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Gas Microstrip Detectors on Resistive Plastic Substrates

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Abstract

Plastics are desirable as substrates for gas microstrip detectors (GMDs) because of their flexibility, low density and long radiation length. GMDs have been fabricated on white Tedlar which has bulk electrical conductivity and on ion-implanted Upilex which has a thin electrically conductive layer on the surface of an insulator. The effect of back plane voltage on the gain of such GMDs is investigated. Three 200 μm pitch, ion-implanted Upilex GMDs were recently tested in a high intensity beam at CERN. The anode signals were read out using fast, low noise, high gain amplifiers. Preliminary results of the test are presented.

1. Introduction

Gas Microstrip Detectors (GMDs) offer a low-cost, radiation-hard solution to the problem of precision tracking of charged particles at high counting rates. Almost all detector proposals for the new high-luminosity hadron colliders supplement inner silicon microstrip detectors with outer GMD trackers [1] [2].

Fabrication methods for GMDs borrow heavily on photo-lithographic techniques developed by the micro-electronics industry. Methods very similar to those used to make glass production photomasks for integrated circuits are employed. Much of the worldwide research on GMDs has, therefore, concentrated on detectors built on rigid substrates such as glass, quartz, and silicon.

To improve tracking momentum resolution and to minimize the probability of photon conversions, GMDs should be constructed on the thinnest practical substrates. Operation of a 10 cm x 10 cm area GMD constructed on a 200 μm thick silicon wafer has been reported recently by the Pisa group [3]. GMDs of similar dimensions, on borosilicate glass, are being developed by the NIKHEF group [4] for use in the SMC experiment at CERN.

However, rigid thin substrates (including some of the more desirable electronic conductive glass substrates) are fragile and require very careful handling during processing steps to minimize breakage. An alternative to these rigid but breakable glass-like substrates is resistive plastic. The radiation length contribution of a thin plastic substrate GMD tracker can be significantly less than that of a glass GMD tracker because of the low densities and the long radiation lengths of plastics [5]. Figure 1

shows a typical plastic GMD to establish the terminology used in this paper.

2. GMDs on Resistive Plastics

Standard micro-electronic photo-lithographic methods cannot be used to fabricate GMDs on plastic substrates. A new technology has to be developed which requires close collaboration with industry. Until recently, insufficient industrial support has been a limiting factor and progress in the field has been slow. As a result, only a few groups have thus far published results on plastic GMDs. [6] [7].

Bouclier *et al.* [7] have fabricated GMDs in-house at CERN on Kapton [8] and white Tedlar [9] substrates using printed circuit board techniques. GMDs built on Kapton (which is an insulator) show a rapid drop in gain, even at low rates, soon after turn on. White Tedlar (bulk resistivity $4.0 \times 10^{14} \Omega \text{ cm}$) GMDs, on the other hand, could withstand rates as high as $10^6/(\text{mm}^2.\text{sec})$ without any drop in gain for short periods of time. The Tedlar GMDs, however, still showed long-term gain drop, presumably because the resistivity of Tedlar is too high.

An ideal GMD substrate candidate should have current-voltage proportionality. This implies that the electrical conduction mechanism is based on electrons, unlike many common glasses which derive their conductivity from the movement of positive ions. A Texas A & M University group has identified a number of plastic substrate candidates [11] with suitable electrical conduction properties.

In addition to substrates with bulk resistivity, it is possible to use insulating supports with one surface layer rendered slightly conductive by suitable surface treat-

ment. The surface layer of an insulator can be imparted a controlled resistivity by ion-implantation or by deposition of a thin film of a semiconductor. Surface modified polyimides, such as Kapton or Upilex [10], appear to be quite promising as GMD substrates.

Polyimides can withstand relatively high processing temperatures and generally have good mechanical and handling characteristics. They are also radiation hard. Ion-implanted polyimides should be even less affected by radiation, as they are already saturated with radiation damage by ion bombardment.

3. R & D on Plastic Substrates

For the past two years, in collaboration with industry in Canada and the US, the Carleton/CRPP group has been working on developing the technology to build GMDs on thin plastic substrates such as 100 μm thick white Tedlar and on 125 μm thick ion-implanted Upilex. A special effort has been made towards solving the problems of large area metalization and lithography on thin plastic substrates.

The Spire Corporation has developed low cost, large area ion-implantation processes for producing polyimide sheets with controllable surface resistivity [12]. Substrates of desired surface resistivity can be produced readily by the vacuum baking of polyimide sheets followed by a controlled ion-implantation dose of 80 keV Ar^+ ions. No active cooling is used during the ion-implantation procedure.

The uniformity of surface resistivity for some ion-implanted samples with a nominal surface resistivity of $4.0 \times 10^{13} \Omega/\square$ has been measured. The actual measured

values for a large 30 cm x 30 cm sheet varied from $1.0 \times 10^{13} \Omega/\square$ to about $1.0 \times 10^{14} \Omega/\square$. This spread in the surface resistivity (constant within a factor of 10) should be quite acceptable for the production of GMDs.

Radiation hardness tests for both Tedlar and ion-implanted Upilex have been made at the spallation neutron source at the Rutherford Laboratory in the UK. The surface resistivity of both types of samples was found to be unchanged within a measurement error of about 15% after an exposure to 10^{13} neutrons/cm² (equivalent to about 10 years for the SSC forward tracker, the ITD).

As plastic substrates are not rigid, it is difficult to make wire bond connections to plastic GMD prints. A convenient method has been found and is currently being used to make reliable electrical connections between the electrodes on the plastic prints and the traces on the printed circuit board where the GMD print is mounted. Several different types of high density heat seal connectors (HSCs) [13] are available for use with large flat panel display systems. An HSC contains hot melt thermoset adhesive with electrically conductive traces. HSCs, suitable for GMD application, may be fabricated on 25 μm thick polyester film. The conductive traces are made of etched copper for pitches less than 250 μm . For larger pitches, the traces are made of silver ink with embedded gold micro-spheres.

3.1 Print Fabrication on White Tedlar

Following earlier work by the Sauli group at CERN [7], GMDs with aluminum electrodes were produced by Precision Photo Mask Inc. (PPM), Montreal, Canada. The overall quality of lithography for the 1.6 cm x 5 cm prints was good. Aluminum

was deposited by sputtering and has good adhesion. The prints were produced by wet etching. The resistance of the deposited metal was about 10 times higher than that of pure aluminum. This is suspected to be due to contamination during the sputtering stage. The high metal resistance led to a noticeable reduction of signal amplitudes for events located farther away from the external connection points of the anode strips to the fast, low-impedance amplifiers. The chamber life time was also reduced in case of sparking.

PPM has also produced large area (15 cm x 15 cm) GMD prints on Tedlar with aluminum electrodes. The exercise was intended mainly as a demonstration of the feasibility of large area metalization and micro-photo-lithography on plastics. The quality of lithography on the demonstration prints was similar to that of the 5 cm length aluminum on Tedlar prints. Recently, using wet etching methods, PPM has produced 5 cm length GMD prints on Tedlar with gold electrodes. Metalization was done by sputtering gold on top of a thin layer of nickel which serves as an adhesion layer. The quality of the prints is good. The resistivity of the gold metal layer is as expected; there do not appear to be any contamination problems. The gold prints on Tedlar are currently being tested. PPM is also in the process of producing small and large area gold prints on ion-implanted polyimides.

Figure 2 shows a photograph of a Tedlar GMD print with gold electrodes. The print was made by PPM, Canada. The electrical connections to the mounting printed circuit board were made using high density heat seal connectors (HSCs).

3.2 Print Fabrication on Ion-Implanted Polyimides

Most of this work has been done at the in-house facilities of Spire Corporation. The process involves image reversal photo-lithography and metalization followed by lift-off. Metalization is done by electron beam evaporation. Multilayer Ti-Cr-Au metalization is needed to improve adhesion on the ion implanted surface. As metal adhesion is generally better on non-implanted Upilex, it may be advantageous to do the ion implantation after the lithography. GMD prints, which have been ion-implanted after lithography, have been produced but not yet tested.

Figure 3 shows a scanning electron micro-photograph of a recent generation Spire print on ion-implanted Upilex. The quality of lithography is good in terms of adhesion, edge quality and defect density. Three such prints were used recently in a beam test, described below, at CERN.

The in-house facilities at Spire currently limit the largest size of GMD prints to about 10 cm x 10 cm. Work is in progress to fabricate larger area prints on ion-implanted polyimides with the help of outside vendors.

4. Operation of Tedlar and Ion-implanted Upilex GMDs

At present, only preliminary data on rate effects and charging phenomena on Tedlar GMDs exists. Charging effects, similar to those reported by the Sauli group [7], have been seen. GMD prints on ion-implanted Upilex, because of their lower surface resistivity, are much better at withstanding high rates without loss of gain. Figure 4 shows the gas gain for a 200 μm pitch ion-implanted Upilex GMD as a function of the counting rate of 8 keV copper K_{α} x-ray photons. There was no change in the GMD gain up to the highest measured rate of about 10^6 photons/(mm².sec).

In terms of operating characteristics, we find it easier to get higher gains for Tedlar GMDs as compared to those fabricated on ion-implanted Upilex. For GMDs on Tedlar (which has bulk electrical resistivity) gas gains above 3000 are easy to obtain for a variety of gases. For GMDs on ion-implanted Upilex (with an electrically conductive surface layer), the gains are generally lower.

The effect of the back plane potential on the gas gains has been investigated. The back plane voltage contributes significantly to the gas gain for Tedlar GMDs. With increasing back plane voltage, the gas gain increases for Tedlar. For an ion-implanted Upilex GMD there is no effect; the gas gain remains constant with increasing back plane voltage. Figure 5 shows this different behaviour for the two types of GMDs.

The difference in the gas gain between GMDs constructed on bulk conductive and surface conductive supports can be understood as follows. With the decreasing resistivity of the surface, the voltage gradient in most of the anode-cathode gap becomes almost linear and the electrical field almost constant. The effective width of the anode strips increases and the anode surface electric field is reduced. At the same time, the thin conductive layer at the surface acts as a Faraday cage. This layer shields the GMD region above from the back plane electrical charges which would otherwise increase the anode surface field.

Electric field calculations were done using a simple model to understand the differences between GMDs built on bulk and surface conductive supports. The CERN GMD electrostatic simulation program MSFIELD [14] was used. The model for the calculation has a two layer substrate. The bottom layer is a bulk conductor with

the resistivity of Upilex ($10^{17} \Omega \text{ cm}$). The resistivity of the top $2 \mu\text{m}$ thick layer is varied between $10^{14} \Omega \text{ cm}$ and $10^{17} \Omega \text{ cm}$. At the low end of the range of calculation, one has the case of a thin conductive layer on a high resistivity bulk support; i.e. ion-implanted Upilex. At the upper end of the range of calculation, one recovers the case of a single layer substrate with a uniform bulk resistivity.

Figure 6 summarizes the results of the model calculation. The figure shows the the average electric fields $1 \mu\text{m}$ above the surface of the anodes for a $200 \mu\text{m}$ pitch GMD as a function of electrical resistivity of the surface layer. The two sets of curves are for back plane voltages of 0 and - 500 volts respectively. For both cases all other voltages were constant; anodes at ground, cathode at - 500 V and the drift plane at - 1600 V. When the resistivity of the thin surface layer is small compared with the resistivity of the bulk volume, there is complete shielding, and the back plane voltage has no effect on the anode surface field. When the resistivity of the surface layer equals that of the bulk substrate, there is no shielding, and the back plane voltage contributes to the anode surface field.

5. Preliminary Beam Test Results of Ion-Implanted Upilex GMDs

In a RD-28 [15] beam test, performed jointly with the UK groups, three $200 \mu\text{m}$ pitch GMDs on ion-implanted Upilex were tested in a high intensity beam at CERN during the month of July, 1993. Each GMD had 24 read-out channels; 16 individual anodes and eight groups of 8 anodes ganged together. The GMD prints were connected to the electronics and the high voltage lines on the supporting printed circuit boards using HSCs as described above. The gas used was argon/isobutane 80/20 and the gas gain was about 800.

The anodes were read out using 24 channel front end amplifier cards with QPA02 chips. The QPA02s amplifiers were originally designed at Fermilab [16] for silicon strip detectors. The amplifier cards were supplied by Fermilab and modified by us for GMD applications. Figure 7 shows the differential output signals of the amplifier for an impulse charge injected at the input. The rise time is less than 10 ns with the total pulse width being about 30 ns. There is some ringing for very fast signals. After installation in the CERN test beam area with the GMD connections made, the response for Fe^{55} 5.9 keV x rays was somewhat slower at the end of the 15 meter cable: a rise time of about 20 ns and a total pulse width of about 50 ns. The measured amplifier gain was about 10 mV/fC and the r.m.s. noise charge (at the input of the amplifier) achieved in the test beam area was about 2000 electrons.

The anode amplifier signals were read out into a DL300 [17] 100 MHz flash ADC (FADC) system. The FADC and the data acquisition system were provided by our RD28 collaborators from the UK. Figure 8 shows schematically the beam test set-up and the read-out and the data-acquisition system. There were a total of 48 FADC channels available for our use with the 3 Upilex GMDs and so 16 individual anodes per GMD were selected for FADC read-out. However, several anodes were disabled due to high voltage problems.

During the test, the intensity of the 205 GeV/c secondary beam was varied from fairly low rates to a high of about 10^5 particles/(mm².sec) during the spill. No variation in pulse height was observed even at the highest beam intensities. At a beam intensity of 10^4 particles/(mm².sec) during the spill, Figure 9 shows the FADC hits in the anodes of the three GMDs for an event in which a particle traversed the ac-

tive regions of all three GMDs. For clarity, the regions of the FADC signals above a nominal threshold of 15 mV are shaded black.

Figure 10 shows the efficiency of one of the 3 GMDs. Efficiency was calculated using events where signals in two of the GMDs indicated a particle passing through the active region of the third GMD. Efficiency is shown as a function of the threshold required to identify a signal in the third GMD. The FADC pedestal and the measured r.m.s. noise charge are also shown in the figure.

6.0 Conclusion

Gas microstrip detectors have been fabricated on thin resistive plastic substrates. Micro-photo-lithographic techniques, suitable for plastic substrates, are being developed in collaboration with industry. Progress has been slow compared to that on more traditional rigid substrates. However, the technical problems are being solved. Feasibility of fabrication of large 15 cm x 15 cm GMD prints on thin plastic substrates has been demonstrated. At present, polyimide plastics with modified surface resistivity appear to be excellent candidate substrates for GMDs. Small 5 cm long, 200 μ m pitch GMDs, fabricated on ion-implanted Upilex, have been successfully tested in a high intensity beam at CERN. A lot still remains to be done in terms of perfecting the fabrication of high quality, large area prints and in terms of systematic studies of aging and high rate effects for GMDs on thin plastic substrates.

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FIGURES

FIG. 1. A typical gas microstrip detector on a thin, resistive plastic substrate.

FIG. 2. A 400 μm pitch GMD print with gold electrodes on white Tedlar made by PPM, Canada. 500 μm pitch heat seal connectors (HSCs) were used to make electrical connections to 1 mm wide anode and cathode pads at 2 mm pitch.

FIG. 3. A scanning electron micro-photograph of the anode-cathode region near the ends of the anodes. The 200 μm pitch GMD print with gold electrodes was made by Spire Corporation on ion-implanted Upilex.

FIG. 4. Measured gas gain as a function of detected x-ray rate for a 200 μm pitch ion-implanted Upilex GMD. The surface resistivity of the print was about $10^{15} \Omega/\square$.

FIG. 5. Measured gas gain as a function of the back plane voltage for a Tedlar and an ion-implanted Upilex GMD. The back plane voltage strongly influences the gain for the GMD built on bulk conducting Tedlar.

FIG. 6. The average electric field at the anode surface as a function of the resistivity of the surface layer for back plane voltages of 0 and - 500 volts.

FIG. 7. Response of a QPA02 amplifier to an impulse charge.

FIG. 8. Schematics of the Beam test set-up and read-out electronics for the three 200 μm ion-implanted Upilex GMDs.

FIG. 9. FADC hits for an event in the three ion-implanted Upilex GMDs. The data for the middle GMD is shifted by 1 FADC channel to account for a slight misalignment.

FIG. 10. GMD efficiency as a function of FADC pulse height threshold. The pedestal and the r.m.s. noise charge at the input of the amplifiers are shown. The beam intensity during the spill was 10^4 particles/(mm².sec).

Fig 1

Fig 2

Fig 3

Fig 4

Fig 5

Fig. 6

Fig. 7

Fig. 8

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GMD1

GMD2

GMD3

Fig. 9

Fig. 10

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