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Abstract

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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, in different experimental conditions. The tested detectors differed in the technology adopted for the full dry processing of gold.

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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 affects significantly its lifetime. Metalisation, processing, substrate, gas purity and composition, assembling materials and components must be taken under control.

We have found [3] that a fundamental choice to get optimal performance of a MSGC is the kind of strip metal. 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 allows to avoid 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]. Vice-versa, 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, eventually produced in the avalanche by pollutants, to attach to it. Coating by polymers and therefore ageing of MSGC has been drastically reduced working with gold strips.

Another important role is played by the substrate material and, in particular, by its electrical characteristics.

It is well known infact, 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 material ($\sim 10^{15} \Omega/\square$) are preferable to avoid the effect of charging-up of the substrate [7,8,9]. 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 $\approx 5\%$ of sodium ions content) allow to obtain, if correctly biased, good rate capabilities and low charging effects [2,10]. Nevertheless, some worries still exist on the long-term behaviour of the electrical properties of the bulk. It is not yet clear if effects as ion migrations, drift of the resistivity or trapping of charge in the substrate can originate and cause some changes in the operation of the detector. On the other hand substrates with electronic conductivity (semi-conducting glasses [11]) are heavy, fragile, expensive and not industrially available for large area detectors.

As 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 semiconducting glass (Pestov glass).

Ion implantation, performed on different types of substrate (glass, quartz, SiO_2 , 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} have been obtained. On the other side, this process is slow and expensive and for these reasons not very suitable when detectors with very large area are required. Furthermore it has been shown by the RD-28 collaboration [11] that, while in some cases the resistivity of implanted glasses has resulted to be rather stable in time, in some other it has increased by orders of magnitude in 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, it is to coat the substrate surface with a thin layer with electronic conductivity. Indeed, it has been shown [12,13] that coating the surface with a layer of a material having a bulk resistivity $10^4 \div 10^5$ 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 coatings techniques are industrially available. They can be applied, at low prices, also to large area detectors and they are fully compatible with the photolithographic process.

Our group has experienced two kinds of coating techniques:

- - the plasma deposition of a thin layer of a diamond-like film, and
- - the sputtering on a thin standard glass (D263) of $\sim 1 \mu\text{m}$ of electronic conducting glass (Pestov glass).

This latter method is discussed and the results of tests on MSGCs with Pestov-glass coatings are reported in the contribution to these Proceedings by Gong, Bellazzini et al..

In this paper we show the results of the operation of MGSCs with gold strips built on glasses treated with diamond-like films.

Figure 1: Galvanic growth: full dry processing steps

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 ($\sim 1000 \text{ \AA}$) of a mixture of $sp^2 - sp^3$ states of diamond-graphite. We started to apply such technique to the surface treatment of the substrates some years ago but our first tentatives failed due to the fact that we were not able to remove the thin graphite layer on top of the film to tune appropriately the resistivity. Recently, when successful operation of MSGCs built on this kind of coating were reported by different groups at CERN [14] and SEFT [15], we came back to this solution. We exploited immediately one of the key points of this technology: the industrial availability. 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 to study and to optimize several parameters:

1. the values of resistivity;
2. the type of substrate;
3. the compatibility with the full dry processing of gold;
4. the gain, counting rate and life time of the detector;

5. the scheme of the film deposition: *undercoating*, i.e. deposition on the glass substrate before the metallic micro-strip patterning or *overcoating*, i.e. deposition directly over the micropattern.

For the production of the MicroStrip detectors we contacted two Italian Companies, ALENIA and CETEV, which use different full dry processes to pattern the gold micro-strips: respectively, the galvanic growth and the reactive sputter etching. The widths of the anode and cathode strips of all the chambers we have tested are $9\text{ }\mu\text{m}$ and $90\text{ }\mu\text{m}$, respectively, and the pitch $200\text{ }\mu\text{m}$. The overall dimension of the detectors was $26 \times 26\text{ mm}^2$.

Figure 2: Reactive sputter etching: full dry processing steps

2.1 The 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 Ti as a migration barrier) with gold on top of it. It follows the deposition of a photopolymer and the photolithographic process (b) to pattern it. Next

step is the galvanic growth of the gold layer (c) and the subsequent stripping of the photopolimer (d). The process ends with the etching of the multilayer thin film (e) down to substrate surface 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, the DESAG 263, 300 μm thick. We measured a surface resistivity at the end of the process of $3\div 6 \cdot 10^{15} \Omega/\square$.

2.1 The reactive sputter etching

Using a different gold process, the reactive sputter etching, other MSGCs on DLC substrates were produced. This process is schematically explained in fig. 2.

On a very clean coated glass substrate it is sputtered a metallic multilayer similar to the one described in fig. 1 but with an additional layer of Ni-Cr over the gold layer (a). The photopolimer, deposited on it, is masked according to the desired strip pattern and then photolitografically etched (b). It follows 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 $\sim 5 \cdot 10^{15} \Omega/\square$.

3. SHORT-TERM TESTS

Firstly we measured the static, D.C., characteristics of the detectors.

Figure 3: Leakage current vs cathode voltage: MSGC with DLC glass and galvanic growth

We 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 of 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 $2.6 \cdot 10^{15} \Omega/\square$ and $5 \cdot 10^{15} \Omega/\square$,

respectively. Both kind of detectors had ohmic behavior and no hysteresis was found in ramping up and down the high voltage (fig.s 3 and 4). We found a different behaviour in a MSGC with uncoated D263 glass. In this case the deviation from linearity can be ascribed to effects of polarization or ion migration in the bulk.

Figure 4: Leakage current vs cathode voltage: MSGC with DLC glass and reactive sputtering

The stability in time of the leakage current has been monitored for 12 hours. During this period a slight decrease of the current of only few percent has been observed. Fig. 5 shows the leakage current stability obtained for the MSGC with surface resistivity of $6 \cdot 10^{15} \Omega/\square$, in which the galvanic growth process was used.

Figure 5: Time stability of the leakage current

A set of short-term measurements were performed by irradiating the detectors at a

rate of $10^4 \div 10^5$ photons/mm² with a Cr X-ray source (5.4 KeV). The Cr tube linearity was checked to be within 2%. The gas filling used in all tests was Ne-DME.

With the same detector and for the same time interval, the stability of response has been measured under irradiation. After 10 hours of data taking the beam was switched off and the data acquisition paused for nearly one hour after which the signal amplitude was again registered.

Figure 6: Stability of response with time

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 sec) the signal current of this detector has been recorded at different bias settings.

Figure 7: Short-term measurement of gain stability (charging)

Drift and cathode voltages were changed while the back electrode was always referred to ground. No gain drop due to charging effects was observed for all the different voltage settings (fig. 7).

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

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 (fig.s 9 and 10) using a gas mixture of Neon-DME in equal proportions.

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

The presence of a light noble gas in the mixture allows to work at higher voltages [16,17] respect to a mixture with Argon or Xenon and, as a consequence, to reach higher gains. Indeed, the strong suppression of UV-light emission by the Ne atoms in the

avalanche process causes a significant reduction of the photon feedback which is, at the end, 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. Vice-versa the gain of the detector with coated substrate seems completely undependent from the presence of a back plane and of any possible re-arrangement of charge in the bulk due to it.

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

A parameter that must be taken under control, especially in the case of very thin film, is the uniformity of the coating deposition on the substrate.

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

This is very important when large area detectors are required. Fig. 11 and 12 are a longitudinal and transversal scanning of a MSGC with surface resistivity of $\sim 3 \cdot 10^{15} \Omega/\square$. A good uniformity of response was measured in both directions.

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

When high rates of ionizing particles have to be efficiently detected, the high-rate behaviour becomes a very important parameter to be studied.

Figure 13: Rate capability: MSGC with DLC glass and galvanic growth

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 $\sim 10\%$. Fig. 13 shows the rate capability obtained with a MSGC with DLC and surface resistivity of $\sim 3 \cdot 10^{15} \Omega/\square$ 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. With equal experimental conditions we reached a counting rate ~ 10 times higher with the coated MSGC than with the uncoated one.

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

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.

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

Using a highly clean gas system, but standard components for the assembling of the detector, like vetronite frame and mylar window, araldite for glueing 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 longer than 40 days (fig. 15). The measure 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 $\sim 3 \cdot 10^5$. No variation of gain was found during the whole time period which corresponds to an integrated charge of 70 mC/cm of strip.

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

Fig. 16 shows the correspondent distribution of the mean pulse height. The spread in signal amplitude is only 2%, rms.

In 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 crucial for this insensitivity is the suppression of UV-light production during the avalanche. This can be obtained by using light noble gasses (like He or Ne) and at least 50% of an effective UV quencher (DME). UV-light is, indeed, a well known catalyst or accelerator of the polymerization processes [18].

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 process for the patterning of the micro-strip structure have been tested: the galvanic growth and the reactive sputter etching. Both 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 during 12 hours, have been measured. No

Figure 17: counting rate stability with charged particles: MSGC with DLC glass and galvanic growth

serious charging effects have been observed for different bias settings. Gain 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 have 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 particle, carried out for more than 40 days which correspond to ~ 7 years 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, *undercoating* 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 *overcoating* technique. We have tested a first sample of MSGC coated with a thin layer ($500\text{\AA}$) of surface resistivity of $10^{15} \Omega/\square$, obtaining enough good 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 from the accumulation of charge over the insulation layer on top of the strips but further investigations are necessary. Furthermore we are going to test a set of MSGCs where the coating has been made over an 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 do not influence anymore the operation of the detector.

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