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ScienceDirect
Nuclear Instruments and Methods in Physics Research A 591 (2008) 42–45
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Characterisation of an epitaxial GaAs/Medipix2 detector using fluorescence photons

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Available online 20 March 2008

Abstract

A high-purity GaAs sensor of 110 μm thickness has been bump bonded to a Medipix2 readout chip. The room temperature spectroscopic response of this device to fluorescence photons in the energy range from 8 to 28 keV is presented and compared to the response of a 300 μm thick Si sensor, also bonded to a Medipix2 chip. The measured photopeak responses are used to calibrate both detectors. The depth of depletion of the GaAs sensor is estimated to be ~50 μm at 140 V sensor bias voltage from measurements made using the 8 keV Kα line of a Cu target X-ray tube.

PACS: 07.85.Fv; 29.40.Gx; 29.40.Wk; 81.05.Ea

Keywords: GaAs; Medipix2; X-ray imaging

1. Introduction

At present, silicon is the standard sensor material used for direct detection of X-rays due to its relatively low cost and the availability of homogeneous, well-characterized and high resistivity wafers. However, in applications in the energy range from 10 to 100 keV the photo effect conversion efficiency decreases rapidly with photon energy. Moreover, Compton scattering significantly increases for photons with energies above 40 keV, surpassing the photo effect at about 55 keV, thus limiting strongly the spectral performance of the detector system above these energies. Si as a sensor material is therefore generally limited to applications using energies of below 40 keV. As a consequence, high Z sensor materials are of strong interest for a wide range of X-ray applications. Progress in material homogeneity and processing technology recently opened the possibility to fabricate detector-grade devices from GaAs. For this material, Compton scattering is less probable than photoelectric conversion up to about 150 keV. Good carrier lifetime and high mobility in GaAs together with a large band gap of 1.4 eV make GaAs a promising candidate for a room temperature solid-state detector material [1].

2. Detector system

A 110 μm thick p–i–n GaAs sensor and a 300 μm thick Si sensor were bump bonded to Medipix2 [2] readout chips. The Medipix2 chip has an active matrix of 256 × 256 cells, covering an area of 1.98 cm^2. Within each 55 μm square pixel a shaping preamplifier, a double-threshold window discriminator and a 13-bit counter are implemented. Each pixel can compensate for up to 10 nA of leakage current individually. For the measurements presented here, the chip has been used in single-threshold mode only. The detection threshold can be linearly adjusted from ~1000e$^-$ up to ~40 000e$^-$. The measured threshold dispersion over the matrix is less than 100e$^-$ rms, and the equivalent noise charge (ENC) of a pixel is ~140e$^-$ rms [3].

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doi:10.1016/j.nima.2008.03.020

The reference detector was made of 300 μm thick high resistivity n-type float zone (FZ) silicon and used standard planar p+ on n diodes. The GaAs sensor was made of high-purity epitaxial GaAs grown by using the hydride vapour phase epitaxy (HVPE) method, with a final sensor thickness of 108–111 μm. The front-end contact was implemented as a p–i(n) junction. A detailed description of the sensor and the contact preparation can be found in Ref. [4]. The GaAs Medipix2 assembly was shipped after bump bonding in a X4 gel–pak [5]. After removal of the assembly from the X4 gel–pak, the sensor was cracked into four pieces. The cracks were most probably created when applying vacuum to the gel–pak as a consequence of the strong adhesion of the X4 gel–pak in combination with a small scratch in the sensor surface, see photo in Fig. 1a. The cracks in the sensor, which were created near to pixel (196,150) followed the <110> crystallographic directions and extended to the sensor edges in all the four directions. Fortunately, the detector performance was very little affected by this accident, as can be seen from the image of a ^{90}Sr source in Fig. 1b. This indicates that no significant increase in the generation of the leakage current is induced by cracks and the lateral extension of the distortion of the pixel response is limited to the pixel pitch of 55 μm. Note that the readout chip used was not perfect and that column 242 is nonfunctioning. Also the adjacent columns show higher noise levels. Column 242 and its immediate neighbours have been masked in all subsequent measurements.

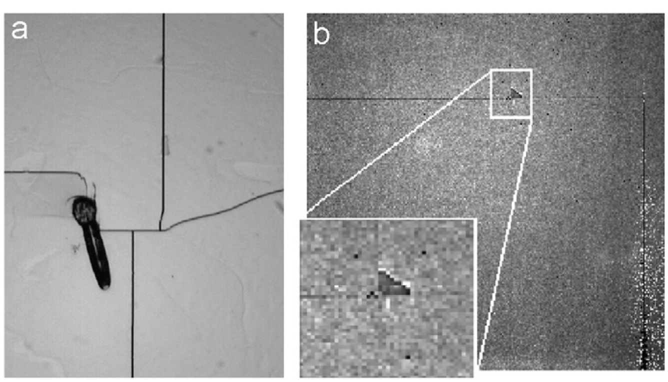

Fig. 1. Origin of the crack in the GaAs sensor. (b) ^{90}Sr image with 60 s acquisition time. The origin of the cracks is indicated by the white square together with a zoom into the region around the origin.

3. Measurements

Following the cracking of the detector, the stability of the leakage current with time of the GaAs assembly was measured from 10 to 160 V sensor bias. Above 140 V sensor bias voltage, the leakage current showed instabilities [4], and therefore all subsequent measurements were made with bias voltages <140 V. The sensor leakage current of the reference Si assembly used increases exponentially above 80 V. (It was stable with time.) The maximum bias voltage in the subsequent measurements with this detector was therefore fixed at 90 V.

3.1. Energy calibration

All fluorescence measurements were performed using a PANalytical X-pert system [6], with a Cu target X-ray tube operated at 50 kV and 10 mA. Sheets of different materials were placed ~10 cm in front of the tube and the backward emitted fluorescence photons were detected.

To calibrate the Medipix2 threshold DAC of the GaAs assembly fluorescence photons from Cu (8.05/8.9 keV), Cd (23.1/26.1 keV), In (24.2/27.3 keV), Pd (21.2/23.8 keV) and Sn (25.7/28.4 keV) plates were used. Fig. 2a shows the measured spectra derived from threshold scans performed with 120 V sensor bias. Pixels from a square region of interest (column 60–80, row 65–80) were used to calculate the spectral response. The variation in the threshold position of the individual pixels was removed by realigning the individual threshold scans, prior to averaging and taking the derivative of counts at each threshold value. In the same way fluorescence photons from Cu, Cd, In and Pd

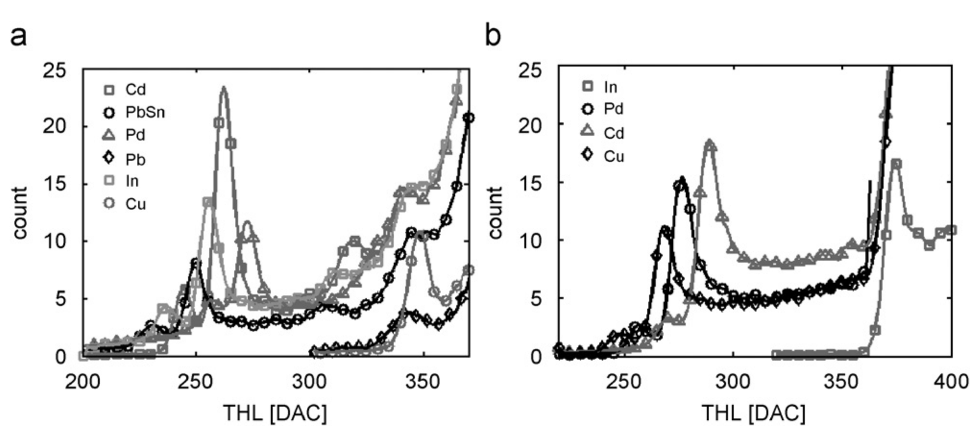

Fig. 2. Measured fluorescence spectra, computed from the pixels in rows 65–80, columns 60 to 80. (a) *K* fluorescence spectra of Cd, Sn, Pd, In and Cu measured with the MPX2/GaAs assembly at 120 V sensor bias. The *L*-lines of Pb (10.5/12.6 keV) overlap with the *K*-lines of Ga (9.2/10.2 keV) and As (10.5/11.7 keV) and could not be fitted properly. (b) *K* fluorescence spectra of Cd, Pd, In and Cu measured with the MPX2/Si assembly at 90 V sensor bias.