Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 576 (2007) 239–242
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Investigation of charge carrier transport and charge sharing in X-ray semiconductor pixel detectors such as Medipix2

Alexander Korn[a,*], Markus Firsching[a], Gisela Anton[a], Martin Hoheisel[b], Thilo Michel[a]

[a]*Physics Department 4, University of Erlangen, Germany*
[b]*Siemens AG Medical Solutions, Forchheim, Germany*

Available online 6 February 2007

Abstract

The output of X-ray semiconductor pixel detectors such as Medipix2 depends on various effects, such as the primary energy distribution inside the sensor layer, the diffusion of the generated charge carriers during the drift, the discrimination of the input signal by a threshold, and detection of scattered quanta originating from the detector parts behind the sensor layer. In this study we introduce an advanced Monte Carlo simulation including all these effects. The simulation was verified for energy distribution functions by performing threshold scans of monoenergetic radiation with the Medipix2.

PACS: 07.07.Df; 07.85.−m; 78.70.Ck; 78.70.Dm; 78.70.En; 87.57.−s; 87.59.−e; 87.62.+n

Keywords: Medipix; Simulation; ROSI; Charge sharing; Backscattering

1. Introduction

For the development of applications for novel photon counting pixel detectors such as Medipix2 [3] the properties of the device have to be well known. Monte Carlo Simulations are powerful tools to examine these properties.

There are several processes turning an induced charge cloud into an increment of the detector counter. The generated charge carriers drift inside the sensor layer due to an applied electric field towards the detector electrodes. During this drift they diffuse into different directions. Any motion perpendicular to the drift direction leads to a spatial spread. This spread depends on the applied electric field as well as on the depletion voltage which is a property of the semiconductor used as a sensor material. For higher electric fields the effect of velocity saturation of charge carriers in a semiconductor has to be considered. Finally the charge carriers are collected by the detector electrodes, the input signal is discriminated and counted as long as it is above the threshold level. With small pixels there is a considerable chance that more than one pixel collects a certain amount of charge. This can lead to multiple counts or a missing count depending on the energy threshold of the pixels.

Another source of spatial spreading are quanta which are scattered by the detector components behind the sensor layer such as bump bonds or silver-filled glue. This effect was also implemented in the simulation by including all assembly parts as scatter objects.

In this study we describe the implementation of the complete detector Medipix2 into a Monte Carlo simulation. While the energy deposition in the sensor layer of the detector can easily be covered by well-established codes like EGS4, charge spreading, counting and backscattering from detector parts on the other hand have to our knowledge up to now not been implemented in Monte Carlo simulations.

For validation of the simulation, the average energy distribution function was measured with the Medipix2 detector using a monoenergetic source. We chose to compare the energy distribution function because it is very sensitive to charge spreading.

*Corresponding author. Tel.: +49 9131 852 7121; fax: +49 9131 15249.
E-mail address: alexander.korn@physik.uni-erlangen.de (A. Korn).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2007.01.159

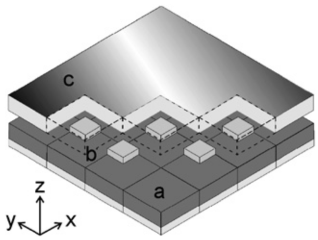

Fig. 1. Detector geometry used in the simulation. Behind the silicon sensor (c) the bump bonds (cuboids, b), the electronics (a) and a silver layer at the bottom were implemented as scatter objects into the simulation.

2. Simulation

In order to simulate the output of the detector, not only the energy deposition of the incident quanta has to be considered but the transport and the collection of the charge carriers inside the sensor as well. The exact geometric setup with all detector parts is also important, because fluorescence quanta can lead to additional counts almost anywhere in the detector [4,5].

The simulation is carried out in three steps which have been implemented into a Monte Carlo simulation called ROSI (Roentgen simulation)[1] by Giersch et al. [1].

The first step of the simulation is the exact implementation of the geometry of the setup, including all detector parts as scatter objects. Fig. 1 shows the geometry used in the simulation.

Besides the sensor layer being the actual detector, every single bump bond (65,536 objects) consisting of a tin–lead alloy, a 700 μm silicon layer as an ASIC and a layer of silver behind the silicon with a thickness of 7 μm representing the silver-filled glue behind the electronics are implemented as scatter objects.

The second step of the simulation is the deposition of energy inside the sensor layer. This step is covered by the well established EGS4 code which is already included in ROSI. The output of this second step is an event tree with information on the location and the energy deposition of each electromagnetic interaction inside the sensor layer.

The third step transforms the information gained by the second step into the detector response which may be an image or a threshold scan. It includes charge sharing, counting, and noise.

To model the energy loss of the charged particles, their energy is divided up into energy packages of 3.6 eV each, i.e. electron–hole pair creation energy of silicon. These packages are then distributed along the track calculated by step two of the simulation. Each package is projected onto the *x*–*y*-plane with a lateral shift added in order to simulate diffusion. This shift is calculated using a 2D Gaussian probability density function with a variance $\sigma\{t[z, E(z)]\}$ depending on the drift time [2]. The drift time depends on the gradient of the applied electric field. The knowledge about conductivity or the depletion voltage, respectively, is necessary, to calculate the exact field gradient and thus the diffusion process. For electric fields above 10^3 V/cm the effect of velocity saturation begins to reduce the effective mobility of the charge carriers in the semiconductor, leading to longer drift times.

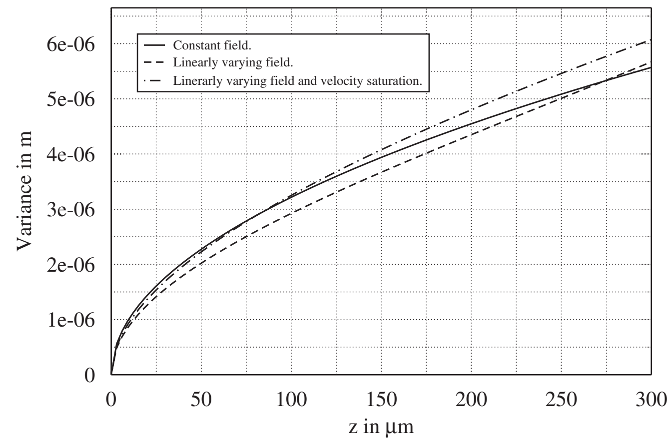

Fig. 2. Variance of the diffusion as a function of the height of charge generation (*z*). The solid line gives the variance for a constant electrical field, while the broken line is for a linearly varying field and the broken line with dots represents the calculation for the linearly varying field and the additional effect of velocity saturation.

The variances of the diffusion σ were calculated for a constant field of 2.1×10^3 V/cm, a linearly varying field ($U_{bias} = 150$ V, $U_{depl} = 48$ V) and a linearly varying field showing the effect of velocity saturation. In Fig. 2 the variances for all cases are plotted as a function of the *z*-coordinate. Although the electric fields are rather different, the resulting variances are quite similar.

Using these variances in our simulations, we realized, that the calculation times were reasonable only for constant fields and therefore confined ourselves to this case.

After having distributed all energy packages, the final energy deposition per pixel is calculated by adding up the energy packages and varying the resulting energy by superposing some additional noise. This noise is considered to have a Gaussian distribution. It consists of electronic noise, threshold variations in the pixels and fluctuations in the charge carrier generation (Fano factor). Finally, the resulting energy in a pixel is compared to a given static threshold and, if found to be larger than the threshold, the counter of that pixel is incremented.

3. Experiment

For validation of the simulation results, several threshold scans were taken. As an X-ray source we used an X-ray tube with a tungsten anode (Siemens Megalix CAT) together with a 4-in. silicon wafer acting as a monochromator. Fig. 3 shows a drawing of the experimental setup.

[1]ROSI is published under GPL. www.pi4.physik.uni-erlangen.de/Giersch/