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Gas Microstrip Detectors on Polymer, Silicon and Glass substrates*

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We present results on the performance of Gas Microstrip Detectors on various substrates. These include a 300 μm anode-anode pitch pattern on Tempax borosilicate glass and ABS/copolyether, a 200 μm pattern on Upilex "S" polyimide, Texin 4215, Tedlar, ion-implanted Kapton, orientation-dependent etched flat-topped silicon ("knife-edge chamber"), and iron-vanadium glass, and a 100 μm pitch pattern on Upilex "S" and ion-implanted Kapton.

1. INTRODUCTION

Gas Microstrip Detectors (GMD) are, in principle, one of the most useful among the position-sensitive devices under development [1,2]. One can conceive of GMDs in many configurations: from postage stamp to order of square meter sizes and from pitches typical for MWPCs down to the order of tens of microns. We do not yet know the true boundaries of the GMD "phase space".

We are endeavouring to make GMDs of the smallest pitch possible and of the largest surface area recognizing reasonable economic constraints. Additional limitations are given by technologies and mechanical properties associated with particular GMD substrates. Thus, one may eventually find that the finest pitch is not consistent with the largest area device area. But we do not have definitive limits on these variables as of yet.

2. SUBSTRATE RESEARCH

Over the past year, we have, in collaboration with members of the Intermediate Tracking Group [3] of the SDC collaboration [4] and F. Sauli's laboratory at CERN [2], investigated many possible substrate candidates and are continuing to do so. We have made first-pass evaluations of on the order of 100 different substrates for planar GMDs [5]. In parallel, a longer-term effort on non-planar geometries is now bearing some fruit. The planar GMD substrates evaluated have all been plastics or glasses.

First pass evaluations are made by testing the surface resisitivity of sample materials in air. The electrodes are painted or shadow-masked (evaporated Al) on and are parallel lines of about 50 mm × 15.5 mm in the case of painted electrodes and 25 mm × 7.75 mm when the shadow mask is employed. The gap between lines was about 1.59 mm

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wide in most cases. If the sample is stable and ohmic, the bulk resistivity is also measured by painting square patches on opposite sides of a thin section and surface resistivity tests are done in ultra–high–purity N_2. The apparatus consists of a Droege-type low current power supply, a pico-ammeter and a field cage. Typically, voltages up to 2500 volts are used. Our tests differ from ASTM D-257 standard in that we do not employ a guard electrode. Typically, adding a guard electrode raises the measured surface resisitivity by about 30% . We do not recalibrate our data.

The canonical figure of merit used is a $R_{surface}$ of $10^{13}\,\Omega/\square$. This level of conductivity seems to be low enough to defeat surface charge up at high rates, high enough to give reasonably low levels of Joule heating in an SSC/LHC experiment and high enough to limit shot noise to a few mV. This is a rule-of-thumb number but we get very interested in a material if it is within a factor of ten of the preferred $R_{surface}$ and/or is tunable to this value. Also, the material must have ohmic behaviour, have the promise of radiation hardness and not be significantly water-vapor dependent for conductivity. An example is shown in Fig.1.

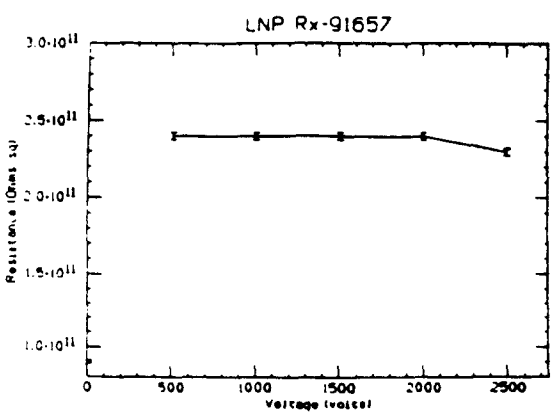

Fig.1 Surface resistivity in air of ABS/copolyether

Tested materials that have looked good by these criteria are polyurethanes, polysiloxane silastics, copolyether (-O-R-O-R-O-) alloys of thermoplastics such as ABS and polyesters, flat display glass, FeO loaded glasses such as Pestov (iron-vanadium), Murano and Moscow glasses, and ion-implanted polyimides (Kapton and Upilex "S").

Each of these materials presents unique processing problems. Polyurethanes and the polysiloxanes are very soft and we do not know how to metallize them. We have tried Al vapor deposition on polyurethane sheets but adhesion was poor. ABS-copolyether, a thermoplastic, is very chemically reactive to normal processing solutions but we have successfuly put a microstrip pattern on this material.

3. CHAMBER TESTS

As of this date, we have studied chambers made on the substrates listed in table 1. The resistivities quoted are measured in air as described above.

Table 1 Chambers built and tested

substrate	thickness $[mm]$	pitch $[\mu m]$	$R_{surface}$ $\Omega/\square$
Tempax glass	1.75	300	$3\cdot10^{15}$
ABS-copolyether	1.55	300	$2\cdot10^{11}$
Si knife-edge	0.275	200	$> 10^{17}$
Upilex "S"	0.127	100, 200	$4\cdot10^{16}$
ion-impl. Upilex	0.127	200	$1\cdot10^{11}$
Tedlar	0.10	200	$1\cdot10^{16}$
Texin 4215	0.25	200	$2\cdot10^{13}$
Fe/V glass	1.0	200	$2\cdot10^{12}$
ion-impl. Kapton	0.127	100, 200	$4\cdot10^{13}$

The knife-edge chamber is built from a (100) silicon wafer. A pedestal structure is formed by orientation dependent etching, followed by oxidizing a 3 μm thick standoff layer

at the shaped surface, then coating the surface with aluminium and etching part of it away again to form anodes and cathodes onto the pedestal areas. The SiO_2 surface, a good insulator, showed an unmeasurable high resistivity in its chamber configuration, placing it in the region somewhere above $10^{17}\,\Omega/\square$. Unlike previous versions of knife edge chambers [6], the anode pedestal is not sharpened to an actual edge (Fig.2).

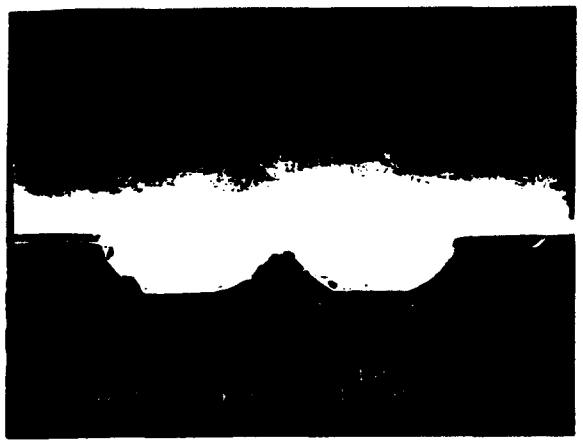

Fig.2 Cross section of knife-edge chamber

3.1 Experimental Setup

Of the chambers listed in table 1, we have manufactured one to a few each in-house, except for the two ion-implanted ones (Upilex and Kapton) which were made using our mask and provided by industry [7]; those two feature gold metallization while we have been using aluminium throughout.

Our standard mask for chamber manufacturing has a pitch of 200 μm anode to anode. The widths of the anodes and shaping cathodes are about 8 μm and 144 μm, respectively (Fig.3). On the side, there are small test fields of 200 μm and 100 μm pitch, the latter being obtained by reducing the shaper cathode of the former by 100 μm to 44 μm (Fig.3b). An earlier mask with 300 μm pitch, used on Tempax and ABS-copolyether, has a larger gap between the anode and shaper cathode, leaving those at widths of 13 μm and 44 μm. The drift plane in our test setup

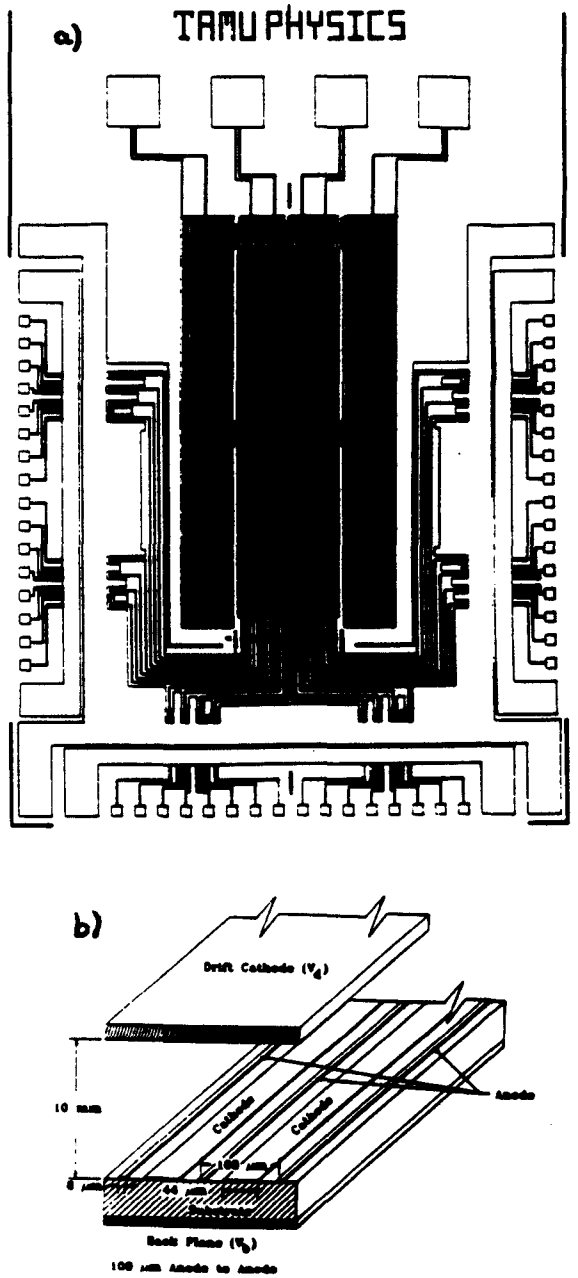

Fig.3 Chamber design:
a) 200 μm pitch mask
b) closeup view, 100 μm pitch

is placed 10 mm above the chamber pattern. We use P-10 as our standard operating gas and in a few instances we have recently worked also with Argon-Isobuthane at a 75-25 mixing ratio. No effort has been spent yet to optimize the choice of the gas. For our tests, we usually connect all anodes together and thus read just one combined signal out. The signals are processed through a preamplifier (ORTEC 142PC) and a main amplifier (ORTEC 485 or similar) into a multichannel analyzer. The in-house tests were all performed with a ^{55}Fe X-ray source. The iron-vanadium chamber has also been exposed for a few days to a low intensity beam of charged pions of 7 GeV/c momentum at CERN, and some measurements with 8 keV X-rays have been done at Rutherford-Appleton Laboratory on the ABS-copolyether chamber in cooperation with the respective local groups (F.Sauli et al., J.E.Bateman et al.).

3.2 Results

The spectra from the ^{55}Fe source show routinely a resolution for the 5.9 keV line of about 20% or a little higher. We obtained our best resolutions with the Tempax chamber (17.7%) and our homemade 200 μm Upilex chamber (16.7%, Fig.4).

For the two 100 μm chambers, the results are not much different although overall the gain is less and the escape peak from the Argon gas is less well discernible. A comparison of the electric fields in a 200 μm and a 100 μm chamber is given in Fig.5, for equal voltages in the two cases chosen to be those for the largest gain we have obtained with the 100 μm Upilex chamber. (For a discussion of the Upilex chambers, including the gains, see below subsection 3.5.) To date, there is no evidence that, in principle, one could not proceed to even smaller pitches. The gain relative to the 100 μm case will be lower again but we have not attempted at all yet to push the gain up hard to its limits.

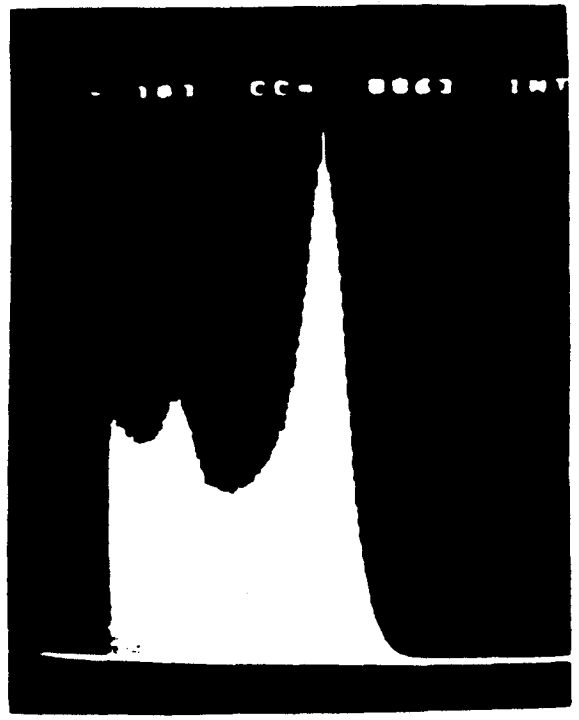

Fig.4 ^{55}Fe spectrum (Upilex, 200 μm)

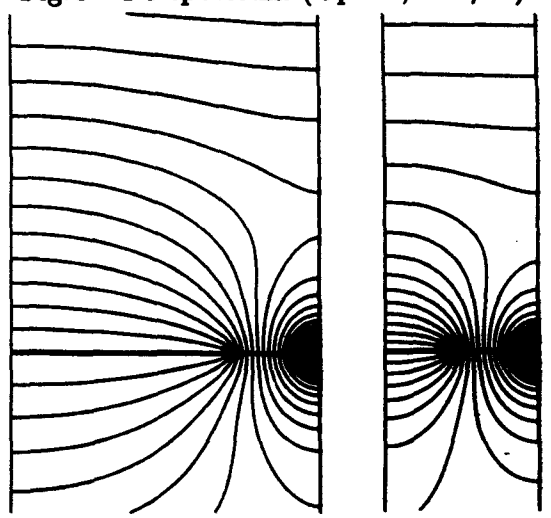

Fig.5 Electric fields for pitches 200 μm and 100 μm; half cells are shown cathode to anode.

This has been confirmed by Bateman and

Connolly [8] who are currently studying our ABS-copolyether chamber.

In the following, we discuss some of our chambers in a little more detail.

3.3 *Al* on TEMPAX borosilicate glass

Tempax is easy to metallize with evaporated *Al*. One obtains a good ^{55}Fe spectrum with this substrate and it has been studied as a chamber extensively at CERN and Rutherford Appleton Laboratory. We have achieved 17.7% resolution FWHM on a 300 μm pitch Tempax chamber. While a group at Rutherford Appleton Laboratory has reported that Tempax glass cannot take the heat associated with sputtering *Au* or wire bonding [9] we have recently successfully bonded gold-wires to gold metallization on Tempax and so far not observed any damages due to the bonding. Our resistivity data show that the material is non-ohmic with a measured resistance in a chamber configuration of about $10^{17}\ \Omega/\square$, more than an order of magnitude beyond our measurements both in air and dry nitrogen. Even a 1.75 mm thick Tempax chamber shows marked sensitivity to backplane voltage.

3.4 *Al* on ABS-copolyether

The ABS-copolyether [10] we originally obtained was impossible to process. However, we obtained a metallizable grade and finally succeeded to manufacture a chamber on it though this material is not made for lithography. Its measured resistance in air is $2 \cdot 10^{11}\ \Omega/\square$. In dry N_2 this increases 50 fold and reaches an asymptotic limit if a few days under 1000 Volts. Polyester/copolyether has but a 10 fold increase in R while exposed to 400 V in dry gas. The resistivity is tunable and copolyether is used in dry cell battery applications for charge transport. At first, a 300 μm chamber would not hold voltage without considerable noise but after several days of conditioning, it settled down and caused no further problems in this regard even after exposures to air. It demonstrates little sensitivity to the backplane voltage although it is with 1.55 mm thickness thinner than the Tempax. Spectra on the order of 20% FWHM resolution were routinely obtained. This material is ohmic. Bateman and Connolly at Rutherford Laboratory have exposed this chamber to 8 keV X-rays [8]. At rates in the order of $10^3\ mm^{-2}\ s^{-1}$, they observed gain losses of about 25%, accompanied by a deteriorated resolution, that were immediately recovered when the incident rate was reduced. At a rate of $2.5 \cdot 10^4\ mm^{-2}\ s^{-1}$ applied for over two hours, permanent damage in form of reduced gain was found. A careful analysis of these effects and more data is in progress.

3.5 *Al* on unimplanted Upilex

Upilex "S" is a Kapton-like material. It is easily aluminized whereas we have had no success with evaporating *Al* on Kapton. Data with ^{55}Fe source are very similar to that of ABS and Tempax. However, we employed a much more realistic GMD mask (Fig.3a) and had 200 and 100 micron anode-to-anode pitch chambers working on Upilex. (For a spectrum from a 200 μm chamber, see Fig.4.) The anode line width is measured to be 6 μm, a little smaller than the 8 μm on the mask due to the etching procedure. The nominal cathode line widths are 144 μm and 44 μm respectively.

We obtained a gain of 2000 with the 200 μm device at a shaper voltage of $-385\ V$ and a gain of 500 with the 100 μm test area at $-360\ V$ on the shaper cathode. The other voltages were kept at $-600\ V$ for the drift cathode, at ground with the help of a megaohmish resistor for the anode, and at $-240\ V$ and $-260\ V$ on the backplanes. The gains are shown in Fig.6 as a function of the shaper cathode voltage with all others being kept constant. These voltages are, taking out the

trimming for higher gains, fairly typical for all chambers we have worked with to date.

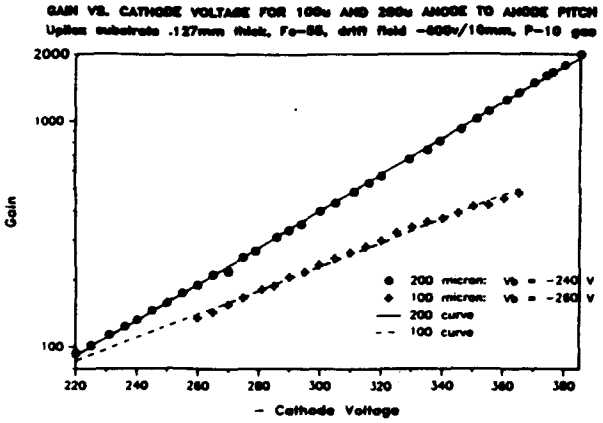

Fig.6 Gain from Upilex chambers (200 μm and 100 μm pitches)

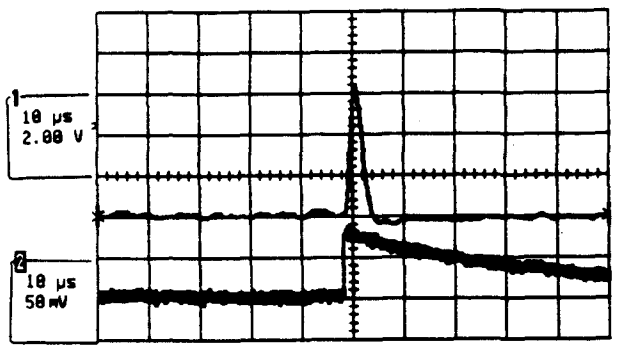

Fig.7 Pulse shapes from preamplifier (lower trace), main amplifier (upper trace)

3.6 *Au* on implanted plastics

The ion-implanted Upilex chamber is a 200 μm device that suffers from having too low a resistivity: it is 10^{11} $\Omega/\square$ which is totally independent of water vapor. Shot noise overwhelmed any possible signals. Increasing resistivity by two orders of magnitude should cure this problem. An additional noteworthy result from working with this chamber is that we successfully practiced wire-bonding on this material.

On implanted Kapton, we have looked so far mostly at the 100 μm version. Its surface resistivity ($4 \cdot 10^{13}$ $\Omega/\square$) is in the desired range, and the chamber was quickly made operating. The pulse shapes for the 100 μm chamber after the preamplifier and the main amplifier and a pulse height spectrum are shown in Figs.7 and 8. In this case we have used Argon-Isobuthane (75-25 mixture) as the drift gas. At identical operating voltages it showed only little difference compared to P-10.

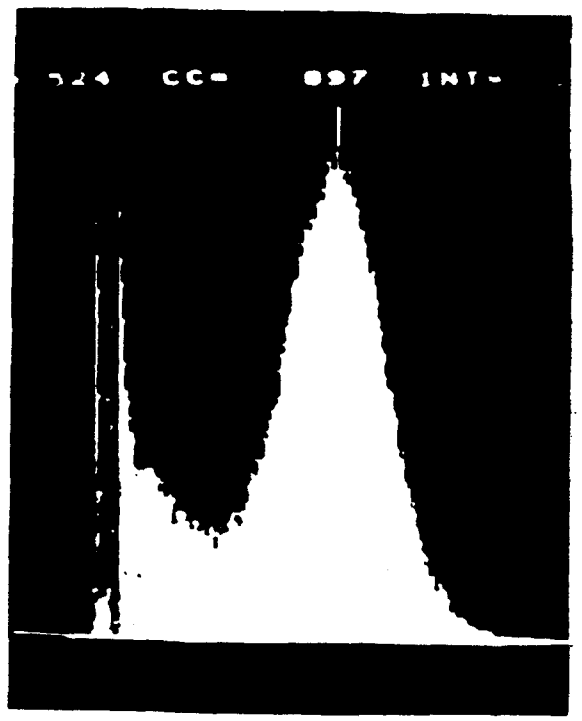

Fig.8 ^{55}Fe spectrum, implanted implanted Kapton, 100 μm

3.7 *Al* on Knife Edge Chamber

We obtained a gain of close to 2000 on a ODE-etched Knife Edge chamber (Fig.9). The electrode structure is nearly identical to that of the 200 μm unimplanted Upilex

device and it runs nearly about as well except that the increased capacitance associated with having only a 3μ SiO_2 layer standing off the back plane made for poor spectra. Voltages are very close to that of Upilex for the same gain.

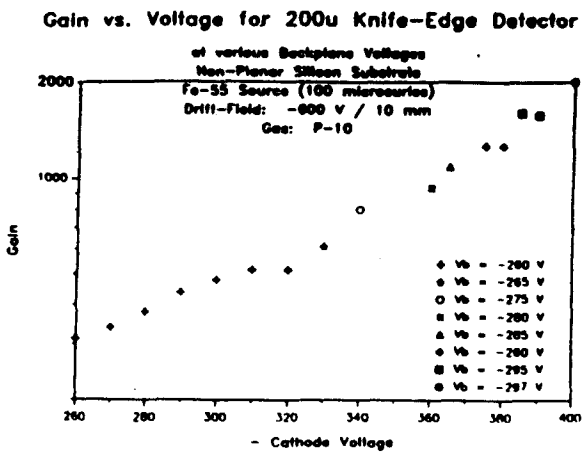

Fig.9 Gain from knife-edge chamber

3.8 *Al* on Iron Vanadium Glass

The iron-vanadium glass shows a surface resistivity of $1.2 \cdot 10^{12}\ \Omega/\square$, very close to the desired $R_{surface}$ value. The production of a chamber has been fairly easy. The resolution for the $5.9\,keV$ signal from ^{55}Fe was measured to be about 20% in the very first test of the chamber. The signal size corresponded to a gain around 500-600, no tuning for increased gain nor improved resolution has been done on this chamber.

4. SUMMARY

We have studied a large number of substrate materials for gas microstrip chambers and have built chambers on some promising materials. A number of plastics have turned out to be good candidates warranting further attention, as has the iron-vanadium glass. The nonplanar knife-edge design also appears to be a competitive option. Testing for the specific high-rate, high-radiation environment at hadron colliders like SSC and LHC has just begun and will be intensified in the immediate future.

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