EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN-PPE/97-21
8 January 1997

"DIAMOND" OVER-COATED MICROSTRIP GAS CHAMBERS FOR HIGH RATE OPERATION

A. Barr[a] , B. Boimska[b] , R. Bouclier, M. Capeáns, W. Dominik[b], M. Hoch, G. Manzin[c] , G. Million, L. Ropelewski, F. Sauli, A. Sharma[d]

CERN, Geneva, Switzerland

ABSTRACT

We describe the recent developments on the diamond-like carbon (DLC) over-coated Microstrip Gas Chambers made on drawn glass substrates. MSGC surface coating with thin DLC layer of stable and controlled resistivity was proposed to overcome the limitation of detector operation due to surface charging-up under avalanches. This brings also advantages for the detector manufacturing technology. The thin layer, deposited on top of a manufactured MSGC (over-coating), demonstrates excellent mechanical properties and very good stability. We report on recent measurements with DLC over-coated MSGCs of various surface resistivities (ranging from $10^{13}\Omega/\square$ to $10^{16}\Omega/\square$) on D-263 and AF45 glass substrates. Over-coated MSGCs exhibit good rate capability for the resistivity of the surface around $10^{15}\Omega/\square$. Stable operation up to 50 mC/cm of accumulated charge from avalanches has been demonstrated.

Paper presented by W. Dominik at the
5th International Conference on Advanced Technology and Particle Physics,
Villa Olmo, Como, Italy Oct. 7-11, 1996

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[a] Ecole Nationale de Physique et de Chimie Industrielle de Paris, France
[b] On leave of absence from Institute of Experimental Physics, University of Warsaw, Poland
[c] INFN Legnaro, Padova, Italy
[d] GRPHE, Université de Haute Alsace, Mulhouse, France

1. INTRODUCTION

Microstrip Gas Chambers (MSGC) [1] with their high electrode granularity are intrinsically capable to detect ionizing radiation efficiently with good localization accuracy. The relatively short ion collection time of the detector makes it possible to achieve stable operation up to very high radiation rates. However, for detectors manufactured on boro-silicate glass substrates, the effect of charging up of the insulating surface between the metallic strips by the accumulation of ions from avalanches makes the gain rate-dependent even at moderate radiation fluxes [2].

It has been demonstrated also that drift of the glass substrate resistivity due to ion migration in the electric field (substrate polarization effect) results in a time-dependent gain drop, thus degrading the performance of the detector within a few hours after applying the voltage [3]. The technical solution to overcome the limitations due to both charging-up and polarization, relies on coating the surface of the support of the MSGC with a thin layer of material with low but stable electric conductivity. The thin film should be chemically compatible with the gases used for the chamber filling, it should resist to the chemicals used during the photo-lithography process to form the electrodes and it should have good adhesion to the metal strips.

A very reliable and promising solution using thin diamond-like carbon (DLC) coating of the glass before the metal structure engraving was developed and substantial improvements of the detector operation stability and durability under high avalanche rates have been demonstrated [4]. The resistivity of the surface can be controlled during the Plasma Assisted Chemical Vapour Deposition (PACVD) [5] process in the range of values from 10^7 to 10^{16} Ω/❒. The thin DLC film is also mechanically very hard.

The idea of using the same technique of coating to cover the final structure of electrodes engraved on the glass is quite natural. From the detector manufacturing point of view, the over-coating solution has several advantages over the undercoated version. The thin film protects very fragile and very delicate structure of electrodes against accidental mechanical damages and possible corrosion during the detector assembling, storage and operation. It makes also the cleaning procedure easier and safer. The possibility of correcting defects of the engraved metallic structure before the final diamond coating is also very attractive.

Some doubts exist on the medium and long-term effects of charges on the coating. The rate capability and long-term stability of "diamond" over-coated Microstrip Gas Chambers on glass support were studied and are here discussed.

2. DETECTOR AND EXPERIMENTAL METHOD

For all described measurements we have used a standard MSGC design (MS-9) having 100*100 mm^2 sensitive area, a strip width of 100 μm for cathodes and 7 μm for anodes, with a cathode-anode pitch of 100 μm (center-to-center). The structures of chromium strips were engraved on a glass supports 300 μm thick and coated by Plasma Assisted Chemical Vapour Deposition (PACVD) process with DLC films of 500 Å and 1000 Å thickness and various surface resistivities. The desired value of resistivity is obtained using a proprietary doping technology[(1)].

Two types of substrate materials were tested:

- D-263[(2)] boro-silicate drawn glass of low alkali content, $\rho = \sim 3*10^{15}$ Ωcm,
- AF-45[(2)] modified boro-silicate alkali free drawn glass, $\rho = \sim 2*10^{17}$ Ωcm.

The detector structure mounted on the metallic plate (grounded during operation of the detector) with a stainless-steel grid as drift electrode at 7 mm distance from strip plane has been enclosed in gas tight stainless-steel box with 100 μm aluminium window of the size corresponding to the dimensions of the detector. Negative polarity voltages were applied to the grid in order to provide the drift/charge-collection field; cathode strips were connected together and to the high

(1) SURMET Corp., Burlington MA, USA

(2) DESAG - Deutsche Spezialglass AG, Grüneplan, Germany

voltage source through a 10 MΩ protection resistor. Anode strips in groups of 20, kept on ground potential, were individually accessible for read-out.

The chambers were tested with Argon - DME (50:50) in open flow and clean conditions (only vacuum-grade materials like stainless steel, aluminium, glass and ceramics were used for detector box construction and gas mixing system [6]). An X-ray generator delivering the iron fluorescence line of controlled intensity has been employed during the high rate irradiation.

During the long-term irradiation measurements the double beam method has been used (Fig. 1). The radiation flux from the X-ray generator was collimated simultaneously on two groups of strips of the MSGC; the radiation intensity on the one of groups was lowered by inserting a thin metallic absorber on the front of it. Thus one could obtain the ratio of intensities in the high- and low-irradiated area of about 10. Each group had independent electronic read-out chain. During long-term exposures, pulse heights from high (pk1) and low (pk2) irradiated MSGC areas were monitored every 15 minutes at momentarily lowered radiation flux in the MSGC. Avalanche currents on the high voltage strips and on the drift electrode were measured at the high radiation flux. Assuming that ageing does not occur in the low-irradiated section, the pulse height from this area serves as a reference for long-term gain stability measurement in the highly irradiated region.

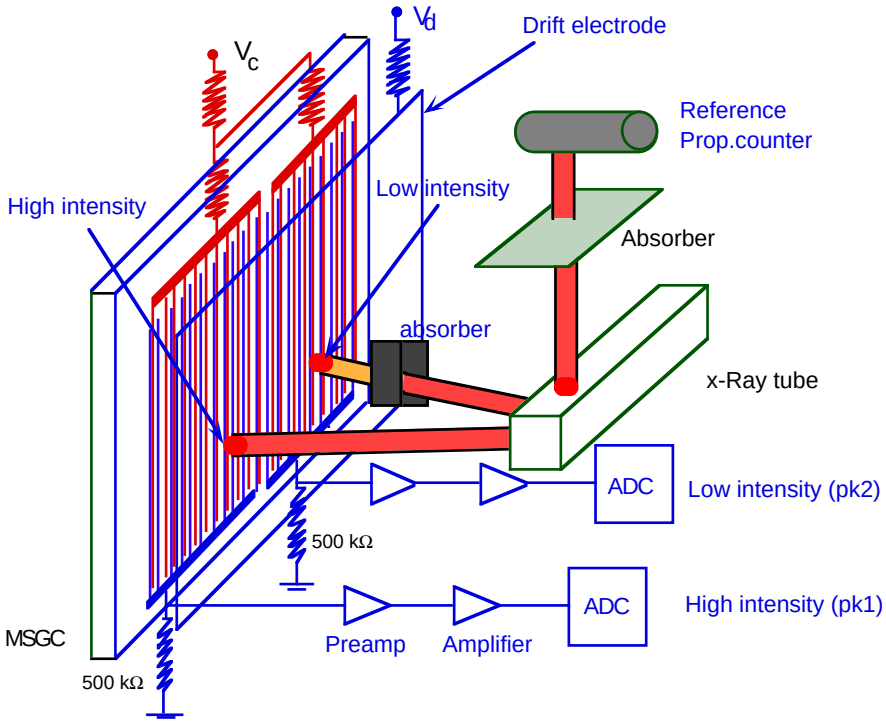

Fig. 1. Sketch of the double beam set-up for long-term measurements.

Additionally, a single wire proportional counter was operated in the same gas line following the MSGC. The information from the low irradiated area of the MSGC and from the single wire counter permit to correct the pulse height from the area exposed to high radiation flux, for the effects of temperature, pressure and gas composition fluctuations. Pulse height fluctuations in the MSGC, that are caused by variations of the external parameters may be larger than 20% during the continuous test of several months.

The detailed description of the long-term measurement technique and the procedure of corrections is given in [7].

3. MEASUREMENTS AND RESULTS

The operation of the over-coated MSGC appear to be similar to the operation of the undercoated one having the same structure of electrodes and resistivity of the surface; differences in the operation may come from charging up of the surface of the coated electrode by charges from the avalanches in gas, if the coating exhibits the features of an insulator. The presence of local insulating spots would result in progressive modification of the amplifying electric field in the vicinity of the strips. A large fraction of ions produced in the avalanches are neutralized on the cathode strips; in presence of locally insulating centers, the surface may charge up, thus modifying the electric field and degrading the charge avalanche process.

The effect of charge accumulation on the surface of the detector should appear as a short term degradation of the charge gain under irradiation; it is also expected to worsen the energy resolution of the MSGC.

3.1. Uniformity of the surface resistivity.

The uniformity of surface resistivity of the MSGC plates has been verified on a probe station before the assembly of the detector. The voltages were applied to individual electrodes through needles connected to the voltage source and to a picoamperometer. For a strip length of 100 mm, surface resistivity up to 10^{17} Ω/❐ can be reliably measured on our probe station.

Measurements made on the over-coated microstrip plate on AF45 support confirm good uniformity of the surface resistivity, reported already for the undercoated plates [8], obtained in the PACVD process. The value of the surface resistivity deduced from the resistance measured between individual anodes and neighboring cathodes is close to desired one (10^{15} Ω/❐) with a dispersion below 50% at the base of the distribution (Fig. 2). Such variation of the surface resistivity at the level of 10^{15} Ω/❐ does not cause significant nonuniformities of the detector gain [9].

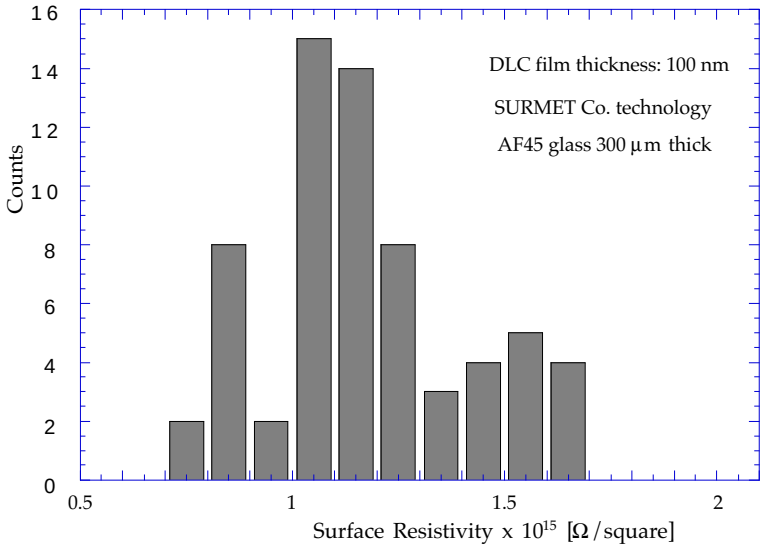

Fig. 2. Surface resistivity of the over-coated MSGC on AF45 glass substrate.

3.2. Charge gain of the detector.

Charge gain at the level of $6*10^3$ may be achieved for moderate drift field of 450 V/mm (Fig. 3). Discharges observed under irradiation set the maximum voltage allowed on the cathodes of the MSGC (~610 V). It should be noted that in the case of the over-coated MSGC accidental discharges do not result in damages or shorts between anodes and cathodes.

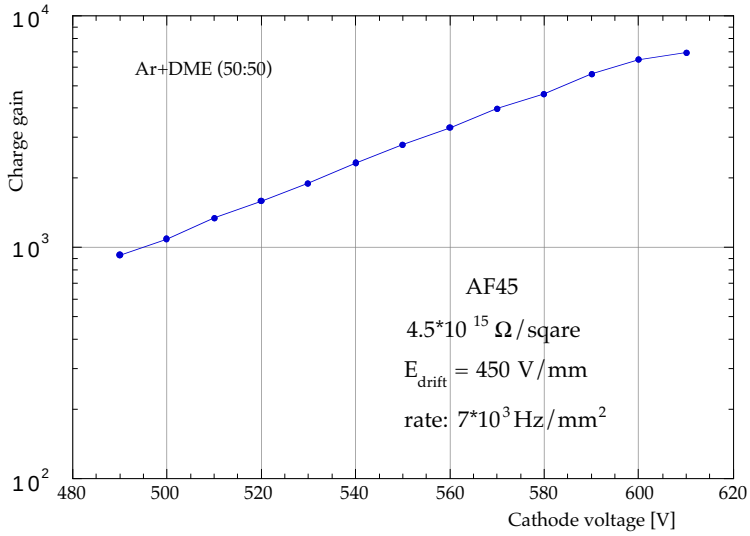

Fig. 3. Charge gain as a function of cathode voltage.

The over-coated MSGC becomes operational immediately after applying the voltages. Even for surface resistivity around 10^{16} Ω/❒ no conditioning is needed. The pulse height spectrum obtained for a 6 keV X-rays from ^{55}Fe, at moderate radiation rate, with the over-coated MSGC with the resistivity of the surface $\rho=2*10^{13}$ Ω/❒ demonstrates the stability of the charge multiplication process (Fig. 4). The energy resolution at the charge gain M close to 2000 is 20% (FWHM). For the MSGCs with high surface resistivity (in the range of 10^{16} Ω/❒) the energy resolution is similar.

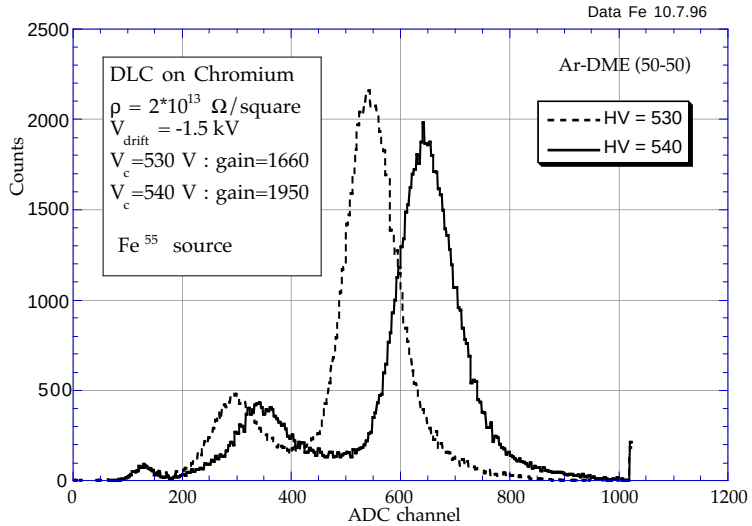

Fig. 4. ^{55}Fe pulse height spectra recorded for two cathode voltages.

3.3. Effect of drift field.

The current of positive ions from avalanches is shared between the cathode strips and the drift electrode; the sharing depends on the drift field strength (Fig. 5).

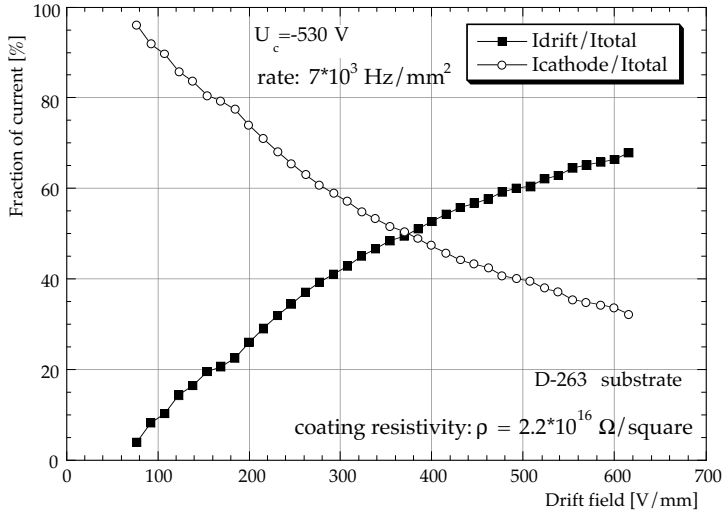

Fig. 5. Avalanche current sharing between the cathodes and the drift electrode vs drift field.

For drift field close to 600 V/mm, about 70% of ion current flows to the drift electrode. The results presented in the figure 5 were obtained in the range of drift fields up to 600 V/mm only, because of a limitation on the maximum voltage on the drift electrode caused by discharges on the high voltage connector. One can estimate that at the drift field of 1 kV/mm (required for fast charge collection and in order to minimize the error of the position measurement in magnetic field) about 80% of ions from avalanches will flow towards the drift electrode. Large ion current towards the drift electrode at high drift fields is typical for MSGCs.

The charge gain of the MSGC is also sensitive to the strength of drift field for given voltage on the cathodes [10]. Result presented in figure 6 shows that at drift fields above 400 V/mm the charge gain increases. In the figure, the cathode and drift currents are shown, as well as the total avalanche current, as a function of the drift field. The cathode and the drift currents were measured independently; the total current, sum of the two partial currents, corresponds to the electron current flowing to the anode; it is a measure of the charge gain in the MSGC.

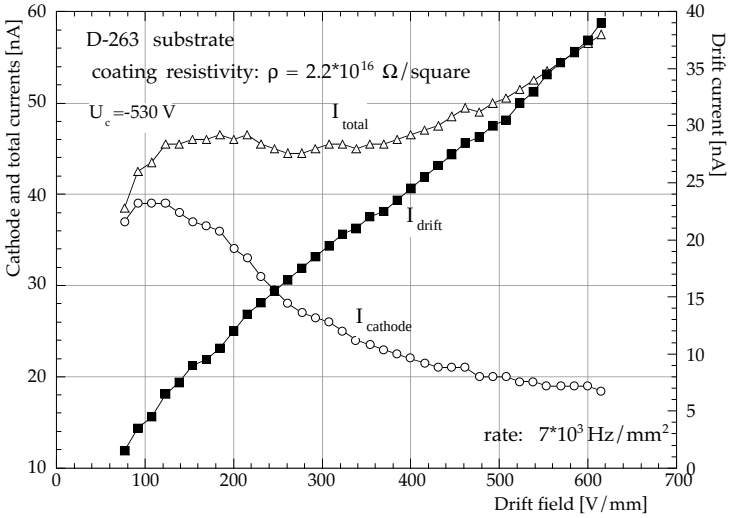

Fig. 6. Avalanche current as a function of drift field in the MSGC.

In the range of applied drift fields, charge multiplication in the uniform electric field in the gap was not observed for Ar-DME(50:50) gas mixture. The effect of the increase of charge gain for large drift fields has its origin in the strengthening of the electric field in the vicinity of the anodes.
Higher drift field may be advantageous, resulting in lower ion current to the cathode strips and thus, possibly extend the chamber life time, under the assumption that ageing is due to attack of the electrode surface by ions or the deposit on cathodes of polymerization products.

3.4. Rate capability.

Stability of the charge amplification process of the MSGC at increasing rates of avalanches is of great importance for detector operation in a high radiation environment.

The rate capability measurements, performed for an avalanche size of $2.5*10^5$ electrons, show that the charge gain of the over-coated MSGC is constant for rates up to 10^6 Hz/mm^2 for resistivity of the coating film up to few times 10^{15} Ω/❐. For both, AF45 and D-263 supports the gain varies less than 5% up to the maximum delivered rate of $2*10^6$ Hz/mm^2 (Fig. 7).

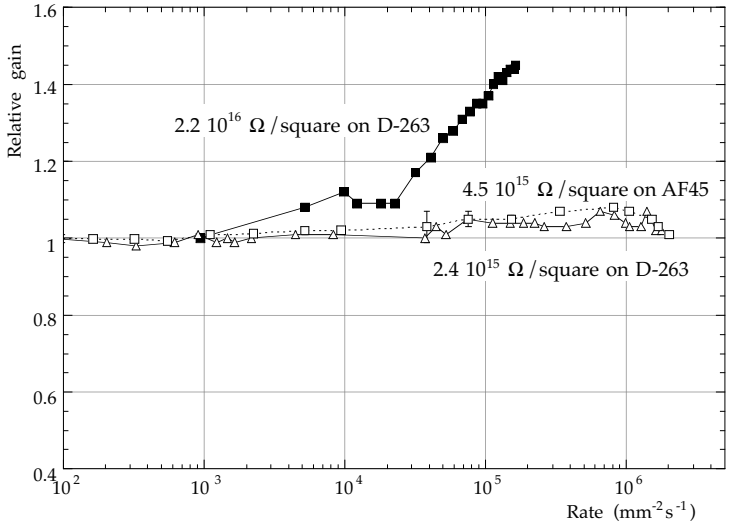

Fig. 7. Relative gain as a function of rate measured for MSGCs with different coating resistivities.

For higher resistivity of the coating, an increase of charge gain with irradiation rate was observed. In the case of the MSGC on D-263 coated with the DLC layer of $2.2*10^{16}$ Ω/❐ and operated at the same charge gain measured for the avalanche rate 10^3 Hz/mm^2, the gain increases by ~40% at the rate of 10^5 Hz/mm^2 and has the tendency to increase further with the rate. This effect is different from the usual degradation of the charge gain reported for MSGCs made on the boro-silicate glass and on the semiconductive substrate of high resistivity [11]. This increase of the detector gain with rate may provoke instabilities of detector operation (discharges) at high radiation flux operating at high gain. From this point of view the resistivity of the surface of a coated MSGC should not exceed few times 10^{15} Ω/❐.

3.5. Long-term stability of an over-coated MSGC

The long term stability of the over-coated MSGCs has been studied systematically. The chambers operated at charge gain of M=1000, measured at the avalanche rate of 10^3 Hz/mm^2, have been exposed to intense, continuous flux of the X-ray generator. Figure 8 shows the results of the long-term irradiation of two over-coated MSGCs, on D-263 and AF45 supports. The MSGC on D-263, having surface resistivity of $2.2*10^{16}$ Ω/❐, was exposed to the detected radiation flux of $3.3*10^5$ Hz/mm^2, resulting in the current density of 22 nA/mm^2. For the MSGC on AF45 with

surface resistivity of $4.5*10^{15}$ Ω/❐, the avalanche current density was 14 nA/mm^2. Drift fields were set to 420 V/mm and 350 V/mm, respectively for detectors on D-263 and AF45 supports.

The long-term behaviour of over-coated MSGC appears clearly after normalization of the pulse height in the highly irradiated area (pk1) using the monitor pulse (pk2) from the low irradiated region (Fig. 8). The amplitude of the pk1 pulse at the beginning of the measurement has been normalized to unity.

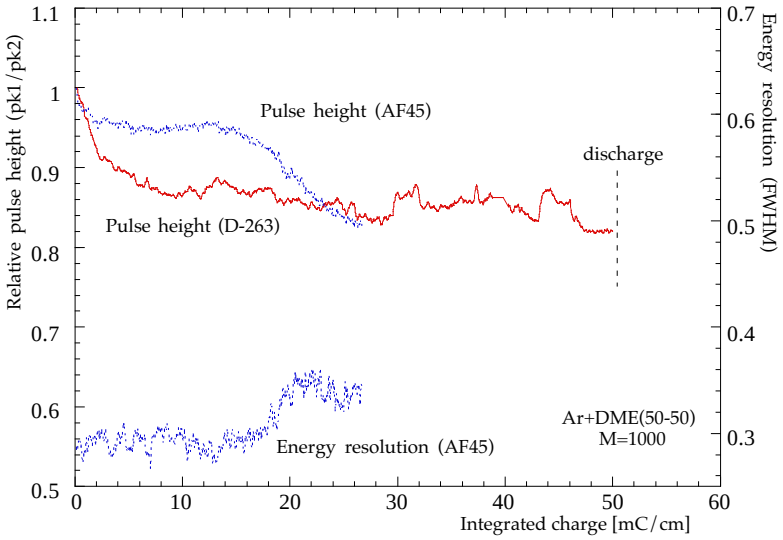

Fig. 8. Long-term stability of charge gain of the over-coated MSGCs.

In the case of the MSGC on D-263, the charge gain decreases by about 10% during the first irradiation period corresponding to an integrated charge of about 3 mC/cm, and remains stable afterwards until the chamber reaches its life limit. Then, either abrupt degradation (like in the case of the measurement presented in the figure) or continuous decrease of charge gain with energy resolution worsening is observed. The over-coated MSGC on D-263 glass substrate has withstood an integrated charge of 50 mC/cm of strip, corresponding to a total of about 10^9 counts/mm^2.

A locally degraded chamber can hold nominal voltages, but even a moderate radiation flux in the damaged area provokes discharges. On optical inspection after opening the detector, one could easily recognize the highly irradiated damaged area: rough surface with melted edges of both cathode and anode strips. The zone of damages is limited to the region of intense irradiation. This final degradation of the surface has been definitely set by discharges in the gas in the irradiated region at the end of the detector operation.

The measurement with the MSGC on AF45 glass substrate shows a much smaller (less than 5%) initial drop of the normalized pulse height. The detector exhibits stable operation up to a total integrated charge of about 15 mC/cm of strip; above this level gradual degradation of the normalized pulse height has been observed. Optical inspection of the irradiated area shows a discoloration of the surface of strips, but no mechanical damages neither to the DLC layer nor to the electrodes. Therefore degradation of the gain can be interpreted as classical ageing caused by the polymerization process [6]. This will be further studied in cleaner gas conditions.

For the reasons indicated, the described long-term measurements were performed at moderate drift field. One can expect that at higher drift fields the effect of ageing will be less pronounced, if the positive ions bombarding the surface of cathodes are responsible for the detector operation degradation. Then the cathode current should be 2-3 times smaller and both harmful processes - polymerization and the etching of the DLC layer by ions, should be attenuated.

The possible role of ion migration in the bulk of the support and its contribution to the damage of the coating should be also mentioned. The initial slewing of the normalized pulse height, systematically observed for DLC coated MSGCs with high resistivity of the layer on ion-

conducting glass, can be attributed to the dynamic polarization of the substrate due to slow ion migration in the bulk under the influence of avalanche currents. The argument for this hypothesis is the much smaller (almost negligible) initial pulse height slewing in the case of the MSGC on the alkali-free AF45 support.

3.6. Temperature conditioning of the DLC layer

During the development a systematic study of temperature effects on the characteristics of the coating was undertaken. Heating effects are an important concern of the MSGC manufacturing procedure, since some stages of detector construction may require the thermal treatment at elevated temperatures.

Samples of DLC coating on D-263 glass were baked in nitrogen atmosphere for two hours in progressively increasing temperature; after each run the plates were cooled, still in nitrogen, and the resistivity of the coating was measured at room temperature (Fig. 9).

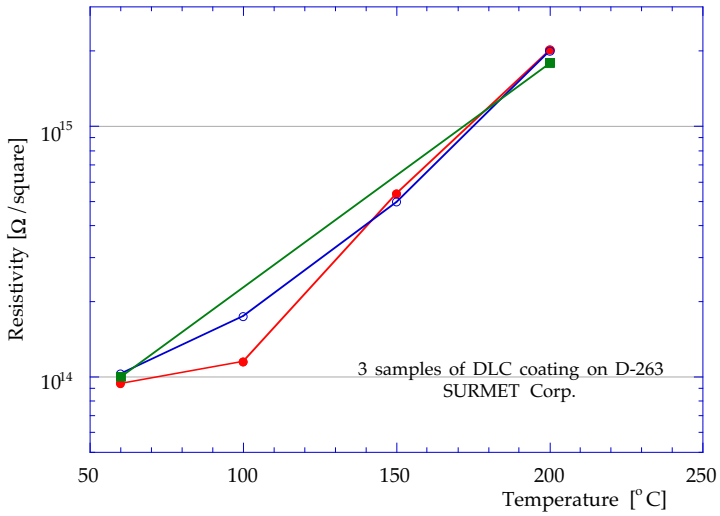

Fig. 9. Resistivity of DLC coating as a function of baking temperature; measurement for three samples of coating on D-263 glass.

Data at 60°C (temperature of CVD deposition) correspond to the initial resistivities. Up to a temperature of 200°C the resistivity of all samples increases; at 200°C the resistivity is more than 10 times higher than the initial one. After the heat treatment in this range of temperature the characteristics of the coating remain stable, without any degradation of mechanical properties. Hence, this procedure may be employed to tune the resistivity of a DLC layer to higher values.

4. CONCLUSIONS

The over-coated Microstrip Gas Chambers operate well up to charge gain above 5000 for Argon + DME (50:50) gas mixture. Detectors made on D-263 and AF45 drawn glass and coated with the DLC layer with the resistivity at the level of 10^{15} Ω/❐ exhibit stable and constant charge gain for the radiation flux above 10^{6} Hz/mm^{2}.

A thickness of about 1000 Å of the DLC coating seems to be adequate for the over-coated MSGC. At this thickness, the uniformity of the thin film parameters should be relatively easy to obtain in mass production.

Operating the MSGC at high drift fields would possibly extend its life-time by reducing the amount of ions bombarding cathode strips.

A study of the long-term behaviour confirms that the DLC over-coated MSGC operated in clean gas conditions can withstand an integrated charge collection on the strips of 50 mC/cm.

An initial shift of the normalized pulse height is observed, less pronounced for the MSGC made on the alkali free AF45 glass than in the case of the low alkali content D-263 glass. This systematic shift is below 5% in the case of the AF45 support, smaller than pulse-height variations due to pressure and temperature changes during a long operation period.

The results obtained with the DLC layer exposed to high rate of avalanches encourages to conceive the extension of this type of electrode coating technique to other types of gaseous detectors, as for example Parallel Plate Chambers with resistive electrodes and MWPCs with resistive flat cathodes.

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