Simulation of Caliste-SO response

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ABSTRACT

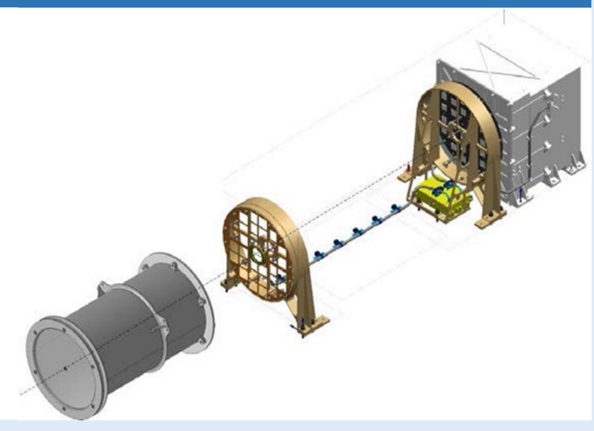
Caliste-SO is CdTe X-ray detector designed for STIX (Spectrometer/Telescope for Imaging X-rays) instrument. In semiconductor detector various effect like hole tailing can affect measured spectra. Additionally, detectors anode is divided into 12 pixels arranged in 4 stripes in order to measure Moiré pattern. In such type of detector charge sharing between pixels occurs and also influence on measured photon energy. Our main purpose was to calculate the charge sharing with regard to incoming photon energy. We present the simulation of Caliste-SO response using Geant4 toolkit and dedicated software written in Interactive Data Language (IDL). Geant4 was used to simulate particles interactions with the detector and dedicated software to calculate instrumental effect: Fano and electronic noises, hole tailing and damage layer. We report here the results of this simulation.

Spectrometer/Telescope for Imaging X-rays (STIX)

STIX provide us with images and spectra of the Sun in 4-150 keV energy range with high spatial and spectral resolutions. The principle of the image reconstruction relies on measuring Fourier components of photon source with set of grid pairs. Each pair of grids generate a Moiré pattern and encode direction of incoming photons. Next, the pixelised CdTe semiconductor detector detect large-scale intensity distribution of the pattern, which is a Fourier component of the image. An image can be reconstructed using many such Fourier components.

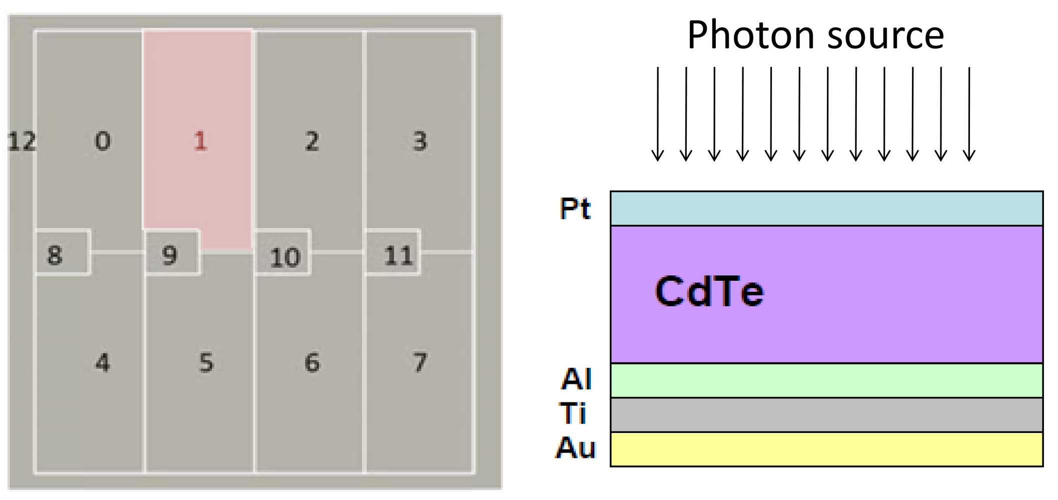
Mechanically, there are three modules in STIX:

- **X-ray window**, which provide thermal shielding and rejection of low-energy X-ray photons.
- **The Imager** holds 30 pairs of tungsten grids with different pitches and orientations, registering different Fourier components.
- **Detector Electronics Module** with Caliste-SO detectors and IDPU.



Model geometry and physics

Caliste-SO detector is divided into 12 pixels and a guard ring. Figure below shows the structure of the pixel division with one of the big pixels highlighted and information about the detector composition.



The simulated photon source was planar and cover whole detector area. Photons were monoenergetic and felt at the right angle to the crystal surface. The distribution on the surface was uniform.

The Livermore physics list was used in the simulation, which is dedicated to low energy physics. Following physical processes were included in our simulations:

- for photons:
  - Photoelectric effect,
  - Compton scattering,
  - Gamma conversion,
  - Rayleigh scattering,
- for electrons:
  - Multiple scattering,
  - Coulomb scattering,
  - Ionisation,
  - Bremsstrahlung.

Caliste-SO detectors

Caliste-SO is a special designed for STIX instrument X-ray detector. It is manufactured in the 3D Plus technology and consist of: CdTe sensor and the dedicated front-end electronics. It provides good spectral resolution in hard X-rays.

The CdTe crystal size is 10×10 mm and its thickness is 1 mm. The sensor is divided into 12 pixels arranged into 4 stripes (Figure above). Disabling pixels in strips allow to limit too high photon flux observed during large solar flares, by reducing an active area of the detector. Additionally, entire crystal is surrounding by guard ring designed to eliminates edge effects.

There are two electrodes in the CdTe sensor (Figure above):

- cathode made of 15 nm thick platinum layer,
- the multilayer anode, consisting of 50 nm thick aluminium, 15 nm titanium and 80 nm gold layers.

The Caliste-SO is developed by CEA/Irfu (France) and Paul Scherrer Institute (Switzerland).

Geant4

Geant4 is a toolkit to simulate particle interaction with matter by Monte Carlo method. There are implemented physical process, which are used in many fields of science like nuclear physics, particle physics, accelerators, space engineering, and medical physics. This tool is useful for simple simulations as well as analysis of whole large experiments like the Large Hadron Collider.

The package contains a broad suite of physical models (including electromagnetic, hadronic and optical), which covers a wide range of energies from ~250 eV up to several TeV. Existing physical models are being improved and extended continuously.

Methods

Charge sharing (double count induced by one photon) is the consequence of dividing the detector into pixels. This phenomenon is caused by two effects:

- **Fluorescence in detector material – fluorescent count**,
- **Division of a charge cloud – splitted count**.

The first effect was simulated in the Geant4 toolkit. The event was classified as a double count when deposited energy was higher than 4 keV (detection threshold) in two or more pixels.

Second effect was calculated as following:

Calculation of the distribution of charge cloud on the electrode
Described by second Fick`s law

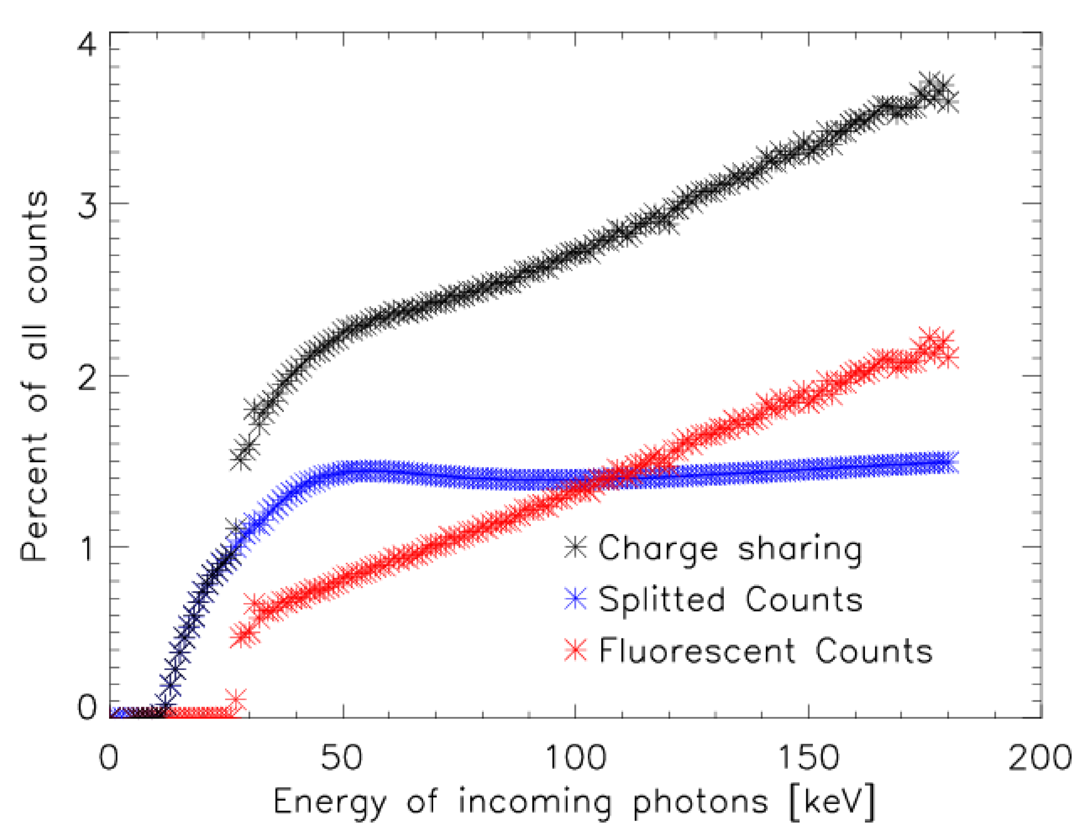
Calculation of maximal distance from the pixel boundary where cloud can be splitted into two pixels
Distance from pixel boundary when adjacent pixel collects charge higher than the 4 keV threshold

Determination of an area where charge cloud is splitted
The places of the photon absorption in the detector body where splitting occurs

Calculation of the probability of double events occurrence
The area where the charge sharing occur divided by the whole crystal area

Calculation of the probability of splitted counts depending on photon energy
Different absorption depth have a different probability of double events occurrence

Energetic dependence of splitted counts
Constructing energy depended map of probability



Detector effects

During the collection of carriers, which were generated by a photon absorption, several effects may influence the number of carriers reaching electrodes:

1. *Hole tailing*. In CdTe material, holes are characterized by mobility more than ten times smaller then electrons. Therefore, some fraction of holes does not reach electrodes and detector register lower total charge. This effect can be noticed e.g. for higher energy spectra lines in a tail towards lower energies. To describe this effect we used Hecht equation.
2. *Fano noise*. The quantity of electron-hole pairs generated by identical photons during photon absorption is can vary. This phenomena occur as a broadening of measured spectral features. Therefore, simulated spectra was convoluted with a Gaussian function with full width at half maximum (FWHM) calculated from Fano equation. FWHM of the Fano noise increases with energy of absorbed photons.
3. *Electronic noise.* The electronic noise also broadens spectral features. In our simulations we blurred simulated spectra using a Gaussian function with constant (not energy dependent) FWHM.
4. *Damage layer.* Measurements of the of Caliste-SO detectors reviled that photons absorbed in the front part of the detector generating less signal than expected. The result is similar to hole tailing, but dependent on absorption depth not energy. The layer has 5 µm. In measured spectra this phenomena produces a tail towards lower energies in a spectral features.

Results

Graph in the middle column shows:

- **charge sharing** dependence on energy of incoming photon. This effect is strongly energy dependent and for Caliste-SO detectors reaches 3.5% for 150 keV photons.
- The probability of **fluorescent counts** is shown by a red colour. This phenomena starts from 27 keV (cadmium emission line) and grows rapidly in 31 keV (tellurium emission line). Next, it constantly grows with photons energy ingress.
- The probability of **splitted counts** is marked by a blue colour. It starts from 8 keV because this is a minimal energy necessary to register two counts from one photon (2 × 4 keV threshold) and grows with energy of incoming photons up to 50 keV. The growth is caused by the increasing size of carriers clouds. Above 50 keV the growth is neutralised by a higher probability of deeper photon absorption.

Charge sharing strongly dependent on energy of incoming photon. In STIX instrument double events will be not registered in the collected spectra. This will affect measured energy spectrum. Therefore, it is necessary to develop proper models of this effect and dedicated software which will reduce the influence of charge sharing effect on scientific data.

Referencess

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