OPERATION OF HIGH RATE MICROSTRIP GAS CHAMBERS

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ABSTRACT

We describe recent measurements carried out in well controlled and reproducible conditions to help understanding the factors affecting the short- and long-term behaviour of Microstrip Gas Chambers. Special care has been taken concerning the gas purity and choice of materials used in the system and for the detectors construction. Detectors built on glasses with surface resistivity in the range 10^{13} – 10^{15} $\Omega/\square$ have shown satisfactory performance as they do not show charging-up process at high rate and stand the large doses required for the future high luminosity experiments (~ 10 $\text{mC}\cdot\text{cm}^{-1}\cdot\text{yr}^{-1}$). Concerning the lifetime measurements, it has been observed that chambers manufactured on high-resistivity glass are far more susceptible of suffering ageing than detectors made on low resistivity, electron-conducting supports, independently of the metal used for the artwork (chromium or gold) at least in clean gas conditions. The successfully operation in the laboratory of detectors manufactured on diamond-coated glass with a surface resistivity around 10^{15} $\Omega/\square$ confirms the last statement. Results from a long-term, high rate beam test are also reported.

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We describe recent measurements carried out in well controlled and reproducible conditions to help understanding the factors affecting the short- and long-term behaviour of Microstrip Gas Chambers. Special care has been taken concerning the gas purity and choice of materials used in the system and for the detectors construction. Detectors built on glasses with surface resistivity in the range 10^{13} – $10^{15} \Omega/\square$ have shown satisfactory performance as they do not show charging-up process at high rate and stand the large doses required for the future high luminosity experiments ($\sim 10 \text{ mC}\cdot\text{cm}^{-1}\cdot\text{yr}^{-1}$). Concerning the lifetime measurements, it has been observed that chambers manufactured on high-resistivity glass are far more susceptible of suffering ageing than detectors made on low resistivity, electron-conducting supports, independently of the metal used for the artwork (chromium or gold) at least in clean gas conditions. The successful operation in the laboratory of detectors manufactured on diamond-coated glass with a surface resistivity around $10^{15} \Omega/\square$ confirms the last statement. Results from a long-term, high rate beam test are also reported.

1. THE MICROSTRIP GAS CHAMBER

The demand for low cost, yet highly granular devices has led to the development of the MSGC after its invention by A. Oed in 1988 [1]. These new counters, that have raised much interest in the detector community due to their key features, are gaseous chambers working in the proportional mode. The basic structure of the MSGC consists of alternated thin anode and cathode strips, typically around ~ 10 and $100 \mu\text{m}$ wide, laying on a substrate. The distance between electrodes of the same kind (pitch) is usually $200 \mu\text{m}$, and the drift distance (gas gap in which the ionization is produced) is defined by an upper electrode placed at 3–10 mm. The back side of the support plate, the backplane, can be metallized to form an extra field-defining electrode. The electronic signals are negative on anodes and positive induced pulses on the cathodes; a fraction of the signal, roughly inversely proportional to the substrate thickness, is also seen by the backplane; suitably stripping this electrode would allow, in principle, the two-dimensional read-out of the device. Part of the signal is also induced on the drift electrode. The position measurement is obtained calculating the centroid of the charge distribution over the cathode or anode strips. Owing to the small anode-to-cathode distance, the charge collection is a process relatively fast and high localization accuracy and counting rate capability are guaranteed. Fig. 1 [2,3] shows the rate capability of a standard MWPC and several MSGCs fabricated on different types of substrates; the chamber made on the lower resistivity glass holds without any gain loss a photon flux above $2 \times 10^6 \text{ mm}^{-2}\cdot\text{s}^{-1}$ for an avalanche size of 3×10^5 electrons

(estimated value to detect minimum ionizing particles perpendicular to the detector), and all MSGCs operate comfortably above the expected particle rate at the intermediate tracking detector of CMS ($\sim 4 \times 10^4 \text{ mm}^{-2}\cdot\text{s}^{-1}$).

Figure. 1 Rate dependence on gain for several MSGCs built on substrates with different resistivity.

2. DETECTOR CONSTRUCTION

The MSGCs, although fast and granular enough to cope with the high luminosity of LHC experiments, were showing in the early stages of their development a strong tendency to age. The problem, detected as a fast and usually irreversible degradation of their performance during irradiation, was rapidly associated with the ageing phenomenon observed in MWPC and gaseous detectors in general. For MSGCs the nature of the substrate and mainly the gas mixture, materials used to assembly the detectors and in the gas distribution system play a major role in their long-term behaviour. For high rate applications,

some limitations have arisen: DME-based mixtures are better than hydrocarbons [4], and gas pollution whether coming from the gas cylinders or construction materials has to be avoided [5,6], the latter point restricting the assembling technique; only vacuum-grade materials and epoxies are used. An operating device is assembled gluing a rectangular Vectra frame on the strips plate and adding on top a thin glass cover made conductive in the inner side; the standard drift distance is 3 mm. To prevent discharges in the high field regions at the end of strips, passivation with a thin layer of epoxy for chromium strips and of polyimide for gold strips is made with silk-screening. Gas connections are usually made of stainless steel.

3. BASIC TYPES OF MSGCs

The selection of the strip metal and the technology for the deposition of the strips is, a priori, governed by the available techniques able to produce chambers at reasonable costs. Chromium chambers realized with the wet etching technique have shown good quality (the metal adherence and the strip border shape are excellent) and low cost; nevertheless, the high ohmic resistivity of chromium (~ 10 times larger than that of aluminium, for example) may limit its use, for fast applications, to chambers with a strip length smaller than 10 cm [3]. Aluminium as strip metal has been satisfactorily used in the production of MSGCs, although its use in LHC detectors appears nowadays to be limited in view of the long-term behaviour [7]; it is still a matter of controversy whether aluminium chambers age faster than others due to the metal itself or to the production technology. Photolithographic etching and lift-off are been also used; chambers made with gold strips are more expensive and delicate to handle (strips are easily scratched or damaged), but show good long term behaviour [7,8]. The choice of the substrate material is also crucial. An extensively used insulator is the boro-silicate glass Desag D-263, because of its low cost, excellent surface quality, long radiation length, and its availability in thin plates. However, its high resistivity ($\sim 10^{15} \Omega\cdot\text{cm}$) and ionic conductivity leads to the polarization and charging-up of the dielectric supporting the strips [9]; both effects result in short-term instabilities in the operation of the detector, and are usually manifested as loss of gain with different relaxation times. Another different process leading to the degradation of plates made on high resistive supports is related with their the long-term exposure to radiation. Under clean conditions and regardless from the metal used for the strips, it appears that the exposure rate plays a critical role in determining the ageing rate (Fig. 2); no gain drop is detected when measurements are done at high current densities ($>30 \text{ nA}\cdot\text{mm}^{-2}$) which should be taken into account when trying to extrapolate to realistic

conditions, in particular to the LHC rates ($<1 \text{ nA}\cdot\text{mm}^{-2}$), results obtained at high currents in few days or weeks. Apparently, also the time scale seems to play a role in the process taking place in the irradiated region; the gain drop slowly recovers to the initial value after stopping the irradiation, suggesting a temporary modification of the electrical properties of the support.

Figure 2. Dependence of the rate of ageing with the charge density for a D-263 plate.

Figure 3. Long-term behaviour of a S-8900 chamber with chromium strips under optimal cleanliness conditions.

Several methods have been tried to reduce or avoid the mentioned limitations. The use of substrates with adequate resistivity ($<10^{12} \Omega\cdot\text{cm}$), electronically conductive, eliminates the short-term modifications because charges can move in the substrate. The maximum allowable conductivity is fixed by power dissipation due to dc currents in the glass and/or the noise. MSGCs fabricated on electron-conducting glasses, with resistivity in the range of 10^9 – $10^{12} \Omega\cdot\text{cm}$ have demonstrated, in addition, high stability over long periods of irradiation (Fig. 3). However, the use at large scale is limited because these glasses are difficult to obtain with a thickness below 500 μm ; due to its high iron content (the radiation length is 4–7 cm as compared to 12 cm for boro-silicate Desag glass), they can not be accepted as part of a inner tracker detector in LHC until good quality, thin plates are available.

4. DIAMOND-COATED MSGCs

4.1 Introduction

In view of the good results obtained with electron-conducting glasses, several methods of conditioning the surface resistivity of commercial, low cost, boro-silicate glasses have been developed recently. These techniques include metallic-ion implantation or doping by diffusion [10,11] and coating of the surface with thin layers of electron-conducting material [12,13]. Both ways of conditioning allow to reach an effective surface resistivity which optimizes the counting capability of the device, indicating that the resistivity of the material close to the surface mostly determines the rate capability. Nevertheless, this approach has led to unstable operation of the detectors due to difficulties to obtain uniform layers over large surfaces, residual reactivity of thin films with the substrate itself, air moisture or light, damages resulting from the photolithographic process to deposit the metal strips or the interaction with ions and radicals in the avalanches.

4.2 Diamond-like carbon coating

In 1995 the Diamond-like carbon (DLC) coating¹ of insulating MSGC substrates was introduced by Sauli et al. [14]. Some aspects a priori positive were that it is a well-known technology industrially available, the coating is mechanical hardness, chemically inert, with good optical surface quality and uniform over large areas, attainable in a wide range of resistivities and at low cost. The uniformity of the layer over large samples and the stability in time of the resistivity are reported in [14].

4.3 Basic characteristics of DLC coated MSGCs

The conductive layer can be applied on a dielectric substrate followed by the deposition of the metallic strips (under-coated MSGC) or on the top of a manufactured MSGC (over-coated MSGC). The latter is a simpler technology because the strips can be engraved in the bare glass without concern of damaging the layer; also defects in the strips occurring in the photolithographic process due to imperfections in the layer are avoided. In this paper we present the performance of DLC under-coated detectors manufactured on 300 μm thick boro-silicate D-263 glass engraving the chromium strips by standard acid wet-etching or gold strips by lift-off. Results on over-coated MSGCs are reported in [15].

For under-coated plates, an increase of 50 V is necessary to reach the same gain than with an uncoated chamber because the field is modified due to surface currents. The gain as a function of the X-

ray flux stays stable (gain ~ 2000) up to rates in excess of $10^6 \text{ mm}^{-2}\cdot\text{s}^{-1}$, as shown in Fig. 4.

Figure 4. Rate capability of two MSGC plates with chromium and gold strips on DLC under-coated D-263.

The long-term exposure to X-rays of a under-coated detector with gold strips assembled and operated under conditions close to the CMS experiment requirements is shown in Fig. 5. A banana shaped module, the so-called 'open' solution where the front-end and service electronics of each chamber are also embedded in the gas volume [16], with two coated plates with gold and chromium strips was installed in a clean gas system. The gas mixture was Ar-DME [50-50] with an exchange rate of half renewal/hour. The gain of the gold MSGC stays stable after accumulating $>70 \text{ mC/cm}$ of strip during the continuous irradiation (3 months). This result confirms our belief that the low resistivity of the support plays a role in preventing the ageing process, or at least, its detectable effects.

Figure 5. Gain as a function of the collected charge of a coated plate with gold strips assembled inside an "open geometry" module (electronics inside the gas volume).

5. OPERATION OF DLC COATED MSGCs IN A HIGH RATE BEAM

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In order to check the assembly procedure and continuous operation of a small but complete system of MSGCs, several $10 \times 10 \text{ cm}^2$ detectors made on diamond-like coated D-263 glass fully equipped with readout electronics were exposed ~ 6 months to a high intensity muon beam ($10^4 \text{ mm}^{-2}\text{s}^{-1}$) at CERN [17]. The monitoring task includes a thorough examination of each device before installation in the beam such as the measurement of substrate resistivity, shorts finding, pulse height analysis, gas gain calibration, rate capability and testing of the final electronics. The later verification of effects of long-term ambient variations and ageing and the subsequent evaluation of their detection efficiency and the monitoring of accidentals rates are also done to demonstrate the long-term survival of a representative system in realistic beam conditions.

The gas distribution, Ar-DME [50–50], is done in parallel with a flux per chamber around 8 cc/min. A single wire proportional counter is connected in series to the gas system to monitor the gas quality. High voltage and ambient parameters in the beam area are also recorded. The trigger is defined by the coincidence of 3 scintillators with 100 cm^2 active area.

Each chamber is equipped with 4 Premux128 front-end chips including a charge sensitive preamplifier followed by a CR-RC shaper and two capacitors that can be connected or disconnected to the shaper output through digital controlled switches. The readout is made through a shift register, reading the contents of different channels serially. A double correlated sampling of the signal is made to readout the charge per strip. The analogue outputs (one per MSGC) from the chambers are sent through a coaxial double cable (180 ns) to a fast amplifier and then digitized by a flash ADC. The readout frequency is set to 1 MHz.

In Fig. 6 a typical event is shown. Due to the high rate and the long timing ($\sim 1 \mu\text{s}$) needed for the double correlated sampling, many hits of positive and negative polarities are present in each plane per event; the latter are expected from the trigger and the opposite polarity is present because a real signal may be subtracted instead of the baseline.

The trigger area was reduced from 100 to 1 cm^2 installing a small counter at the edge of the detector area. Although the background is not modified, it gives more chances to tag on the trigger track enhancing the ratio of trigger to background in the defined area (Fig. 7), thus facilitating the timing studies and data analysis procedure.

The cluster reconstruction is done finding the number of consecutive strips over a threshold (2 times the rms of pedestals). After a precise alignment of the chambers, one plane is taken as reference and clusters are search within a determined window (3 pitches) in the rest of planes. All possible

combinations are tried with the candidates fitting a straight line; the reconstructed track is then selected on the basis of a chi-square minimization.

Figure 6. Typical event from the high rate beam test.

Figure 7. Wire map with a 1 cm^2 counter in the region between the strips 25 and 80. The muon beam covers the full active area of the chambers.

Plates with chromium strips have a signal to noise ratio around ~ 27 , being slightly better for gold chambers due to the signal attenuation along the strips for the first ones.

No significant differences in the operation of under- and over-coated chambers have been found. Chambers have been fully efficient ($\sim 98\%$ in the small counter region), operating under Ar-DME, Ne-DME or pure DME; as shown in Fig. 8, the efficiency out of the counter region, thus for off-time tracks, is slightly lower but constant independently of the exposure rate. Larger inefficiencies are due to missing channels (broken strips, missing bonds or dead electronic channels). The spatial resolution is evaluated from the residuals distribution after subtracting the errors due to the intrinsic resolution of the detectors used to predict the position; as expected, it is about $40 \mu\text{m}$ (Fig. 9).

Nevertheless, the continuous operation of the chambers has been more difficult than expected. Probably the long test procedure and interventions in the laboratory as well as the limited gas exchange and almost undetectable gas leaks in the set-up have been

major difficulties to successfully operate the MSGCs. The influence of heavily ionizing particles and the long-term exposure of the chamber components to DME vapour may have affected the operation of the devices, independently of their exposure to the high rate beam. All these factors are presently under investigation.

Figure 8. Typical chamber efficiency; the lower values out of the small counter region are due to off-time tracks and locally due to accidental missing channels (broken strips, missing bonds or dead electronic channels).

Figure 9. Distribution of residuals; spatial resolution is around 40 μm .

6. CONCLUSIONS

Several measurements realized with Micro Strip Gas Chambers made on substrates with different resistivity and several metallizations have been carried out in well controlled and reproducible conditions, to help understanding the factors affecting their short- and long-term behaviour. Special care has been taken concerning the gas purity and choice of materials used in the system and for the detectors construction. Detectors built on glasses with surface resistivity in the range 10^{14} – $10^{16} \Omega/\square$ have shown satisfactory performance as they do not show

charging-up process at high rate and stand the large doses required for the future high luminosity experiments ($\sim 10 \text{ mC}\cdot\text{cm}^{-1}\cdot\text{yr}^{-1}$). Concerning the lifetime measurements, it has been observed that the measured ageing rate (if any) depends from the current density at which the ageing test is done, and can be substantially larger at low dose rates, particularly for MSGCs manufactured on high-resistivity glass. Moreover, we have found evidence that, equal being all other conditions, chambers manufactured on high-resistivity glass are far more susceptible of suffering ageing than detectors made on low resistivity, electron-conducting supports, independently of the metal used for the artwork (chromium or gold) at least in clean gas conditions. The successful operation in the laboratory of detectors manufactured on diamond-coated glass with a surface resistivity around $10^{15} \Omega/\square$ confirms the last statement. The difficult operation of fully equipped coated $10\times 10 \text{ cm}^2$ plates in a long-term, high rate test beam needs further investigation to understand the real causes of the problems; the effect of heavily ionizing particles, the long-term exposure of the chambers components to DME vapour or the possible pollution of the gas mixture (air and water due to the gas leaks or unknown contaminants) may have affected the chamber operation independently of their operation at high rate.

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