Gaseous Pixels

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Abstract

Several years ago a revolutionary miniature TPC was developed using a pixel chip with a Micromegas foil spanned over it. To overcome the mechanical stability problems and improve the positioning accuracy while spanning a foil on top of a small readout chip a process has been developed in which a Micromegas like grid is applied on a CMOS wafer in a post processing step. This aluminum grid is supported on insulating pillars that are created by etching, after the grid has been made. The energy resolution (measured on the absorption of the X-rays from a ^{55}Fe source) was remarkably good. Several geometries have since been tested and we now believe that a 'Gas On Slimmed Silicon Pixel chip' (Gossip) may be realized. The drift region of such a gaseous pixel detector would be reduced to a millimeter. Such a detector is potentially very radiation hard (SLHC vertexing) but ageing and sparking must be eliminated.

Key words: Pixels, Ingrid, Gossip.

1 Principle of operation

Gossip is a pixel detector without a solid state detection layer. Instead the signal is formed in a thin gas layer (1 mm) and amplified in a gap (50 μm) between the surface of a CMOS chip and a Micromegas-like grid [1]. A minimum ionizing particle will on average produce about ten ion-electron pairs in the 1 millimeter drift space. These electrons drift toward the grid through the low field drift region (100 V over 1 mm). The maximum drift time is only 16 ns due to the small size of the drift distance. Between the grid and the readout chip a high electric field is created in which each electron will initiate an avalanche. With a potential difference of 400 V over a distance of 50 μm, a gas multiplication or gas gain of 1000 can be reached. The basic principle is shown in figure 1.

It has been shown that the Medipix chip [2] can be used to detect signals created by an electron induced avalanche when a Micromegas is mounted on

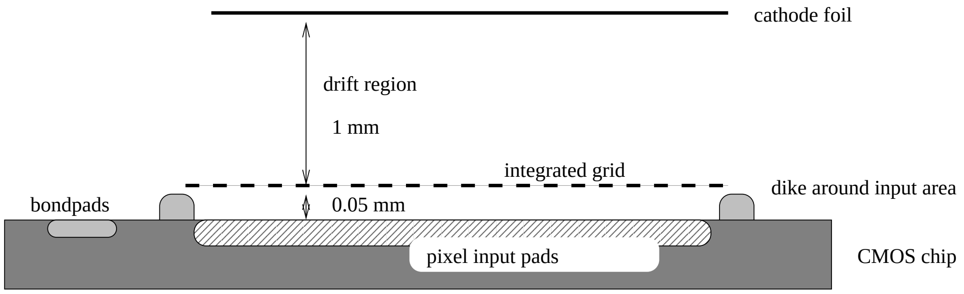

Fig. 1. Principle of operation of a Gossip sensor.

the chip [3]. For these measurements a drift volume of 14 mm was used thus constructing a small time projection chamber. At present we are developing a detector with a 1 mm drift region over a readout chip that carries an integrated grid. An existing chip (like ATLAS or CMS pixel chip) will be used to build the first true Gossip prototype. Until now several grid geometries have been tried and proved to be successful. The integrated grid (InGrid [4]) can be adapted to match any pixel pitch.

Recently the first measurements were performed with a drift region as small as 1.2 mm. In this measurement only a single electrode was used in combination with a charge integrating preamplifier with a slow shaping time of a few μs (Amptek 250). A ^{90}Sr source was used to generate minimum ionizing particles. In figure 2 the resulting pulse height distribution is shown. The line shows a fit based on the assumption that the number of primary electrons fluctuates according to a Poisson distribution. This distribution is convoluted with noise and gain fluctuations. The voltages on the cathode and the grid were -800V and -600V respectively. The voltage difference between the grid and the anode was 600V corresponding to a gain of 10^3.

2 Radiation hardness

Through constant flushing of the gas volume, direct radiation damage is usually not an issue in gaseous detectors. Ageing processes may cause however the formation of deposits on the electrodes. First ageing tests do not show a significant degradation in performance of the chamber. A setup with a Micromegas grid has been irradiated with X-rays during two months. The charge collected on the anode was 0.3C/mm^2 which is equivalent to $2{\cdot}10^{16}$ charged particles per cm^2. The gain decreased with a factor of four but was fully recoverable by increasing the field. In the proposed layout the gas gain and the electrical field near the anode are very moderate compared to most wire chambers.

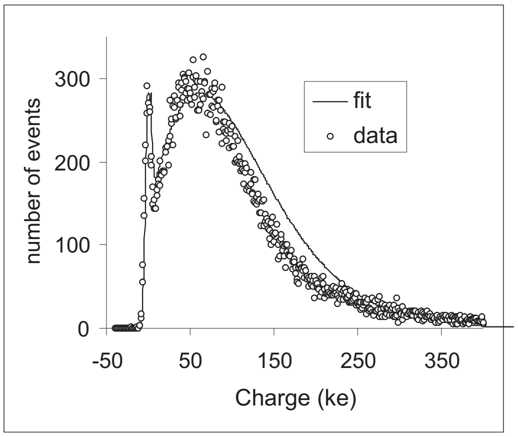

Fig. 2. Measured pulse height distribution in 1.2 mm drift region. The primary electrons create an avalanche in the 50 μm between the Micromegas and the anode (in this setup a single electrode). The peak around zero is corresponds to a fraction of 4% empty triggers caused by Bremsstrahlung.

3 Spark protection

In principle each single electron created in the drift region (on expects roughly 10 electrons from a minimum ionizing particle) will initiate the development of an avalanche in the region between the grid an the anode. When a given particle deposits much more energy and thereby releases many primary electrons, this may cause such a huge avalanche that the readout chip is actually destroyed. This could be due to melting or evaporation of the surface layers or to an over-voltage on the input of the CMOS preamplifier. Without protection these effects are indeed observed in the lab.

Two protection mechanisms are proposed and under construction. Firstly an amorphous silicon layer is applied on top the CMOS wafer before the grid is applied. This highly resistive layer is supposed to spread the charge caused by a spark. The layer also offers direct protection against melting of the thin surface layers on the input pads. Secondly, wafers are being equipped with double grids on top of each other (TwinGrid). The TwinGrid will be operated such that the avalanche or gas gain takes place between the first and second grid. The region between the second grid and the chip will have a lower field and serves to transport the signal to the chip without further amplification. This structure actually has some other interesting consequences since the second grid may suppress the ion signal. As a result the signal development may become much faster (electron drift over 50 μm).

In figure 3 a picture of the TwinGrid is shown. The insulating pillars are easily recognized as well as the double layer of grids. The pitch between two holes

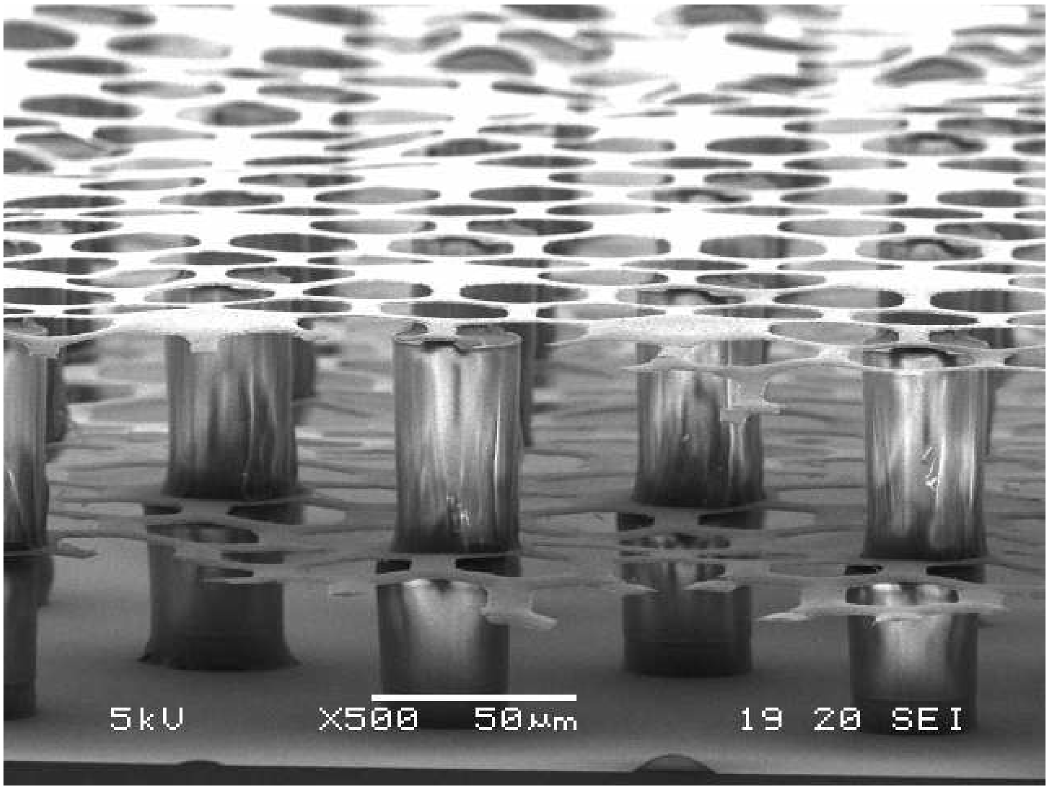

Fig. 3. TwinGrid test structure. Two grids on top of each other to prevent sparks to the CMOS chip.

in the grid is 50 μm.

4 Readout chip

In 2005 a preamplifier circuit was designed that exploits the fact that the input capacitance of a Gossip detector is very low compared to present detectors. The first prototype of the fast (40 ns peaking time), low-noise (ENC = 60 e- (RMS) and low-power (2 μW per channel) input circuit for the Gossip chip has been successfully implemented in 0.13 CMOS technology. At the end of 2006 the design of the first small scale pixel chip with the same preamplifier but know equipped with a TDC for each pixel has been submitted.

5 Outlook

The material in the Gossip detector will be dominated by the CMOS chip. Since no bump bonding is required it should be possible to (back)thin the readout chip. Sofar no wafer thinning has been tried. The absence of bump bonding in the production process may give substantial saving in the costs.

To fill the detector with gas we propose to fully surround it with gas at ambient pressure so the construction does not need to accommodate pressure differences. Since there is no radiation damage of the gas there is no need (no harm either) in cold operation of the detector. A modest cooling of the front-end electronics will be necessary but the entire system can run at room temperature.

A prototype Gossip detector is being developed. This detector combines for the first time all elements of the Gossip principle. The CMS pixel chip will be used with a post processed grid. Several detectors will be made and put together in a beam telescope. At the same time developments will continue in the design of a front-end chip that will fully profit from the negligible input capacitance and reduced power consumption.

References

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