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ELSEVIER

Operation of MSGCs with gold strips built on surface-treated thin glasses

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Abstract

We report the results of tests of MicroStrip Gas Chambers with gold strips fabricated on surface-treated thin glasses. The electrical properties of glass substrates are discussed and different solutions for surface coatings are presented. Short- and long-term measurements of stability of the response have been carried out on MSGCs with diamond-like coatings, under different experimental conditions. The tested detectors differed in the technology adopted for the processing of gold.

1. Introduction

Since its introduction [1,2] the MicroStrip Gas Chamber (MSGC) has aroused great interest for its ability to operate at high counting rates and with high spatial resolution. Nevertheless many parameters in the manufacture of a MSGC affect significantly its lifetime. Metallisation, processing, substrate, gas purity and composition, assembling materials and components must be kept under control. We have found [3] that a fundamental choice to get optimal performance of a MSGC is the kind of strip metal used. In particular, the use of low specific resistance metals for the anode strips ($<50\ \Omega$ cm) is mandatory when working with long strips and fast electronics. It avoids a position dependent attenuation of the signal and an increase of the detector noise. A low resistivity metal, commonly used in microelectronics, is aluminum or a silicon–aluminum alloy. Unfortunately, aluminum is a very active metal and it is known to react vigorously with the species produced in the avalanche plasma. It induces a very fast ageing of the detector [4,5]. Conversely, gold is chemically inert and has a resistivity even lower than aluminum. It does not interact with the avalanche plasma and, furthermore, it is very difficult for the polymers, produced in the avalanche by pollutants, to attach to it. Coating by polymers and therefore ageing of MSGCs has been drastically reduced working with gold strips [3,4]. Another important role is played by the substrate material and, in particular, by its electrical characteristics. It is well known in fact, that during the avalanche process there could be an accumulation of positive charge on the surface of the substrate which would cause a local weakening of the electric field and consequently a reduction of the detector response [6]. For this reason sufficiently low surface resistivity materials ($\sim 10^{15}\ \Omega/\square$) are preferable to avoid the effect of charging-up of the substrate [7–9]. The conductivity required to drain away this positive charge can be obtained exploiting the electrical properties of the bulk or of the surface of the glass substrate. Two types of bulk conductivity can be distinguished: ionic and electronic. Substrates with ionic conductivity but low alkali content (the industrial glass DESAG 263 has $\approx 5\%$ sodium ion content) can give, if correctly biased, good rate capabilities and low charging effects [3,5,10]. Correct bias for uncoated substrates means high drift field ($\simeq 10$ kV/cm) and back cathode put at anode potential. Nevertheless, some worries still exist on the long-term behaviour of the electrical properties of the bulk. It is not yet clear if effects such as ion migration, drift of the resistivity or trapping of charge in the substrate can occur and cause some changes in the operation of the detector. On the other hand substrates with bulk electronic conductivity (the so-called *semi-conducting* glasses [11]) are heavy, fragile, expensive and not industrially available for large area detectors. As an alternative, the substrate surface in contact with the gas can be suitably treated to increase its conductivity. Reduction of the surface resistivity can be obtained with well established techniques such as ion implantation, plasma deposition of a thin layer of diamond-like carbon or sputtering of semi-conducting glass (Pestov glass). Ion implantation, performed on different types of substrates (glass, quartz, SiO_2,

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sapphire, ...) using various ions (C, B, Fe, P, ...), has given good results in reducing the surface resistivity. Values ranging from 10^{10} to 10^{15} $\Omega/\square$ have been obtained. MSGCs firstly used in a high-energy physics experiment with success were built on ion implanted quartz [12]. However, this process is slow and expensive and for these reasons is not very suitable when detectors with very large area are required. Furthermore it has been shown by the RD-28 collaboration [13] that, while in some cases the resistivity of implanted glasses is rather stable in time, in some others it has increased by orders of magnitude within a few weeks after having applied an electric field to the substrate. This effect could be due to a mechanism of ion diffusion from the surface into the bulk. A way to prevent any disturbance due to ionic conduction in the bulk and, in some sense, to act as a shield against these bulk instabilities, especially when high voltage is applied, is to coat the substrate surface with a thin conductive layer. Indeed, it has been shown both theoretically [14–16] and experimentally [17] that coating the surface with a thin layer of a material having a bulk resistivity from 10^4 to 10^5 times lower than the substrate bulk resistivity, makes the detector operation fully insensitive to any change in the electrical properties of the glass substrate itself. These coating techniques are now industrially available. They can be applied, at low prices, to large area detectors and they are fully compatible with the photolithographic process. Our group has built MSGCs using two kinds of coating techniques:

- the plasma deposition of a thin layer of a diamond-like film, and
- the sputtering of ~1 μm of electronic conducting glass (Pestov glass) on a thin standard glass (D263).

This latter method is discussed and the results of tests on MSGCs with Pestov glass coatings are reported in Ref. [18]. In this paper we report on the results of the operation of MGSCs with gold strips built on glasses treated with diamond-like films.

2. The diamond-like coating solution

The diamond-like coating (DLC) technique consists in the low pressure plasma assisted chemical vapour deposition (LPCVD) of a thin film (~1000 Å) of a mixture of sp^2–sp^3 states of diamond–graphite. Several groups, including ours, had tried some years ago to apply such or similar techniques to the surface treatment of the substrates, but these first attempts failed due to the difficulty of appropriately tuning the resistivity (see for example Ref. [13]). Recently, surface resistivity in the useful range comprised between 10^{12}–10^{15} $\Omega/\square$ has been obtained by different groups at CERN [19] and SEFT [20] and MSGCs built on this kind of coating have been reported operating successfully [19,21]. We have therefore decided to come back to this solution, exploiting immediately one of the key points of this technology: the industrial availabilty. Quite easily we obtained glass plates coated by SURMET Corp. (Burlington MA, USA) with the requested values of resistivity and we started a research program aimed at studying and optimising several parameters:

- the values of resistivity;
- the type of substrate;
- the compatibility with the gold processing techniques;
- the gain, counting rate and lifetime of the detector;
- the scheme of the film deposition: *under-coating*, i.e. deposition on the glass substrate before the metallic micro-strip patterning or *overcoating*, i.e. deposition directly over the micro-pattern.

For the production of the MicroStrip detectors we contacted two Italian companies, ALENIA and CETEV, which use different processes to pattern the gold microstrips: respectively, galvanic growth and reactive sputter etching.

These technologies are quite typical of the field of *thin film* patterning and *multichip module* (MCM). The widths of the anode and cathode strips of all the chambers we have tested are 9 and 90 μm, respectively, and the pitch 200 μm. The overall dimension of the detectors was 26×26 mm^2.

2.1. Galvanic growth

Fig. 1 shows, step by step, the full process to obtain gold strips by galvanic growth. The process starts, after an accurate cleaning of the coated substrate, with the deposition, by sputtering (a), of a thin film of a metallic multilayer (Ni–Cr, for a better adhesion to the glass and Pt as a migration barrier) with gold on top of it. Next comes the deposition of a photopolymer and the photolithographic process (b) to pattern it. The next step is the galvanic growth of the gold layer (c) and the subsequent stripping of the photopolymer (d). The process ends with the etching of the multilayer thin film (e) and the deposition of a passivation layer (polyimide, f) on the detector edges to avoid sparking effects. Some samples of MSGCs were fabricated with this technique on DLC glasses. The bare substrate was a standard boro-silicate glass (DESAG 26) 300 μm thick. We measured a surface resistivity at the end of the process of $3\text{–}6 \times 10^{15}$ $\Omega/\square$. The active area was 26×26 mm^2.

2.2. Reactive sputter etching

Using a different gold process, the reactive sputter etching, other MSGCs on DLC substrates of the same active area were produced. This process is schematically explained in Fig. 2. A metallic multilayer similar to the one described in Fig. 1 but with an additional layer of Ni–Cr over the gold layer (a) is sputtered on a very clean coated glass substrate. The photopolymer, deposited on it, is masked according to the desired strip pattern and then

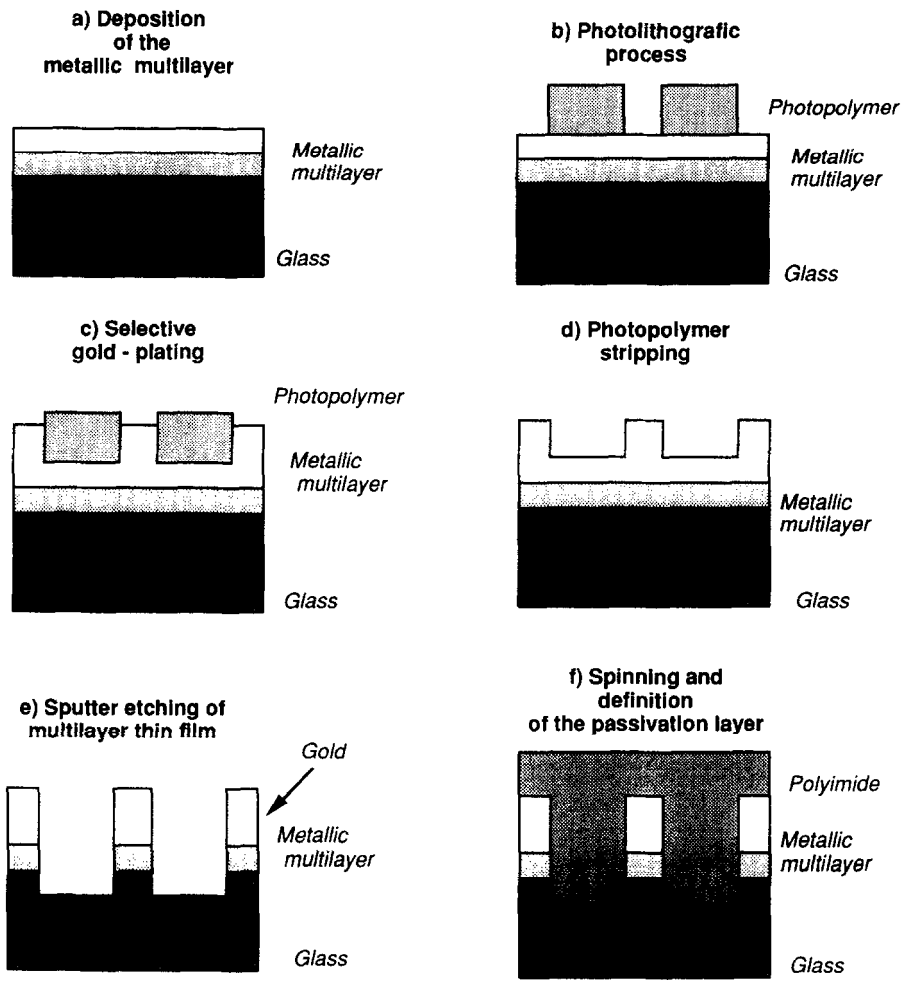

Fig. 1. Full dry processing steps: galvanic growth.

photolithographically etched (b). next comes the reactive ion etching (RIE) of the upper layer of Ni–Cr which defines the mask (c) to be used for the reactive sputter etching of the microstrip structure (d). The last steps of the full process are the removal of the Ni–Cr mask with RIE (e) and the deposition of a polyimide layer for passivation (f). In this case, the surface resistivity at the end of the process was $\sim 5 \times 10^{15}\ \Omega/\square$.

3. Short-term tests

Firstly we have studied the static, DC, characteristics of the detectors. We have measured the leakage current of a group of 64 anode strips as a function of the cathode voltage for the two types of MSGCs which differed only in the gold process. At 500 V cathode voltage we measured a leakage current of 11.2 nA for the MSGC where the galvanic growth process was used and 6.0 nA in the MSGC obtained with the sputtering technique, corresponding to a surface resistivity of $2.6 \times 10^{15}\ \Omega/\square$ and $5 \times 10^{15}\ \Omega/\square$, respectively. Both kinds of detectors had ohmic behaviour and no hysteresis was found in ramping up and down the high voltage (Figs. 3 and 4). We found a slightly different behaviour in a MSGC built on uncoated D263 glass. In this case the deviation from linearity can be ascribed to effects of polarisation or ion migration in the bulk. The stability in time of the leakage current was monitored for 12 h. During this period a small decrease of the current of only few percent was observed. Fig. 5 shows the leakage current stability obtained for the MSGC with surface resistivity of $6 \times 10^{15}\ \Omega/\square$, in which the galvanic growth process was used.

Secondly, a set of short-term, dynamic, measurements were performed by radiating the detectors at a rate of 10^4–10^5 photons/mm^2 with a Cr X-ray tube (5.4 keV) to test the short-term stability of response under irradiation. The linearity between output flux and tube current was checked to be within 2%. The gas filling used in all tests was Ne–DME. The detector was irradiated for 12 h at a

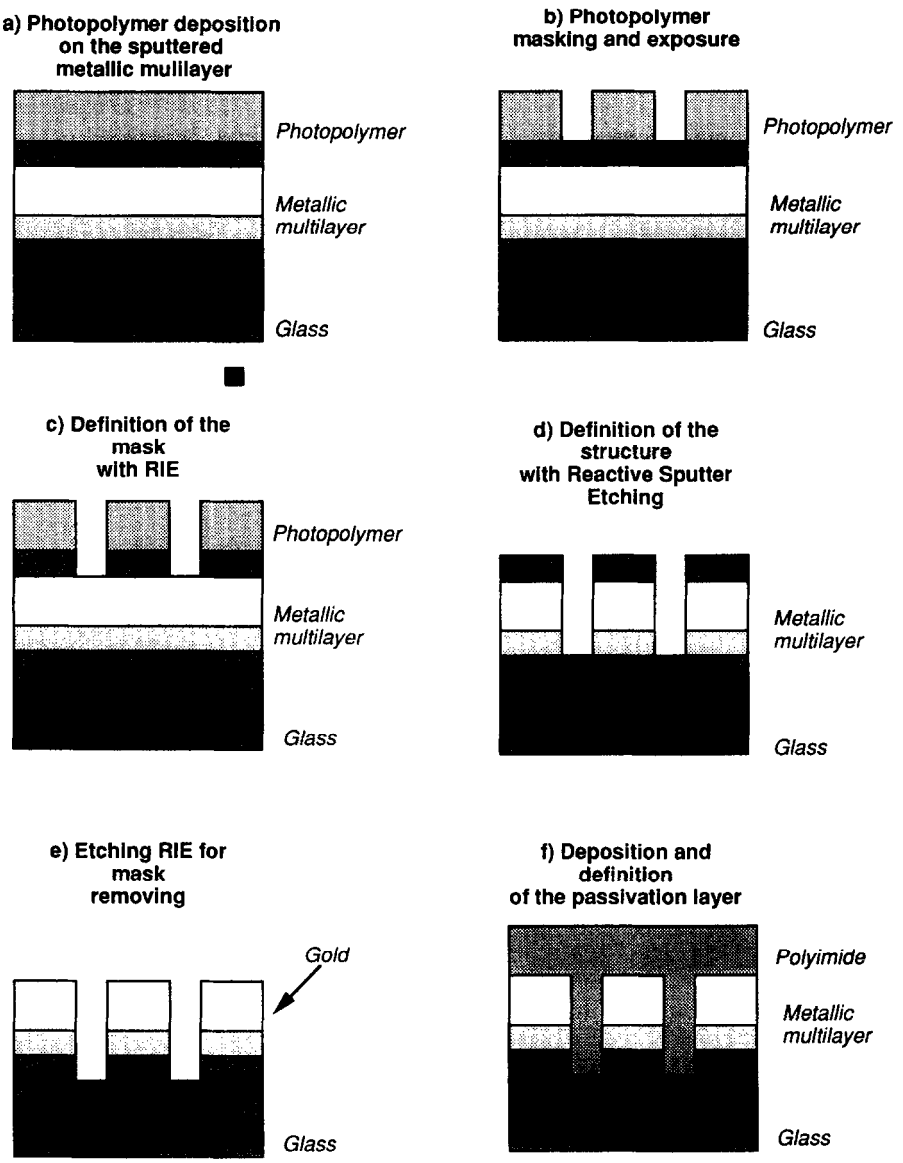

Fig. 2. Full dry processing steps: reactive sputter etching.

rate of 50 kHz/mm^2. After 10 h of data taking the beam was switched off and the data acquisition paused for nearly 1 h after which the signal amplitude was again registered. No evident change in pulse height was observed (Fig. 6). With this measurement we have excluded the existence of any subtle bulk effect due to the interaction of the radiation with the substrate. For a very short time interval (~60 s) the signal current from points of this detector never irradiated has been recorded at different bias settings. Drift and cathode voltages were changed while the back electrode was always connected to ground. No gain drop due to charging effects was observed for all the different voltage settings (Fig. 7). The gas gain of a MSGC with diamond-like coating and, for comparison, of a similar MSGC with uncoated substrate has been studied as a function of the drift voltage (Fig. 8) and cathode voltage (Figs. 9 and 10) using a gas mixture of Ne–DME in equal proportions. The presence of a light noble gas in the mixture allows higher working voltages [22,23] with respect to a mixture with argon or xenon and, as a consequence, results in higher gains. With respect to DME–CO_2 (60–40) this *lighter* mixture has been shown to have a much larger gain at the same voltage condition [24]. Our experience indicates that with this mixture it is possible to work in much safer conditions than with argon-based mixtures. Indeed, the strong suppression of UV-light emission by the Ne atoms in the avalanche process causes a significant reduction of the photon

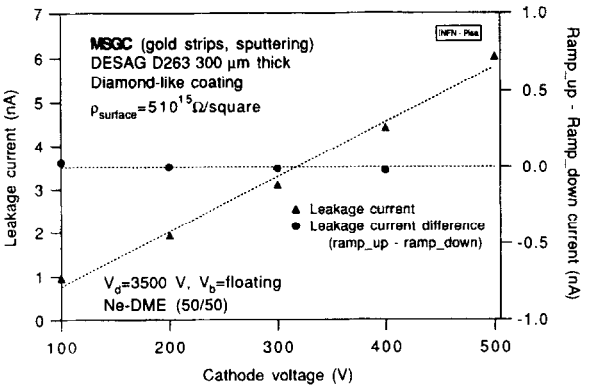

Fig. 3. Leakage current vs cathode voltage: MSGC with DLC glass (galvanic growth).

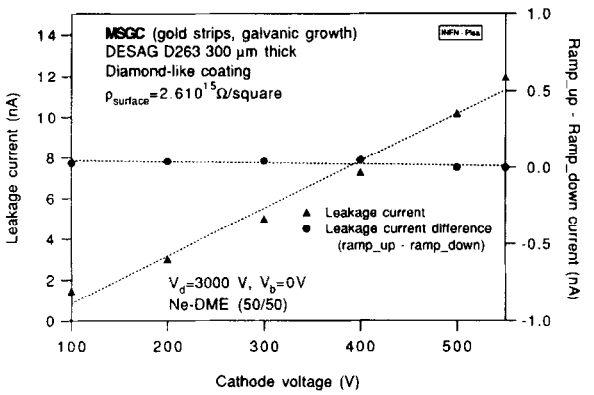

Fig. 4. Leakage current vs. cathode voltage: MSGC with DLC glass (reactive sputtering).

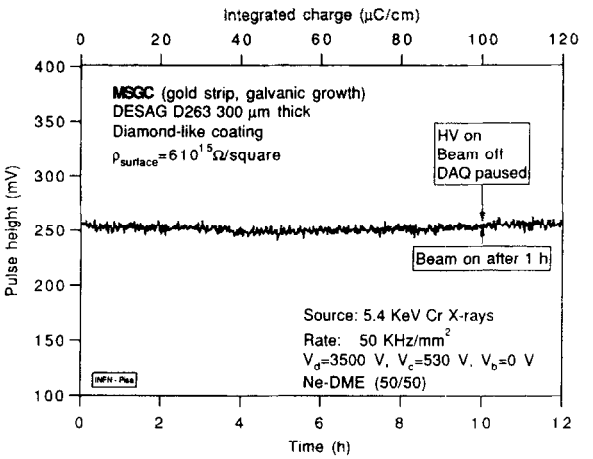

Fig. 6. Stability of response with time.

feedback which is, after all, the main factor limiting the gas gain. In the uncoated case we have observed a slightly higher gain, probably due to a reinforcement of the electric field around the collecting anodes, but also a higher dependence on the voltage conditions of the back electrode. Conversely the gain of the detector with coated substrate seems completely undependent of the presence of a back plane and of any possible re-arrangement of charge in the bulk due to it. We believe that this shielding against any substrate effects is the major advantage in the use of these kinds of coatings. An important parameter when working with very thin films is the uniformity of the coating deposition on the substrate, especially when large area detectors are required. Figs. 11 and 12 are a longi-

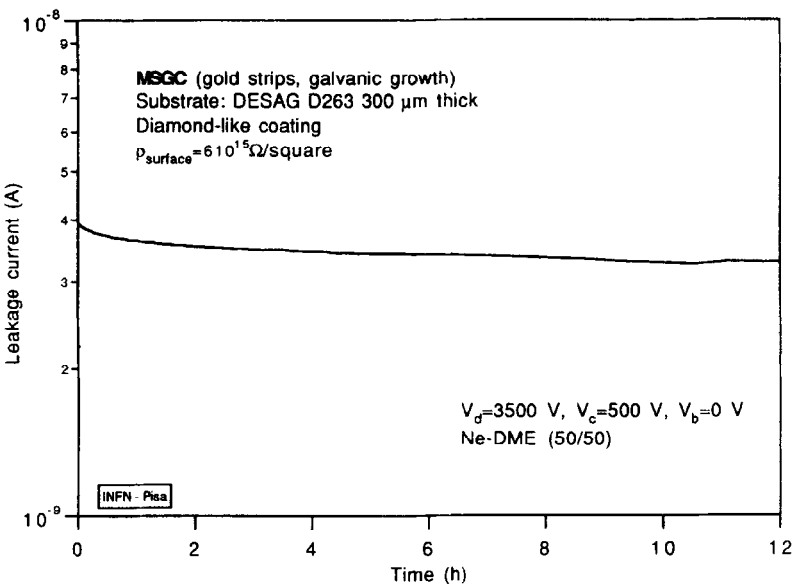

Fig. 5. Time stability of the leakage current.

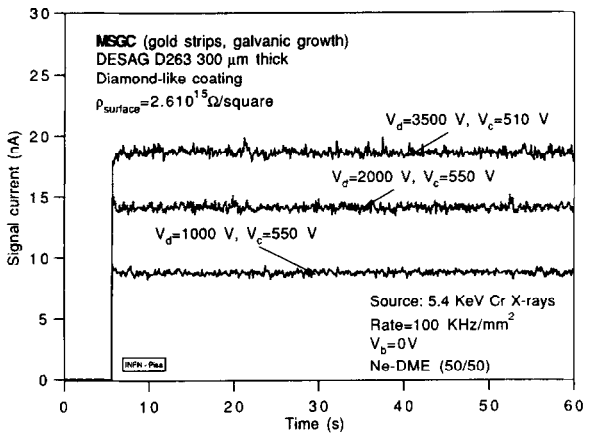

Fig. 7. Short-term measurement of gain stability (charging).

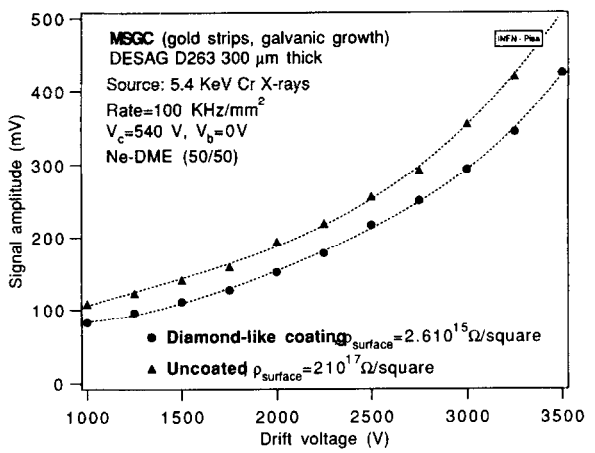

Fig. 8. Gain as a function of the drift voltage: comparison between DL-coated and uncoated glass.

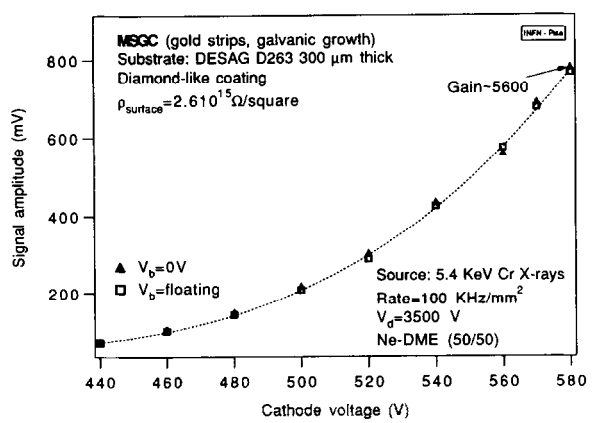

Fig. 9. Gain as a function of the cathode voltage: MSGC with DLC glass.

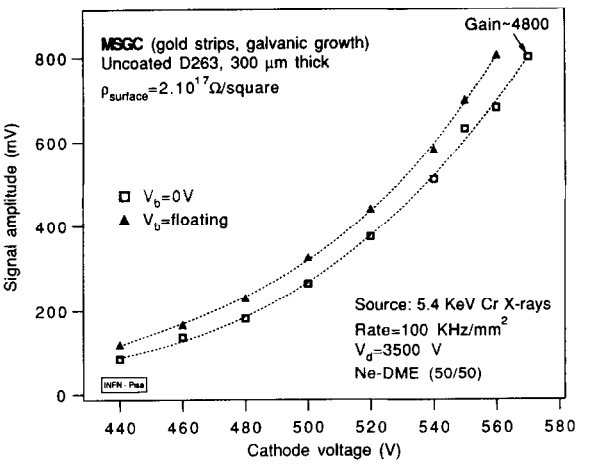

Fig. 10. Gain as a function of the cathode voltage: MSGC with uncoated glass.

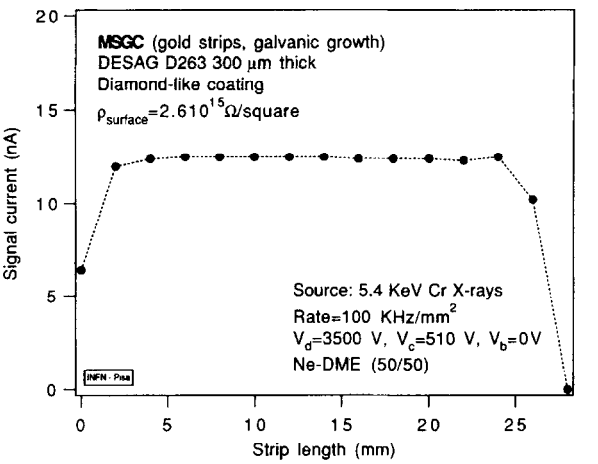

Fig. 11. Uniformity of response along the strip: MSGC with DLC glass and galvanic growth.

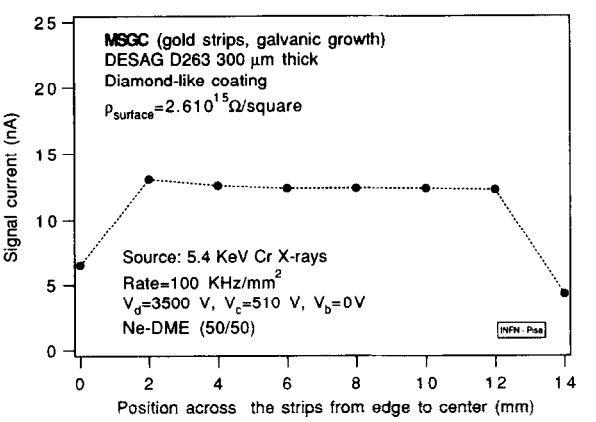

Fig. 12. Uniformity of response across the strips: MSGC with DLC glass and galvanic growth.

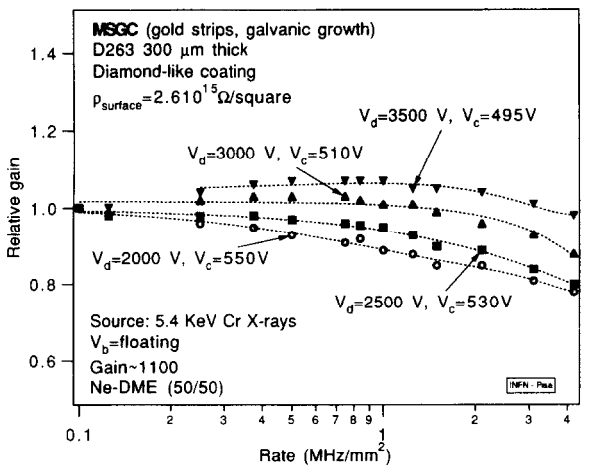

Fig. 13. Rate capability: MSGC with DLC glass and galvanic growth.

tudinal and transversal scanning of a MSGC with surface resistivity of $\sim 3 \times 10^{15}\ \Omega/\square$. We measured a uniformity of response of 1–2% along and across the strips. When high rates of ionizing particles have to be efficiently detected, the high-rate behaviour becomes a very important parameter to be studied. We have measured counting rates well in excess of 1 MHz/mm^2 in all the samples we have tested with maximum gain loss of ~10%. Fig. 13 shows the rate capability obtained with the MSGC with DLC and surface resistivity of $\sim 3 \times 10^{15}\ \Omega/\square$ at different settings of cathode and drift voltage corresponding to an average value of gain of ~1100. A comparison of the rate capability between a coated and an uncoated MSGC is shown in Fig. 14. Even if the rate capability of uncoated, but correctly biased, substrates, is enough for LHC applications, we have reached, under equal experimental conditions, a counting rate ~10 times higher with the coated MSGC than with the uncoated one.

4. Long-term tests

The deterioration of the detector response arising from long-term exposure to high fluxes of charged particles is always a critical point to overcome. Using a very clean gas system, but standard components for the assembling of the detector, such as a vetronite frame and mylar window, araldite for gluing and standard rubber O-ring for tightness, we have obtained very good results of gain stability testing a MSGC with gold strips continuously for a period of 42 days (Fig. 15). The measurement was carried out using an intense radioactive source of charged particles, 20 mC of ^{90}Sr, and a mixture of Ne(50)–DME(50). The mean avalanche charge was $\sim 3 \times 10^5$ electrons. No variation of gain was found during the whole time period which corresponds to an integrated charge of 70 mC/cm of strip. Fig. 16 shows the distribution of the mean pulse height. The spread in signal amplitude is only 2%, rms. Under the same experimental conditions and for the same time interval, the stability of the counting rate with charged particles has been monitored (Fig. 17). A very slight increase, less than 1.5%, has been measured between the first and last point. This demonstrates that the combined use of gold strips and Ne–DME mixture provides a substantial *insensitivity* to ageing, even when working in realistic conditions. We are further exploring the idea that the suppression of UV-light production during the avalanche is crucial for this insensitivity. This can be obtained by using light noble gases (He or Ne) which are quite poor UV scintillators, and at least 50% of an effective UV absorber (DME). UV-light is, indeed, a well known

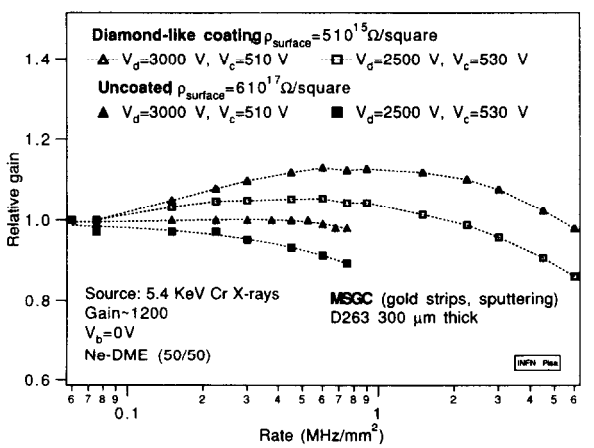

Fig. 14. Rate capability: comparison between D263 with DLC and uncoated AF45.

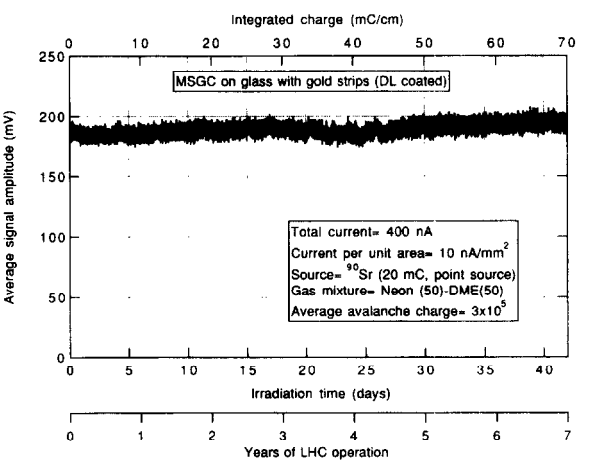

Fig. 15. Long-term stability of response with charged particles: MSGC with DLC glass and galvanic growth.

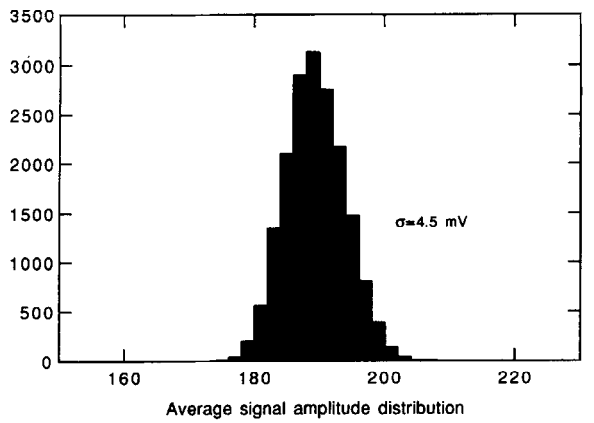

Fig. 16. Average pulse height distribution: MSGC with DLC glass and galvanic growth.

catalyst or accelerator of the polymerization processes [26].

5. Conclusions

We have extensively tested a set of MSGCs with gold strips, fabricated on diamond-like coated substrates. Surface resistivity of the order of $10^{15}\,\Omega/\square$ have been obtained at the end of the photolithographic process. Two types of gold processes for the patterning of the micro-strip structure have been tested: galvanic growth and reactive sputter etching. They have given similar results in all the measurements carried out on the MSGCs. Good uniformity of response along and across the strips, and high stability in time of both the leakage and signal current over a period of 12 h have been measured. No serious charging effects have been observed for different bias settings. Gains of ~5000 have been obtained at 570 V of cathode voltage using a gas mixture of Ne and DME 50–50. A rate capability well in excess of 10^6 Hz/mm^2 has been reached. This is nearly a factor 10 more than the rate obtainable with a MSGC with an uncoated substrate. The long-term measurement of the gain stability with charged particles, carried out for 42 days corresponding to ~7 yr of LHC operation at 50 cm from the beam axis, has shown no sign of ageing in the response of the detector. What still needs a substantial improvement is the cleanliness and reproducibility of the coating process. We have indeed detected a non-negligible increase of the defect density when working with coated glasses. This is particularly important when working with very large area plates as needed in CMS. If we will succeed in this, *under*coating of MSGCs with DLC could be one of the possible solutions to improve the stability and lifetime of the detector. Indeed what is attractive in this kind of technology is the industrial availability, a reasonable cost and the compatibility with the photolithographic processing steps. We are also trying the *over*coating technique. We have tested a first sample of MSGC coated after the patterning with a thin layer (500 Å) of DLC having a surface resistivity of $10^{15}\,\Omega/\square$, obtaining good enough performance at the beginning. In the long term we have observed a loss of signal and a worsening of the energy resolution. This effect could depend on the accumulation of charge over the insulating layer on top of the strips, but further investigations are necessary. Furthermore we plan to test a set of MSGCs where the coating has been made over a completely alkali free glass, the AF45. The choice of this substrate should be preferable in case of surface coating because the electrical properties of the bulk no longer influence the operation of the detector.

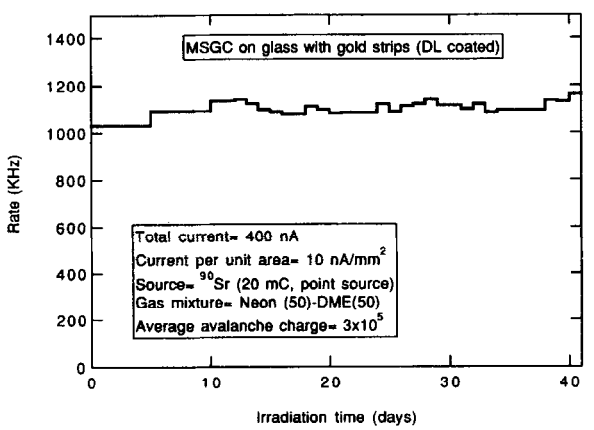

Fig. 17. Counting rate stability with charged particles: MSGC with DLC glass and galvanic growth.

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