HIGH RATE OPERATION AND LIFETIME STUDIES WITH MICRO-STRIP GAS CHAMBERS

J. Bohm*, R. Bouclier, M. Capeáns, C. Garabatos, G. Manzin, G. Million, F. Sauli,
T. Temmel and L. Shekhtman

CERN, Geneva, Switzerland

CERN LIBRARIES, GENEVA

CERN-PPE-94-115

ABSTRACT

Micro-Strip Gas Chambers manufactured on supports with low resistivity, 10^9 to 10^{12} Ohm cm, can withstand the very high rates expected in tracking detectors at CERN's Large Hadron Collider without gain loss due to charging-up. Several technologies allowing to realize supports in this range of resistivity are described, namely electron-conducting glass and thin-layer conductive coatings.

At very high radiation fluxes, the deposition of thin insulating layers on electrodes causes premature deterioration of the detector. The ageing rate is found to be extremely sensitive to the purity and nature of the filling gas, and can be kept small only by a careful selection of the manufacturing materials. Experimental results on ageing are presented for several types of detectors.

Presented at the 6th Pisa Conference "Frontier Detectors for Frontier Physics"
Elba, May 24-28, 1994

* EEC Fellow. Permanent address: Inst. of Physics, Prague University

1. INTRODUCTION

Micro-Strip Gas Chambers (MSGCs) [1] have the active elements, anode and cathode strips, laid on an insulating support; high accuracy photo-lithographic technology allows to manufacture MSGCs with distances between anodes of 200 μm or less. The reduction of pitch, as compared to wire chambers, results in higher rate capability, more accurate localization and better multi-particle resolution [2-4], making MSGCs a unique detector for high luminosity experiments.

In order to operate efficiently at high radiation rates, the use of supports having too good insulating properties should however be avoided; indeed, a fraction of the charge produced in avalanches sticks to the surface of the insulator modifying the electric field with a consequent fast, rate-dependent gain drop [5,6]. This "charging up" effect can be reduced by the use of substrates having moderate conductivity, such as electron-conducting glasses that can be manufactured with resistivity in the range 10^9 to 10^{12} Ωcm [4,7,8], or by coating the supports with thin-film layers reducing the surface resistivity to values around 10^{14} - 10^{15} Ω/square [9-11]. It has been experimentally demonstrated that MSGCs made on low resistivity supports can withstand, without gain modifications and at an avalanche size of 10^5 electrons, detected radiation rates above 10^6 $\text{mm}^{-2}\text{s}^{-1}$ [4].

Exposing the detectors to high rates for long time can result in another charge-related effect: ageing. Production in the avalanches of polymeric compounds cause severe degradation of performances and perturb the counting action or induce discharges; MSGCs have been found to be particularly prone to fast ageing [12]. In this paper we describe recent measurements of long-term operation under sustained irradiation.

To provide a term of reference, we have computed for the geometry of one of the proposed LHC detectors (the Compact Muon Solenoid, CMS) the expected rates of charges generated by the detection and proportional amplification process in a 200 μm pitch, 3 mm drift gap MSGC, as a function of distance from the beam axis in nominal operating conditions (luminosity 1.7×10^{34} $\text{cm}^{-2}\text{s}^{-1}$), see Fig. 1. Data for the charged particle flux have been obtained with simulation programs developed within the CMS collaboration [13]. We have assumed an average avalanche size of 10^5 electrons for a minimum ionizing particle perpendicular to the detector, and taken into account both energy and angular distributions of tracks in the 4 T magnetic field to estimate ionization losses in the gas. As it can be seen in the figure, in the detector closest to the beam pipe (40 cm) the charge rate is about 1 $\text{nC mm}^{-2}\text{s}^{-1}$; for a standard LHC operating year of 10^7 s, this means an integral charge per unit length of strip of 20 $\text{mC cm}^{-1}\text{y}^{-1}$. It should be noted that the above calculation, that does not include backgrounds from the accelerator, is optimistic and might be considered as a lower limit for actual charge rates.

2. EXPERIMENTAL SET-UP

The set-up used for long-term controlled irradiation studies has been described previously [4,12]. The detector under test is mounted facing a collimated X-ray beam provided by a generator; the beam intensity can be adjusted varying the current of the tube and/or the size of the collimator. The X-ray tube provides a peak at an energy of 6 or 8 keV depending on the cathode material. For most measurements an effective beam area of 3 to 5 mm^2 was used; the irradiated spot could be shifted using a micrometric displacement. Detected photon rates above 10^6 $\text{mm}^{-2}\text{s}^{-1}$ could be realized; at an avalanche size of 10^5 and 200 μm pitch, this corresponds to charge rates per unit length of strip up to 40 $\text{nC cm}^{-1}\text{s}^{-1}$ (≈ 4 mC cm^{-1} per day of operation).

After extended studies on ageing properties in different gases [12,14] all measurement here described were realized with an argon-dimethylether 90-10 mixture. We have specially manufactured several clean gas mixers, taking all precautions to eliminate polluting agents and using exclusively stainless steel pipes and metal joints.

For the measurements we have used several models of MSGC plates, similar in size (30 mm by 32 mm) but built on different substrata; all had a pitch (distance anode to anode) of 200 μm with anodes and cathodes 10 μm and 80 μm wide, respectively. At low irradiation rates pulse height spectra could be directly measured, while at the higher rates we recorded current on groups of strips. The radiation tolerance was tested with MSGC plates assembled in different ways and using various materials; the best results have been

consistently achieved mounting the MSGC glass plates in a “clean box” with minimal use of organic materials. Other, more practical construction schemes for the detectors have been tried; the most promising is an all-glass mountings permanently assembled with vacuum-grade epoxies.

3. GAIN AS A FUNCTION OF RATE

With the described set-up, the gain was measured exposing the detectors to the X-ray beam and measuring pulse height and/or current on groups of cathode strips, all anodes being connected together and to the positive HV power supply through a protection resistor. The back-plane, if present, was grounded or connected to a suitable potential, with an AC grounding through a capacitor if necessary. Detectors were operated at gas gains around 10^3 ; for 6 keV X-rays, this corresponds to an avalanche size of about 2×10^5 electrons. The charge rate was fixed depending on the maximum flux tolerated by MSGC plates before the onset of charging up processes.

Fig. 2 show the short-term gain variations as a function of rate for an MSGC manufactured on 300 μm thick borosilicate glass (Desag D263). This glass has a moderate bulk resistivity, around 10^{15} ohm cm, probably due to the high sodium content* and therefore allows to reach higher rates than with MSGCs manufactured on alkali-free glass; the conductivity however is known to be ionic and to depend on the time of application of the voltage [5,6]. Data in Fig. 2 were obtained with the back-plane potential close to the anodic (+500 V) in order to minimize charging-up processes [15]. At the maximum value of charge rate estimated for LHC operation of $1 \text{ nC mm}^{-2} \text{ s}^{-1}$ (Fig. 1), the gain decreases and reaches a rate-dependent plateau at about 90% of the original value. While a detector might be able to operate with such moderate gain reduction, its efficiency can be very easily affected by any change in rate. One can also expect local accumulations of charge, due for example to micro-discharges or to neutron-induced large energy deposits, to affect the detection efficiency; as seen in the figures, typical charging up times are of tens of minutes and recovery times may be longer.

The increase in rate capability obtained choosing a back-plane potential close to the anodic is however penalized by a reduction of gain at a given voltage. As shown in Fig. 3, the maximum operating voltage on the detector before discharge is roughly constant, independently from the value of the back-plane potential; the maximum gain is therefore lower for a positive back plane. Stable operation is correspondingly more critical due to the reduction of the margin between working voltage and discharge, a particularly serious concern when taking into account variations in a large system.

There are moreover some doubts about long-term stability of operation of MSGCs manufactured on sodium-rich borosilicate glass. There is evidence that in the long term (several months to a year) continuous application of the high fields necessary to operate the detector induces the migration of the Na^+ ions towards the cathodes, depleting the region close to the anodes [16]. Such a process has been observed on MSGCs manufactured on borosilicate glass (Corning 7740) and results in a continuing increase of gain at a given voltage, accompanied by a larger sensitivity to charging-up processes and a consequent decrease in rate capability [17]. This crucial point requires further investigations.

Higher rate capabilities can be obtained manufacturing the detectors on low resistivity electron-conducting supports [4,7]. Using a substrate with bulk resistivity of 10^{12} ohm cm the gain remains constant up to charge rates of $5 \text{ nC mm}^{-2} \text{ s}^{-1}$ (10^5 tracks $\text{mm}^{-2} \text{ s}^{-1}$ at an avalanche size of 3×10^5 electrons). At higher fluxes, charging up time constants are much shorter than for the borosilicate glass (seconds instead of tens of minutes) making the detector more immune to local short-term charging up processes. The leakage current due to the low resistivity of the substrate is of about $0.04 \mu\text{A cm}^{-2}$, to be compared with a maximum value expected from the detected radiation at LHC of $0.1 \mu\text{A cm}^{-2}$ (Fig. 1). Higher charge rates (above $100 \text{ nC mm}^{-2} \text{ s}^{-1}$) can be tolerated using lower resistivity glass, with however a corresponding increase in leakage current [4].

* The producer's data sheet characterizes D263 as “very low alkali content”. However, an elemental analysis made by a collaborating group at INFN Legnaro indicates 6.6% Na and 1.7% K.

We have investigated another way of reducing charging-up processes at high rates: coating insulating substrates with thin, electron-conducting layers. The coating can be applied on the supports before manufacturing the MSGC; this brings in however several unknowns concerning metal adherence and resistance to the photo-lithographic processing that are presently investigated, in collaboration with industry. A simpler approach is to coat with thin resistive layers MSGC plates already manufactured on normal glass. We have tested several standard small-size MSGC plates, manufactured on 300 μm thick boro-silicate glass, and coated with a thin layer of lead-silicate electron-conducting glass by RF magnetron sputtering with a technology developed by a group at Laboratori Nazionali INFN in Legnaro [18]. A detailed account of operating characteristics of the "Legnaro" chambers was given in Ref. [11]; as expected, coated plates exhibit a reduced gain dependence from the back-plate potential, when compared to the untreated detectors, and require a slightly higher operating voltage for a given gain. Fig. 4 shows the short-term gain dependence on rate, measured as described in section 2. For this particular plate the layer thickness was about 400 $\text{\AA}$, and the measured surface resistivity 10^{15} ohm/square. In the figure, data for the coated plate are compared to the measurements realized in similar conditions for an identical but uncoated chamber; in the measurements, the avalanche size was about 2.3×10^5 and 1.5×10^5 respectively.

Another method of coating supports to reduce surface resistivity has been developed by a group at TRIUMF, Vancouver, and consists in sputtering a thin layer of nickel in oxidizing atmosphere [10,19]. We have obtained and tested several standard MSGC plates (chromium on D263) covered with a 200 $\text{\AA}$ layer of nickel oxide [20], and tested their performances and rate capability. Measurement of the leakage current between anodes and cathodes provides a surprising result: the current is unaffected by the presence of the layer, and yields a value of surface resistivity essentially equal to the one of bare glass (above 10^{17} ohm/square); this conflicts with the nominal expected value, around 10^{15} ohm/square. The gain of the chamber appears to depend on the back-plane potential much in the same way as for the uncoated MSGC. The behaviour at high rates is however completely different, as shown in Fig. 5: the gain increases with the flux to eventually reach a plateau at a flux above $2 \times 10^4 \text{ mm}^{-2} \text{ s}^{-1}$ ($1 \text{ nC mm}^{-2} \text{ s}^{-1}$), a trend not reported by the authors of Ref. [19]. We are continuing our investigation to understand the peculiar behaviour of the detector, that we think could be caused by non-uniformity in the resistivity across the nickel oxide layer (the inner side, towards the metal strips, being much more insulating than the outer side exposed to the gas).

4. MSGC AGEING

Micro-strip detectors exposed for extended time to high radiation fluxes have been found to suffer permanent deterioration of performance and reduction of gain in the irradiated area. In severely damaged chambers, optical inspection of the exposed surface clearly shows the presence of discoloration or deposits easily identified as results of polymerization processes induced in the gas by the avalanches. If the irradiation is stopped before too severe damage, the deposits can be removed from the aged plate by careful cleaning and the detector recovers its initial gain [12]. The rate of ageing appears to be extremely sensitive to the presence of trace impurities either in the gas or released by the materials used for assembly. In previous work, operation without noticeable ageing up to 130 mC cm^{-1} of charge has been demonstrated in very clean laboratory conditions. This result has been recently reproduced, using a new MSGC detector with gold strips manufactured on an electron-conducting glass of 10^9 ohm cm (see Fig. 6). There are indications that the nature of the substrate and the metal used for the strips may play a role in the ageing rate; figure 6 shows also the larger ageing rate measured, in the same system, for a plate made on higher resistivity glass (10^{12} ohm cm) with chromium strips. On the other hand, as shown in Fig. 7, the same chromium detector operated in a cleaner system (curve corresponding to Set-up 2) has an ageing rate comparable with the one found for the gold detectors.

The sensitivity of the chamber lifetime to small amounts of pollutants is demonstrated by the very fast ageing of detectors built using conventional framing and assembly materials. We have undertaken a systematic search to find clean materials and to develop technologies allowing to manufacture MSGC detectors that can be used in

realistic experimental set-ups [12,14]. The most promising results have been obtained with the assembly schematically shown in Fig. 8, named "glass chamber". A thin (0.5 to 1 mm) rectangular glass frame is glued with high-grade epoxy directly on the MSGC plate; gas input and output connections are provided through holes drilled in the glass frame. A thin glass cover, conductive on the inner face, is pasted on the frame and constitutes the drift electrode; the drift region is 3 mm thick. The assembly is very light; we have manufactured prototype chambers having 80 by 80 mm² active areas using 300 μ m D263 glass with a total weight around 20 grams. Signal and HV connections are provided, after assembly, by wire bonding on pads at the ends of the corresponding electrodes on the MSGC plate a few mm longer than the frame in the direction of the strips. Fig. 9 shows the best result of ageing tests realized with a glass chamber made with chromium strips on D263 glass; the gain decrease is 10% after 12 mC cm⁻¹ of charge, a promising albeit not yet sufficiently good result in view of long-term use at LHC.

Work is in progress to understand the relative importance of the various constituents (including the irradiation flux) in determining the ageing rates.

REFERENCES

- [1] A. Oed, Nucl. Instrum. Methods **A263** (1988) 351.
- [2] F. Angelini, R. Bellazzini, A. Brez, M.M. Massai, G. Spandre, M. Torquati, R. Bouclier, J. Gaudaen and F. Sauli, Nucl. Phys. **23A** (1991) 254.
- [3] M. Geijsberts, F.G. Hartjes, J.G. Pannekoek, J. Schmitz and F. Udo, Nucl. Instrum. Methods **A313** (1992) 377.
- [4] R. Bouclier, G. Million, Yu.N. Pestov, L. Ropelewski, F. Sauli and L.I. Shekhtman, Nucl. Instrum. Methods **A332** (1993) 100.
- [5] R. Bouclier, J.J. Florent, J. Gaudaen, G. Million, A. Pasta, L. Ropelewski, F. Sauli and L.I. Shekhtman, Nucl. Instrum. Methods **A323** (1992) 240.
- [6] J.E. Bateman and J.F. Connolly, RAL-93-096 (1993).
- [7] Yu.N. Pestov and L. I. Shekhtman, Nucl. Instrum. Methods **A338** (1994) 368.
- [8] L. Alunni, R. Bouclier, G. Fara, Ch. Garabatos, G. Manzin, G. Million, L. Ropelewski, F. Sauli, L.I. Shekhtman, E. Daubie, O. Pingot, Yu.N. Pestov, L. Busso and S. Costa, CERN-PPE/93-179 (6.10.1993). Subm. Nucl. Instrum. Methods.
- [9] S. Brons, W. Brückner, M. Heidrich, I. Konorov and S. Paul, CERN/PPE 93-194 (25.10.94)
- [10] M. Salomon, J. Armitage, M. Dixit, W. Faszer, D. Lam and G. Oakham, IEEE 1993 Nucl. Sci. Symp., San Francisco (2-5 November 1993).
- [11] R. Bouclier Ch. Garabatos, G. Manzin, F. Sauli, L.I. Shekhtman, T. Temmel, G. Della Mea, G. Maggioni, V. Rigato and I. Logachenko, CERN-PPE/93-192 (29.10.1993), IEEE Nuclear Science Symposium, San Francisco (2-5.11.93)
- [12] R. Bouclier, C. Garabatos, G. Manzin, G. Million, F. Sauli, T. Temmel and L. Shekhtman, CERN-PPE/94-63 (29.3.1994).
- [13] V. Muhtinen and M. Pimia, private communication at CERN.
- [14] R. Bouclier, M. Capéans, C. Garabatos, R.D. Heuer, M. Jeanrenaud, T.C. Meyer, F. Sauli and K. Silander, CERN-PPE/94-40 (9.2.1994). Subm. Nucl. Instrum. Methods.
- [15] J.J. Florent, J. Gaudaen, L. Ropelewski and F. Sauli, Nucl. Instrum. Methods **A329** (1993) 125.
- [16] E. Bateman and J.F. Connolly, RAL-92-085 (December 1992).
- [17] A. Oed, private communication.
- [18] G. Della Mea, V. Rigato, R. Dal Maschio, C. Sighele and P. Colombo, J. Am. Ceram. Soc. **76** (1993) 2930.
- [19] M. Salomon, J. Armitage, G. Chapman, M. Dixit, J. Dubeau, W. Faszer, L.A. Amel and G. Oakham, TRI-PP-94-24 (1994). Subm. Nucl. Instrum. Methods.
- [20] Courtesy of M. Salomon, TRUMF Vancouver (Canada).

FIGURE CAPTIONS

Fig. 1: Expected charge rates for MSGC plates operated at nominal LHC luminosity in the CMS detector, as a function of distance from the beam pipe. An avalanche size of 10^5 has been assumed for minimum ionizing particles perpendicular to the plates.

Fig. 2: Relative gain as a function of time for different X-ray (charge) rates. MSGC on D263 glass, back-plane potential close to the anodic.

Fig. 3: Dependence of absolute gain from the back-plane potential (300 μm D263 glass). The discharge voltage is about constant, implying reduced maximum gain at positive back-plane voltage (close to the anode potential).

Fig. 4: Relative gain as a function of rate for a standard MSGC on D263 glass, and the same coated with a thin electron-conducting lead silicate layer.

Fig. 5: Relative gain as a function of rate for a standard MSGC on D263 glass coated with a thin layer of nickel oxide.

Fig. 6: Long-term gain variation (ageing) of a MSGC made with gold electrodes on low resistivity glass (10^9 ohm cm), and of one made with chromium on moderate resistivity glass (10^{12} ohm cm).

Fig. 7: Long-term gain variation measured on the chromium MSGC in two different experimental systems. Set-up 1 is the same as for the measurement in Fig. 6; set-up 2 corresponds to a cleaner system.

Fig. 8: Schematic assembly of the "glass chamber" manufactured using high-grade epoxy and glass frames.

Fig. 9: Gain as a function of accumulated charge measured in the glass chamber.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9