10/30-11/5/94

CONF-94/0398-1

The Operation of Plastic MSGCs at High Rates

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Abstract

The operation of MicroStrip Gas Counters (MSGCs) on a Upilex (polyimide) substrate is described. The surface resistivity of the substrate was reduced by ion implantation or by coating with a thin film of nickel oxide. Results are presented concerning the surface resistivity and its stability. The lowering of the substrate resistivity allows MSGCs to operate at very high rates and several devices were tested in a high flux X-ray beam. Substrates with optimum resistivity showed no gain changes whereas gain changes were seen on those with higher resistivity.

MSGCs of two different pitches were produced and tested. Both have an active area 1.6 cm across and 5 cm in a direction parallel to the electrodes. The first device contains 80 anode-cathode pairs with an inter-anode separation, or pitch, of 200 μm . The anode and cathode widths are 12 and 88 μm respectively. The other device, which contains 40 anode-cathode pairs, has a pitch of 400 μm and 20 and 88 μm wide anodes and cathodes. With present quality, 75% of the prints we receive are defect free, the remainder having only one defect. We now print 200 μm and 400 μm pitch MSGC patterns plus some test structures on a 11 cm $\times$ 11 cm sheet of Upilex. This demonstrates our ability to produce large patterns using fabrication processes optimized for Upilex [1].

I. INTRODUCTION

Microstrip gas counters are a new type of particle detector developed for tracking applications in future high luminosity experiments, such as the Large Hadron Collider (LHC) at CERN. The performance requirements imposed on the detection system by these new accelerators warrant the development of completely new technologies, such as MSGCs, to overcome the limitations of current wire chamber technology. Two of the key features provided by the MSGCs are improved spatial resolution and high count rate capability. These features also allow MSGCs to be used in medical imaging applications where low photon energies are involved, such as mammography. The MSGC's capability to detect individual photons at a high rate would allow the fast acquisition of an X-ray image and would significantly reduce patient dose.

The requirement that the MSGC be able to operate in a high flux environment imposes strict constraints on the structure, materials and processing used in the fabrication of the MSGC. Ultimately, each MSGC must demonstrate reliable operation, i.e. maintain a stable gain with time and with flux in excess of $10^5 \text{ mm}^{-2}\text{s}^{-1}$. In this report, we show that an MSGC which consists of a pattern of gold electrodes deposited on a suitably treated Upilex (plastic) substrate, easily exceeds the high count rate requirement of next generation colliders, and matches the requirement for medical imaging applications.

II. SUBSTRATE CHARACTERISTICS

It is expected that, in order to achieve a stable avalanche gain at particle fluxes as high as $10^5 \text{ mm}^{-2}\text{s}^{-1}$, the substrate of the MSGC must either be a bulk conductor with a bulk resistivity of $10^{11} \Omega \text{ cm}$ or display a surface resistivity, ρ_s , in the range of 10^{13} to $10^{14} \Omega/\square$. Otherwise, the high rate performance is compromised by the deposition of avalanche ions on the material between the electrodes. This results in a modification of the field in the multiplication region in the gas above the anode, and a loss in gain.

A. Resistivity Modification

Polyimide plastics are good candidates for MSGC substrates because of their low mass, flexibility, and good radiation hardness. We use Type-S Upilex [2] which has excellent surface quality and better scratch resistance than Kapton [3]. However, this material has a high volume resistivity of $10^{17} \Omega \text{ cm}$ and exhibits a value of ρ_s in excess of $10^{18} \Omega/\square$ for our 125 μm thick substrates. The surface resistivity was lowered using the techniques of ion implantation or coating with a thin film of nickel oxide (NiO).

The ion-implantation was performed by Spire [4] who used 80 keV argon ions and total doses ranging from 10^{14} to $5 \times 10^{15} \text{ ions/cm}^2$. Surface resistivities of 10^{11} to $6 \times 10^{15} \Omega/\square$ have been obtained. The conductivity is not

modified via the incorporation of a dopant in the matrix, as is the case for semiconductors, but by the formation of a 0.1 μm thick amorphous carbon layer on the substrate's surface [5].

Alternatively, a thin coating of nickel was deposited over the microstrip pattern by sputtering from a nickel target in an atmosphere of argon at 100 mTorr. The resulting film, measured to be 30 to 50 nm in thickness, was almost completely oxidized. The resulting ρ_s was found to slowly increase with time. Thus, for the NiO coated MSGC discussed in section III B., ρ_s was found to start at $10^{12} \Omega/\square$ and to stabilize at $5 \times 10^{13} \Omega/\square$ in a matter of weeks. The measured surface resistivity was larger than that simply inferred from the film's thickness and from the bulk resistivity of NiO. Hence, the final ρ_s may also depend on the structures in the film which in turn are strongly influenced by the sputtering parameters [6].

B. Radiation Hardness

In some applications, the MSGCs will be exposed to very high radiation fields. Polyimides are known to have excellent radiation hardness; tolerances to gamma, electron and neutron doses as high as several giga-rads without change of mechanical properties are specified by the manufacturer.

In the LHC environment, the MSGCs will be located in regions of the inner tracking detector that will receive neutron doses of the order of 10^{13} neutron $\text{cm}^{-2}\text{yr}^{-1}$. To check the stability of ion-implanted Upilex we measured the resistivity of a substrate before and after exposure to approximately 10^{14} neutrons cm^{-2} . This exposure was made at the Spallation Neutron Source at DRAL in the U.K.. We found that for a sample of ion-implanted Upilex with a resistivity of close to $10^{14} \Omega/\square$ the resistance changed by less than 20%. This change was smaller than the measurement uncertainty.

C. Resistance to Chemical Attack

There have been reports [7] [8] that polyimides are susceptible to chemical attack from dimethylether (DME) and carbon tetrafluoride (CF_4) gases which are commonly used in MSGCs. We measured the effects of exposure to both DME and CF_4 on Upilex, Kapton, various materials used to construct MSGC chambers, and Heat Seal Connectors (HSC) [9], used to make connections to the prints. In addition we studied white Tedlar [10], a polyvinylfluoride (PVF) which is a bulk-conducting MSGC substrate candidate.

Samples of each material were prepared and their masses were measured to an accuracy of 0.06% using a Mettler H10T scale. The length between two scribe marks on each sample's surface was measured to within 0.1% using a travelling microscope. The samples were exposed to pressurized (3 bar absolute) CF_4 and DME for 2 months. As a control samples were also exposed to dry nitrogen at atmospheric pressure.

Polyethylene, several fibreglass laminates (G5, G7, G10, G10/FR4, FR4), and the HSCs all had mass or length changes of less than 1% with DME and no significant change with CF_4 . Polyvinylchloride (PVC) and Tedlar reacted with the DME as evidenced by significant mass or length increases. It appeared that the DME reacted with the halogens in these materials and X-ray analysis showed the chlorine content in the PVC was significantly less after the exposure. The polyimide samples, Upilex and Kapton, did not have any measurable mass or length changes with either gas.

III. TESTS USING X-RAYS

A. Experimental Method

The high rate measurements were performed using an Oxford Instrument, copper-targeted X-ray generator. The main X-ray was an 8 keV K_α Cu line which meant that a photon of this energy, when absorbed in a gas, typically produced 15 times more ionization than a minimum ionizing particle and hence presented a worst case scenario for rate effects. Typically, the 400 μm pitch MSGCs were operated with a cathode voltage, V_c , of -650V to -680V and a drift voltage, V_d , of -2000V. The anodes were grounded and the backplane voltage, V_b , was varied from 0V to V_c . For the 200 μm pitch device, V_c was lowered to -450V. In both types of detectors the drift gap was 4.0 mm.

By using a combination of X-ray generator parameters (voltage and filament current), collimation and filtration, a range of interaction rates in the MSGC from 25 to almost $10^7 \text{ mm}^{-2}\text{s}^{-1}$ could be maintained on an area as small as 4 mm^2 .

Two different methods were used to determine the gain stability with flux. They were: i) pulse amplitude method and ii) steady state current method. In the first case, the pulses from a single anode or a group of anodes were amplified using an Ortec 142 PC charge-sensitive preamplifier. Its signals were further amplified using an Ortec 450 main amplifier and were acquired using a personal computer based MCA. One then compared the calibrated peak position, N_e of a measured spectrum (shown in figure 1), to the primary number of electron-ion pairs produced by an 8 keV photon, N_p . For example, $N_p = 307$ for a 90/10 mixture of argon and isobutane. The measured gas gain was simply $G = N_e/N_p$. This method could not be used at very high rates because of pile-up in the electronics.

It should be noted that the pulse amplitude method provided a relative gain measurement. The size of the signal seen by the MCA also depended on the ratio of the positive ion collection time to the shaping time of the amplifier. The voltages and shaping times remained constant throughout the experiment, resulting in a fixed factor between the relative gain and the absolute gain.

At high flux, the steady state avalanche current, I_{ss} , flowing from the anodes to the cathodes and to the drift electrode was measured. Provided that the interaction

Figure 1: Cu x-ray spectrum obtained using a 400 μm pitch MSGC at low rate. The 8 keV peak and Ar escape peak are visible.

rate, R , was known, this provided the avalanche charge and the true gas gain free from shaping time effects. In this case $G = I_{ss}/R\bar{N}_p e$, where $\bar{N}_p$ is the average number of primary electron-ion pairs produced per absorbed X-ray. $\bar{N}_p$ is taken as the average pulse height from a spectrum acquired at low rate, such as shown in figure 1.

At very high X-ray tube output the interaction rates could not be measured directly by counting pulses. Hence, using a "bad geometry" which guaranteed a low R even at the maximum X-ray tube filament current, it was shown that the incident X-ray flux was proportional to the filament current to better than 3%. Second, with the "tight" geometry used to measure the MSGC gain at high flux, the X-ray tube output was calibrated at low filament current, where R could be measured directly. This calibration curve was then used to yield the value of R at high flux. The error in this case was found to be less than 10%.

There was an overlap region around $10^4 \text{ mm}^{-2}\text{s}^{-1}$ where the gain could be measured in relative terms, using the pulse amplitude method, and in absolute terms, using the steady state current method. This allowed us to combine the low flux data and the high flux data and to present, on the same plot, curves extending from $10 \text{ mm}^{-2}\text{s}^{-1}$ to $2 \times 10^6 \text{ mm}^{-2}\text{s}^{-1}$.

B. Results

The high rate operation of 3 types of MSGCs produced on Upilex is presented in this section. In the first category we report on MSGCs produced on substrates which have values of ρ_s in the range of 10^{13} to $10^{14} \Omega/\square$. Such substrates were either ion-implanted or were coated with a NiO film. Next, we study the high flux behavior of MSGC produced on substrates with higher values of ρ_s in the range of 10^{15}

Figure 2: Gain vs backplane voltage for the 3 resistivity ranges. The two lower resistivity prints exhibit shielding from backplane potential, whereas the very high resistivity print shows a pronounced backplane dependence.

to $10^{16} \Omega/\square$. Finally, we discuss the rate capability of MSGCs produced on insulating substrates, i.e. having values of ρ_s in excess of $10^{18} \Omega/\square$.

1) *Low Resistivity Substrate:* We tested two 200 μm MSGCs produced on ion-implanted Upilex and a 400 μm device produced on a NiO coated Upilex substrate. For the first two devices, values of ρ_s of 2×10^{13} and $2 \times 10^{14} \Omega/\square$ were measured. In the case of the NiO device, ρ_s was $5 \times 10^{13} \Omega/\square$ at the time of testing.

One effect of having a conducting surface layer, whether ion-implanted or coated with NiO, was to shield the gas region from the backplane voltage. This translates into a gain which was independent of the backplane voltage, as shown in figure 2.

The MSGC with the NiO coated substrate displayed some gain loss even at low rate, as shown on figure 3. A reversible gain drop of the order of 20% was observed over the space of 1 hour. The loss of gain was localized and fully reversible upon removal of the source. The rate of the decrease in gain was correlated to the incident photon beam intensity but the final gain value appeared independent of the photon flux. This apparent gain loss is unexplained in light of the low resistivity of this sample. The two ion-implanted devices did not show this gain drop, despite their higher values for ρ_s . For the NiO coated device, the following high rate results were obtained in the condition where the gain has been allowed to stabilize.

Figure 4 displays the dependence of the gain on the detected photon flux for the three low ρ_s samples under study in this section. The ion-implanted devices were tested in a 90/10 Ar/isobutane mix while the NiO coated device was tested in a 90/10 Ar/DME mix. As expected, one observed

Figure 3: Gain as a function of time for various rates obtained for the MSGC produced on a NiO coated substrate. One observes a reversible gain drop of about 20% in 1 hour

the independence of the gain on flux up to the maximum rate used of $10^5 \text{ mm}^{-2} \text{ s}^{-1}$ or greater.

2) *High Resistivity Ion-Implanted Substrate:* Some detectors were produced on substrates having high surface resistivities in the 10^{15} to $2 \times 10^{16} \Omega/\square$ range. Such detectors displayed a *transient* backplane dependence, i.e. a gain which reacted to changes in the backplane voltage but which recovered in seconds to the original gain value. The gain, once stabilized, was independent of the backplane voltage, as shown on figure 2.

The gain variation with flux for four such detectors is shown in figure 5 for tests performed in a 90/10 mix of Ar/isobutane. We observed that the gain increases with flux in the low flux region, attained a maximum around $5 \times 10^4 \text{ mm}^{-2} \text{ s}^{-1}$ and fell off. This behavior will be discussed in section IV. Such detectors were successfully used in a telescope configuration at a beam test and yielded good efficiency and spatial resolution [1].

3) *Insulating Plastic Substrate:* Figure 2 also displays the backplane voltage dependence of a MSGC with a value of ρ_s in excess of our $10^{18} \Omega/\square$ detection limit. The substrate was originally implanted and the absence of conductivity was blamed on an overly vigorous plasma cleaning prior to the metalization. Many devices of this type were obtained and they all displayed the backplane voltage dependence as well as rapid gain loss using a only a weak ^{55}Fe source. This corresponds to a flux of a few particles $\text{mm}^{-2} \text{ s}^{-1}$ and higher intensity studies using the X-ray generator were not attempted. We also tested a $400 \mu\text{m}$ MSGC produced on another plastic, Tedlar, having a bulk resistivity of $10^{14} \Omega \text{ cm}$ and an equivalent surface resistivity of $5 \times 10^{16} \Omega/\square$. At the following operating voltages:

Figure 4: Gain vs flux for two $200 \mu\text{m}$ ion-implanted devices and for a $400 \mu\text{m}$ NiO coated device.

Figure 5: Gain vs flux for $400 \mu\text{m}$ high resistivity ion-implanted MSGCs.

$V_k = V_p = -600\text{V}$ and $V_d = -1000\text{V}$, the Tedlar MSGC displayed the same gain loss behavior as the high ρ_s Upilex prints. Other groups have found that Tedlar prints can be made to operate at reasonably high rates using a suitable set of operating voltages [11].

IV. DISCUSSION

The low resistivity devices ($\rho_s < 2 \times 10^{14} \Omega/\square$) show stable gains with X-ray fluxes of up to $10^6 \text{ mm}^{-2}\text{s}^{-1}$. This confirms and expands upon results obtained by other groups with low resistivity substrates such as semiconducting glass. At the other extreme, the high resistivity ($\rho_s > 10^{18} \Omega/\square$) substrates show the expected gain loss with even quite low rates.

The intermediate resistivity samples ($10^{15} < \rho_s < 10^{16} \Omega/\square$) show an interesting gain variation that first increases and then decreases with increasing flux. A possible explanation of these features is described here.

The difficulty in modelling changes in gas gain as a function of particle flux is that the gas gain is dependent on the electric field in the MSGC which is itself dependent on the various currents flowing in the gas and in the substrate. As the avalanche current is itself a function of the gas gain, the problem is a circular one. We therefore take an iterative approach, first calculating the static field from the voltages applied to the electrodes. The distribution of avalanche current is then determined from the fraction of field lines that start (or end) on each electrode and the substrate surface. Currents crossing the gas-substrate interface are modeled as small current sources (or sinks) on this interface, which are then fed back into the electric field calculation. New current distributions are generated and the process is continued until a stable situation is reached.

Using this approach, the following qualitative results were obtained. Bulk conducting prints were characterized by a current of ions crossing into the substrate near the cathode strips, which had the effect of lowering the E-field over the anode at high flux and reducing gas gain. This effect was diminished for surface conducting prints for two reasons: a lower fraction of field lines beginning in the avalanche region ended on the substrate surface, and the conducting layer was more efficient at removing this excess charge.

Electrostatic field calculations for MSGCs have indicated that the presence of a thin conducting layer has the effect of spreading the field lines in the vicinity of the anode onto the nearby substrate [12]. The result is an increase in the effective anode width, and a loss in peak electric field (corresponding to a loss in gas gain). Our model suggested that in such a detector some avalanches occur over the substrate near the anode resulting in a flux of electrons crossing into the substrate. Prints with a highly conducting surface layer swept away this extra charge without visible effect, but prints with more resistive surface layers experienced an elevated anode E-field due to these currents, and

therefore an increased gas gain. Furthermore, the calculated gain increased as the flux, and therefore the electron current, increased. This is precisely the response of our high resistivity ion-implanted detectors.

V. CONCLUSION

We have presented the high rate operation of MSGCs produced on plastic substrates. These devices are now manufactured with large defect-free active areas. In addition, we presented two processes by which the surface resistivity of the substrate can be lowered to within the range which allow stable operation up to flux values of $10^6 \text{ mm}^{-2}\text{s}^{-1}$. These fluxes are similar to those which would be found in a medical imaging environment, and exceed the requirements of LHC operation. We have found that devices produced on those ion-implanted substrates which still display a large resistivity exhibit a gain which increases, goes through a maximum and then decreases with increasing rate. This behavior was qualitatively described using a model.

ACKNOWLEDGMENTS

We would like to thank Mike Edwards of DRAL for irradiating the polyimide samples. This research has been supported by the National Sciences and Engineering Research Council of Canada.

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