Discharge Protection and Ageing of Micromegas Pixel Detectors

A.A.Aarts[a], V.M. Blanco Carballo[b], M. Chefdeville[a], P. Colas[c], S. Dunand[d], M. Fransen[a], H. van der Graaf[a], Y. Giomataris[c], F. Hartjes[a], E. Koffeman[a], J. Melai[b], H. Peek[a], W. Riegler[e], C. Salm[b], J. Schmitz[b], S. M. Smits[b], J. Timmermans[a], J.L. Visschers[a], N. Wyrsch[d]

***Abstract*–GridPix is a gas-filled detector in which a Micromegas is combined with a CMOS pixel chip. The GridPix detector, originally developed for the readout of TPCs, can be applied as X-ray imaging device. With a drift gap of only one mm, GridPix could be well applied as radiation hard, low power, (and therefore) low-mass vertex (track) detector. A procedure to construct a Micromegas onto a Si wafer, using chip production technology ('wafer post processing'), has been developed. A method to protect the CMOS anode pixel chip against discharges has been studied. An ageing test of a Micromegas chamber has been carried out, after verifying the chamber's proportionality at a very high dose rate**

I. THE GRIDPIX CHAMBER

A new gaseous detector has been realized combining a Micromegas grid with the Medipix-2 pixel CMOS chip [1, 2, 3]. In a small drift volume of 14 x 14 x 14 mm^3, primary electrons from cosmic muon tracks drift towards the grid. After passing a grid hole, they enter the 50 μm wide gap between the Micromegas, put at a potential of around -400 V and the pixel (anode) chip, put at ground potential. Due to the strong electric field, the electron will initiate an electron avalanche, and the resulting charge signal can activate the preamp-shaper-discriminator circuitry in the pixel beneath the hole. We have recorded track images from minimum ionizing cosmic muons. From this data we could derive that the efficiency for detecting single electrons was better than 90 percent.

This 'GridPix' readout can be applied in gas-filled detectors in general, but the application in TPCs, in μ-TPCs and in TRDs may boost their performance since individual 3D information of all primary electrons becomes available. In principle, the only limit to the spatial resolution is diffusion. The drift volume and choice of gas can be optimized for the detection of X-rays: since the point of quantum-gas interaction can be reconstructed from the (3D) ionization pattern, precision imaging seems possible.

With a drift gap of only 1 mm, the GridPix detector can be applied as vertex detector in environments of intense radiation (Gas On Slimmed SI Pixels: GOSSIP). Whereas in Si detectors the charge signal originates from electron-hole pairs in the depletion layer, in GOSSIP electron-ion pairs are created in the drift volume: a single cluster containing a single electron is sufficient for track detection. In Si, the signal is amplified by low noise amplifiers, while in GOSSIP the signal is amplified in the avalanche gap. Since the input pads of the pixels can be rather small, the source capacity at the preamp input can be as small as 10 fF. Given the pulse height distribution, the fast signal development [1], and a gas gain of 1 k, the parameters of the low-noise amplifiers in the GOSSIP pixel chip can be chosen such that their power can be as low as 2 μW per pixel. The standard CMOS pixel chip can be thinned to 50 μm, reducing the detector's mass to a minimum.

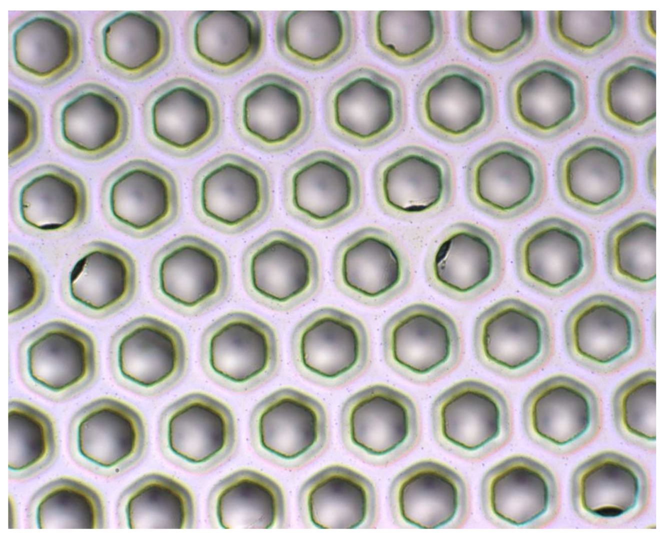

Fig.1. Top view of InGrid. Note the insulating pillars (SU-8 epoxy) centered between the grid holes [4].

This thin Si appears as a foil, and opens a new window on ultra-light detector construction. Furthermore, in GOSSIP, there are no bias currents.

II. INGRID

By means of 'wafer post processing', a Micromegas-like grid onto a Si wafer [4] was made. With this technology, a CMOS pixel chip can be combined with a grid, forming an integrated

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[a]NIKHEF,Kruislaan 409, Amsterdam 1098 SJ, The Netherlands
[b]University of Twente/Mesa+ Institute,Hogekamp 3214, PO box 217, Enschede 7500 AE, The Netherlands
[c]DAPNIA, CEA Saclay, F91191 Gif sur Yvette CEDEX, France
[d]Institue de Microtechnique, Université de Neuchâtel, Breguet 2, CH-2000 Neuchâtel, Switzerland
[e]CERN, Geneva, Switzerland

readout device of a gas volume (InGrid). The sub-μm precision of the grid dimensions and avalanche gap size results in a uniform gas gain. The diameter of the insulating pillars between the Si wafer (anode) and the grid can be as small as 30 μm: they can, therefore, be positioned between the grid holes, thus avoiding dead regions (see Fig.1).

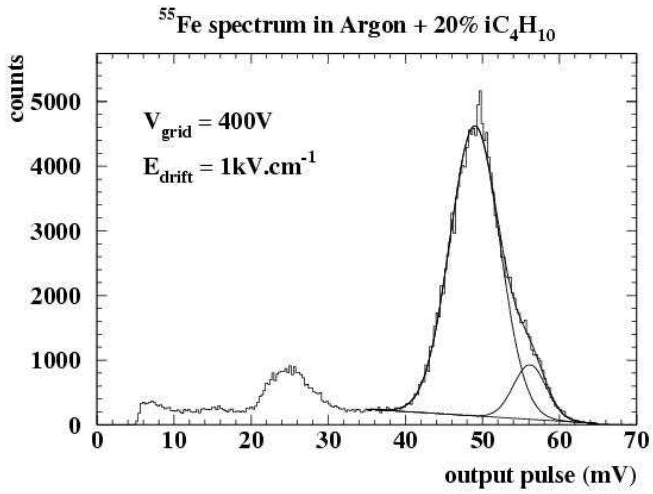

Fig. 2 The pulse height spectrum of ^{55}Fe photons. Note the non-symmetrical photo peak due to the 6.49 keV photons.

On a 4” wafer, 19 areas were made with different geometry: the grid hole pattern (square and hexagonal), the hole pitch and the hole shape (square, round and hexagonal) were varied. As grid support, pillars (with several diameters and pitches), as well as ‘dykes’, were made from SU-8 epoxy. In the latter, each grid hole has its own gas-filled cell.
We tested the InGrid wafer in a small chamber in which a drift volume was formed by placing a cathode foil 10 mm above the wafer.

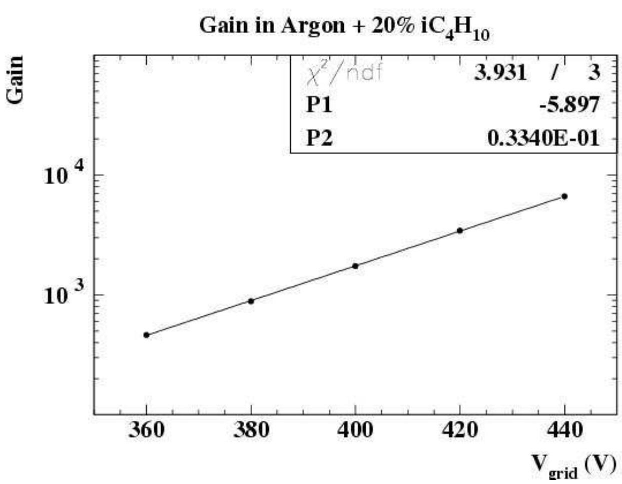

Fig. 3: The gas gain as a function of the grid potential.

We connected a low-noise charge sensitive preamplifier [5] with an integrating time constant of 1 μs to the grid. The charge signal from the grid is completed within 50 ns, and the preamp output signal is therefore precisely proportional to the charge signal from the grid [1].
In Fig.2, the energy resolution of the InGrid of Fig. 1 is shown. The non-symmetry of the photo peak of ^{55}Fe photons is clearly visible. The source emits X-ray quanta of 5.90 and 6.49 keV with a ratio of 9:1. Due to differences in absorption, we left this ratio free in the fit of the pulse height spectrum. The width (RMS) of the 5.90 keV peak was σ = 6.5 %. We found similar results from the InGrid field with a ‘dyke’ geometry.
We have calibrated the gas gain carefully by injecting precisely known charge pulses into the grid. In Fig. 3 the gas gain versus the grid potential is shown for a mixture Ar/Isobutane 80/20. The precise exponential relation is expected given the precision in InGrid geometry.

III. Discharges

A problem associated with gas-filled proportional chambers is sparking. When an electron avalanche reaches the Raether’s limit [6,7], it may evolve into a discharge. We assume that the density and energy of the participating electrons becomes high, forming a conductive plasma. This creates a conductor between the participating electrodes until the local field strength has dropped below the level that electrons are extracted from, in our case, the grid electrode. As a result, a good fraction of the stored charge is transferred. Due to this effect, the readout electronics can be damaged, specially in the case of GridPix detectors, where a Micromegas or InGrid is placed directly on a pixel chip. The damage can be due to the plasma that locally melts or evaporates the chip material, or by a breakdown of electronic circuitry, due to too high potentials or charges.
Detectors such as the Resistive Plate Chamber [8], in which one or both electrodes are made of a high resistive material, exhibit a quenched discharge, as the resistive layer prevents the instant drain of the charge deposited by the discharge [9]. This not drained-off charge creates a compensating electric field that produces a local drop in the applied field. The discharge amplitude, typically a constant fraction of the charge stored in the assembly of the participating electrodes, is thus reduced.
In this work, a high resistive ‘Silicon Protection’ layer (SiProt), made of hydrogenated amorphous silicon (a-Si:H), has been built, and this layer has been used to cover the anode of a Micromegas detector. Besides its quenching effect, this layer also prevents the evaporation of the thin metal input pads on the CMOS anode chip, due to the spark plasma.

Charge from an avalanche, being the result of ‘normal’ single electrons, will arrive and stay on the a-Si:H layer facing the pixel input pad. This surface charge induces a large fraction onto the pixel input pads, forming the avalanche signals at the pixel inputs.

The resistance of the a-Si:H layer should be sufficiently small to compensate the surface charge while the potential drop of the surface should be less than about one volt in order not to reduce the gain. The maximum volume resistance of the a-Si:H layer depends therefore on the expected detector current (thus on count rate, gas gain and primary ionization). Since this compensation current flows from all pixel input pads in parallel, the volume resistance can be as high as $10^{11}\ \Omega$ cm, which is a typical value for non-doped a-Si:H. For GOSSIP, applied at Super LHC, a value of $10^{9}\ \Omega$ cm may be necessary.

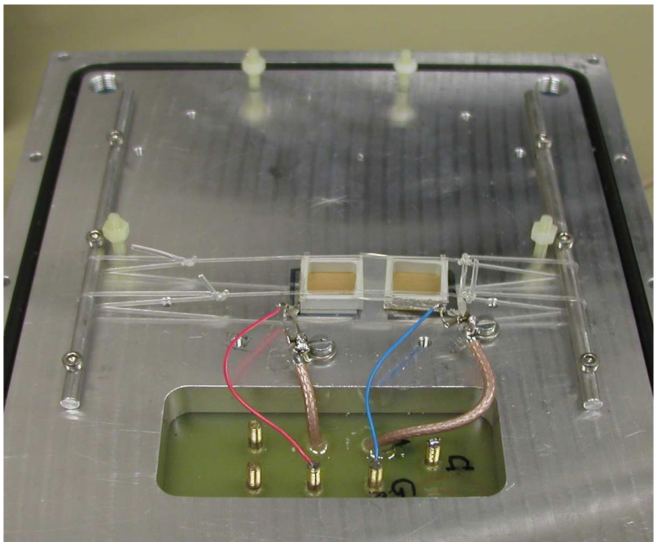

Fig.4: A protected and unprotected anode with both a Micromegas on top.

IV. The Amorphous Silicon Protection layer

The application process of the high resistive anode begins with the deposition of a 200 nm thick aluminum layer on a silicon 4" (dummy) substrate. After this step, a 3 µm thick layer of a-Si:H is deposited by Very High Frequency plasma-enhanced chemical vapor deposition (VHF PE-CVD) at 70MHz and temperatures around 200 °C. [10]. This processing temperature, as well as the relatively mild plasmas produced in VHF PE-CVD, compared to RF PE-CVD, are fully compatible with conventional CMOS processing. The process can therefore be included in a waferscale postprocessing sequence on a CMOS detector array.

V. Measurement of discharges

In the chamber shown in Fig.4, both a protected and a not-protected Si anode were mounted. Since the discharge signals are quite large, the anodes were read out directly with a fast digital oscilloscope, without preamplifiers. A carefully designed attenuation network enabled to visualize fast signals without reflections.

The chamber was flushed with a Ar/Isobutane 80/20 mixture. In the gas input line, a container with Thorium was included. The produced Radon gas decays under the emission of α-particles which generate discharges. The proportional signals and discharges are clearly separated (see Fig. 5). The peak position of the narrow distribution in Fig. 6 corresponds to a fraction of 0.5 – 0.9 of the stored charge in the grid-anode capacity (~32 pF x 400 V), depending on the HV setting. The peak at -0.034 V are overload signals caused by the discharges. With their amplitude of more than tens of volts they are way out of scale.

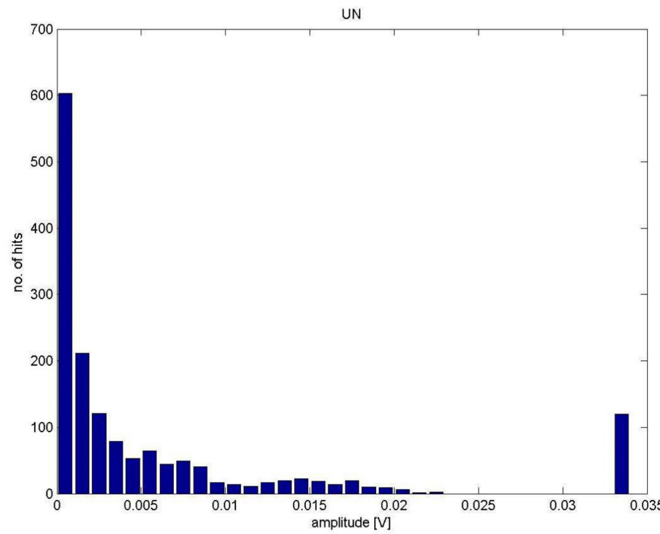

Fig. 5. The (proportional) signal distributing of α–particles. In the right-hand corner discharges are registered in the overflow.

There is a clear difference in the discharge process of the protected and the unprotected anode (shown in Figs. 7 and 8). The discharges on the unprotected anode have a larger prompt charge pulse, while the protected anode gives smaller charge signals which are spread in time.. This could be explained by a different development in time: first the discharge is halted by the charge build-up on the surface of the a-Si layer. Then a discharge follows, slightly displaced over the a-Si surface.

The ratio of the number of discharges between the protected and unprotected anode is the same for lower voltages. For grid

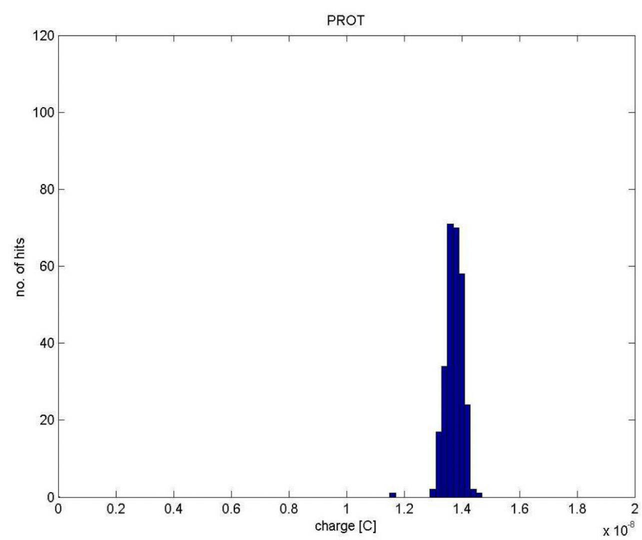

Fig.6: Spectrum of discharge signals at the protected anode.

VI. GAIN AND CURRENT MEASUREMENTS

The gains of protected and unprotected detectors were measured by means of an ^{55}Fe source emitting 5.9 keV X-rays. Photons (collimated to a 1 mm diameter pencil beam) converted in a 1 cm drift gap filled with an Argon 20% Isobutane gas mixture. The drift field was set to 300 V/cm. Signals from both detectors were further amplified, shaped and recorded on a digital scope. The currents through the Micromegas meshes were also measured.

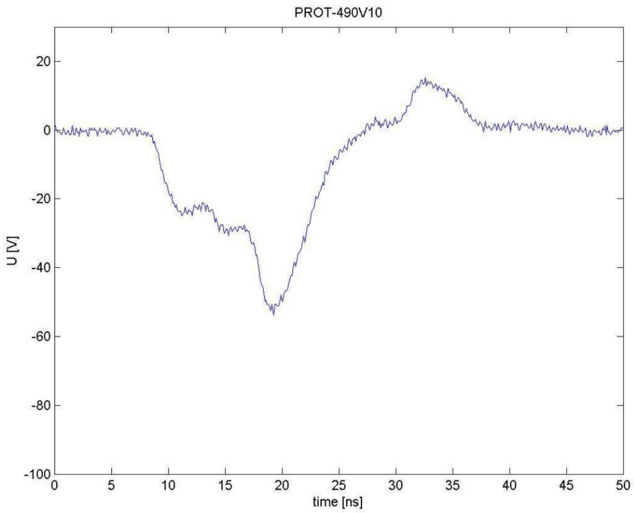

Fig. 7. Typical discharge on the protected anode, grid at -490V

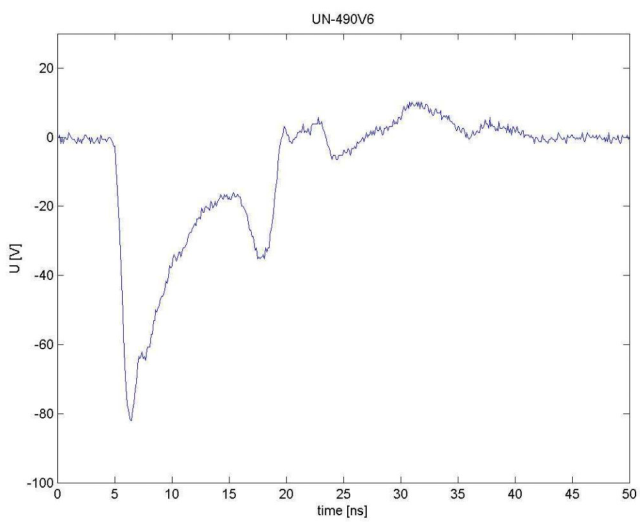

Fig. 8. Typical discharge on the unprotected anode, grid at -490V

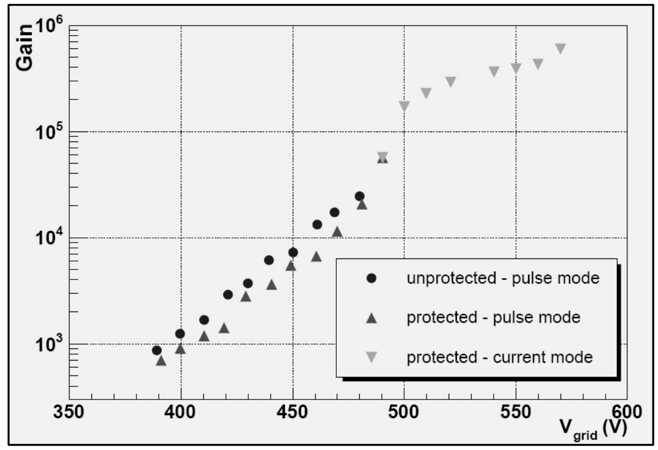

Fig. 9: Gain of protected and unprotected detectors in Argon 20% Isobutane.

The gain curve of the unprotected detector was drawn by measuring the pulse areas for grid voltages rising from 390 V (over 50 µm) to 480 V (Fig. 9). Above 480 V, the spark rate becomes too high to operate the detector any longer. Over this range of gain the current is too small to be recorded accurately.

In the same way the gain of the protected detector was measured up to 490 V. At 480 V, the gain of both detectors are similar; above 480 V, the protected gain rises super exponentially with the grid voltage, possibly because of UV photons that trigger secondary avalanches. However, no sparks were observed and the grid voltage could be increased further. At 490 V, with a gain of 57 k, the pulses from the preamplifier started to saturate. Nevertheless, the current was significant enough (2 µA) to allow an accurate measurement. The gain at higher grid voltage was thus calculated by converting current into gain. At 500 V the gain is 170.10^3 and a plateau is reached because of the voltage drop across the resistors in series with the grid. The current was measured to be 21 µA at 570 V and still no sparks were observed. Above a 570 V, a destructive spark occurred that burned one pillar of the Micromegas mesh, creating a conductive path from the grid to the anode. The detector was not operable anymore even at low grid voltage.

VII. CHAMBER AGEING

In the most common ageing effect, deposits are formed on the chamber electrodes. Assuming that this effect is proportional to the integrated charge density on the anode, GOSSIP should withstand a large irradiation dose due to its large ratio of the anode surface and gas volume, and due to its low gas gain (~ 1k). In a first test, the ageing of a Micromegas chamber was measured using a 90/10 Ar/Methane mixture. The chamber was built from standard materials, including Kapton tape, G10, Viton O-rings, PVC insulated wires, and epoxy (Araldite).
The Micromegas grid, mounted in a frame, was placed onto a polished aluminium anode block. By means of a carefully calibrated charge preamplifier the charge signals from the grid

could be measured, and the current through the anode could be registered by measuring the voltage drop over a serial resistor. This set-up was irradiated with photons from an ^{55}Fe source, and the absolute relation between the gas gain, current and counting rate was certified, and dark currents were below the level of 0.1 nA.

We then irradiated the chamber with 8 keV X-ray quanta from a Cu target, which, in its turn, was irradiated with photons from an X-ray tube.

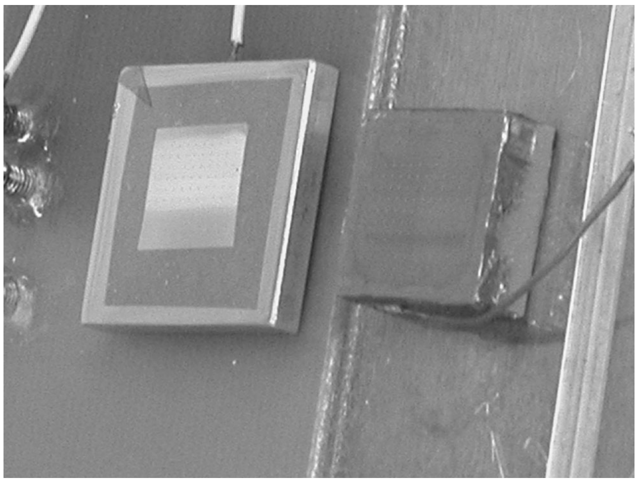

Fig. 10. The anode block and (turned-over) Micromegas. Roughly half of the surface was shielded against irradiation with X-rays.

We varied the current through the tube and found that the chamber current changed proportionally up to a current density of 0.5 μA/mm^2 (reached with the maximum power of the X-ray tube, and with a gas gain of 11 k). We then covered half of the grid surface with Pb, shielding this part of the detector from irradiation.

During a period of two months, we noticed a slow but regular decrease of the anode current. After collecting 0.3 C/mm^2 at the irradiated area of the anode block, we re-calibrated the chamber: no change in the ^{55}Fe pulse height spectrum was observed at the non-irradiated region of the anode. At the irradiated area, the gain was reduced by a factor ~4 (recoverable by an increase of the potential difference between anode and grid). A clean white deposit containing Si, C and O was found on the anode (see Fig.10). The Micromegas was clean, while the cathode foil showed a deposit containing similar elements as the anode [11].

Based on this test, and assuming that GOSSIP can operate with a gas gain of 1 k, a radiation dose of 2 x 10^{16} tracks/cm^2 could be achieved. More ageing studies are required in order to obtain essential knowledge of the ageing processes.

VIII. Conclusions

By means of wafer post processing technology, a Micromegas-like structure can be created on top of CMOS pixel chips. By applying a 3 μm thick layer of hydrogenated amorphous silicon, a means of protection against discharges may be achieved. Testing this protection on pixel chips will show if this is adequate. An ageing test of a Micromegas chamber indicates that the intrinsic ageing process, in terms of the deposit per unit of collected charge per surface, may be compared to proportional wire chambers. Due to the large ratio of the anode surface and the chamber volume, and due to the low required gas gain, the application of the gas-filled GOSSIP detector as vertex detector in future high-radiation environments seems well possible, but more knowledge of the ageing processes in gas-filled detectors is required.

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