Investigation of the hybrid pixel detector based on the Timepix ASIC and GaAs:Cr sensor

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Introduction

The Medipix/Timepix is family of a hybrid pixel detector readout chip designed by an international Medipix Collaboration together with CERN and EUDET. The hybrid (this means that a semiconductor sensor layer is bonded on to an electronics layer) pixel detector technology was initially developed for particle physics detectors, but the Medipix chip has shown that the technology is also good for X-ray imaging and spectroscopy.

Unlike CCD detectors, which operate exclusively on an integral basis, the Medipix type detector allows for single photon counting, and obtaining information about the incident radiation's spectrum. Furthermore, its readout system consists of an independent circuit for each single pixel, rendering it extremely fast, but with a drawback: there are differences in the sensitivities of its pixels, which make equalization and calibration procedures necessary.

The Medipix detector family has been in development since the 1990's, and is currently on its third generation. The evolution consists of increasing the number of transistors per pixel and adding some specific functions. The Timepix readout chip was developed as updated version of the Medipix 2 readout chip (single photon counting semiconductor detector which features adjustable energy thresholds allowing multispectral X-ray imaging is based on the Medipix 2 readout chip). The detector based on the Timepix ASIC included an energy measurement feature and consequently it can be used to measure the particle track and particle energy simultaneously. Another important improvement on the Medipix 3 ASIC is the new charge summing mode (CSM), which makes it possible to compensate for the charge sharing effect via inter-pixel communication, optimizing the photon counting process and spectroscopic information obtained.

Silicon is the standard semiconductor sensor material for pixelated detectors of Medipix type. Due to its homogeneity and stability it provides a high detector and image quality. However, because of its low Z number, Si has a low X-ray absorption efficiency at energies above 20 keV and is therefore not optimal as sensor material for medical imaging and non-destructive high Z material analysis. The compound semiconductor sensor materials GaAs (31, 33) and CdTe (48, 52) have a higher Z than Si (14) and therefore a better X-ray absorption efficiency. The recent progress in growing and processing of these materials improved detector quality and make them interesting as efficient sensor material for X-ray imaging applications. For investigations on these sensor materials they are bump bonded to Timepix/Medipix readout chips. In this project the detector based on the Timepix readout chip and GaAs:Cr sensor is studied.

Fig.1 The hybrid pixel detector Timepix with USB interface FITPix

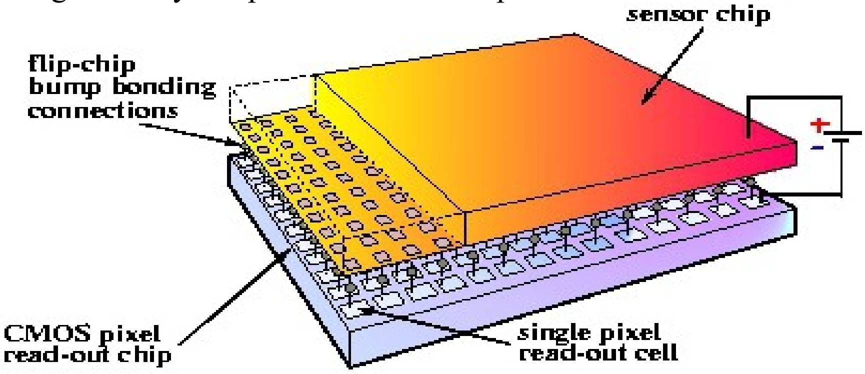

Fig.2. The structure of the Timepix detector

The gallium arsenide doped by chromium (GaAs:Cr) is a new promising material developed at the Tomsk State University. The GaAs sensors were produced by means of the Liquid Encapsulated Czochralski method (LEC). The initial LEC GaAs material is doped by a shallow donor Sn or Te. Then the layers of electronic conductivity type of the material is compensated by a deep acceptor Cr by means of controlled diffusion at high temperature. This results in a semi-insulating GaAs material with a high resistivity and a high value of an electron diffusion length (in comparison with LEC GaAs).

The structure and functionality of the Timepix detector

First in the world assembly of the Timepix ASIC and GaAs:Cr sensor made for JINR Laboratory of Nuclear Problem is shown on fig. 1. One can see two of the three main parts of which a Timepix assembly always consists of: the sensor layer and the Timepix ASIC (fig. 2). The readout interface (e.g. USB-readout FITPix) is necessary to extract the data from the ASIC and transmit it to the PC. The semiconductor sensor layer (silicon Si, cadmium telluride CdTe and gallium arsenide GaAs) is the part of the detector. The size of the sensor material is usually about 1.4 cm x 1.4 cm and it is 0.3 mm - 1 mm thick. Particles which are passing the sensor material are scattered and deposit their energy within the sensor layer. By extracting this energy from the sensor we can make the particle tracks "visible". The ASIC has two main purposes: on the one hand it is needed to extract the deposited energy information out of the sensor and on the other hand together with the electrodes on the sensor backside it provides the pixelation of the sensor layer. The pixel grid on the ASIC is connected to the sensor layer by the bump-bonds. One pixel on the ASIC is quadratic and has a side length of 55 μm. In investigated detector the pixel pitch is 55 μm. But chips with 110 μm and 220 μm pixel pitch are available as well. The dimension of pixel matrix is 256 x 256 (for 55 μm pitch).

Each pixel of the Timepix detector has four different working modes: the medipix mode, the time-of-arrival mode (TOA), the time-over-threshold (TOT) mode, the one hit mode. The TOT mode is used if the collected energy deposition for each pixel is of interest. The Timepix detector running in TOT mode measures the charge collected in each pixel. As the device contains 65536 independent channels and as their response can be never identical it is necessary to perform an energy calibration for each of them. The calibration method was developed in JINR Laboratory of Nuclear Problem is using characteristic X-rays emitted by fluorescent materials in the energy range of 6 to 60 keV. For each emission line and pixel a spectrum is measured and fitted by model function. To allow an unambiguous correlation of the TOT signal and energy deposition only single pixel clusters were included into the spectra. Energy response curves for each pixel are, thus, obtained and fitted by an empiric function with coefficients a, b, c and t.

For the interaction between the detector and the user the Pixelman software is used. It provides all features that are necessary to communicate and work with the detector. The Pixelman software package is used by more than 20 research institutes in Europe.

The design of experimental setup

The experimental setup consists of the following parts:

1. Two X-Ray tubes with different anod type

2. Set of metal foils with different thickness for observation characteristic lines of metal

3. Set of radioactive gamma sources for the calibration verification

4. Set of phantoms for X-Ray imaging

5. Timepix detector with cooling system for semiconductor sensor (GaAs is very sensitive for changing the temperature)

6. HV power supply with an inbuilt ammeter

7. PC for data acquisition

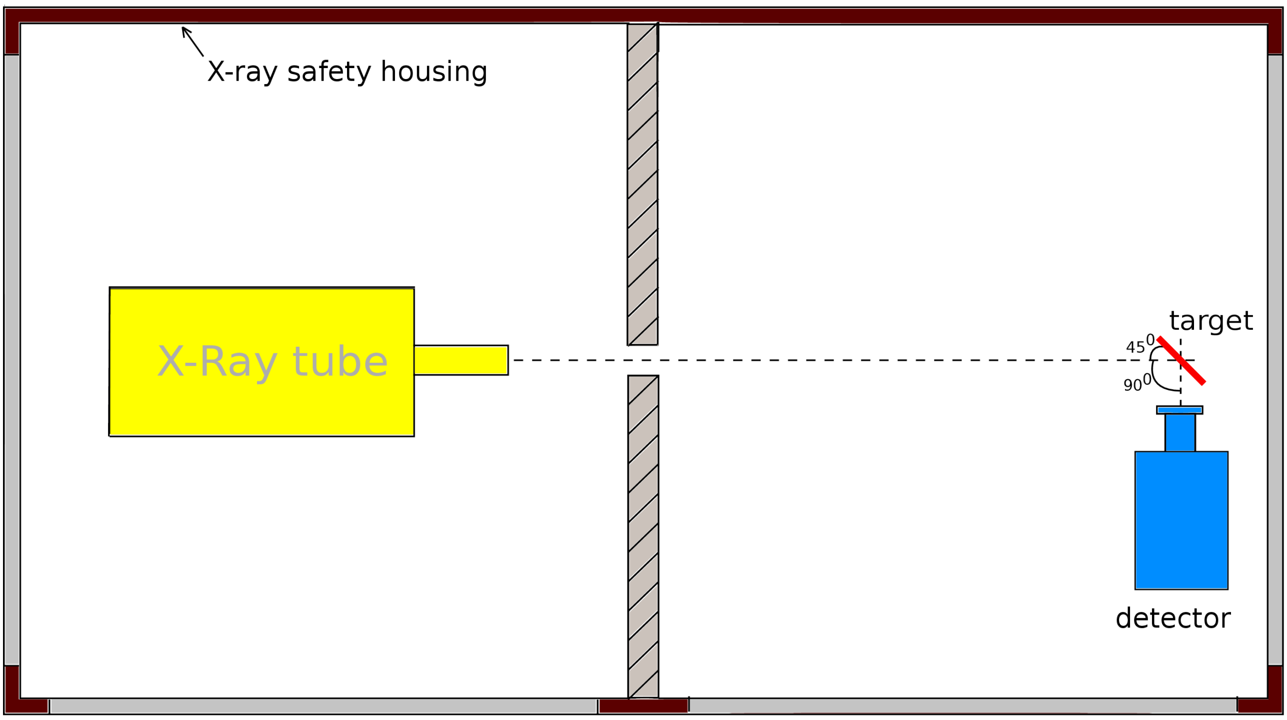

Fig.3. The design of an experimental setup

General research program

Students will study the following topics:

1. Common and special information about X-Ray emission and spectroscopy

2. Principles of functionality hybrid pixel detector based on Timepix ASIC

3. Pixelman is software package for Timepix/Medipix acquisition data control

4. Calibration of the energy resolution of Timepix detector in Time-over-Threshold mode (perhaps in Medipix mode) using characteristic x-ray emission and radioactive gamma sources

5. Investigation the temperature stability and count rate dependence on bias voltage.

6. Comparison the efficiency of the Timepix detector with Si and GaAs:Cr sensors concerning to X-Ray imaging

7. Application of the Timepix detector with GaAs:Cr for X-Ray biomedical imaging and high Z material number identification

All readout data from Timepix detector is proccesed in the ROOT software. A good knowledge of C++ programming language and the ROOT software (http://root.cern.ch) is required.

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