7, 8] in imaging or diffraction experiments.

Since the particle fluxes in these cases may exceed $10^4$ Hz/mm², the stability of the gas gain at high rate is important. Due to the smaller electrode distances and the higher electric field, the MSGC suffers less from space charge than the multi wire proportional chamber (MWPC). At high rate operation however, the presence of the insulating substrate provokes the problem of surface charge-up. This causes a decrease of the gas gain [1, 9, 10]. Also the ageing appears to be connected to the insulating properties of the substrate. Common methods to extend the high rate capability and the lifetime of the MSGC are optimisation of the electric field, modification of the surface resistivity of the substrate, and appropriate choices of the electrode materials and gases.

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2Corresponding author, email: f.van.den.berg@iri.tudelft.nl, phone: +31 15 2783776, fax: +31 15 2796422
<table>
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<th>manufacturer</th>
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<td></td>
<td>thickness in $\mu$m</td>
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Table 1: Specifications of the substrates manufactured on D263. The thicknesses of the different metalisations e.g. coatings are indicated in square brackets (in $\mu$m).

istics of this layer to obtain a resistivity in the correct range, which is stable in time. Best suited is an amorphous carbon film with H and Si dopants [18], while the resistivity of a hard coating (generally used for protection of tools) is unstable. The surface resistivity of the layer can be varied between $2 \cdot 10^{14}$ and $6 \cdot 10^{16} \, \Omega/\square$, with a thickness between 100 and 170 nm. We settled on a coating with surface resistivity $R \approx 10^{15} \, \Omega/\square$, whose uniformity is better than 1% over the detector area of 4 cm$^2$. The stability in time is good, see figure 2.

The temperature dependence of the resistivity of both the polydiamond as the S8900 coating amounts to about 5%/°C.

3 Experimental setup

The experimental set-up consists of a stainless steel box with readout electronics, gas system and X-ray tube. We followed the recommendations of [19] and [20] to the gas system and applied materials. A detailed description of the set-up can be found in [21].

The pulse heights on the anode groups are measured by a preamplifier - ADC system. In parallel, the currents of the groups are determined with a precision of 5% and a sensitivity of 100 pA. Current meters in the negative high voltages lines to cathode strips and drift plane allowed monitoring of the ion currents in the detector.

We used an X-ray source with chromium anode which emits photons with an energy distribution peaking at 5.4 keV. After collimation, the beam enters the MSGC providing a maximum flux of more than $10^5 \, \text{Hz/mm}^2$. We have used two different beam spots to investigate the high rate behaviour, i.e. a round spot with an area of about 1 mm$^2$, which will be referred to as "small spot", and a rectangular spot with dimensions 3.5 mm (along the strip direction) and 20 mm (perpendicular to the strips), which we will call "large spot". The spot sizes have been measured at the substrate position. The stability of the X-ray intensity was checked by a drift tube. The temperature inside the box is measured and data was corrected by a factor of about 2%/°C to get a smooth curve. In a second set-up, which is similar to the one described above, we used a 20 mCi Sr-90 source instead of an X-ray tube for irradiation.
ionisations (> 100 electrons), but enhanced by the wish for a high dynamic range of the order of $10^5 - 10^6$ necessitating a more stringent noise reduction. In this aspect, it is worrying that in this study, the maximum attainable gain in MSGCs with semiconductive coatings is not higher than 1000.

4 Rate dependence of the gas gain

First we investigated the high rate capability of D263 substrates. Figure 5 shows the beam profile in case of the small spot (see section 3 for a definition of the 'small' and 'large' spot) together with the relative gas gain at each individual strip along this profile for different rates. The gains have been normalised to their values at low rate (0.2 kHz/mm²). In the next figure (figure 6), high rate dependences are depicted for different strip positions in the small irradiation spot (corresponding to figure 5) and for the large beam spot. Note that the curves obtained for different strips within the small spot irradiation are however difficult to compare to each other, as edge effects play a significant role in the signal for the side strips.

Figure 7 shows the high rate dependences of an MSGC on bare D263 glass under 'large' spot irradiation, for different cathode strip and drift plane voltages, plotted against the current density. We observe that for our substrates produced on uncoated D263 glass, the gain drop exceeds 20% above a current density of about 1 nA/mm². This value is close to the expected current density at LHC applications (~ 0.6 nA/cm) [24].

The redistribution of the positive ion currents (i.e. cathode strip and drift plane currents), corresponding to three of the four curves in figure 7, is demonstrated in figure 8. At high anode strip currents the charging of the substrate surface deteriorates the dipole electric field between the anode and cathode strips, resulting in a smaller ion fraction moving to the cathode strip. The currents for a lower gas amplification are shown as well for comparison. The highest current density of each curve corresponds to the maximum intensity of the X-ray source. We observe that the redistribution of the ion currents scales with the anode current density $J$, and that operation of our MSGC on bare borosilicate glass becomes critical at a current density of 1 - 2 nA/cm. Nevertheless, it should be remarked that the considerable gain drop at high rate is still less dangerous than the increased risk on sparks near small defects of or pollutants on the strip pattern at high rate operation.

Compared to insulating substrates, the high rate capability of semiconductive substrates or substrates with a semiconductive coating is usually better, as the smaller surface resistance of these substrates results in less charge-up. The upper plot in figure 9 shows the high rate behaviour obtained with borosilicate substrates with coatings of polydiamond (overcoating) and S8900 (undercoating). Compared to the rate curve of an MSGC on uncoated borosilicate glass, the coated substrates have superior high rate characteristics. The high rate capability of our overcoated substrates was limited to about $1 \cdot 10^5$ Hz/mm² by the occurrence of sparks due to charge-up of the coating. For undercoated substrates the drop at the highest rate achievable in our set-up ($2 \cdot 10^5$ Hz/mm²)
To estimate the substrate area affected by the polymeric deposit, we used a 'small' round beam spot of about 1 mm², (see section 4). In figures 10 and 11 the diminution of the anode currents during the ageing run is shown. Each data point represents the (relative) current of two adjacent strips. The anode strips had to be paired to have sufficient current signal. The high rate behaviour before and 1 day after this test is presented in figure 12. It is remarkable that a significant gain drop is observed even for side strips that have received about 10 times less charge in total. The high rate curves after ageing resemble the curves obtained for coated substrates, which have comparable gain values, see figure 9. In all the subsequent ageing studies, we used the 'large' rectangular beam spot (see section 4).

We compared in our set-up the ageing characteristics of bare borosilicate substrates with different strip metalisations, namely aluminium, copper and nickel (figure 13). Before irradiation, all substrates were cured at 200 °C in air, aiming the removal of chemical products remaining from the etching procedure. We observe a much faster ageing for aluminium and copper than for nickel. Earlier results obtained without curing the substrates in advance [23] indicate that the ageing of MSGCs with gold and nickel metalisation are comparable. Visual inspection of the substrates revealed a dark deposit on the edges and the top of the anode strips. We did not see a significant deposit on the cathodes.

Figure 14 demonstrates the ageing of a D263 substrate with aluminium strips using two types of irradiation: the X-ray tube and a 20 mCi Sr-90 source. No significant difference is observed. The same figure shows also the results of our attempts to remove the polymeric layer by an acetone bath, but this was not fruitful, as the gain drop was not recovered. Cleaning with other solvents, like alcohol, propanol, Cs₂, and isoamyl acetate was equally unsuccessful.

As a remedy to ageing of counters produced directly on borosilicate glass, semiconductive coatings like Schott 8900 (S8900) or polydiamond on top of the insulating substrate were introduced [11, 12] which were claimed to extend the long term stability up to the LHC demand of 100 mC/cm. We tested substrates with a S8900 undercoating and golden strips (see figure 15). The runs had to be terminated before an accumulated charge of 3 mC/cm was reached, as large current instabilities appeared, combined with a sudden rise of the leakage current (from ~ 0.5 nA/cm to a few µA/cm). However no strip damages were observed. All the tested S8900 coated substrates suffered sooner or later from this problem, especially when submitted to rates exceeding 5 \cdot 10^4 Hz/mm². A possible explanation would be a breakdown in the S8900 glass due to the migration of sodium ions from the borosilicate bulk into the coating [29].

Figure 15 shows also the ageing behaviour of a polydiamond overcoated substrate (see section 2). At Q = 2 mC/cm discharges occurred under high rate irradiation, while at low rate, the counter still worked properly. By visual inspection, we observed that the coating in the aged zone had a darker colour, and the edges of the strip under the coating were damaged.

Concluding, we observe that a semiconductive coating on the borosilicate substrate reduces the ageing in the MSGC, but that it introduces a higher risk on breakdown. Further enhancement of the coating quality might improve its long term stability during sustained irradiation.
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[13] Philips Centre for Manufacturing Technology,
Building SAQ, P.O. Box 218, 5600 MD, Eindhoven, The Netherlands

[14] SRON, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands


[16] VTT Electronics, P.O. Box 1101, FIN-02044 VTT, Finland

[17] VITO, Boeretang 200, B-2400 Mol, Belgium

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Figure 1: Surface resistivity of S8900 coating in time, corrected for temperature variations. The potential between the anode and cathode strips is 500 V. The different curves correspond to the six strip groups on the substrate.
Figure 3: The absolute gain at various settings of the back- and drift plane potentials. The gains are deduced from anode current measurements at a count rate of 2.4 kHz/mm². The substrate used here is Desag-263 with aluminium strips. The distance of the back plane to the strips is 350 ± 50 μm. Dashed fitted straight lines serve as guide to the eye.
Figure 5: Spot irradiation of a D-263 substrate with aluminium strips: beam profile and relative gain for each strip individually. For each strip, the gain is deduced from ADC measurements. The gains are normalised to their values at low count rate (200 Hz/mm²), and amount to about 1000. The numbers indicated just above the curves are the count rates at the centre of the beam spot.
Figure 7: Gain versus anode strip current for a bare D263 substrate. Spline fits are guidelines.
Figure 9: High rate behaviour for coated and uncoated substrates. Relative gain plotted versus the count rate (upper figure) and versus the anode current (lower figure). Same symbols are used in both figures.
Figure 11: Ageing of the pairs of strips in the beam spot. The current relative to its initial value is plot versus the collected charge on each pair.
Figure 13: Ageing for substrates with different strip materials: normalised gain versus accumulated charge.
Figure 15: Ageing of MSGCs with coated substrates.