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Characterisation of a GaAs(Cr) Medipix2 hybrid pixel detector

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ABSTRACT

A semi-insulating GaAs(Cr) sensor of 300 μm thickness with a bulk resistivity of 10^9 Ω cm and no guard ring structures 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 at different sensor biases is measured and compared to the response of a reference detector with a 300 μm thick Si sensor. The measured responses show that the full volume of the GaAs(Cr) is active and indicate a charge collection efficiency of 90%. The spatial resolution if this device is 8 lp/mm.

1. Introduction

At present silicon is the sensor material most widely used in direct detection system, for charged particle detection as well as for X-ray detectors. The relatively low cost and the industrial availability of homogeneous, high resistivity and well characterized wafers make it the de facto standard sensor material. However, its low atomic mass and low density limit its application to the X-ray energies below 40 keV, since the photoeffect conversion efficiency decreases rapidly with photon energy. Moreover, Compton scattering significantly increases for photons with energies above 40 keV, surpassing the photoeffect at about 55 keV, thus limiting strongly the spectral performance of the detector system at higher energies. As a consequence high Z sensor materials are of strong interest for a wide range of X-ray applications. Epitaxial GaAs material using rectifying contacts and a depleted detector bulk material [1–3] offer excellent charge collection and long carrier lifetimes, but the achievable thickness of the epitaxial layer is limited and depletion at room temperature can be difficult. An alternative is presented by photoconductive sensor made from Cr compensated GaAs [4]. The possibility of growing layers with a thickness of up to 1 mm makes it a very interesting candidate for high Z sensor material.

2. Detector system

A semi-insulating GaAs(Cr) sensor of 300 μm thickness and without guard ring structures has been bump bonded to a Medipix2 readout chip [5]. 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 is implemented. Each pixel can compensate individually for up to 14 nA of positive and up to 7 nA of negative leakage current. The detection thresholds can be linearly adjusted from ~1000 up to ~40,000 e$^-$. The threshold dispersion over the matrix is less than 100 e$^-$ rms and the equivalent noise charge (ENC) of a pixel is ~140 e$^-$ rms. For the measurements presented here the chip has been used in single threshold mode only.

The GaAs(Cr) sensor under investigation has a bulk resistivity of 10^9 Ω cm. Both sides are metalized with ~1 μm gold on top of 50 nm vanadium. The metal layer is structured on the readout side into pixel contact pads of 30 μm diameter, in order to bump bond the sensor onto the readout chip. The GaAs sensor was operated with negative bias voltage in order to collect electrons. As a reference detector a Medpix2 bump bonded to 300 μm thick high resistivity n-type float zone (FZ) silicon with standard planar p+ on n diodes, operated in positive polarity and collecting holes, has been used in all measurements.

3. Measurements

3.1. Leakage current

The IV curve measured with the GaAs sensor, already bump-bonded the Medipix2 readout chip, can be seen in Fig. 1. The sensor clearly shows resistive behavior with a total resistivity of 2.1 × 10^7 Ω. The dominating leakage path is via the dicing edges of the sensor. The maximum allowed leakage current of 7 nA/pixel of the Medipix2 leaves a large margin even if assuming the total leakage current to be equally shared between all pixels.

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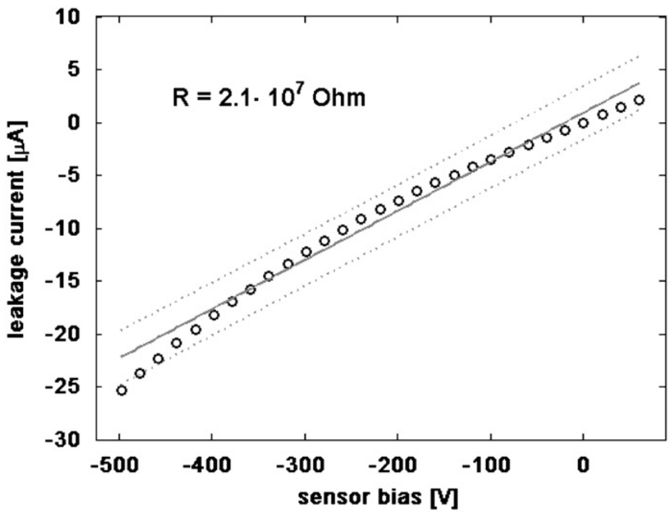

Fig. 1. Leakage current as a function of sensor bias.

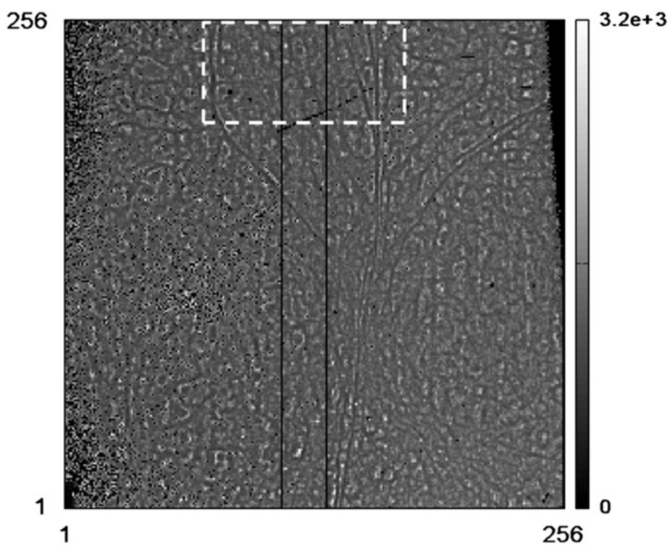

Fig. 2. Detector response to uniform irradiation with a Cu-target X-ray tube operated at 20 keV.

3.2. Homogeneity and bump bonding

Fig. 2 shows the response to uniform irradiation with a Cu-target X-ray tube operated at 30 keV. On the left hand side of the detector numerous pixels are not connected to the readout chip. Also in the upper right corner an area is not connected. The non-responsive columns in the center of the detector are defective columns of the readout electronics. The total bonding yield is 93%. Fig. 3 is a microscope image of the backside contact of the GaAs assembly, corresponding to the area marked in the irradiation image. Inhomogeneities in the sensor surface are clearly visible and match the variations in counted photons in Fig. 2.

3.3. Fluorescence measurements

The spectral response was measured by scanning the threshold DAC from the chip noise floor at $\sim$1000 e$^-$ up to just above the

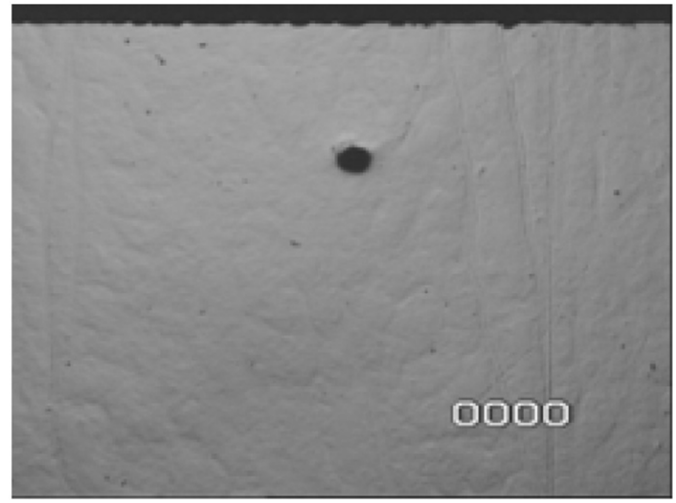

Fig. 3. Microscope image of the backside contact of the GaAs assembly, corresponding to the marked area in the picture above.

energy of the X-ray emission line. The residual variation in the threshold position of the individual pixels over the whole was removed by realigning the individual threshold scans prior to averaging and then taking the derivative of the averaged scans to obtain the spectra. Pixels from a square area (columns 160–240, rows 100–200) were used to calculate the spectral response. All fluorescence measurements were performed using a PANalytical X-pert system [6] with a Cu target X-ray tube operated at 60 kV and 10 mA. Targets of Cu, Zr, In, Pd, Cd and I were placed at $\sim$10 cm distance in front of the tube and the fluorescence photons emitted backwards from the target were detected.

3.3.1. Cd fluorescence

In order to identify the optimal sensor bias for the subsequent threshold scans the response to Cd fluorescence photons was measured at several sensor bias voltages. In case of the GaAs sensor the maximum bias voltage was -500 V. The Si sensor was biased up to +400 V. Fig. 4 shows the obtained spectra. The total count rate of the GaAs detector is almost independent of the sensor bias, thus indicating that the active volume remains almost constant. The position of the photopeak on the other hand shifts to higher energies with increasing sensor bias, due to incomplete charge collection at longer transit times. The saturation velocity for GaAs in the literature is at an electric field of $\sim$3 kV cm^{-1}; therefore one would expect the maximum charge collection at $\sim$100 V. With this sample the position of the photopeak is at its maximum at an electric field of $\sim$6 kV cm^{-1}. The Si detector shows as expected the biggest gain in signal height at electric fields below $\sim$10 kV cm^{-1}. With higher electric fields the increase of the photopeak count decreases due to onset of velocity-saturation effects.

3.3.2. Energy calibration

To calibrate the Medipix2 threshold DAC of the two detectors 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 I (28.5 keV) plates were used. The Si detector was operated at +300 V bias voltage, the GaAs at -500 V. From the design value [5] and from previous measurements [1,7] a threshold DAC step of $\sim$40 e$^-$ is expected in case of full charge collection. The Si assembly used here was measured to have 42.5 e$^-$ per threshold DAC step, which is within