Gas gain stability of MSGCs on borosilicate glass

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Abstract

The gas gain stability in Micro Strip Gas Counters fabricated on borosilicate glass has been investigated for operation at high radiation fluxes up to $10^5$ Hz/mm$^2$ in a X-ray set-up. We discuss effects of short and long term irradiation on the gain for different voltage settings and strip metalisations. The application of a high drift field and a back plane on positive potential provides good high rate operation up to $10^4$ Hz/mm$^2$. Ageing is observed to be strongly dependent on the strip metalisation; gold and nickel perform better than aluminium and copper.
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up to $10^5$ Hz/mm$^2$ in a X-ray set-up. We discuss effects of short and
long term irradiation on the gain for different voltage settings and strip
metalisations. The application of a high drift field and a back plane on
positive potential provides good high rate operation up to $10^4$ Hz/mm$^2$.
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gold and nickel perform better than aluminium and copper.

1 Introduction

Future experiments at the LHC, HERA, etc., require high resolution tracking
detectors that sustain particle rates exceeding $10^4$ Hz/mm$^2$. The Micro Strip
Gas Counter (MSGC) can meet these demands, provided the drop of the gas
gain at high rate and after extensive irradiation [1], can be avoided. We have
investigated the behaviour of detectors fabricated on thin (0.2 - 0.3 mm) Desag
borosilicate glass (D263) which we have tested with good results at low rate [2].
We have optimised the electric field and studied long term stability, or ageing, of
a counter on cheap, uncoated, D263 glass. The present understanding of ageing
is based on the assumption that the formation of a polymeric layer is responsible
for the gain drop. The growth of this layer appears to be proportional to
the accumulated charge. As the strip material may act as a catalyst for the
polymerisation process, we have tested MSGCs with aluminium, copper, gold
and nickel strips.

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†On leave of absence from M.V. Lomonosov's Moscow State University, RU-119899
Moscow, Russian Federation
2 Experimental set-up

The experimental set-up consists of a X-ray tube, stainless steel MSGC box and clean gas system.

The X-ray tube emits a beam of photons with a mean energy of 5.4 keV, collimated to an area of 4 mm x 20 mm at the MSGC surface. Each photon produces a cluster of about 300 electrons in an Ar/DME (50/50) gas mixture, that we have used throughout this study. The gas amplification in the MSGC is chosen in the range 1000 - 3000. We have measured the analogue signal and the total current of the (grouped) anodes. In addition, we have monitored the currents of the cathode strips and drift plane, as well as the atmospheric pressure, the temperature in the box and the X-ray intensity. A scheme of the electronics is depicted in figure 1.

The analogue part consists of a fast preamplifier with 10 ns rise time and 30 ns fall time, shaper, discriminator and ADC. The ADC spectrum is shown in figure 2. The maximum ADC rate is about 100 kHz. At higher rates and for long term studies, changes in gain are determined from the anode currents.

The anode currents are measured as a voltage drop over a grounded 4.7 MΩ resistor by a multichannel voltmeter with an accuracy better than 0.05 nA. The currents of the cathode strips and the drift plane are monitored with dedicated high voltage modules.

The MSGC is placed at 5 cm distance from the X-ray source and housed in a clean box with mylar windows of 50 μm thick with an aluminium coating on both sides. The substrate is mounted on an alumina support. The electrical contacts are established via ultrasonic bonding. On the back side, an aluminised mylar foil is glued serving as a back-plane. The cathode plane consists of 50 μm copper coated Kapton foil at 7 mm distance from the substrate. Since ageing is strongly related to the purity of the system [1], we have avoided materials such as plastics, rubber, copper tubing etc. A complete list of materials used for box and gas system is given in tables 1 and 2 respectively.

Throughout the present study the Ar/DME (50/50) gas mixture was flushed at a rate of about 40 ml/min. This ensures a gas refreshing rate of three times per hour. The layout of the "clean" gas system is shown in figure 3.

The pressure inside the MSGC's box was kept at 1120 ± 4 mbar. The gas quality and the X-ray intensity were monitored by a drift tube at ~ 20 cm behind the MSGC box.

Automatic control and data acquisition of the experiments is based on LabView™. During long term irradiation, the currents and the temperature were regularly measured (every 5 - 10 min.). The amplitude spectrum of both MSGC and monitor tube was recorded once in ~ 60 minutes. Every hour the photon flux was cut off for about two minutes by a shutter for a dark current measurement. The measured currents were corrected for temperature variations by a factor of 1%/°C (this is an overall coefficient, in which the temperature dependences of various parameters are combined, of e.g. the intensity of the X-ray source, attenuation of the beam, cross sections and gain).
<table>
<thead>
<tr>
<th>element</th>
<th>materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>box</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>O-ring</td>
<td>Kalrez</td>
</tr>
<tr>
<td>windows</td>
<td>50 μm mylar, 1 μm Al coating on both sides</td>
</tr>
<tr>
<td>glue</td>
<td>Epotec E505</td>
</tr>
<tr>
<td>substrate</td>
<td>Araldite for windows</td>
</tr>
<tr>
<td>substrate holder</td>
<td>Borosilicate glass, metal strip pattern</td>
</tr>
<tr>
<td>clips</td>
<td>Alumina</td>
</tr>
<tr>
<td>supports</td>
<td>Bronze</td>
</tr>
<tr>
<td>back plane</td>
<td>Macor, Delrin</td>
</tr>
<tr>
<td>cathode plane</td>
<td>Mylar with aluminium coating on one side</td>
</tr>
<tr>
<td>wires</td>
<td>50 μm Kapton, ( \lesssim 0.8 \mu m ) copper coating on one side</td>
</tr>
<tr>
<td>solder</td>
<td>Copper, Alumina insulation</td>
</tr>
<tr>
<td>electrical feedthroughs</td>
<td>glass, brass annealed</td>
</tr>
<tr>
<td>thermometer</td>
<td>glass, platinum nickel wire connection</td>
</tr>
</tbody>
</table>

**Table 1:** *Materials in the MSGC housing.*

<table>
<thead>
<tr>
<th>element</th>
<th>manufacturer</th>
<th>type</th>
<th>materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>tubing</td>
<td>Dockweiler</td>
<td>Finetron</td>
<td>SS</td>
</tr>
<tr>
<td>fittings</td>
<td>Swagelok</td>
<td>SS-6-M0</td>
<td>SS</td>
</tr>
<tr>
<td>pressure reducer</td>
<td>Ucar</td>
<td>HSS and HTS</td>
<td>SS, Kalrez</td>
</tr>
<tr>
<td>valve</td>
<td>Nupro</td>
<td>SS-6BG-MM</td>
<td>SS, Silver plated SS O-ring</td>
</tr>
<tr>
<td>mass flow controller</td>
<td>Brooks</td>
<td>5850</td>
<td>SS, Kalrez</td>
</tr>
<tr>
<td>pressure gauge</td>
<td>Eriks</td>
<td>SS-SS6MM-KZ</td>
<td>SS, Kalrez, Hard chrome plated SS stem</td>
</tr>
<tr>
<td>fine metering valve</td>
<td>Nupro</td>
<td>SS-53S6MM</td>
<td>SS, Nickel base lubricant</td>
</tr>
<tr>
<td>lift check valve</td>
<td>Brooks</td>
<td>5866</td>
<td>SS, Kalrez</td>
</tr>
<tr>
<td>pressure controller</td>
<td>Dockweiler</td>
<td>VSR80</td>
<td>SS</td>
</tr>
<tr>
<td>capillary: 4.5m tube</td>
<td></td>
<td>( \varnothing_{\text{inner}}: 1 \text{ mm}; \varnothing_{\text{outer}}: 2 \text{ mm} )</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2:** *The elements of the gas system, with their manufacturer, type and the applied materials (the parts that are in contact with the gas). The latter column is based on information supplied by the manufacturers; "SS" stands for stainless steel.*

3 **MSGC production**

Uncoated borosilicate glass D263 with a thickness of 0.2, 0.3 mm resp., has been used as substrate because of its excellent lithographic and mechanical characteristics and low cost. Strip patterns were produced by standard wet etching techniques. The width of anode and cathode strips was 8 and 89 μm respectively with a 200 μm pitch. The thickness of the strip metalisation is about 1 μm. The anodes and cathodes were grouped by 16 (8) strips. Used
pattern sizes are 20x20 mm and 90x15 mm. The list of substrates is given in table 3.

<table>
<thead>
<tr>
<th>strip material, (thickness (µm))</th>
<th>substrate thickness (mm)</th>
<th>strip length (mm)</th>
<th>$R_{\text{anode}}$ (Ω/cm)</th>
<th>manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu (0.6)</td>
<td>0.3</td>
<td>20</td>
<td>47</td>
<td>Philips ¹</td>
</tr>
<tr>
<td>Al (1)</td>
<td>0.3</td>
<td>20</td>
<td>53</td>
<td>SRON ²</td>
</tr>
<tr>
<td>Au (1)</td>
<td>0.2</td>
<td>90</td>
<td>87</td>
<td>SRON</td>
</tr>
<tr>
<td>Ni (0.7)</td>
<td>0.3</td>
<td>20</td>
<td>1600</td>
<td>Angstrom ³</td>
</tr>
</tbody>
</table>

Table 3: Substrate specifications and manufacturers.

4 Gas gain stability

Changes in gas gain are usually distinguished into short and long term effects. Short term effects occur within a few hours. They arise from modified conditions such as flux and voltages. Long term effects appear at time scales typically longer than days or weeks after extensive irradiation.

Nearly all gain instabilities (except for those related to variations in temperature and pressure) result from a distortion of the electric field in the avalanche region. There are several causes for the changes in the avalanche field: typical short term effects like polarisation of insulators in the electrostatic field due to the high voltages in the detector, charge concentration on the substrate surface, ion movement in the substrate etc. In addition, long term processes such as the depletion of the substrate, the formation of a polymeric layer on the strips, oxidation or physical damage of the strips, will contribute.

We have investigated both short and long term gain stability. We studied the high rate behaviour, as well as ageing for two types of field settings and for different strip metalisations.

Gain modification after switching on the high voltage

Polarisation of the substrate in the electric field usually leads to a drop of gas gain. In figure 4, the stabilisation of the anode current at low rate, 1 kHz/mm² is shown for two different voltage settings, one with high drift field and back-plane on positive potential, the other with low drift field setting and the back-plane at ground potential. A gain drop of about 15% after 400 seconds was observed for both settings. Striking is the difference in duration of the gain stabilisation, which is for the first field configuration more than three times smaller than for the latter.

¹Philips, Eindhoven, The Netherlands
²SRON, Utrecht, The Netherlands
³Angstrom, Moscow, Russian Federation
High rate capability and charging up

Charging of the substrate occurs at the start of irradiation. Usually the change in gain has an exponential form with a time constant dependent on the electric field and radiation flux. The field has to be optimised to avoid charging of the substrate [3]. The "high" field, defined as the configuration with drift field $E_d \geq 500$ V/mm and positive back-plane $V_b \geq 0$ V, looks more promising for high rate operations than the "low" field with $E_d \leq 200$ V/mm and negative (or floating) back-plane potential. A positive back-plane potential reduces the gain, as shown in figure 5.

Under irradiation the surface charge on the substrate distorts the field near the anodes. The stabilisation of the anode current at different rates for "high" and "low" fields is shown in figure 6. The fast component of gain drop ($\leq 10$ s) at high rate can not be recorded in our set-up. Hardly any change in gain for the "low" field configuration is observed, in contrary to the "high" field, where a rise of about 10 - 20% within 10 - 20 minutes occurs.

Figure 7 shows the high rate response for the two voltage settings. Stable operation up to $\sim 10$ kHz/mm² was obtained using the high field configuration. The positive ion flow is shared in approximately equal proportions between cathode strips and drift plane as demonstrated in figure 8. This proportion remains the same at high rate. On the other hand, for a "low" field, most (90%) of the ions drift to the cathode strip, and the charging of the substrate reduces the cathode current $I_c$ more than the drift current $I_d$.

From these short term results, we conclude that the gain variations after applying the high voltage or irradiation are of order 20% and occur within about 30 minutes (D263). Furthermore we observe a considerable difference between the "low" and "high" field in high rate operation mode.

Ageing and long term stability

Encouraged by the positive experience with the high field configuration for elevated fluxes, we have investigated the influence of the voltage settings on the long term stability. Figures 9 and 10 show the ageing for low and high drift fields with the back-plane at zero and positive potential respectively. No significant difference was observed up to an accumulated charge per centimetre anode strip of 0.7 mC/cm. From figure 11, one can see that during ageing, the fraction of ions moving to the cathode strips slightly decreases. By visual inspection we found a thin, dark layer on the anodes, that could be removed with acetone. The polymerisation apparently occurs at the edges and the surface of the anode strip metal.

When a counter is aged, the initial gain can be restored by raising the cathode strip voltage, as shown in figure 12. Afterwards, the ageing rate remains the same or becomes even faster.

The influence of the strip metalisation on the ageing speed was tested by application of different strip metals: aluminium, copper, gold and nickel. The results are shown in figure 13. For gold and nickel, a gain drop about 20 - 30%
after 1 mC/cm was observed. However, the ageing of the aluminium and copper patterns turns out to be much faster (gain drop of 50% at \( \leq 0.1 \) mC/cm).

The long term gain behaviour is a combined effect of the growth of the polymeric layer and its charging up. In figure 14, we can see that for severely aged counters, the gain curves can be described by a time dependent function proportional to \( \frac{1}{(1+t/T)^{0.5}} \), which satisfies a typical charging law for insulators [4].

The origin of the initial gain increase which occurred for all substrates with copper strips, remains undetermined: maybe an oxidation process or residuals of the etching liquids play a role.

5 Conclusion

Remarkably better ageing behaviour for gold and nickel than for copper and aluminium strips shows the influence of strip metalisation on the polymerisation process. The measurements on the various substrates were performed under close to identical experimental conditions. We have not investigated the role of the traces of chemicals used in the production of the strip pattern. We do not exclude that different results may be obtained for substrates produced by plasma etching for example. The drop of the gas gain can possibly be explained in part by the charging up of the insulating polymer produced during ageing. Optimisation of the electrostatic field can improve the high rate capability but not the long term stability of the MSGC.

Acknowledgements

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References

   NIM A332 (1993) 100

   NIM A310 (1991) 88

[3] R. Bellazini and A. Spezziga: 
   INFN PI/AE-94/02

   RD28 status report 16/10/92
Figure 1: The electronics scheme and the data acquisition system of the ageing set-up. Only one of the six connections to the groups of anode- and cathode strips has been drawn. The mono wire drift tube serves as a monitor for the X-ray intensity and the gas composition. In addition, the pressure and the temperature are measured.
Figure 2: Examples of the measured parameters: the anode current and the spectrum obtained from the X-ray source. At the bottom right: degradation of the signal due to ageing.
Figure 3: The gas in- and outlet system.
Figure 4: Stabilisation of the gas gain at the switch-on of the high voltages. \( V_C, V_b \) are the potentials of respectively the cathode strips and the back plane. \( E_d \) is the drift field.

Figure 5: Gas gain in MSGC for different voltages of the cathode strips and the back-plane. (The cathode voltages are negative.)
Figure 6: Short term stability under irradiation for different high voltage settings. The lower three curves below belong to the low drift field, the upper three to the high drift field configuration. All currents have been normalised to their initial values.
Figure 7: High rate capability for two different field maps.

Figure 8: Current of cathode strips \( I_c \) and drift plane \( I_d \), normalised to the anode current \( I_a \), at different rates. The plots in this figure correspond to the curves in figure 7.
Figure 9: Ageing at different drift fields.

Figure 10: Ageing at different rates and different field maps. The dotted vertical line at $Q = 0.3$ mC/cm indicates the separation between the two indicated rates.
Figure 11: Ageing curve of gold strips with the drift plane current ($I_d$) and cathode strip current ($I_c$) relative to the anode current ($I_a$).

Figure 12: Ageing and restoration of gas gain.
Figure 13: Ageing for different strip metalisations.

Figure 14: Ageing and charging for aluminium and copper strips. The lines are fits of the function $\frac{1}{1+Rt}$ to the data. $R$ is the rate and $G_0$ the initial gain.