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DEVELOPMENT OF MICROSTRIP GAS CHAMBERS ON SUBSTRATA WITH ELECTRONIC CONDUCTIVITY

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Abstract

This paper describes several recent developments on Microstrip Gas Chambers (MSGCs). We have studied the operating behaviour of the detectors in different gas mixtures; maximum stable gains have been achieved in mixtures of argon and dimethyl-ether (DME) in almost equal proportions. Using detectors manufactured on semi-conducting glass substrates, capable of withstanding very high rates (above $10^6 \text{ mm}^{-2}\text{s}^{-1}$), we have demonstrated extended lifetime without gain modifications up to a collected charge of 130 mC cm^{-1} in clean laboratory operating conditions. We have also verified that relaxing the requirements on cleanness conditions, either in the gas mixing system or in the detector construction, may result in fast ageing of the devices under irradiation. As an alternative to the semi-conducting glass, we have developed a novel technique to coat regular glass with a thin lead silicate layer having electron conductivity; a new development consisting in coating already manufactured MSGCs with the thin semi-conducting layer is also described. The preliminary results show an excellent rate capability for this kind of devices, intrinsically simpler to manufacture.

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1. OPTIMIZATION OF MSGC OPERATING CONDITIONS

The maximum gain observed in MSGCs before breakdown can reach and exceed 10^4 , but in many cases discharges are observed at lower values. The exact mechanism of breakdown is under investigation, and probably depends upon factors that are an outcome of the manufacturing technology, such as the sharpness of the edges of strips and the surface status of the supports; the aspect ratio strips-to-insulator may also play a role, and an optimization of the MSGC geometry making use of a program that allows to compute electric fields and gain in the chambers [1] is on the way in our group. We will report here selected results concerning the choice of the operating gas; a more detailed discussion can be found elsewhere [2].

We have found that mixtures of argon and xenon with DME allow particularly stable operation at gains well above 10^3 . While most of the previous measurements were realized with small concentrations of DME [2, 3], it appears that higher safe gains can be achieved with larger concentrations, as shown in Fig. 1. For this measurement, we have irradiated a

Fig. 1: Gain as a function of anodic potential for Ar-DME mixtures.

small size MSGC with a low rate 5.9 keV x-ray source and measured the gain increasing the voltage until discharge precursors are detected (an increase of the leakage current and of the singles counting rate with source removed). The optimum is obtained at a high DME concentration, about 40%, although this requires a larger value of the anode to cathode voltage. The dependence of the maximum voltage on the quencher concentration suggests that the discharge mechanism is related to the avalanche multiplication in the gas (as against some surface phenomena), as already indicated by studies on the operation of the detectors at high pressures [4]. We suspect that one, and perhaps the dominant, mechanism of discharge is a consequence of the ejection of electrons from the cathode edges, either by field emission or ion bombardment, followed by the growth of an avalanche in the high field region around the cathode; on reaching the anode, the charge is further increased by the normal avalanche multiplication and may reach a critical size for discharge. Smoothing of the cathode edge profiles and optimization of the anode to cathode distance and of their widths are ways to improve the operation; there are indications that coating the detector with a material having a high work function allows to operate the detectors at higher voltages*.

* See the contribution of M. Salomon et al. at this Symposium

2. LIFETIME UNDER SUSTAINED IRRADIATION

For high rate-long term irradiation studies we have used the system described in [3] and here briefly summarized. MSGC plates under investigation were mounted in either of two set-ups: a "clean chamber", consisting in a stainless steel vessel with a thin aluminium window to allow irradiation, in which the plates are mounted and wired avoiding as much as possible any organic material, and a "standard chamber" realized with more conventional fibreglass frames assembled with O-rings and epoxy. The gas mixer itself was either a custom-made system using stainless steel tubing and all-metal mass flow meters (referred to as a "clean mixer"), or a more conventional, CERN's "standard mixer" that makes use of nylon tubing and various kinds of synthetic joints in the flow meters and valves. An x-ray generator permits to impart high doses of radiation on a small area of the detector; the gain of the detector is continuously monitored through a measurement of current and, if rate permits, of the pulse height spectra detected on groups of cathode strips. An independent single-wire proportional tube, exposed to an attenuated fraction of the beam, allows to correct for ambient and rate variations. The maximum rate at which the detector can be exposed without losses depends on the substrate resistivity; using a semiconducting glass support with 10^9 ohm.cm, we could expose the detector at a flux of 10^6 m m⁻² s⁻¹ [3] thus accumulating, at an avalanche size of 10^5 , about 15 mC cm⁻¹ per day of irradiation.

Fig. 2 shows the very different behaviour of detectors operated in argon-DME and argon-CH₄ mixtures, in otherwise identical conditions (the same MSGC structure in a clean box with a clean mixer).

Fig. 2: Gain as a function of irradiation dose (in mC per cm of strip) measured for argon-methane and argon-DME gas fillings.

The gain in the DME containing gas is not affected up to a collected charge of 130 mC, corresponding to a minimum ionizing particle dose of more than 10 Mrad. In the methane mixture instead, a gain increase at the beginning of operation

is followed by a fast continuing drop. While the reasons for the initial increase are not understood, the subsequent drop is clearly associated with the appearance of polymeric deposits and permanent damages in the irradiated area.

The results of measurements realized with identical detector plates in an argon-DME 90-10 mixture in various conditions and at moderate rates ($\sim 10^2$ photons mm⁻² s⁻¹) are summarized in Fig. 3. The meaning of "clean" and "standard" conditions was explained above; although we do not know for the time being which of the materials used in the standard mixer or chamber assemblies was responsible for the accelerated ageing, the sensitivity of the measurements to very small amounts of pollutants may explain why many groups have reported fast ageing in their MSGC detectors. Our observations should be considered a serious warning on the effects of choices made in the manufacturing of a detector system using MSGCs at high rates, as those foreseen for LHC.

Fig. 3: Gain modification in MSGCs under continuous irradiation for several experimental conditions.

3. DEVELOPMENT OF THIN SEMI-CONDUCTING LEAD SILICATE LAYERS

In parallel with the bulk semi-conducting substrates, we are developing various kinds of surface-treated supports. Based on the results obtained with semi-conducting glass [3], the target value for a suitable surface conductivity for MSGCs to be operated at high rates appears to be in the range 10^{13} to 10^{15} ohm/square. In the framework of the CERN R&D collaboration on MSGCs (RD-28) many types of thin resistive or semi-conducting layers have been developed and tested; in most cases however problems have appeared connected to medium and long term stability of the layer's resistivity in the actual conditions of use of the MSGCs [5].

A very promising solution is the deposition on a substrate of a lead glass silicate, with a technique developed at the INFN-Legnaro Laboratories [6,7]. The layer is made using standard RF magnetron sputtering of a lead-glass target in an argon plasma; the desired value of resistivity can be tuned

operating under reducing ($\text{Ar}+\text{H}_2$), neutral (Ar) or oxidizing ($\text{Ar}+\text{O}_2$) atmosphere. Using this technique and by careful control of the sputtering conditions, we were able to cover values of surface resistivity in the range 10^{10} to 10^{16} ohms/square with a layer thickness between 300 and 1000 Å. Note that, while the sputtering of lead silicate in thin layers is a novel development, the production of surface-reduced semi-conducting lead glass is a well established technology for the manufacturing of micro-channel plates.

Semi-conducting lead-silicate layers were deposited on a variety of supports; the most interesting for MSGCs manufacturing are thin (100 to 300 μm) boro-silicate glasses (DESAG D263) since they are commercially available in large sizes at very low cost, and have the optical surface quality meeting the stringent requirements of the photo-lithography manufacturing process. The maximum size that can be covered at present in our laboratory is of about 50 by 50 mm^2 , but larger areas will be possible in the near future using a new system now almost completed. During the sputtering process, and in order not to risk damaging the actual plate with probe attachments, a smaller control plate is also covered and its resistivity measured independently.

For the measurement of resistivity of the samples, we make electrical contacts on the plate by vacuum evaporation through a mask of a comb-like aluminium pattern, reminiscent of the MSGC structure but at a larger scale; the pattern produces an area of about 1000 squares, allowing measurements of resistivity up to 10^{17} ohm/square with a standard Giga-ohmmeter. The resistivity of the layers appears to be ohmic and stable in time under application of the moderate values of voltage, thus indicating an electronic (as against ionic) conduction mechanism; this is shown in Figs. 4 and 5, providing the measured resistivity as a function of voltage and, at fixed voltage, as a function of time for a typical sample. There seems to be an initial stabilization time, possibly due to changes in the hydrogenation or in the moisture of the plates after manufacturing; this is of course a very important parameter to watch, and detailed studies are on the way using a climatic chamber in Legnaro.

Fig. 4: Resistivity of a 1000 Å lead-silicate layer as a function of voltage.

Fig. 5: Long-term resistivity measured on a lead-silicate layer. The voltage was applied continuously to the electrodes.

A set of small size MSGCs etched on boro-silicate glass plates covered with the described semi-conducting layer are being manufactured at the present time; the first results confirm that the adherence of the lead-silicate glass to the support and of the metal to the layer is good enough to withstand the strains of the photo-lithographic processing, but this point requires further investigations. Another concern is the possible modifications of the thin layer due to the various solvents and acids used in the etching process.

4. COATING EXISTING MSGC PLATES WITH A SEMI-CONDUCTING LAYER

As an alternative to the engraving of MSGC structures on semi-conducting or surface-treated supports, we have tried to cover existing detectors built on insulating substrates with a thin layer of semi-conducting material. This approach, if successful, would greatly simplify the manufacturing process since it avoids the above-mentioned adherence and surface modification problems. An early attempt to coat existing detectors with germanium, realized by a group from the Max Plank Institute in Heidelberg, was very successful and has been described in the RD-28 Status Report [5]; detectors manufactured on glass and Upilex, that exhibit substantial gain drops at small rates due to surface charging-up, could be operated at moderately high fluxes (above $10^5 \text{ mm}^{-2} \text{ s}^{-1}$) without changes in performance after being covered with a thin germanium layer. Since however the target value of resistivity is met using very thin deposits (around 30 Å, a few atomic layers) there is some concern about the long term stability of the layers.

We have made an attempt to cover existing MSGC plates with sturdier, 300 Å to 1000 Å thick lead silicate layers, deposited by RF sputtering as described above. We know that the values of resistivity of such layers are rather stable in time, but a priori one does not know if electrons and ions produced in the avalanches can manage to reach the electrodes through

the layer without adverse effects. The preliminary results seem very promising and will be described here.

Several standard small size (30 by 36 mm² active area) MSGC plates, manufactured on DESAG D263 glass 300 μ m thick with chromium strips, 10 μ m and 80 μ m respectively for anodes and cathodes at a 200 μ m pitch⁺ (anode to anode centers), were coated with lead silicate layers in a wide range of thickness and resistivity. Two chambers were tested so far: the first, having a low surface resistivity of 10^{12} ohms/square, failed to operate due to the excessive leakage current that resulted in permanent damage (possibly due to detachment of the layer due to the local power dissipation). The second, having a 300 Å layer with a resistivity of $2 \cdot 10^{15}$ ohms/square could instead be successfully operated; it is referred to in this paper as LEGNARO II. More plates are being tested now having intermediate values of resistivity ($\sim 10^{13}$ ohms/square).

Fig. 6 shows the local energy resolution of the LEGNARO II chamber exposed to an ⁵⁵Fe 5.9 keV x-ray source at low rate; Fig. 7 shows the measured gain and a counting rate plateau measured with a fixed discriminator threshold (around 10 fC) on the chamber irradiated with the x-ray source at moderate flux. For all measurements, one third of the cathodes (50 strips) were connected together and to the amplifier, all anodes being connected to the HV through a protection resistor. The large capacitance of the detector affects of course adversely the signal to noise ratio, explaining the modest energy resolution observed (about 30% fwhm); we have also noticed position-dependent variations of gain over the active surface, probably indicative of a non-uniformity of the resistive layer; this point, that also affects the energy resolution, requires further investigation.

Fig. 8 shows the gain dependence from the back plane potential; the small variation is indicative of the "screening" effect produced by the surface current in the resistive layer. For comparison, we have reproduced the results of a similar measurement realized on an identical, non-coated MSGC.

Fig. 6: Energy resolution for 5.9 keV x-rays measured in the MSGC coated with a thin lead silicate layer.

⁺ Manufactured by Baumer IMT, Greifensee, Switzerland.

Fig. 7: Gain and counting rate plateau measured with the LEGNARO II chamber.

Fig. 8: Gain dependence from the back plane potential for a standard (uncoated) and a coated MSGC.

A measurement of medium-term gain stability at a moderate flux of 10^3 counts s⁻¹ mm⁻² is represented in Fig. 9 and at a higher rate (10^4 counts s⁻¹ mm⁻²) in Fig. 10; the coated detector shows equal and constant gain at both values of flux (full points). Again for comparison the same measurements realized with an identical untreated MSGC plate are shown in the figures, exhibiting the well known rate-dependent gain drop indicative of charge accumulation on the insulating surface.

Finally, Fig. 11 shows the measured dependence of gain on the radiation flux for the LEGNARO II chamber. This measurement has been realized exposing for short times the same small area in the detector to a collimated 8 keV x-ray beam from a generator, and measuring pulse heights (at small rates) or current with the set-up and the methods discussed extensively in [3]. The gain is not affected up to rates close to 10^7 counts s⁻¹ mm⁻², thus demonstrating the extremely high intrinsic rate capability of the coated plate.

Assuming a uniform conductivity in the 300 Å thick layer, the measured value of surface resistivity would be obtained for a bulk resistivity of around 10^9 ohm.cm; the tolerance to flux in the coated chamber, comparable to the one reached with the MSGC manufactured on semi-conducting glass of the same resistivity, suggests that bulk (as against surface) resistivity is the physical parameter playing the major role in the charge neutralization process.

The work is continuing both at CERN to ascertain the long term behaviour of the coated MSGCs under irradiation, and in the INFN Laboratory to characterize both surface uniformity and long term stability of such layers under extreme ambient conditions.

Fig. 9: Comparison of the time dependence of relative gain for a coated (Legnaro II) and uncoated (standard) MSGC, at moderate irradiation rates ($10^3 \text{ mm}^{-2}\text{s}^{-1}$)

Fig. 10: The same measurement as in Fig. 9, at higher irradiation rates ($10^4 \text{ mm}^{-2}\text{s}^{-1}$)

Fig. 11: Relative gain measured with the coated chamber as a function of irradiation rate.

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