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ScienceDirect
Nuclear Instruments and Methods in Physics Research A 591 (2008) 287–290
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Pattern recognition of tracks induced by individual quanta of ionizing radiation in Medipix2 silicon detector

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Available online 21 March 2008

Abstract

Medipix2 is a semiconductor pixel detector (256×256 pixels, $55 \times 55\,\mu m^2$ each) which can count individual quanta of radiation. The detector will respond differently for different types of radiation. If the acquisition time is short enough with respect to radiation intensity, one can see characteristic tracks of individual quanta in an image taken (e.g., curved lines for electrons, round shaped clusters for alpha particles, heavy ions and slow neutrons, cone shapes for fast neutrons, simple dots for low energy X-rays, etc.). For effective visualization of neutrons, the device has to be equipped by corresponding neutron converter, which converts neutrons to heavy charged particles. By analyzing these patterns, in this so-called ''tracking mode'' of operation, it is possible to distinguish individual tracks and classify them into predefined categories. For each ''cluster'' detected, the features (such as parameters describing the shape and energy deposition estimation) can be extracted and used to distinguish radiation type. The energy deposited can be estimated by using calibration measurements with different types of radiation and variation of the discrimination threshold.

PACS: 29.40.Gx; 29.85.−c; 29.85.Fj

Keywords: Medipix2; Pattern recognition; Online tracks analysis; Dosimetry

1. Introduction

Medipix2 [1] is a hybrid semiconductor pixel detector consisting of a sensor chip (256×256 pixels, $55 \times 55\,\mu m^2$ each), which is bump bonded to a readout chip. The total sensitive area of sensor chip is $\sim 2\,cm^2$. Each pixel contains a preamplifier, two discriminators (energy window possible), a 14-bit pseudo-random counter with overflow detection and 8-bit configuration register (for masking, testing and $2 \times$ 3-bit threshold adjustment in individual pixels).

Such a pixel device can record individual quanta of ionizing radiation. The response of the device is different for different types of radiation. If the shutter time is short enough with respect to radiation intensity, the individual tracks of particles can be seen and clearly separated. A track is composed of pixels where energy deposited by charged particle is above threshold. Examples of different types of radiation as they are registered by the Medipix2 device can be seen in Fig. 1.

One can see characteristic round shape blobs of alpha particles covering tens of pixels due to charge diffusion/sharing between adjacent pixels (Fig. 1a). Multiple scattered electrons lead to curly tracks (Fig. 1b). The 60 keV photons induce signals only in a single pixel or few adjacent pixels, typically 1–4 (Fig. 1c). Protons arising from $^{28}Si(n,p)^{28}Al$ reaction in a neutron beam can generate stub-like tracks (Fig. 1d). The analysis of such individual tracks allows the determination of the components of an unknown radiation field. In such a way, tracks of particles in solid-state silicon are visualized online in a similar way as in nuclear emulsions, cloud chambers or bubble chambers.

2. Track classification

The following algorithms were implemented to the Pixelman software package [2] as plugin for online analysis

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doi:10.1016/j.nima.2008.03.074

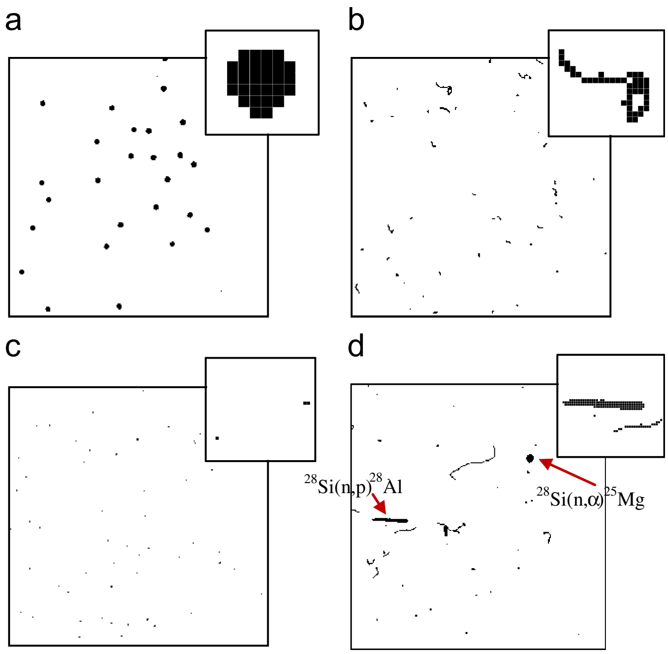

Fig. 1. Response of Medipix2 with 300-μm-thick sensor when illuminated by (a) ^{241}Am alpha source, (b) ^{90}Sr beta source, (c) ^{241}Am XRF source, (d) fast neutrons (up to 30 MeV, 700-μm-thick sensor).

of clusters. The recorded interaction pattern is analyzed and separated to individual tracks. This is done by an eight-way searching routine which finds the "continuous" clusters. In the ideal case when no tracks are overlapping, the registered pattern should be a binary image with zones where registered charge was above selected threshold and zeros elsewhere. Therefore, overlapping tracks can be easily detected and discarded. It is possible to try to separate two overlapping tracks; however, it is not an easy task in general and currently it is not implemented. If the number of overlapping tracks is significant, the exposure time has to be shortened to decrease the probability of such events.

The classification to predefined categories is based on the geometrical features describing the clusters. Following cluster classes were defined:

- dot (e.g., photons <20 keV),
- small blob (e.g., photons ~ 50 keV),
- heavy blob (e.g., alpha particles, heavy ions, slow neutrons),
- straight thin track (e.g., minimum ionizing particles),
- curly track (e.g., electrons, electrons produced by photons >50 keV), and
- heavy track (e.g., protons >1 MeV, neutrons >1 MeV).

The same particle can generate clusters of different type (or with different parameters) at different settings of threshold and bias. Examples for individual categories were considered for fairly low threshold setting. For example, if the threshold is increased, the alpha particle cluster gets smaller as the charge collected in neighboring pixels does not exceed the discrimination threshold.

Geometrical features which are extracted for each cluster includes convex hull, area, volume, number of inner/border pixels, border length, maximum number of pixels on straight line, maximum distance in clusters, etc. These features are used for the computation of parameters that defines a parametric space for classification. If parameters of certain cluster fall to certain parts of parametric space, the cluster is assigned to the corresponding category. For example, the ratio of diameter computed from cluster area and maximum distance in a cluster should be equal to one for perfectly round clusters. If such a computed parameter falls into a specified interval around one, the cluster is sufficiently round and if other conditions like minimum number of inner pixels, ratio of inner and border pixels are fulfilled, the cluster is classified as "heavy blob". These conditions which divide the parametric space into categories can be adjusted with respect to experiment conditions and device settings.

If the track corresponding to one particle is discontinuous, the algorithm can (optionally) try to join such clusters together. It is done by convolving the image formed by "non-heavy" clusters (which are probable to be intermittent) with two-dimensional Gaussian kernel and joins them if the "path" above the selected threshold exists between them. In such a way, the clusters are joined in the direction of existing tracks.

3. Test experiments

The test setup for the pattern recognition procedure consists of a Medipix2 chip with 300-μm-thick silicon sensor and various combinations of three radioactive sources: ^{241}Am alpha source, ^{241}Am X-ray fluorescent (XRF) source and ^{90}Sr beta source. Radiation from these

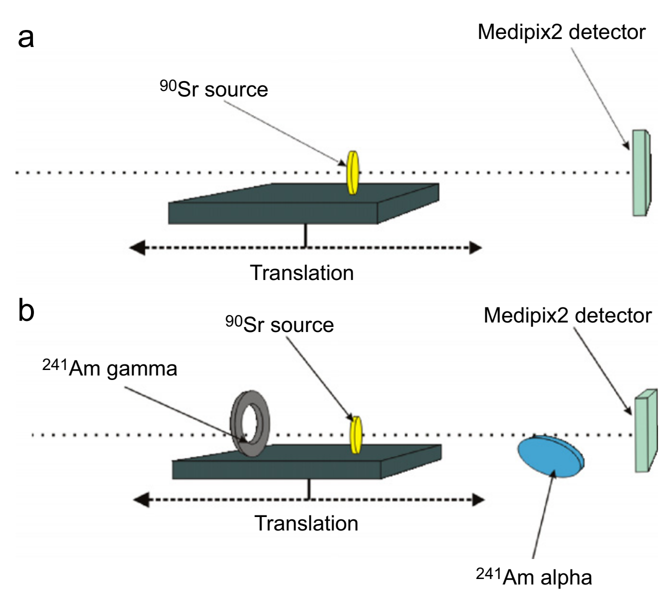

Fig. 2. Measurement setup: (a) ^{90}Sr beta source in different distances; (b) ^{241}Am gamma source and ^{90}Sr beta source in different distances, ^{241}Am alpha source generates constant background.

sources was measured in different distances to see whether it is possible to distinguish radiation type and its intensity by the cluster analysis procedure. In each measurement point 2000 acquisitions were taken, each with exposure time of 100 ms.

3.1. ^{90}Sr beta source on background generated by ^{241}Am XRF source and ^{241}Am alpha source

The small ^{90}Sr source can be considered as a point source at the distance of several centimeters (Fig. 2a). Therefore, the number of registered events should follow Ax^{-2}, where x is the distance between source and detector. Cluster types detected are *dots, small blobs* and *curly tracks*. The number of these clusters in dependence of the distance of the source is shown in Fig. 3a. *Curly tracks* arising from electrons wandering several millimeters in silicon dominate. *Small blob* and *dot* clusters can be caused by bremsstrahlung radiation, low energy electrons or electrons which early leave the sensitive volume.

If ^{241}Am XRF and alpha sources are added as additional sources of radiation (Fig. 2b), we tried to analyze ^{90}Sr *curly tracks* under influence of this background radiation. The dependency of cluster counts on the distance of ^{90}Sr and ^{241}Am (gamma) is shown in Fig. 3b. *Curled track* clusters are generated only by ^{90}Sr so the dependency of their counts on distance should be the same as in the case when the ^{90}Sr source is alone. It can be seen in Fig. 3b that the fit is almost identical and follows Ax^{-2}. *Dot* and *small blob* clusters are generated by both sources (in different distances) so their counts do not follow Ax^{-2} anymore.

^{241}Am alpha source generates constant part of background. The number of alpha particles detected in each frame should obey a Poisson distribution. The distribution of *heavy blob* counts in 500 acquisitions (400 ms each) is shown in Fig. 4. One can see that the data nicely follow a Poisson distribution as expected.

3.2. ^{241}Am XRF source on constant background generated by ^{90}Sr beta source

The ^{241}Am XRF source can be considered as a point source at the distance >20 cm. ^{90}Sr generates constant background. *Dot* clusters are generated by 60 keV photons from ^{241}Am as well as by bremsstrahlung photons generated by electrons from the ^{90}Sr source. Therefore, the number of *dot* clusters detected should be the sum of a constant term (^{90}Sr at fixed position) and an Ax^{-2} term (contribution of ^{241}Am at distance x). The measured data nicely follow $Ax^{-2}+C$ as expected (Fig. 5b).

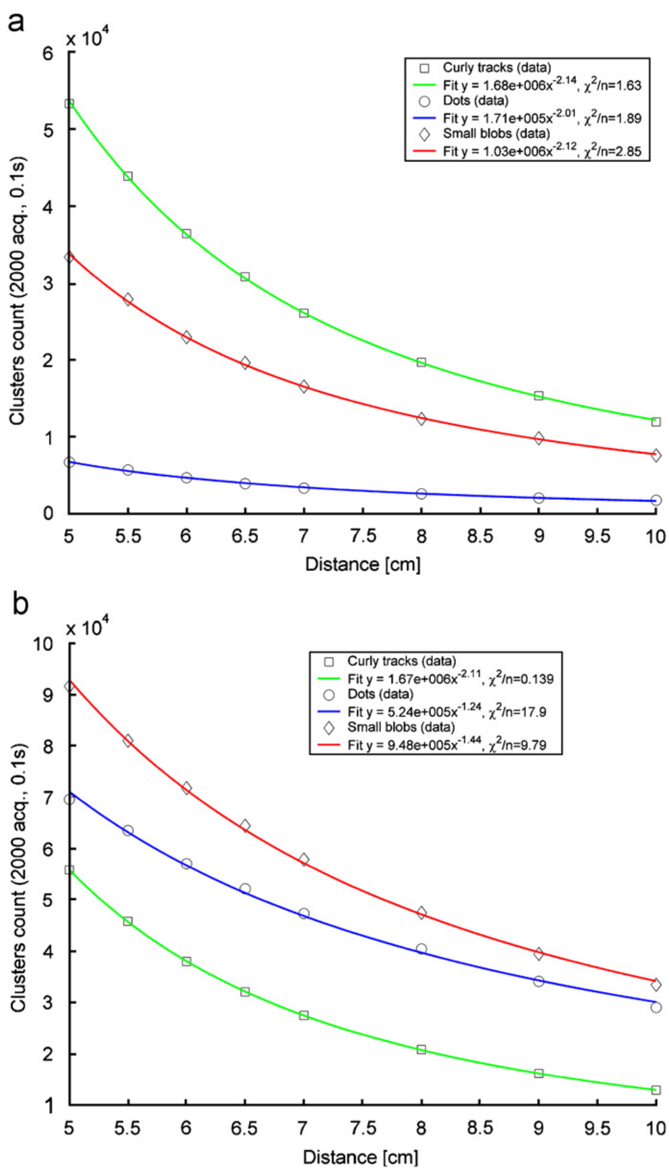

Fig. 3. Fit of dependency of cluster count on distance: (a) ^{90}Sr beta source alone; (b) ^{90}Sr beta source, ^{241}Am gamma and alpha sources.

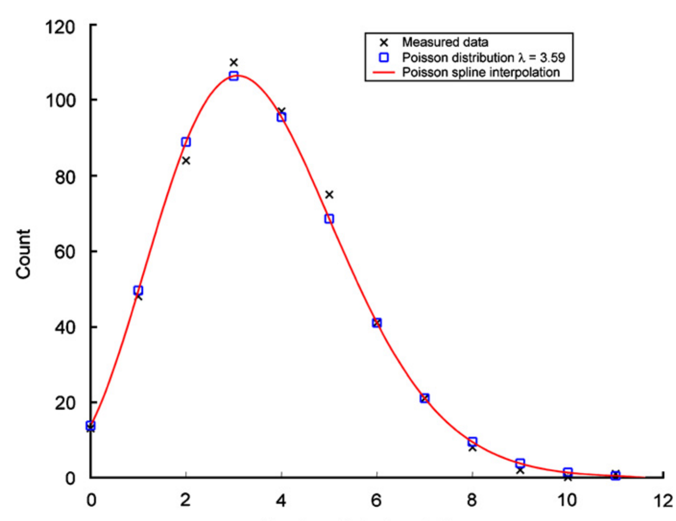

Fig. 4. Distribution of *heavy blob* number found in 500 acquisitions with 400 ms exposure time.

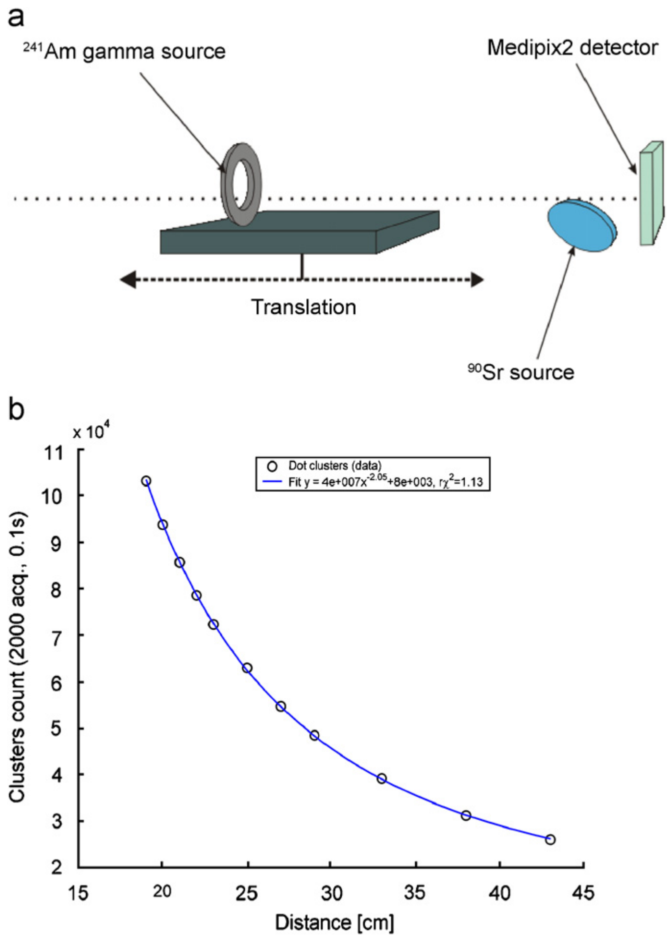

Fig. 5. (a) Measurement setup—^{241}Am XRF source moving, ^{90}Sr beta source generates constant background. (b) Dependency of *dot* cluster count on ^{241}Am.

4. Conclusion

It has been shown that using an individual tracks analysis, it is possible to distinguish individual components of radiation fields composed of alpha, beta and gamma sources. All evaluations were done online by a new cluster analysis plugin for the Medipix2 data acquisition software called Pixelman [2]. Online processing allows significant reduction of data volume for storage. The currently implemented cluster classification is quite coarse. However, it can be extended to extract more application-specific features and finer classification can be implemented.

Significant improvement in recognition of interaction pattern can be done by using a device which is able to measure the energy left in individual pixels. An example of such a device is Timepix [3], a successor of the Medipix2 chip. Each pixel can work in ''time over threshold'' mode and measuring so deposited energy. This additional information can be exploited for finer classification.

The possibility to automatically distinguish different types of radiation and estimate the energy deposition brings a lot of applications including position sensitive charged particle spectroscopy [4,5] and dosimetry (once the number of interaction, radiation type and energy deposition estimation is known, the equivalent dose can be calculated by incorporating weight factors for the different types of radiation).

Acknowledgments

This work was carried out within the CERN Medipix Collaboration. It has been supported in part by the Research Grant Collaboration of Czech Republic with CERN nos. 1P04LA211 and 1P04LA212, by the Fundamental Research Center Project LC06041, and by the Research Programs MSM 210000029 and MSM 6840770040 of the Ministry of Education, Youth and Sports of the Czech Republic.

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