Nuclear Instruments and Methods in Physics Research A 804 (2015) 155–162

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Assembly and test of the gas pixel detector for X-ray polarimetry

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ARTICLE INFO

Article history:
Received 12 September 2015
Received in revised form
17 September 2015
Accepted 17 September 2015
Available online 30 September 2015

Keywords:
X-ray
Polarimetry
Gas
Detector
XIPE
Astrophysics

ABSTRACT

The gas pixel detector (GPD) dedicated for photoelectric X-ray polarimetry is selected as the focal plane detector for the ESA medium-class mission concept X-ray Imaging and Polarimetry Explorer (XIPE). Here we show the design, assembly, and preliminary test results of a small GPD for the purpose of gas mixture optimization needed for the phase A study of XIPE. The detector is assembled in house at Tsinghua University following a design by the INFN-Pisa group. The improved detector design results in a good uniformity for the electric field. Filled with pure dimethyl ether (DME) at 0.8 atm, the measured energy resolution is 18% at 6 keV and inversely scales with the square root of the X-ray energy. The measured modulation factor is well consistent with that from simulation, up to $\sim$0.6 above 6 keV. The residual modulation is found to be $0.30 \pm 0.15\%$ at 6 keV for the whole sensitive area, which can be translated into a systematic error of less than 1% for polarization measurement at a confidence level of 99%. The position resolution of the detector is about 80 μm in FWHM, consistent with previous studies and sufficient for XIPE requirements.

1. Introduction

X-ray polarimetry is expected to be a powerful tool for astrophysics, offering extra information in addition to X-ray imaging, spectroscopy and timing. It allows us to probe the magnetic field via synchrotron radiation or test the geometry via scattering, and is capable of testing fundamental physics such as quantum electrodynamics and general relativity under extreme magnetism or gravity [1–3]. Despite the high demand in astrophysics, X-ray polarimetry has been an unexplored area for 40 years since the experiments on the OSO-8 satellite [4] in 1970s, due to the absence of sensitive technology.

Along with the development of micro-pattern gas detectors, it has become possible to image the tracks for electrons of a few keV in gas chambers, allowing for sensitive X-ray polarimetry depending on the photoelectric effect using the gas electron multiplier (GEM) with pixel readout [5,6]. Compared with other readout techniques, the gas pixel detector (GPD) offers symmetric measurement in the two dimensions and delivers a low systematic error below one per cent even without instrument spinning [6–8]. One of the key elements to the success of the GPD detector is the large-format high-resolution pixel readout chip. Several generations of dedicated ASIC chips have been developed, reaching to a pixel size of 50 μm and a chip size of 1.5 cm × 1.5 cm (105k pixels) [9,10]. Two versions of sealed test chambers, a small one [11] and a large one [7], were designed by the INFN-Pisa group and assembled by Oxford Instrument Analytical Oy. The major improvement for the large version is that the background induced by the wall of the chamber is reduced and the electric field is more uniform [12].

In 2015, the X-ray Imaging and Polarimetry Explorer (XIPE) [3] was approved for phase A study by the European Space Agency (ESA). It is a space telescope concept dedicated to X-ray polarimetry in response to the call for medium-class missions. One of our tasks is to build refillable sealed GPD detectors to test and optimize the gas mixture of the detector. We therefore describe here the assembly of the GPD detectors and some preliminary test results. The optimization of the gas mixture and related tests of the detector will be reported in follow-up papers. Our work is based on the small version GPD, because it is relatively simple in structure and assembly, and sufficient for testing the gas mixture.

2. Detector structure and assembly

We start with the design of the small GPD [6,11], see Fig. 1 for a schematic drawing. The ASIC chip [10] is mounted using low

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http://dx.doi.org/10.1016/j.nima.2015.09.060
0168-9002/

outgassing silver epoxy inside a vacuum tight 304-pin ceramic package, which is soldered onto a printed circuit board (PCB). The bottom of the chip is connected to the electronic background and the heat from the chip is dissipated into the base of the package and then to the PCB board, where a Peltier cooler can be mounted on the other side and multiple via holes are used to increase the thermal conductivity. The surface of the chip is measured to have an orientation tolerance of less than 20 μm with respect to the shoulder of the package using a measuring microscope. The distance between the chip surface and the package shoulder is 0.8 mm, which is the induction distance between the anode and the bottom layer of the GEM. The GEM foil is manufactured by SciEnergy Inc. It is 50 μm thick insulated by liquid crystal polymer; the laser-etched holes have a diameter of 30 μm and a pitch of 50 μm in a hexagonal pattern. Four knife-edge clamps are used to apply tensions to the GEM foil and a FR4 frame is fixed on it to keep the tension using double sided sticky tape. The framed GEM foil is then placed right above the shoulder of the ceramic package; the frame is just outside the package and is in the air side so that the choice of its material is not important. A ceramic spacer of 1 cm thick (the drift distance) stands above the GEM foil and supports the cap of the chamber, which is a titanium plate with a 17 mm × 17 mm square hole sealed with a 100 μm thick beryllium window, both serving as the cathode of the detector. On the top of the titanium plate, a copper tube with a diameter of 6 mm is mounted for vacuum pumping and gas filling. All the parts for the main body of the chamber are glued together using low outgassing epoxy and cured at a temperature of 60 °C. The copper tube is welded onto the titanium plate and some epoxy is used to further seal the joint. After the chamber is filled with gas, the tube is cut and sealed using ultrasonic welding. To change the gas mixture of the chamber, we will just cut the copper tube. Before filling the gas, the detector is pumped and baked for weeks until a vacuum down to $\sim 10^{-9}$ mbar.

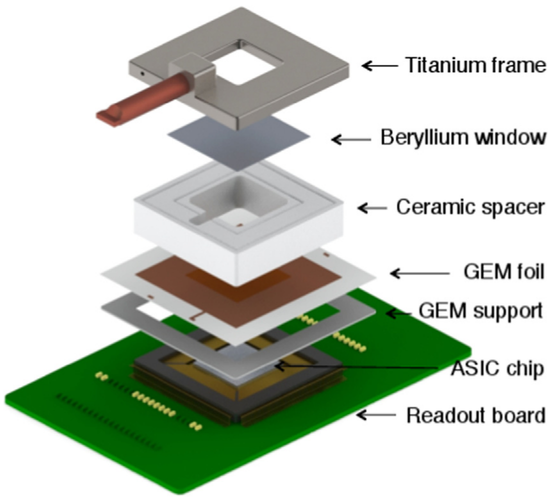

Fig. 1. A schematic drawing of the GPD.

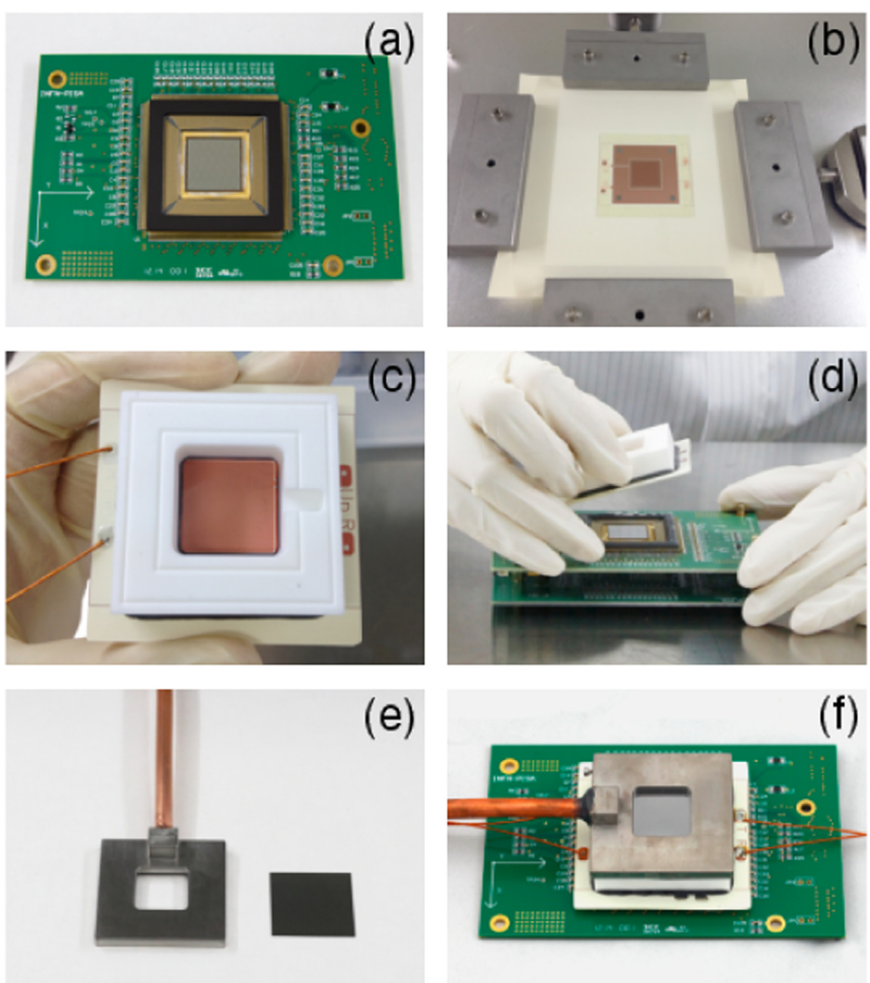

Fig. 2. Detector assembly. (a) ASIC chip in the ceramic package and both on the PCB; (b) GEM framing; (c) spacer and GEM; (d) gluing the spacer/GEM to the package; (e) titanium cap and beryllium window; and (f) a completely assembled GPD.