Gaseous Detectors

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Abstract

The invention of Micromegas and GEMs has made possible the development of a new generation of gaseous proportional detectors . By using a pixel chip as active (anode) readout, Time Projection Chambers become available where all information of the ionization can be read out. With the MEMS technology, developed for the integration of Micromegas and the pixel chip, a new electron multiplier may be feasible. The combination of this multiplier and an Electron Emission foil would result in a new and light detector with sub-nanosecond time resolution.

Keywords: MPGD; Micromegas, pixel readout, amorphous silicon, silicon nitride; Timepix; CMOS post-processing; radiation detectors; discharges; sparks; MEMS technology.

1. Introduction

Since their invention in Manchester in 1908 by Hans Geiger, gaseous detectors have played a major role in particle physics. The small number of electrons, created in the ionization process, can be multiplied in a strong electric (avalanche) field, for instance near the surface area of a thin (anode) sense wire, or recently, in the avalanche holes of Micro Pattern Gas Detectors (MPGD) such as GEMs [1] and Micromegas [2].

With the GridPix [3] detector, each MPGD hole is read out individually by the circuitry in a pixel of a CMOS chip (see fig. 1). For this, we applied the Timepix chip [4]. Since the source capacity at the pixel preamplifier input can be as low as 10 fF, the pixel circuitry is sensitive to avalanches initiated by one single electron. Therefore, if the granularity is sufficient, the GridPix device measures each individual electron liberated in the ionization process in the gaseous (drift) volume, as is shown in fig. 2.

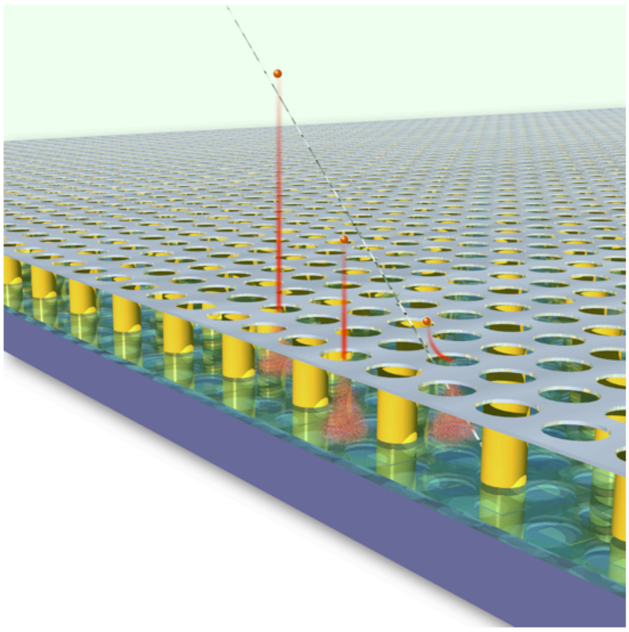

Fig. 1. The InGrid detector. Electrons from the drift volume cause an avalanche in the gap between the pixel chip and the grid.

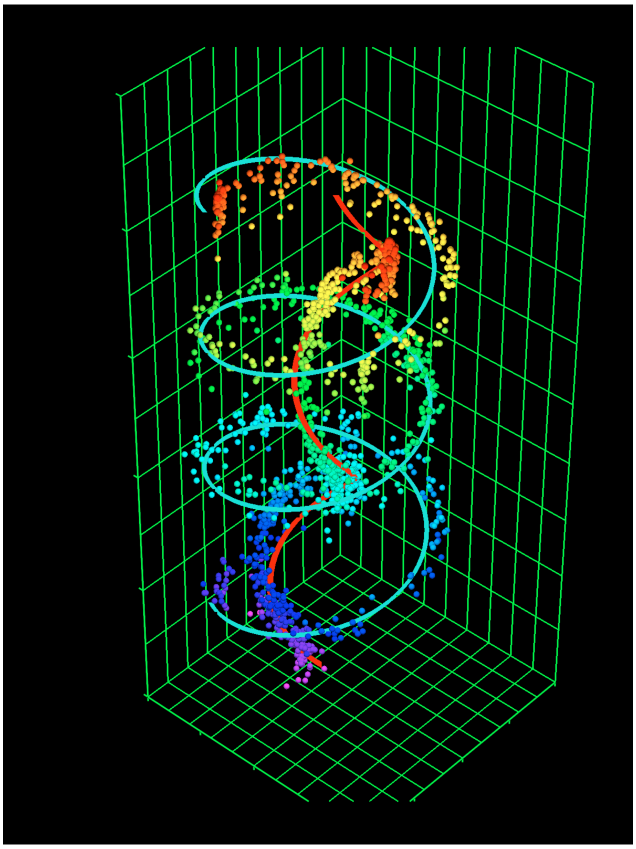

Fig. 2. Two ß's from a ^{90}Sr source, recorded with a Timepix-based GridPix detector. Drift length: 30 mm. Gas: He/i-butane 80/20, with a magnetic field of 0.2 T oriented parallel to the (vertical) drift field.

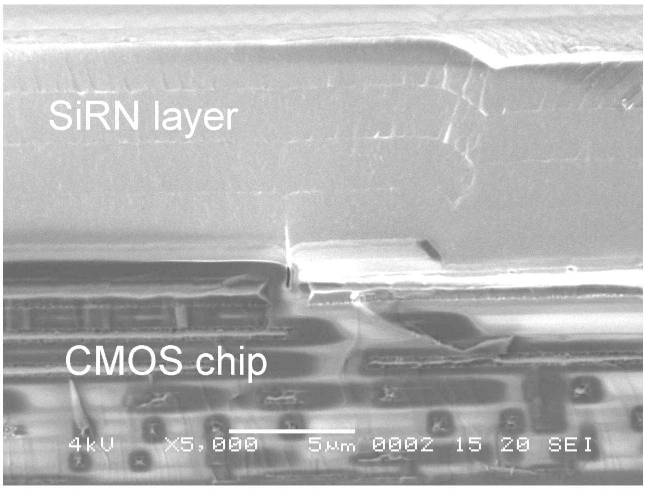

Fig. 3. Cross section SEM picture of a Timepix chip covered with 9 μm SiRN.

2. Sparks: Protection Layer

CMOS chips are know to be sensitive to (electrostatic) discharges, and many Medipix and Timepix chips are destroyed when operating them in Gridpix detectors. This problem is solved by covering the chip with a thin high-resistivity layer. The charge build-up at the layer surface reduces the electrostatic avalanche field, quenching the discharge, as is the case in Resistive Plate Chambers (RPCs). First, doped amorphous Si has been used as layer material [5]; then, easy applicable silicon-rich Si-Nitride (SiRN) is applied (see fig. 3). As the pixel chips can now survive discharges, the discharge process can be studied in detail (see fig. 4) [6].

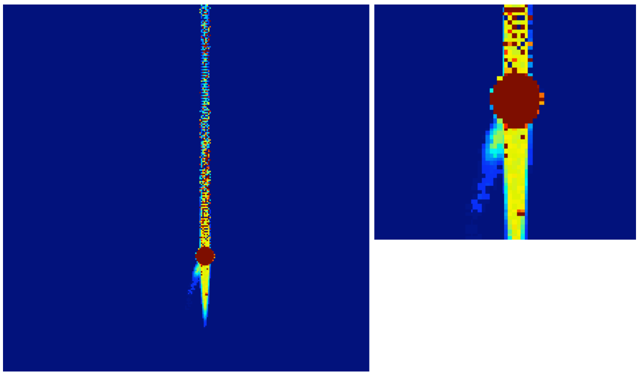

Fig. 4. Left: typical image of a discharge event in a Timepix chip protected with 20 μm a-Si:H. The discharge is seen as a dark circle. The α-particle, which triggers the discharge, can be seen entering the pixel matrix from the bottom left side of the discharge. The pixels activated in the vertical line are due to disturbance of supply voltage and threshold references. Right: detail of the spark event.

In recent tests, protected GridPix/Timepix detectors were exposed to discharges (initiated by α-particles) over a long period of time. After lifetimes of up to months, the chips still suffer severe deterioration. Possible explanations are pinholes in the protection layer, and discharge paths along the edges of the chip. The chip's lifetime is essential for the potential application of GridPix detectors in particle physics experiments. The replacement of the aluminium grid with a layer of silicon-rich Si-Nitride would offer a second discharge quencher, and this is under study. The insulating pillars supporting the grid (see fig. 1) would then be sandwiched between SiRN layers on both sides. To date, the pillars have been made of the photo-resist SU8, but recently pillars made of SiO_2 have come within reach. Their mechanical adhesion is supposed to be better, and the problem of outgassing is eliminated. The combination of SiO_2 pillars with both the protection layer and the grid layer made of SiRN is a promising development in MEMS technology (Micro-Electro-Mechanical Systems).

3. Technology Transfer to industry

The MEMS technology, developed at MESA+, the Institute for Nanotechnology at the University of Twente, to produce the protection layer and InGrid, is being transferred to SMC, Edinburgh in the UK, and to IZM in Berlin. Once this transfer of the technology is complete, wafers with pixel chips are expected to be processed commercially.

4. Applications

A 'Gas On Slimmed Si Pixel' (Gossip) detector is a Time Projection Chamber with a drift length of only 1 mm, and read out with a GridPix detector. It could replace Si pixel (vertex) detectors. If the production costs of Gossip are sufficiently low, it could also replace most other Si tracking detectors, including strip detectors.

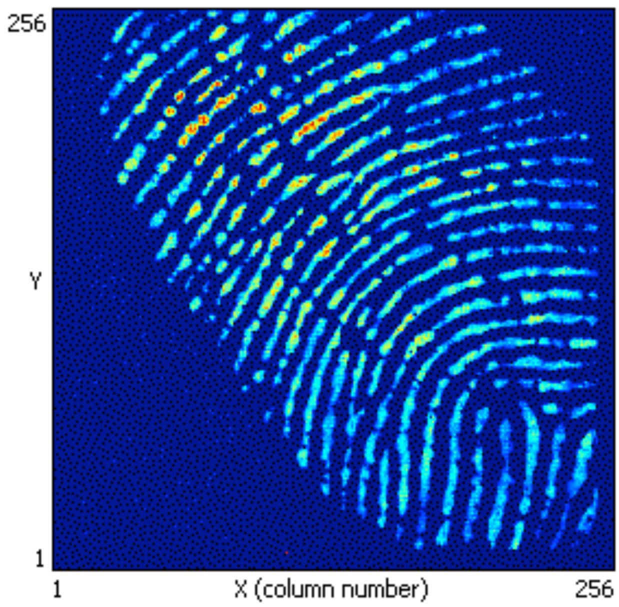

Fig. 5. Image of a fingerprint, taken with a UV-illumined GridPix detector.

In a GridPix or Gossip detector, a track vector is measured, whereas Si tracking detectors measure a track point in space. This is relevant for future Level 1 triggers in the upgraded sLHC experiments where the application of a Si double-layer is being considered. The problematic inter-communication between these two layers is not required for a GridPix TPC where the projected track length is a direct measure for the track momentum and for the particle charge sign [7].

The fig. 5 shows an image from a Gridpix detector, equipped with a quartz window, irradiated with UV light from a low-pressure deuterium arc lamp. The image is the difference between a clean window and a window with a fingerprint. The emission of photoelectrons from the (aluminium) grid, and the transmission efficiency of the photoelectrons which are 'sucked' into the grid holes, would seem to be sufficient. The efficiency of this photon detector is improved by the deposit of a CsI layer on top of the aluminium grid. This photon detector seems to reach the theoretical maximum [8].

Operating Micro Pattern Gas Detectors (MPGD) in cold argon gas has been successfully demonstrated [9]. The readout sensors of bi-phase xenon- or argon-based WIMP search experiments are usually photomultipliers, registering the photons due to ionization and scintillation. We are studying the possibility of replacing the top array of photomultipliers with GridPix detectors. Here, the grids are facing downwards, positioned in the gas phase. With a sufficiently strong drift field, primary electrons, created by an ionizing event in the liquid, are drifting upwards, crossing the phase transition, and then continue drifting in the gas. These electrons can be individually detected by a GridPix detector. Events with 1, 2, or n electrons, generated in a small volume by a WIMP event, can be identified. If the GridPix detector is made sensitive for photons (CsI grid, see above), then the photons created in WIMP events would also be recorded.

With the time-resolved Timepix chip, GridPix detectors provide 3D images of the primary ionization in the drift gap. Using this information, the origin, and the initial direction and energy of the electron, created in the interaction of a photon with the gas, can be measured [10]. And thus the polarization of photons can be measured to a standard that is relevant for astro particle physics. An experiment to test GridPix in a beam of polarised photons at the University of Erlangen-Nürnberg is in preparation.

5. Electron Emission Foil

The primary electrons in Gossip are generated in the thin drift gap. If the grid could be replaced with a foil that was capable of emitting one (or more) low-energy electron(s) after, and at the position of, the passage of a track, then the gas drift gap would no longer be required. Such a track detector would take the form of a pixelised anode with an avalanche gas gap of ~ 50 μm, sealed by the Electron Emission foil (EE foil). The spatial resolution of such a detector would be limited only by the pixel pitch, and the time resolution could be as good as a fraction of a nanosecond, since each electron departing from the foil directly starts an avalanche.

An essential parameter of the EE foil is its efficiency, here defined as the probability that at least one (low-energetic) electron is emitted from the surface, due to the passage of a high-energetic charged particle. This efficiency is optimized by taking into account three effects:

- The binding potential for electrons leaving the surface. Recent experiments have shown that CsI and diamond are possible candidates as materials for the EE foil [11, 12].

- Only the 'skin' of the foil participates in the electron emission: electrons from deeper regions are stopped before they reach the surface. By increasing the skin surface, for example by applying a ribbon surface structure or by the deposit of a 'pillar' like structure, the participating volume can be increased.

- A strong electric 'extracting' field could be applied: this field is also required for electron multiplication.

A highly efficient EE foil may have a high dark current, and therefore noise in its response, due to the emission of thermal electrons. The operation of a detector with this foil as interaction medium may require a low temperature.

6. A MEMS made electron multiplier

By combining a Micro Channel Plate (MCP) with the Timepix chip, Vallerga [13] has developed a single, free-electron sensitive device with potentially superb position- and time resolution. The MEMS technology developed for InGrid detectors could enable the construction of a stack of perforated membrane planes, accurately spaced by insulating pillars (see fig. 1). If made of, or covered with, a suitable (low work function) material, these grids could act as dynodes of a photomultiplier. The transparency of such a grid, in terms of the efficiency of electrons created on the top surface of the grid and entering the holes, has been demonstrated by Melai et al. [8]. The position- and time resolution of such a device could be as good as the MCP-Timepix combination mentioned above. Since the electrostatic forces on electrons are much larger here than the Lorentz force, the detector could operate well in magnetic fields, contrary to photomultipliers.

The grids could also be replaced by ultra-thin membranes. In this case the (multiplied) electrons would not be transferred via holes towards the next grid, but instead would directly leave the bottom surface of the membrane. The path length of the electrons would be short, beneficial for the potential time- and position resolution of this electron multiplier. Due to this shorter path length, the influence of magnetic fields would be further reduced.

The combination of an Electron Emission foil and the multi-grid, MEMS made electron multiplier could form the 'Timed Photon Counter' (TiPC). This detector would be light, fast, and radiation hard. It could potentially have a very good time- and position resolution, and it would be an interesting candidate for sLHC upgrades, and for the experiments at ILC or CLIC.

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