GridPix application to dual phase TPC

Alfonsi, M.; van Bakel, N.; Colijn, A.-P.; Decowski, M.P.; van der Graaf, H.; Schön, R.; Tiseni, A.

DOI
10.1088/1742-6596/460/1/012019

Publication date
2013

Document Version
Final published version

Published in
Journal of Physics. Conference Series

GridPix application to dual phase TPC

Matteo Alfonsi[1], Niels van Bakel, Auke-Pieter Colijn, Michael Patrick Decowski, Harry van der Graaf, Rolf Schön, Andrea Tiseni

Nikhef, PO box 41882, 1009 DB Amsterdam, The Netherlands

E-mail: `malfonsi@nikhef.nl`

Abstract. GridPix is a gas-filled detector with an aluminium mesh stretched 50 μm above the Timepix CMOS pixel chip. This defines a high electric field where gas amplification occurs. A feasibility study is ongoing at Nikhef for the application of the GridPix technology as a charge sensitive device in a dual phase noble gas Time Projection Chamber (TPC), within the framework of the DARWIN design study for next generation dark matter experiments. The smallness of the device and well defined materials allow for high radio-purity and low outgassing. The high granularity of a pixel readout and the high detection efficiency of single electrons of GridPix bring benefits especially in terms of energy resolution for small energy deposits. This feature is interesting also for the measurement of the scintillation yield and the ionisation yield of noble liquids. The accurate measurements of such quantities have a direct impact on the data interpretation of dark matter experiments. The application in dual phase argon or xenon TPCs implies several technological challenges, such as the survival of the device at cryogenic temperature as well as the operation in a pure noble gas atmosphere without discharges. We describe here the recent developments of the project.

1. Introduction

GridPix [1] is a gas-filled detector where an aluminium mesh, the *grid*, is stretched 50 μm above the pixelated Timepix CMOS chip. It is realised by means of wafer post processing technology. The Timepix chip is characterised by a matrix of 256×256 pixels and a pitch of 55 μm. The picture of the microscopic structure in Fig. 1 shows the *pillars*, made of an insulating material[2] and supporting the grid, as well as the pixels pattern on the chip surface. A thin resistive layer[3] over the chip surface protects the pixel circuitry in the event of sparks in the gas.

We investigate the application of GridPix as a charge sensitive device in a dual phase Time Projection Chamber (TPC). The development is part of the alternative charge readout working package of the DARWIN project [2], a design study for the next generation dark matter search experiments with dual phase argon or xenon TPCs.

These detectors are already playing a leading role in dark matter searches, as demonstrated by the latest results of XENON100 experiment [3]. The key concept is the simultaneous measurement of the ionisation and the scintillation light produced by a particle interaction in the liquid phase, which is the sensitive volume of the apparatus. The principle of operation is depicted in Fig. 2. The prompt scintillation light, the so-called *S1* signal, is detected by

[1] Corresponding author
[2] *SU-8 photo-resist* at the current stage [4] [5]
[3] *Si-enriched silicon nitride* at the current stage [5]

photodetectors arrays, typically placed at the bottom of the liquid volume and in the vapour phase above the liquid. The electrons from ionisation are drifted to the liquid surface and extracted to the vapour phase by the applied electric field. Electrons, subject to a higher electric field in this region, produce *electroluminescence* as they collide with the gas atoms along the path to the anode electrode. This delayed scintillation light, the so-called *S2* signal, is detected again by the photodetectors arrays.

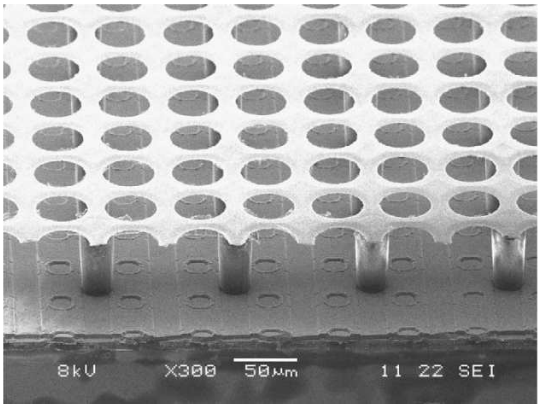

Figure 1. The microscopic structure of a GridPix device.

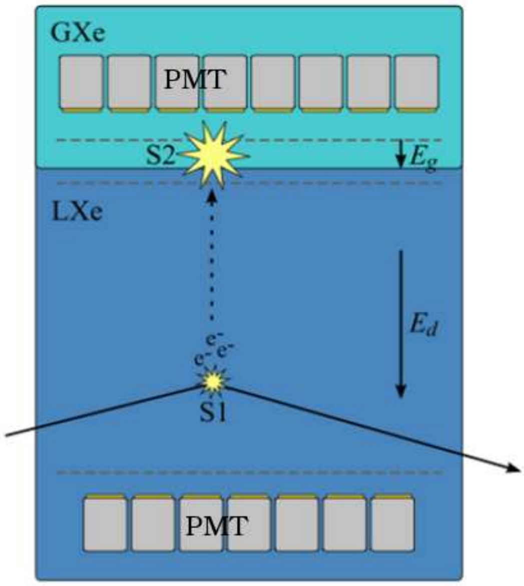

Figure 2. The typical scheme of a dual phase xenon (or argon) Time Projection Chamber.

The delay between the *S1* and the *S2* signals gives the Z-coordinate information, leading to a tri-dimensional position reconstruction. The ratio between the light and ionisation production depends on the density of the energy deposition and can be exploited for particle identification. *Electronic recoils*, i.e. electromagnetic interactions that transfers the energy to an atomic electron, are characterised by a higher charge to light ratio with respect to *nuclear recoils*, produced by neutral particles that transfer the energy to a nucleus.

2. GridPix as direct charge readout

An array of GridPix devices can instrument the TPC in place of the top photodetectors array. In this case the electroluminescence method is not required, but the electrons are collected through the grid holes in the GridPix amplification gap.

The high granularity of a pixel readout can improve the spatial resolution and the discrimination of double scatters. However it is especially effective in order to improve the energy resolution of the detector. The pixels' low noise and the high efficiency in detecting single electrons (close to 100% in Ar/iC_4H_{10} gas mixtures) allow for a digital readout approach. The electron cloud size becomes broader along the drift (in particular in the gas phase) because of diffusion and each electron is very likely collected in a different GridPix hole and detected by a different pixel: therefore the number of ionisation electrons can be inferred from the number of hit pixels.

These features are also interesting for fundamental measurements of the noble liquid scintillation and ionisation yields. The accurate knowledge of such quantities is crucial for dark matter search experiments that adopt noble liquids as target. As an example, the deposited energy is inferred from the amount of scintillation light or ionisation electrons produced. The measurements are performed in dedicated small size setups. As depicted in Fig. 3a, Compton scattering or neutron elastic scattering is exploited in order to deduce the energy deposition from the energy and the direction of the scattered photon or neutron, respectively. Compton scattering is used to obtain the scintillation and ionisation production as a function of the deposited energy for electronic recoils, while neutron scattering allows to understand the response of the medium to nuclear recoils. Systematic errors in these measurements are coming from the uncertainty on the exact spot of the interaction within the active volume (Fig. 3b) and double scatters (Fig. 3c). GridPix can provide an accurate position reconstruction reducing such systematics.

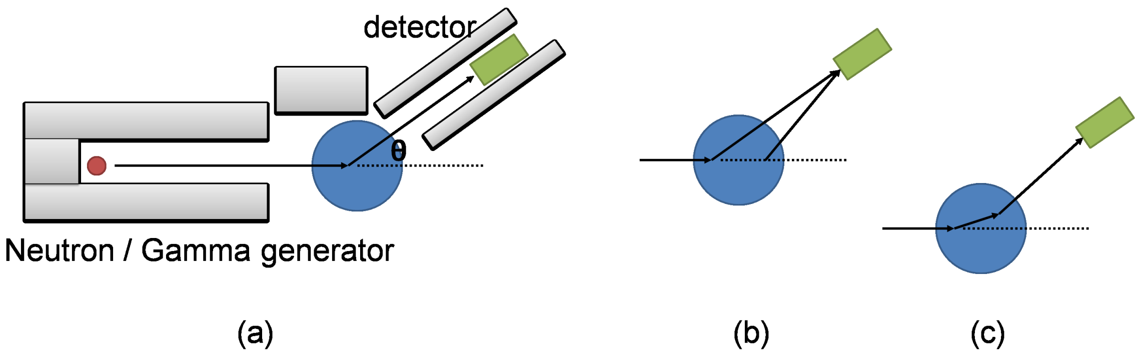

Figure 3. Scheme of the measurements of the scintillation and the ionisation yields of noble liquids for electronic and nuclear recoils. (a) Small size noble liquid detectors (blue) are irradiated by a gamma source (for electronic recoils) or a neutron source (for nuclear recoils). Compton scatterings or neutron elastic scatterings are selected by an additional detector at a specific angle θ. The energy deposited in the noble liquid is deduced from the energy and the kinematics measured with the additional detector. Sources of systematic errors are the uncertainty of the interaction position within the liquid target (b) and double scatters (c).

High radiopurity of all the components of a rare event search experiment is imperative to reduce the background. GridPix is a small device and the mass of the material introduced in the apparatus is therefore small. It is composed mainly by silicon, characterised by very low natural radioactivity. Similar arguments are valid for the outgassing properties of GridPix. The outgassing of materials is also an important property for dual phase TPC because electronegative impurities that dilute in the noble liquid capture the electrons during their drift path, hence reducing the *S2* signal.

3. GridPix operation at low temperature and development of optimised devices

The first measurements of GridPix operated in gaseous argon environment at room and low temperature as well as the test in a dual phase argon TPC are described in [7]. The test in dual phase argon revealed a mechanical weakness of the structure at cold temperature (87 K), due to the different thermal expansion coefficients of materials. As described in [8], a systematic study was performed in a temperature-controlled environment, continuously purged with nitrogen to avoid ice formation from moist air: the problem was identified in the walls, the so-called *dykes*, that support the *grid* along the perimeter of the device. Each side of the perimeter is divided in three sections. The thermal stress produces a loss of adhesion of a section from the underlying protection layer, which is then ripped off by the tension of the shrinking *grid*, as shown in Fig. 4.

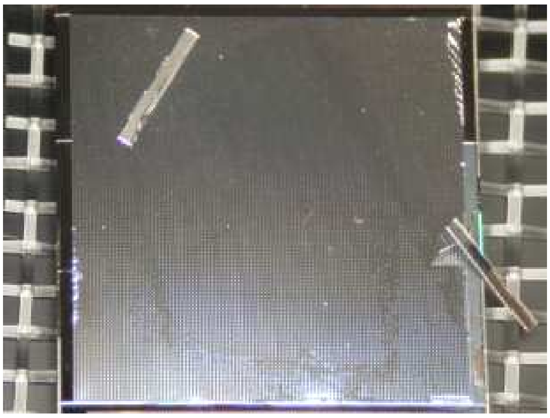

Figure 4. The *dykes* that support the *grid* along the perimeter are the weak point of the structure at cold temperature (∼ 140 K in this test). Under thermal stress they lose adhesion to the underlying protection layer and the tension of the *grid* rips them off.

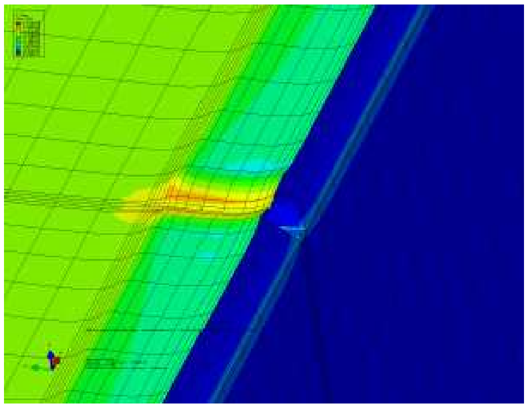

Figure 5. Engineering calculation (Finite Elements Method) of the thermal stress on the GridPix elements at a temperature of 87 K. The maximum stress is found (red region) on the edges of the sections in which the *dykes* are divided, in correspondence of the discontinuity between two sections. In this simulation the *grid* and the pillars are not included.

A similar indication is obtained by engineering calculations (using Finite Elements Methods) of the thermal stress. In Fig. 5 this is shown for a simplified structure without pillars and grid. The red regions emphasise that the discontinuity between two sections is subject to the largest stress.

We investigated with the same engineering tools modifications of the geometry that lead to more robust structures. As shown in Fig. 6, possible solutions are a finer segmentation of the dykes and the introduction of extended structures in addition to pillars for the grid support. Several prototypes with different combinations of these geometries are under production on *dummy* wafers, i.e. on a bare conductive substrate instead of a Timepix wafer. We will study the robustness at cold temperature of these new geometries. The same devices will allow to study the operation in noble gases and to compare with the standard device properties as the maximum achievable gain and gain uniformity.

At the same time, an R&D on the manufacturing process is ongoing for the realisation of a "fully ceramic GridPix", i.e. a device where pillars and *dykes* are made of silicon oxide (an insulator material) or a high resistivity silicon nitride. A successful development in this direction is a breakthrough for the low temperature operation because all the materials of the device can have matching thermal expansion properties. Low outgassing properties and high radiopurity are also expected. Furthermore the realisation of a resistive *grid* made of *Si-enriched silicon nitride* with an internal conductive aluminium network can strongly suppress the discharge development.

4. Future prospects

The GridPix production recently moved to 8" inch wafers. This important achievement demonstrates the possibility of an industrialisation and therefore the reduction of the costs.

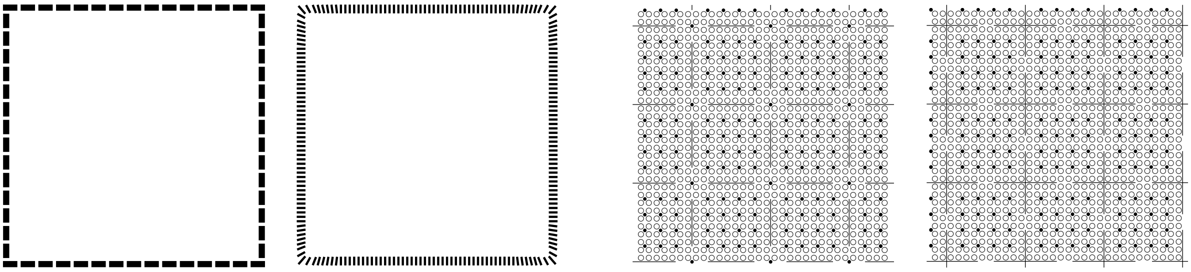

Figure 6. New geometries under study for the support of the grid that combine a finer segmentation of the grid (examples on the left) with the introduction of extended structures in addition to pillars (examples on the right).

The maximum achievable gain and the detection efficiency of single electrons will be measured with these new devices. A pressurised vessel (Fig. 7) allows to simulate at room temperature the higher gas density of a cold environment with a higher pressure. The study will be extended to pure xenon and Xe/CH_4 gas mixtures.

Furthermore we are building at Nikhef a dual phase xenon TPC (Fig. 8). The apparatus will be equipped with a gas recirculation system with hot getters to purify the xenon. We will test the GridPix operation in dual phase xenon and eventually the performance of the device as direct charge readout.

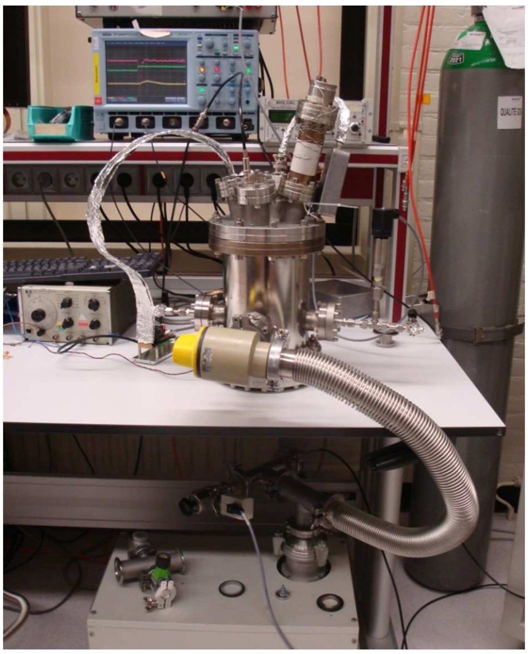

Figure 7. Setup for the measurement of the GridPix properties such as the gain and the detection efficiency of single electrons with different gas mixtures and as a function of the gas pressure.

Figure 8. Cryostat of the dual phase xenon TPC under construction at Nikhef. The detector will be built in the bottom vessel while the top vessels will house the cooling system and the heat exchanger of the gas recirculation.

Journal of Physics: Conference Series **460** (2013) 012019 doi:10.1088/1742-6596/460/1/012019

References

[1] M. Campbell *et al.*, Nucl. Instr. and Meth. **A 540** (2005) 295.
[2] L. Baudis on behalf of DARWIN Consortium, "DARWIN: dark matter WIMP search with noble liquids", arXiv:1012.4767.
[3] E. Aprile *et al.*, Phys. Rev. Lett. **109** (2012) 181301
[4] M. Chefdeville, "Development of Micromegas-like gaseous detectors using a pixel readout chip as collecting anode", PhD thesis (2009), Nikhef.
[5] V.M. Blanco Carballo, "Radiation Imaging Detectors Made by Wafer Post-processing of CMOS Chips" , PhD thesis (2009), Nikhef.
[6] Y. Bilevych *et al.*, 2009 IEEE Nuclear Science Symposium Conference Records (2009) 231.
[7] M. Alfonsi *et al.*, "Development of the GridPix detector for dual phase noble gas Time Projection Chambers", 2011 IEEE Nuclear Science Symposium and Medical Imaging Conference Records (2011) 92.
[8] R. Schön *et al.*, "Operating the GridPix detector in dark matter search experiments", Nucl. Instr. Meth. A, article in press, doi 10.1016/j.nima.2012.11.054.