Dosimetry with CMOS chips

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GCRF lead assay kick-off meeting

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Papers reviewed – 1/2

This talk focuses on papers where the authors use commercial CMOS sensors or even phone sensors:

- LS10 L. Servoli *et al.*: Characterisation of standard CMOS pixel imagers as ionizing radiation detectors, JINST 5 P07003 (2010)
- MP11 M. Paolucci *et al.*: A real time active pixel dosimeter for interventional radiology, Radiation Measurements 46 (2011) 1271-1276
- PP13 P. Placidi *et al.*: Use of a CMOS Image Sensor for an Active Personal Dosimeter in Interventional Radiology, IEEE Transactions on Instrumentation and measurement, Vol. 62, No. 5 (May 2013)
- DW15 D. Whiteson *et al.*: Observing Ultra-High Energy Cosmic Rays with Smartphones, arXiv:1410.2895v2 (2015)

Papers reviewed – 2/2

Furthermore:

MP15 M. Pérez *et al.*: Commercial CMOS Pixel Array for Beta and Gamma Radiation Particle Counting, IEEE Catalog Number CFP 1554E-CDR (2015)

JL16 J. Lipovetzky *et al.*: Particle detection and classification using commercial off the shelf CMOS image sensors, NIM A, 827 (2016) 171-180

Characterisation of standard CMOS pixel imagers as ionizing radiation detectors (LS10) – 1/2

Aptina MT9SH06

- 5.6 $\times 5.6\,\mu\mathrm{m}^2$ with 640 $\times 480\,\mathrm{pixel}$
- $4\,\mu\mathrm{m}$ epitaxial layer
- $10\,\mathrm{bit}$ ADC and gain between 1 and 15.88
- Integration time between $56\,\mu\mathrm{s}$ and $267\,\mathrm{ms}$ (default: $33\,\mathrm{ms}$)
- No window or lense in place

Noise characterisation

- Avergae pedestal and noise values are 40 and 3
- A very weak temperature dependence of the noise in the range from -30 to 30 degree C has been identified

Characterisation of standard CMOS pixel imagers as ionizing radiation detectors (LS10) – 2/2

Readout strategy

- Individual thresholds for all pixels based on their pedestal and noise
- These thresholds are set to achieve less than an active pixel per frame in absence of sources
- For γs ($\varepsilon < 25\,\mathrm{keV}$) a 3x3 matrix around the pixel with the highest ADC count is read out

More characteristics

- A linear response of the cluster signal on γ energy is found
- After cluster signal and #pixel cuts an energy resolution better than $2\,\%$ for the $^{55}\mathrm{Fe}$ photopeak is achieved
- MIPs are detected as well

$\Rightarrow$ **They never give an efficency for their detections**

CMOS sensors for dosimetry for interventional radiology (MP11 and PP13) – 1/2

Goal:

Develope a small, wireless dosimeter for hospital staff which is involved in interventional radiology. The deveice should monitor the dose in real time and as well allow to analyse the data afterwards.

Test set-up

- X-rays from a medical deveice or a X-ray gun get diffused by a PMMA phantom
- The CMOS sensors are mounted on a carrier together with standard TLD dosimeters
- Three sensors tested:
  RAPSO3, $25\,\mu\text{m}$ thickness, $140\,\text{ms}$ integration time, 65536 pixel
  Sensor A, $4\,\mu\text{m}$ thickness, $\leq 267\,\text{ms}$ integration time, 307200 pixel
  Sensor B, $12\,\mu\text{m}$ thickness, $33\,\text{ms}$ integration time, 360960 pixel

CMOS sensors for dosimetry for interventional radiology (MP11 and PP13) – 2/2

Results

- The RAPSO3 detects more photons than the Sensor A model
- A good linearity between the dose measured by the TLD dosimeters and the CMOS sensors is found at distances between $17\,\mathrm{cm}$ and $52\,\mathrm{cm}$ from the phantom

PP13

- Pedestal and noise values are calculated and a measurement is accepted when higher than a threshold *a* (single pixel) and if the total charge in a cluster is higher than a threshold *b*
- Better than $10\,\%$ resolution of the measured dose is reached

In general their counting rates seem rather high so they are not affected by background

Observing Ultra-High Energy Cosmic Rays with Smartphones (DW15) – 1/2

An array of phones should be used to detect particle showers from highly energetic cosmetic rays. (http://crayfis.io)

Readout strategy

- Video recording at 15 to $30\,\mathrm{Hz}$, pixels higher than a threshold *a* and lower than a threshold *b* are stored
- Hot pixel removal after recording, no further noise removal is applied

The detection efficency of Android phones and IPhones for γs and μs have been examined.
However, the energy resolution or other parameters have not been charaterised.

Observing Ultra-High Energy Cosmic Rays with Smartphones (DW15) – 2/2

γ measurements with a Samsung Galaxy S3

- Exponentially falling background spectrum from 10^{-3} to $10 \times 10^{-7}\,\mathrm{Hz}$ as function of the pixel response
- Using γs from $^{226}\mathrm{Ra}$, $^{137}\mathrm{Cs}$ and $^{60}\mathrm{Co}$ spectra have been measured – they all have a similar shape as the background (no peaks), but different maximal rates
- An efficency times sensor area $A\epsilon = (1 - 5) \times 10^{-9}\,\mathrm{m}^2$ has been calculated from the measurements

Tests with μs

- Tracks are clearly visible for muons, parallel to the sensor
- Efficency ($A\epsilon$) is estimated four orders of magnitude larger than for γs

Commercial CMOS Pixel Arrays applied to Beta, Gamma and Alpha Radiation Particle Counting (MP15 and JL16) – 1/2

APTINA MT9V011 0.25''

- 4.6 $\times 4.6\,\mu\mathrm{m}^2$ pixel size and 640 $\times$ 480 pixel
- $4\,\mu\mathrm{m}$ of Bayer RGB filter
- $2.7\,\mu\mathrm{m}$ SiO_2 layer

OmniVision OV5116N

- 4.6 $\times 4.6\,\mu\mathrm{m}^2$ pixel size and 640 $\times$ 480 pixel

Noise analysis

A Fixed Pattern Noise (FPN) has been identified for each chip. It is observed to drift with time, therefore the data is treated with an autoregressive filter.

Commercial CMOS Pixel Arrays applied to Beta, Gamma and Alpha Radiation Particle Counting (MP15 and JL16) – 2/2

- Different event topology visible for γs (down to $^{55}\mathrm{Fe}$) and βs ($\varepsilon > 350\,\mathrm{keV}$) on the one and αs on the other hand
- The spectrum of collected charge differs significantly between αs and the rest

$\rightarrow$ Particle classification possible based on these differences

- **Unfortunately there is no efficiency measurement for different particle species**
- Due to its larger material budget the CMOS with the RGB filter perfroms a bit better in terms of collected charge

Energies and rates of interest

$^{210}\mathrm{Pb}$ decay energies:

- $84(3)\,\%$ via a $63.5\,\mathrm{keV}$ β^-
- $16(3)\,\%$ via a $16.96\,\mathrm{keV}$ β^- and a $46.6\,\mathrm{keV}$ γ

$\rightarrow$ Interesting energy range for CMOS dosimetry in our case

Rate estimation

At a lead concentration of $10\,\mathrm{ppb/g}$ $\mathrm{H_2O}$ there are 0.33×10^{14} Pb atoms per gram:

- About $\sim 10^{-4}$ $^{210}\mathrm{Pb}$ fraction
- A decay rate of $\ln 2/T_{1/2} = 9.9 \times 10^{-10}\,\mathrm{s}^{-1}$

$\Rightarrow$ $3\,\mathrm{decays/s}$ per gram of water

- No efficincies, backgrounds, etc yet taken into account

γ ($\sim 45\,\mathrm{keV}$) and β ($\sim 15\,\mathrm{keV}$) attenuation in:

	γ	β^-
H_2O	$4.0\,\mathrm{cm}$	$5\,\mu\mathrm{m}$
Si	$0.8\,\mathrm{cm}$	$3\,\mu\mathrm{m}$
SiO_2	$1.0\,\mathrm{cm}$	$2.5\,\mu\mathrm{m}$
Air	$38\,\mathrm{cm}$	$48\,\mu\mathrm{m}$

For the $\sim 63.5\,\mathrm{keV}$ β^- the range is one to two orders of magnitude larger.

Summary

- Commercial CMOS deveices have been explored during the last years with respect to their application as radiation detectors
- γs have been detected down to the few keV range
- β detection has been only done for energies of a few $100\,\mathrm{keV}$
- In general a measurement of the lowest possible counting rates or the detection efficiency is missing