Nuclear Instruments and Methods in Physics Research A 780 (2015) 100–106

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Reliable cool-down of GridPix detectors for cryogenic applications

R. Schön [a,*], J. Schmitz [b], S. Smits [b], Y. Bilevych [c], N. van Bakel [a]

[a] National Institute for Subatomic Physics Nikhef, Science Park 105, 1098XG Amsterdam, The Netherlands
[b] MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500AE Enschede, The Netherlands
[c] Physics Institute, University of Bonn, Nußallee 12, 53115 Bonn, Germany

ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form
19 January 2015
Accepted 20 January 2015
Available online 29 January 2015

Keywords:
GridPix
SU-8
Micro-pattern gaseous detector
InGrid
Liquid xenon
Cryogenics

ABSTRACT

In this paper we present thermal cycling experiments of GridPix radiation imaging detectors, in view of a potential application in a cryogenic experiment. The robustness of the GridPix detector is studied for various grid designs, as well as various mechanical and thermal surroundings. The grid design variations had insignificant effect on the grid strength. A low cool-down rate as well as good thermal contact are crucial for the durability of the grid. Further, additional strengthening at the grid edges proved necessary to maintain the integrity of the structure during thermal cycling, which was done using globtop adhesive. The combination of these measures led to 100% survival rate after thermal cycling down to $-130\,^{\circ}$C.

1. Introduction

The GridPix detector is a type of micro-pattern gaseous detector produced by microfabricating a Micromegas grid on top of a 2D pixel readout chip such as Medipix2 or Timepix [1–4]. It offers high-precision imaging of ionizing radiation in two or three dimensions. Micromegas fabrication with microtechnology offers high geometrical precision, high-purity materials and the possibility to mass-produce in existing clean room facilities [5]. In recent years the GridPix detector has come under consideration for weakly interacting massive particle (WIMP) search experiments involving dual-phase noble gas detectors within the R&D programme of the DARWIN (dark matter WIMP search with noble liquids) consortium [6].

To establish the viability of the GridPix option in these experiments, three questions are to be answered: Can the detector be cooled down repetitively without degrading its mechanical properties? Can we reach sufficient gas gain to detect single electrons? Can the electronics operate at cryogenic temperatures of $T_{\ell \mathrm{Ar}} = -186\,^{\circ}$C and $T_{\ell \mathrm{Xe}} = -110\,^{\circ}$C? For a discussion of the second and third question we refer to [7,8], respectively. In this paper we address the first question. We present experimental studies on thermal cycles of a variety of GridPix prototypes, embedded in various thermal environments, and show finite-element-method (FEM) simulations of the mechanical behaviour of the detector during cool-down.

2. Limitations of GridPix at low temperatures

The GridPix detector consists of a silicon microchip fabricated in standard CMOS (Timepix), a few-micrometer thick layer of high-ohmic material (silicon-rich silicon nitride, SiRN), insulating support pillars made of SU-8 photoresist material measuring 50 μm in height, and a 1 μm thick grid made of pure aluminium with holes of 38 μm diameter. In the central region of the GridPix structure, a periodic pattern of pillars physically connects the grid with the microchip, see Fig. 1. At the edges, the grid should be better confined to avoid curling and to suppress sparks due to local field enhancement. Large rectangular SU-8 support-ridges are normally positioned along the edges for that reason. It is however necessary to make periodic interruptions in these support ridges, so-called strain relief gaps, to prevent rupture of the SU-8 material during fabrication [9] and to improve the dissolution of not cross-linked SU-8.

In previous works, the adhesion strength of this material stack was studied under various fabrication conditions and after storage in a high humidity environment [10]. The study showed a clear moisture sensitivity and a strong dependence of adhesion on the details in the fabrication process.

It can be expected that a GridPix detector with poor adhesion properties in the layer stack will delaminate upon thermal cycling, as a result of the different thermal expansion coefficients (CTE) of the used materials. The suspended aluminium grid may wrinkle or tear under thermal cycling, as the thicker and stiffer silicon substrate dictates the physical dimensions of the structure at all temperatures.

* Corresponding author.
E-mail address: rolfs@nikhef.nl (R. Schön).

http://dx.doi.org/10.1016/j.nima.2015.01.075
0168-9002/

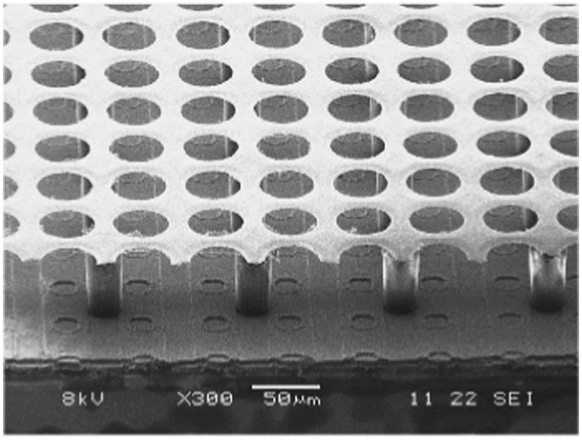

Fig. 1. Microscope picture showing the cross-section of a GridPix detector. A layer of silicon-rich silicon nitride protects the pixels of the Timepix readout chip against discharges. SU-8 pillars support the aluminium grid.

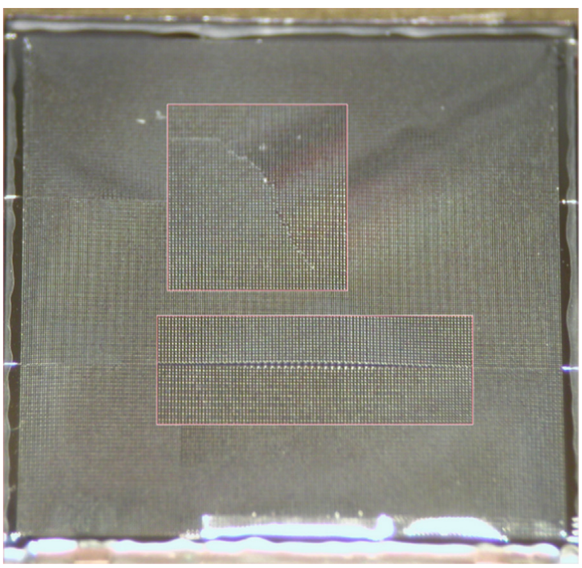

Fig. 2. Picture of the damaged grid after operating a GridPix inside the test cryostat of the ArDM experiment. During the cool-down of the argon gas inside the cryostat to −186 °C the detector was still working as expected. It was not until the filling the lower cryostat with liquid argon that the data suggested a breakage of the grid. The picture was taken after warming up and opening the cryostat.

A preliminary test of operating a GridPix in the prototype chamber of the Argon Dark Matter (ArDM) experiment [11] confirms this. After the exposure to dual-phase argon at −186 °C the grid showed severe damage, see Fig. 2. The ruptures in the grid start at the strain relief gaps of the SU-8 edge-support that are fixed to the substrate by globtop (epoxy).[1]

The robustness of GridPix detectors against thermal cycling was tested by controlled cool-down with liquid nitrogen to −130 °C. At this temperature, close to $T_{\ell Xe}$, the thermal stress is lower than at $T_{\ell Ar}$. First the samples were dried in a vessel in view of the moisture sensitivity mentioned above. The vessel was flushed with N_2 for 12 h at room temperature; then heated to 80 °C; then, after 30 min at 80 °C, cooled down and flushed in N_2 for several hours at room temperature.

The vessel was then inserted into a dewar with liquid nitrogen, well above the liquid surface. This provides cooling at a rate controlled to about 1 K/min by a heating element inside the vessel. The setup further includes thermometers near the samples and at the vessel bottom, see Fig. 3. The vessel is cooled to −130 °C and kept at this temperature for 30 min before gradually warming it up to room temperature.

The grids of two out of four devices survived the thermal cycle. The two other grids show similar damage: segments of the support ridge lifted off the protection layer. This is the result of the stress culminating at the borders as mentioned above. It points to an increased stress between the SU-8 and the SiRN layer in regions where the SU-8 structure is large. On the other hand, the two surviving samples indicate that a GridPix application in this cold environment is technically within reach.

3. SU-8 pattern modifications

Finite-element simulations[2] were conducted to investigate and visualize the effects of temperature cycling on the GridPix configuration. The thermal and mechanical properties of all employed materials as well as the thickness of the layers are listed in Table 1. We can assume that the silicon substrate imposes its lateral dimensions on the whole configuration thanks to its superior thickness. As clear from the table, the thermal expansion mismatch is highest at the SiRN–SU-8 interface, so this is a likely plane for delamination. A typical simulation result is shown in Fig. 4a. All thermal expansion mismatch tends to culminate at the edges, leading to a tendency of the aluminium to rupture starting from the edges, as observed in the aforementioned tests. Moreover, the peak stress values in the material stack shift from the grid to the substrate, see Fig. 4b, beneath the added support structures.

Based on the simulation results, several new designs were made with different SU-8 support features at the edge and in the pixel matrix area of the GridPix chip. The alternative edge designs and the reference are shown in Fig. 5. Further, bar structures were designed into the central region, aiming to form a more rigid construction which could lead to less aluminium excursion at the edges, see Fig. 6. The design sizes match the Timepix and Medipix readout chips [3,4].

Two dummy wafers with these modified designs and the reference GridPix design [10] were fabricated at Fraunhofer IZM Berlin to evaluate the differences between these patterns in terms of mechanical strength, thermal cycling robustness, and detector performance. Each wafer has 8 reference designs plus 9 instances of 11 modified designs (see [7] for further detail). The wafers have in common the silicon substrate, the SiRN protection layer of 2 μm thickness, the SU-8 structures and the aluminium grid, i.e. the integrated grid (InGrid) structure. One wafer, however, has an additional gold layer between the silicon substrate and the SiRN layer. This gold layer serves as anode to read out electrical signals in a setup discussed in Section 5.

4. Thermal cycling experiments of modified SU-8 patterns

The multiple samples allowed for a systematic study of the decisive factors influencing grid stability during thermal cycling. The following experimental conditions were varied:

- the SU-8 ridge structure (cf. Fig. 5);
- the SU-8 active area structure (cf. Fig. 6);
- samples with gold electrode and without;

[1] The used globtop is Dymax 9001-E-v3.1 UV/VIS adhesive [12].

[2] The simulations were performed with the Abaqus finite element analysis software [13].