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Medipix2: Processing and measurements of GaAs pixel detectors

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Abstract

For applications with high-energy X-ray photons (30–120 keV) semiconductors with high Z like CdTe and GaAs are required. In comparison with silicon detectors, the absorption of GaAs is higher. GaAs wafers had been prepared and flip-chip bonded to the Medipix2 readout chip at the Freiburger Materialforschungszentrum (FMF) using a low-temperature process. For this work, 300-μm-thick wafers were chosen for first measurements. The pixel and backside contacts were processed with Ti–Pt–Au to form Schottky contacts. The surface of the samples was passivated with BCB. The pixel pitch was 55 μm (standard Medipix) and 110 μm. The performance of these GaAs detectors was studied for different radiation sources and X-ray tubes. The efficiency of the GaAs assemblies is compared to 700-μm-thick Si assemblies. The number of detected quanta in 300 μm GaAs is 10 times higher than in 700 μm Si for γ-rays at 44 and 60 keV. This can be explained by the higher absorption of the GaAs.

Keywords: Pixel detector; Medipix; GaAs; Semiconductor

1. Introduction

Single chip and wafer-based processing technology for pixel sensors has been developed during the last few years at Freiburger Materialforschungszentrum (FMF). Recently, a process for deposition of low melting solder bumps combined with a fluxless flip-chip-bonding technique was built up [1]. This process was used for the fabrication of Medipix2 assemblies with GaAs sensors. Semi-insulating, 3 in. GaAs wafers with a thickness of 300 μm were processed as pixel detectors, flip-chip bonded to the Medipix2 chip and compared with existing Si-detector assemblies. First, measurements are presented in this paper showing promising results.

For most applications in the field of X-ray imaging with radiation in the energy range of 10–120 keV, a photo-absorption as high as possible is required in the detector. Since silicon (in reasonable thickness) does not fulfill this requirement, high Z materials like (Cd,Zn)Te [1] or GaAs [2–6] are good alternatives. Important advantages of GaAs with respect to Cd(Zn)Te are the uniformity of material properties and availability of large wafers up to 6 in.

At 300 K, a 700-μm-thick Si detector has an intrinsic detection efficiency of less than 20% at photon energies of 30 keV whereas 300 μm GaAs can absorb more than 80% of the incoming quanta. At 60 keV, this GaAs sensor even has an efficiency that is a factor 10 higher than 700 μm Si (Fig. 1).

2. The Medipix2 readout system

The Medipix2 electronic readout chip was developed by the Medipix2 Collaboration [7,8] at CERN. It consists of 256×256 picture cells. Each pixel of $55 \times 55\,\mu m^2$ size contains: charge sensitive preamplifier with pulse shaper, two thresholds for working in the so-called window or in single discrimination mode and a 13-bit counter. The preamplifiers can handle either input polarity—positive or negative. The chip is therefore suited for use with different sensor materials including GaAs and Cd(Zn)Te since it can work in ‘‘electron’’ or in ‘‘hole’’ detection mode.

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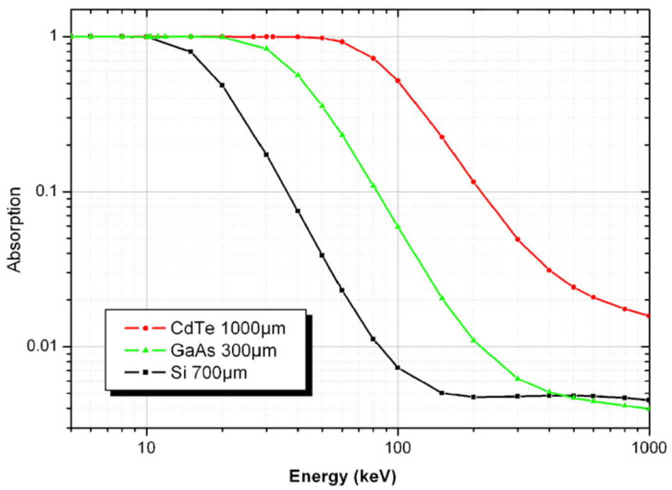

Fig. 1. Absorption probability vs. photon energy of semiconductor detectors of reasonable thickness: Cd(Zn)Te 1 mm; GaAs 0.3 mm; Si 0.7 mm.

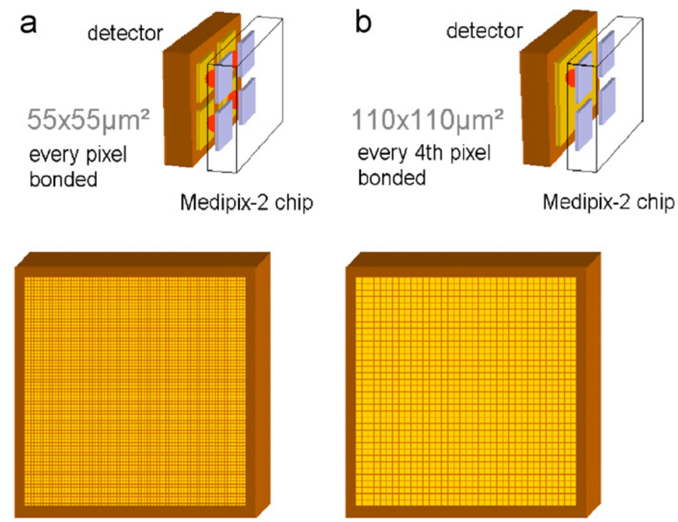

Fig. 2. Special contact processing on GaAs semiconductor to achieve different pixel sizes (a) normal design: 55 µm × 55 µm, connecting every pixel; (b) 110 µm × 110 µm, leaving three out of four readout channels unconnected.

3. Processing details

From an unprocessed 3″ GaAs wafer to a bondable Medipix2 detector several processing steps have to be applied to the semiconductor material:

- deposition of metal–semiconductor contacts,
- (in this case Ti–Pt–Au to form Schottky contacts),
- passivation of the pixel contact surface by BCB,
- solder–bump–metal deposition,
- reflow process (to form solder balls),
- sawing/dicing of the wafer.

Larger improvements to the standard electroplating process have been achieved at FMF by realizing an electroplating free process for solder deposition [9]. The homogeneity of the bump ball sizes over the wafer could significantly be increased.

After these steps both devices—the sensor and the Medipix2 readout chip—can be flip-chipped. In order to decrease the stress to the GaAs semiconductor low melting indium–tin bump metal was used for the interconnections. For chemical reduction of oxides on the bump metal, we developed a fluxless bump-bonding process. In former measurements, flux residues appeared to have negative effect on image quality due to capacitive coupling between pixels resulting in charge loss.

For some application, the high intrinsic spatial resolution of the Medipix2 chip (55 µm × 55 µm) is not required. Hence, we designed contact geometries for different pixel sizes on the sensor connecting only one readout pixel out of 4 and 9—for pixel sizes of 110 µm × 110 µm and 165 µm × 165 µm, respectively (see Fig. 2).

The energy resolution is improved with bigger pixels due to reduction of charge sharing.

4. Experimental results

4.1. X-ray images

For first acquisitions, we used a Siemens Heliodent MD X-ray tube with tungsten target, 60 kV anode voltage and 1.5 mm aluminum filtering as radiation source. Fig. 3 shows the images of a standard TTL chip as object, taken with a GaAs assembly of (a) 55 µm × 55 µm and (b) 110 µm × 110 µm pixel size. In case of the smaller pixels (a) about 90% of all pixels were successfully connected to the Medipix2-chip while for the larger pixels (b) the interconnection efficiency is at 98%. In both cases, the missing bonding of some pixels is due to not perfect parallelism of the bond partners. This will be solved in the near future.

Clearly visible is a decrease in spatial resolution with increased pixel size: in Fig. 3a, one can identify the wire bonds of ~20 µm thickness inside the TTL chip, the larger pixels (b) cannot resolve these structures.

The modulation transfer function MTF was measured using the edge method. After threshold equalizing of the chip a sharp Pb-edge was used as object between a 60 kV X-ray tube and the GaAs sensor. A 3° tilt between edge and detector columns was applied for the measurements. The Medipix chip was used in single-threshold mode with low-threshold discriminator set to 8 keV. At 30% MTF level, we measure (Nyquist frequencies in brackets) spatial resolutions of 6.5 (4.6) and 10.2 (9.1) lp/mm for 110 and 55 µm pixels, respectively. Due to charge sharing in the sensor, we do not achieve twice the resolution for the smaller pixels in comparison to the 110 µm pixels.