X-Ray Imaging in Tokamaks: Characterization of a C-MOS Imager (Medipix-2)

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Introduction

It is nowadays evident that imaging and/or tomographic X-ray diagnostics will be based on photon counting mode, rather than on current mode (SBD or AXUV diodes). In addition the advantage of energy discrimination is meanwhile well established. In the last ten years gas detectors (GEM) allowed us to investigate this new approach. On the other hand, the new generation of C-MOS imagers allows a higher pixel density but with greater limitations in active area, time resolution and flexibility. The C-MOS imager Medipix-2 was characterized in laboratory as 2-D Soft X-ray imaging detector to assess its potential for imaging in magnetic fusion plasma experiments.

Description of Medipix-2

The Medipix-2 photon counting chip was developed at CERN in the Medipix-2 Collaboration, in which INFN is a member, [1]. The detector is formed by a square matrix of pixels (256×256), each one 55×55 μm^2, resulting an active area = 1.4×1.4 cm^2 (Fig.1). Each pixel of the semiconductor sensor (300 μm thick of Si) is bump-bonded to the corresponding channel of the chip (ASIC), providing the analog and digital treatment of the signal. The X-ray photon is converted into the semiconductor and electric charges are collected to the pixels and transferred to the underneath ASIC. The "USB Interface" is used to connect the Medipix-2 detector to a personal computer. The CMOS chip performs single photon counting in each pixel cell and data are accumulated in a 13-bit counter per pixel. Thanks to the photon counting mode, it is affected only by the shot noise, related to the Poissonian statistic distribution.

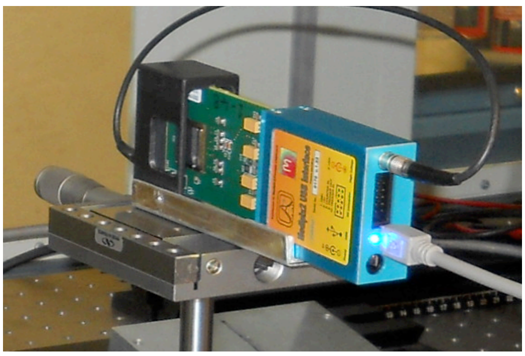

Figure 1 A C-MOS Imager: Medipix-2

Characterization of Medipix-2

The Medipix-2 was characterized at ENEA to study its properties at different X-ray energies. The ASIC is equipped with low-threshold discriminators. The adjustable threshold is globally set for all pixels. Minimization of the spread of the pixel threshold distribution is carried out by a fine tuning (equalization) of individual thresholds via software algorithm. The energy response of the detector in the X-ray range 0÷30 keV was assessed by scanning the adjustable threshold. Count rate for each pixel was linear up to at least 5 MHz of randomly arriving photons. The read-out time for a full frame is about 10 ms; considering the time needed for data transfer to the computer, a continuous acquisition can be done at about 10 Hz. The electric charges produced by the conversion of the photon drift to the pixel side and then collected. The transversal dimension (cluster size) of this bunch of charges can be greater than the size of the pixel. In this case the total charges are collected by two (or more) adjacent pixels and if both signals are over threshold, it produces two (or more) counts. The cluster size at different X-ray energies has been therefore studied, by using the fluorescence lines (Fe, Pb and Mo) and the source of BaCs at low rates and time acquisition equals at 0.1 s. It is important to have few counts over the whole camera (order of hundreds) in order to exclude the possibility of contemporary adjacent photons. In this condition the average cluster size at each energy has been calculated as

$$\text{Cluster size} = \text{counts} / \text{spot number}$$

where spot number (detected photons) and counts are on the whole camera. The measurements have been done in such a way the counts per pixel was 1 at maximum.

Cluster size as function of energy, shown in Fig. 2, is constant and equal to 1 for energies up to 6.4 keV, and then it increases linearly up to 2, as expected. In order to evaluate the energy response of the detector, the acquisition mode Time over Threshold (ToT) was used. In this mode, it is possible to measure the time during which a pulse is above

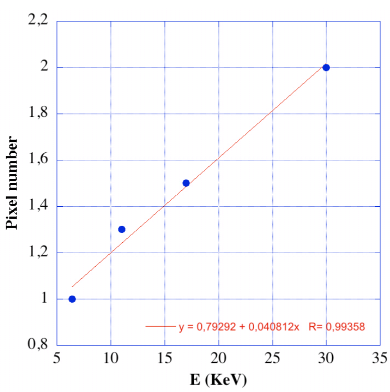

Figure 2 Cluster size as function of energy

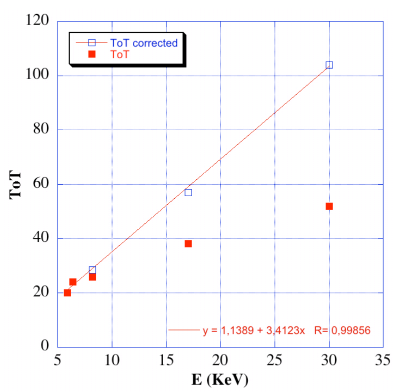

Figure 3 ToT as function of energy: ToT (red squared) and ToT corrected by cluster size (blue squared)

threshold. This quantity is proportional to the pulse amplitude; therefore the ToT allows a measurement of the energy deposited in the sensor. We have measured the linearity in energy of the Medipix-2, for different X-ray energies, with the ToT measurements at low fluxes and short time acquisition (0.1 s or 0.01 s) to have one count/pixel maximum. The average ToT is equal to the total ToT divided by the pixel counts. In Fig. 3 the ToT as function of the energy is shown and a linear response up to 12 keV is observed. At higher energies (12÷30 keV) the linearity is lost, indicating a saturation. This is due to the different cluster size at each energy. However, after correcting the ToT response by appropriately accounting for the cluster size, the Medipix2 response becomes linear in the whole range of interest 3÷30 keV (Fig. 3).

The detection efficiency of the Medipix-2 was estimated as a function of photon energy in the range 3÷30 keV (Fig. 4) by utilizing an absolutely calibrated X-ray source (Moxtek 50 kV Bullet) and a spectroscopic Si-PIN diode (AMPTEK XR-100CR). In our experimental set up, SXR line transitions have been generated by fluorescence on different samples (KCl, Fe, Cu, Pb, Mo) or by means of radioactive sources of Fe^{55} and BaCs. In order to measure the photon flux impinging on the detector, spectra were measured with a Si-PIN diode, put in place of the Medipix-2 detector.

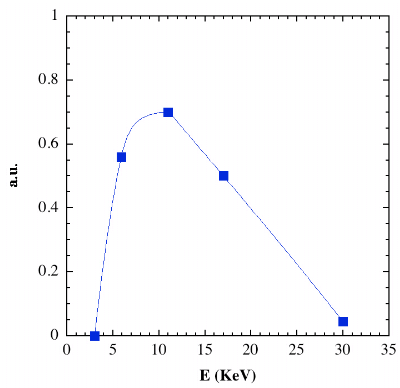

Figure 4 Detection efficiency of the Medipix-2

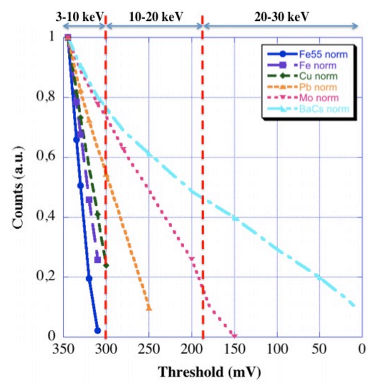

Figure 5 Normalized threshold scan for different energy spectrum

Energy discrimination in bands has required scans in threshold of all the pixels for different monochromatic X-ray sources [2]: KCl (3 keV), Fe^{55} (5.9 keV), Fe (6.4 keV), Cu (8.2 keV), Pb (10.4 and 12.5 keV), Mo (17.4 keV), BaCs (30 keV). We have used the X-ray tube at 25 kV-10 μA for Fe, Pb and Cu fluorescence, while at 45 kV-5 μA for Mo. Threshold scan at different energies (Fig. 5) reveals that Fe and Cu lines are not discriminated by the Medipix-2. However, based on these results, three energy bands can still be defined, albeit with a non-negligible overlap: 3÷30 keV (Threshold=345 mV), 10÷30 keV (Threshold=300 mV) and 20÷30 keV (Threshold=180 mV). However, it is possible to operate by subtraction to obtain two completely separated bands (3÷10 keV and 20÷30 keV).

Imaging properties

The Medipix-2 imaging capability has been tested using the X-ray tube: 10 kV and 10 μA. The image of the samples is obtained putting them just in front of the detector to check structure, contrast and spatial resolution. In Fig. 6 the image of a GEM foil: the Medipix-2 response is uniform on the whole area without any distorsion and the exagonal structure is recognized. In Fig. 7 the zoom of a rectangular mesh with wires of 50 μm and pitches of 150 μm and 250 μm is shown. At low energy, where the cluster size is 1, the spatial resolution is equal to the pixel dimension (55 μm).

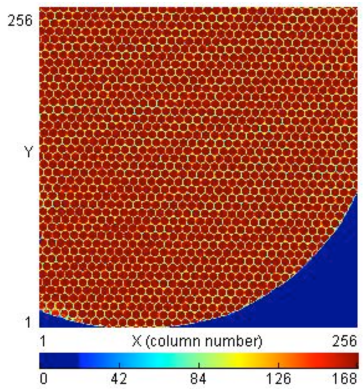

Figure 6 Radiography of a GEM foil

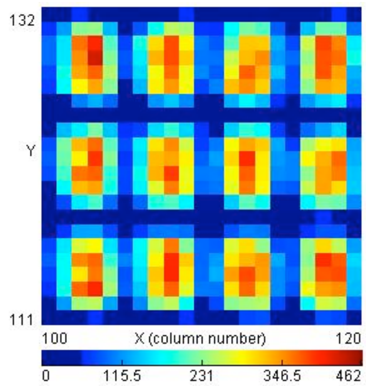

Figure 7 Zoom radiography of a rectangular mesh with wire of 50 μm

Conclusions

Detection efficiency was measured utilizing absolutely calibrated X-ray sources, with particular attention to the low energy side. The imaging properties have been checked and the spatial resolution was found to be of the order of the pixel (~55 μm). On the other hand, energy discrimination was found to be limited, allowing for only 2 or 3 energy bands. In addition framing rate is very low, about 10 Hz. Despite these limitations, the high 2D spatial resolution of the system, in photon counting, could represents an attractive feature for application in magnetic fusion experiments, particularly if coupled with X-ray optics [3].

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References

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