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NEW RESULTS ON THE DEVELOPMENT OF THE GASEOUS PIXEL CHAMBER

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Abstract

The gaseous pixel chamber is a wireless detector working in limited streamer mode, developed within the LAA project at CERN. Its excellent properties have already been described. We present here the latest tests and results obtained during the development of this device. Included are various tests that we have made to extend both the range of operational voltage and that of the gas mixtures. Finally, we will discuss some ideas we have for further development.

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1. INTRODUCTION

The gaseous pixel chamber has been described previously [1–3]. Essentially, it is a foil consisting of a small anode spot surrounded, some distance away, by a cathode area in the same plane. Figure 1 shows a cross-section of this device built of Kapton foil. Both geometries, the square cell and the hexagonal one, shown in fig. 2, work well, but obviously with different operational characteristics. The voltage is applied to the anode spot by means of a plated-through hole. We mount this foil in a gas-tight box, through which we cause various gas mixtures to flow. Electrons are liberated by a charged particle passing through the gas volume above the foil. These electrons undergo gas amplification as they approach the anode. Finally, limited streamers are formed and therefore large signals appear on various electrodes. The various designs we have tested in the past are listed in table 1. We will describe this work below.

2. ELECTRIC FIELD

The cross-section of the gaseous pixel chamber is shown in fig. 1. Although it is a surface device, there are two places where the thickness of the Kapton foil may be important. The first is the surface of the Kapton insulator, just above the high-voltage bus line. The other place is around the anode. This is a 500 μm diameter pad on the surface of the Kapton, connected via a 200 μm diameter plated-through hole to the anode bus line on the back of the foil. Field lines will emanate from the sides of this plated-through hole, and also from the pad and bus lines on the back of the foil. These field lines will pass through the surface of the Kapton close to the anode spot. We show these field lines¹⁾ in fig. 3, assuming that the surface is not charged by free electrons or ions, and ignoring the effect of the high-voltage bus itself. We believe that surface charges, which may build up from the primary ionization in the non-sensitive volume, will easily be removed by the very low conductivity of the Kapton base material, at least for rates of the order of tens of kilohertz per square centimetre. The gas volume in which electrons from primary ionization are guided towards the anode (sensitive volume) is shaded.

Field lines, which end on the Kapton surface between the anode and the cathode, are considered to be useless from the point of view of signal generation. These field lines, which are bent towards the anode inside the Kapton, would end on the rear bus line, if it was there. So, for a small surface area between the anode and the surrounding cathode above the bus line, the shape of the sensitive layer is possibly changed. However, there must still be some field lines which start on the upper surface of the cathode and end on the anode. The strength of the electric field, seen by ionization from tracks which cross the pixel close to the

¹⁾ Calculations of electric potentials were done with the finite element program ANSYS of Swanson Analysis Systems Inc., Houston, Texas, USA.

bus line, may be different from other parts of the pixel. This may give a variation of the plateau curve of the chamber as a function of localization of the track inside the pixel. We have not observed effects such as this with efficiency or gain. However it is not easy to measure variations inside the pixel with statistical significance.

The foils described in the following tests have all been mounted above a ground plane. The ground plane is a glass epoxy printed-circuit board 0.8 mm thick with copper laminated to one side. The pixel foils were attached to the non-copper side with double-sided tape. The copper side was grounded. Obviously the electric field in the Kapton substrate, and in the gas volume above, will be modified by the proximity of this ground plane. This proximity can be changed by altering the thickness of the ground board and the geometry of the ground plane. Studies on these effects are still under way.

Nowadays there is a lot of interest in other devices built on surfaces. These are known as gaseous microstrip detectors [4, 5]. The operation of these devices seems to depend strongly on the substrate used. There has been an attempt to build these devices on a Kapton foil [6, 7]. However, the gain has a dependence on the flux of particles; also the Kapton has a memory of exposure to high fluxes that can last for extended periods (days). We have not observed such effects with our pixel devices, which seem stable after an initial time period of 10 min or so. Further work is in progress to try and understand this difference in behaviour between the two devices.

3. FOIL-THICKNESS TESTS

We have performed two tests concerning the thickness of the foil. The first was to have extra dielectric printed onto the surface. This was actually 'solder mask' material²⁾ used in standard printed-circuit manufacturing. The geometry and dimensions of this mask are shown in fig. 4. The second test was to make the Kapton foil thicker. The thickest Kapton foil available is 125 μm . In our case this was covered with two layers of glue to make a total substrate thickness of 175 μm . We asked the manufacturer³⁾ of the copper-covered Kapton material to glue two layers of Kapton together, before adding the copper layers. Thus we had a laminate of two layers of 125 μm thick Kapton which, together with the glue layers, made a laminate of dielectric substrate of 325 μm thickness in total.

We constructed 'chambers' with these two foils by adding a 'roof' board. The geometry was of type 1 (see table 1): the roof board has a large pad mounted opposite to the anode and a grid aligned with the foil cathode plane; the foil and the roof board are 8 mm apart. We installed these two chambers in a test beam in the CERN East Hall. Data were taken with a FORTRAN program developed with the MacUA1 [8] system running on a Macintosh

²⁾ The material we used was LAMINAR DM dry film solder mask manufactured by Morton Thiokol SA, Igny, France.

³⁾ GTS FRANCE, GTS Matériaux flexibles SARL, Les Ulis, France.

II computer. In fig. 5 we show the efficiency for detecting 6 GeV/c pions for the standard 'mask' and thick Kapton foil in pure isobutane.

We find the detection efficiency for the mask pixel chamber to be higher than the standard pixel (100% compared with 98%). We think that this is due to having the dielectric thicker above the high-voltage bus line, so that fewer electrons are needed to charge the surface (and also fewer are needed to keep the surface charged). The single-thickness and double-thickness foils operate in a very similar manner. However, we found, when doing radioactive source tests in the laboratory, that the voltage where spontaneous breakdown occurs is higher with the thick Kapton. For this reason we used the thick Kapton substrate for the remainder of the tests.

4. GAS-MIXTURE TESTS

With the double-thickness Kapton material we made foils with a 10 mm square cell grid (type 2) and a 6 mm hexagonal cell geometry (type 3). We used various gas mixtures during our beam tests. In fig. 6 we show the response of the type 2 chamber to minimum ionizing particles with four different argon-isobutane gas mixtures. In fig. 7 the same measurements, but with three different CF₄-isobutane gas mixtures, are shown. Both sets of measurements were done with a rate of approximately 20000 particles per cm²/s.

The admixture of argon reduces the operating voltage of the foil by ~ 500 V (with 10% of argon). However, the maximum operating voltage also seems to be reduced. So, overall, in terms of plateau length, there is no gain with this mixture.

The CF₄-isobutane gas mixture behaves differently. It does not actually lower the working voltage, but it extends its maximum value. The plateau stays flat at the almost 100% level over more than 1.5 kV. This extension of the maximum operating voltage can perhaps be explained by the dissociative electron capture in CF₄. In high electric fields the drifting electrons can gain sufficient kinetic energy between collisions to crack the CF₄ molecule [9, 10]. One of the remaining parts takes the negative charge and has very little mobility. This effect could shift the spark mode to higher voltages. However, when the CF₄ fraction is pushed higher, more and more electrons are lost. So, finally, the efficiency stays low. This is shown in fig. 8.

In fig. 9 we show the results of efficiency measurements with the type 3 chamber. With various gas mixtures, including dimethyl ether and ethane, the anode voltage is considerably lower with this than with the type 2 chamber. However, there are difficulties in getting a really long plateau. This geometry, together with the 375 μ m anodes, seems to define a limit in the reduction of the cell size.

Off-line, a 'pixel' was selected by having the highest anode and pad signals. The information from the external drift chambers was then used to localize the track position within this particular pixel. This is shown in fig. 10 for an 8 mm pitch hex type chamber (type 4).

5. SMALL ANODE CHAMBERS

5.1 Description of the chopped-wires chamber

One of the parameters that we believe to be important is the diameter of the anode spot. Obviously the diameter of the hole defines its lower limit. The smallest hole that we can produce at CERN is 200 μm in diameter and is mechanically drilled. Lasers can be used to make holes (either by burning or ablation) and are already being used for mass production of circuit boards. These are still early days for our use of this technology, but we have started trying to construct foils with very small laser-made holes. In the mean time we have tested a foil of type 1, where we used a 200 μm diameter unplated hole, and no anode pad. We then inserted a 50 μm gold-plated tungsten wire. The connection to the high-voltage bus was performed with a conductive epoxy. We tested two versions of this chamber: one where the wire protruded above the foil by about 300 μm , and another where the wire was cut level with the surface. Both chambers worked well, but the chamber with the protruding wire worked better, especially for high concentrations of isobutane. The foil with the cut-off wires was also much more noisy and we think this is caused by having the sharp dielectric edge close to the high-field region. In some cases the cut wire disappeared down the hole. For these reasons we will only present the results from a foil with the wire protruding by 300 μm (type 5 chamber). However, we think that it will not be necessary to have anodes that protrude from the surface by 300 μm to obtain results as good as ours with this device.

5.2 Test results of the chopped-wires chamber

We constructed the chamber using a roof board in a way similar to that described above. All the anodes were 'bussed' together. In fig. 11 we show the efficiency for detecting 6 GeV/c pions for a variety of argon and isobutane mixtures. For pure isobutane the knee of the plateau is at 4 kV. This should be compared with 6 kV for a standard pixel chamber with the same anode-to-cathode spacing. The voltage where sparking occurs (~ 7 kV) should be the same (we did observe a spark at 6 kV with the small anode chamber, but think that this may be due to the 'home-made' nature of the device). Remarkably, we found that it worked with very little quencher in the gas mixture. With the standard pixel chamber we found that with more than 20% argon in isobutane, the chamber had voltage breakdown before it reached full efficiency for minimum ionizing particles.

In fig. 12 we show the charge spectrum for various gas mixtures with the chamber operating at the plateau voltage. The first plot shows limited streamer operation with pure isobutane. The second plot also shows limited streamer operation with higher gain due to argon. The third plot has a double peak. We think that the higher peak is when two streamers are formed (on each side of the anode), since, with this concentration of isobutane, photons produced in the streamer process can travel to a region where a second streamer can grow.

The final two plots probably represent the situation when the pixel is working in proportional mode (or some mode where a low number of photons are produced).

In fig. 13 we show the charge spectrum for the chamber, with 96% argon and 4% isobutane, at its operational voltage of 1000 V (data identical to those of fig. 12e). There is a very clean peak separated from the pedestal. There are also peaks at two, three, four and five times the charge of the first primary peak. After some investigation we conclude that these are due to more than one pixel firing when more than one particle traverses the chamber.

5.3 Laser-ablated foil—Description

This construction, with thin chopped wires, is obviously only practical for building small laboratory-style devices. It is necessary to find some construction method with inherent mass-production techniques (such as photolithography). One way could be to fabricate the very small holes by laser ablation.

We have constructed a foil (type 6) with this advanced technique of laser ablation. We reduced the pitch of the square cells to 5 mm. The distance to the cathode is 1.65 mm and the distance to the roof is 5 mm. The diameter of the laser-ablated holes is 50 μm and the diameter of the anode is 100 μm . This foil is a first attempt to 'mass produce' a small anode-surface chamber. The laser-ablation technique is nowadays a well-established industrial production process. However, it is non-trivial to keep the error level low at all stages of this process [11].

Before giving some of the results that we obtained with this foil we wish to comment on the construction technique. It is based on the cracking of chemical bonds of molecules by photons with the correct energy, and not by burning. With this method the unfocused light from excimer lasers can be used to vaporize the base material. By masking this base material (we used a copper mask), small holes can be produced. Precision in the submicron range with perfect vertical walls can be reached. The first step is the preparation of a mask so that the laser only attacks the foil where we want the 50 μm holes to be. We simply etched this mask into the copper layer of the standard Kapton laminate. This step is critical because dust particles in the micron range during the photo process create pinholes in the etched copper layer. The pinholes in this layer will create pinholes in the Kapton during the exposure to the laser. The foil is then exposed to the excimer laser light. The next production step is the metallization of the holes. This is a non-trivial step because of the high aspect ratio of the depth to the diameter of the holes. It is necessary to use ultrasound equipment in the chemical baths, otherwise the processes are unreliable. Finally, standard photolithographic etching techniques can be applied to produce the design of anodes and cathodes on this foil. Obviously very good alignment precision is needed in order to match the tiny plated-through holes with the high-voltage bus lines and the anode pads. In our first attempt to produce a small anode chamber we suffered from having pinhole defects in the Kapton layer (as described above). These additional, practically invisible, holes in the Kapton foil considerably

reduced its high-voltage strength. Fortunately, these extra holes were so small that there was no metallization created there in the following steps of the treatment. Otherwise, there would have been a lot of short circuits, which it would have been impossible to find and cure.

Recently, we have received a new batch of ablated and plated-through foils, where extra masks, made of 100 μm Cu/Be foils, had protected the surface between the intended holes. Furthermore, with the new foils the laser was used to ablate half the hole from each side. The probability for extra through-going pinholes due to mask defects is thus greatly reduced. Work is in progress with these foils. The results shown below are from a foil with the defect discussed above.

5.4 Laser-ablated foil—Test results

We operated this foil in an argon-CF₄-isobutane gas mixture and reached full efficiency; but it was not possible to fully investigate the plateau because of the defects in the foil. However, already with this particular, rather substandard foil, one can see the great potential of this technology. In fig. 14, it can be seen that the knee voltage of the plateau is reduced by about 2 kV. In fig. 15 we show the charge spectrum of the laser-ablated foil chamber together with a double-layer Kapton chamber of type 2. The average charge is reduced by about a factor of 5. The drift-time spectrum, which we show in fig. 16, remains basically unchanged. Thus it seems that the reduction in cell size does not make the chamber faster, because drift velocity is reduced by the much lower working voltage. In fig. 17, we show gain measurements with an ⁵⁵Fe source. One can see the large reduction in anode voltage as a result of increasing the material thickness, and of reducing cell and anode size. The step-like behaviour of the data points is an artifact of the measurement technique.

6. POSITION RESOLUTION

We have taken some data with the standard pixel chamber (type 1) to determine the position resolution. The chamber was mounted in a test beam in the CERN East Hall. The position of the incoming particle was measured with two sets of drift chambers. In fig. 18 we show a scatter plot for the radial distance of the particle from the anode as a function of the drift-time recorded from the pixel chamber. A clear band is seen. We fitted a curve to this band and used it to calculate the radial distance from the drift-time measurement. A histogram of the residuals is shown in fig. 19. The FWHM is 760 μm . We think that the contribution to this width from the measurement error made by the external drift chambers is small.

7. FUTURE DEVELOPMENTS

Perhaps one of the most critical tasks ahead is to find a way to reduce the anode size. This would also allow us to reduce the anode-to-cathode spacing and thus make large gains in resolution and time response. At present, we are limited by the minimum drill size of 200 μm . However, lasers are becoming frequently used in various production facilities. For

example, it is possible to use a CO₂ laser to punch a 75 µm hole through 300 µm glass fibre board [12]. Furthermore, this laser can be pulsed at 50 Hz thus making 50 holes per second, which is a much higher rate than with mechanical drilling. Thus it seems that we will want to use lasers both to decrease the hole size and to increase the ease of fabrication.

Alternatively, there are technologies on the market which make use of photosensitive polymers. These are basically polyimides such as Kapton. The breakdown voltage through the material is in excess of 100 V/µm. Holes can be produced with basically the same technology (exposing and etching) as used in standard printed-circuit board fabrication. It is possible to produce holes as small as 25 µm in diameter ⁴⁾.

The reduction in anode size may also allow us to work in proportional mode and certainly the results of section 5.2 seem to hint at this.

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⁴⁾ Ultrastrate technology, Contraves AG, Zurich, Switzerland.

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Table 1
Characteristics of various foil chambers

Type	Chamber	Anode pitch (P) (mm)	Clearance diam. (D) (mm)	Anode diam. (d) (μm)	Hole diam. (h) (μm)	Foil thickness (t) (μm)
1	Square cell	10	7	500	200	170
2	Double Kapton	10	7	500	200	325
3	Hex. 1	6	4.56	375	150	325
4	Hex. 2	8	5.26	500	200	325
5	Chopped wire	10	7	50	200	170
6	Laser ablation	5	3.3	100	50	170

Figure captions

- Fig. 1 : Cross-section of the gaseous pixel chamber; symbols refer of table 1
- Fig. 2 : Top view of the square cell and hexagonal designs; symbols refer to table 1
- Fig. 3 : Drift lines of the gaseous pixel chamber with uncharged Kapton surface
- Fig. 4 : Solder mask layer applied to the gaseous pixel chamber
- Fig. 5 : Efficiency for detecting 6 GeV/c pions
- Fig. 6 : Efficiency for detecting 6 GeV/c pions for Ar–isobutane
- Fig. 7 : Efficiency for detecting 6 GeV/c pions for CF₄–isobutane
- Fig. 8 : Loss of efficiency for detecting 6 GeV/c pions in CF₄ gas mixtures with a type 3 hexagonal chamber
- Fig. 9 : Efficiency for detecting 6 GeV/c pions for various gas mixtures with type 3 hexagonal chambers
- Fig. 10 : Position of minimum ionizing particles firing a single pixel of type 4 chamber
- Fig. 11 : Detection efficiency for 6 GeV/c pions for various gas mixtures; type 5 chamber
- Fig. 12 : Charge spectra of type 5 chamber with various gas mixtures
- Fig. 13 : Charge spectrum of small anode chamber (type 5) (rebinning of fig. 12e)
- Fig. 14 : Plateau curve of a laser-ablated foil chamber (type 6) compared with a type 2 chamber
- Fig. 15 : Charge spectrum of a laser-ablated foil chamber (type 6) compared with a type 2 chamber

Fig. 16 : Drift-time spectrum of laser-ablated foil chamber (type 6) compared with a type 2 chamber

Fig. 17 : Charge as a function of anode voltage for various chambers

Fig. 18 : Scatter plot of drift-time as a function of radial distance from the anode

Fig. 19 : Distribution of residuals for the radial distance

Figure 1

SQUARE DESIGN

Anode pitch P

HEXAGONAL DESIGN

P

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

$\square$	CF ₄ / I-C ₄ H ₁₀ / Ar (40.3 % / 40.3 % / 19.4 %)
$\circ$	CF ₄ / DME (40 % / 60 %)
$\diamond$	pure DME
$\times$	CF ₄ / I-C ₄ H ₁₀ (10 % / 90 %)
$+$	CF ₄ / C ₂ H ₆ (45.5 % / 54.5 %)
Δ	CF ₄ / DME / Ar (14.9 % / 67.2 % / 17.9 %)

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19