Response and spectroscopic performance of a CdTe pixel detector at deep sub-microsecond signal processing time

M. Sammartini, M. Gandola, F. Mele, B. Garavelli, D. Macera, P. Pozzi, G. Bertuccio

***Abstract*— Advanced scientific and industrial applications based on x and γ ray spectroscopic imaging need systems able to handle high incoming radiation flux (>1 Mcount/s). Guaranteeing a fast response, without compromising the spatial and energetic resolution, still presents a complex challenge and it is object of the most recent research worldwide. Room temperature operation and high absorption efficiency (up to 100 keV of photon energy) is required in many applications and CdTe or CdZnTe detectors are the best semiconductor detectors. In this framework we have developed a research grade spectroscopic system based on a pixelated Schottky CdTe detector coupled to SIRIO-6, a CMOS charge preamplifier specifically designed to have ultra-low noise and fast response in order to study the response and spectroscopic capability of CdTe pixel detectors at very short signal processing times. The fast rise time of the system (10 ns) paired with its low noise allows to accurately acquire current signals from the detector, well-discriminating electron and hole components, thus enabling the extraction of crucial parameters for optimal operation. At the optimum peaking time of 600 ns an unprecedentedly reported linewidth of 510 eV FWHM on the 59.54 keV of ^{241}Am source has been measured with an intrinsic energy resolution of 314 eV, additionally allowing to accurately evaluate the Fano factor (F=0.12±0.02) even at room temperature. Deep sub-microsecond spectroscopy at 50 ns with trapezoidal pulse shaping (50 ns flat-top) has been successfully accomplished with linewidths of 600 eV and 455 eV FWHM on the 59.54 keV of ^{241}Am and pulser lines.**

***Index Terms*— Cadmium Telluride (CdTe), Pixelated radiation detector, X and γ ray spectroscopy**

I. Introduction

NOWADAYS x and γ ray spectroscopic imaging is an essential tool in a large variety of fields such as medical diagnostics, homeland security and product quality control. To rise to the challenge of the most advanced scientific and industrial applications, spectroscopic systems are required to deliver high performances, in terms of spatial and energy resolution, as well as to respond to the incoming radiation within an extremely short time period. Additionally, compact dimensions are another desired feature, therefore room temperature operation is mandatory in order to avoid bulky and electrical power consuming cooling systems. Compound semiconductor detectors, especially based on Cadmium Telluride (CdTe), are ideally suited to be employed in these spectroscopic systems since the high atomic number (48/52) ensures high absorption efficiency for photons in the 1-100 keV range and the wide bandgap (≈1.5 eV) guarantees low leakage currents. It has been experimentally verified that CdTe detectors, when coupled with low noise electronics, can achieve the high energy resolutions necessary for accurate radiation spectrometry [1]. However fast response spectroscopic systems, able to handle high incoming radiation flux (>1 Mcount/s) without compromising the energy resolution, still set a complex challenge and currently are the object of the most recent research worldwide [2].

In this work we present the results of the study carried out on a Schottky CdTe detector with the following two purposes: to examine meticulously the CdTe response at very short signal processing times, in order to determine its capabilities and limits to effective operation, and to evaluate the spectroscopic performance down to deep sub-microsecond range using a state of the art custom designed readout electronics.

II. The spectroscopic system

The study was carried out on a 1 mm thick CdTe detector of 32 squared pixels (0.75 mm side) manufactured by Acrorad (Japan). The front pixelated surface presents Schottky contacts formed by deposition of Au/Ti/Al on the crystal. A guard ring is placed around the pixels (anodes) to ensure the sinking of all external leakage currents. The contact of the back is a full planar Pt electrode which produces a nearly ohmic contact (cathode). At room temperature and at a working bias voltage of 700 V, the pixel tested shows a leakage current of 28 pA that corresponds to a current density of 5 nA/cm^2. The front end electronics is constituted by SIRIO, a fully integrated charge sensitive preamplifier (CSP), operated in pulsed reset mode, with 2.9 electrons r.m.s. intrinsic noise at 12.8 µs peaking time and room temperature [3]. Minimization of noise and high signal speed were the guidelines for the design of the dedicated board, that besides the detector and CSP, houses a power supply filtering stage and a wide-band low noise amplifier that takes the CSP output and feeds it to an external commercial Digital Pulse Processor (DPP) and Multi Channel Analyzer (MCA).

III. Optimum spectroscopic performance

Spectra of an uncollimated ^{241}Am radioactive source, placed at about 1.5 cm above the detector, were acquired for different working conditions from a single pixel: bias voltage up to 700V and trapezoidal (50 ns flat top) pulse shaping with peaking time ranging from 5.6 µs down to 50 ns. In order to avoid the effects of polarization, the acquisition of each spectrum was started immediately after the application of the detector bias. The best resolution spectrum at room temperature (+ 20 °C) is obtained

M. Sammartini, M. Gandola, F. Mele and G. Bertuccio are with the Department of Electronics, Information and Bioengineering of Politecnico di Milano, Como Campus, Via Anzani 42, 22100 Como, Italy, and with INFN Milano.
B. Garavelli, D. Macera, P. Pozzi are with XNEXT s.r.l., Via A. Bono Cairoli, 30, 20127 Milano, Italy
(Corresponding author: giuseppe.bertuccio@polimi.it, tel: +39 0313327346)

at 700 V of detector bias voltage and 600 ns of peaking time. The high intrinsic energy resolution (314 eV FWHM) of this spectrum allows to discriminate many escape and fluorescence lines from as low as 0.6 keV and the 59.54 keV with 510 eV FWHM, which to our best knowledge is the highest energy resolution measured at room temperature with CdTe. Such high resolution allows to extract accurately the Fano factor for CdTe, which is of interest since the lack of documentation in literature, except for two works at low temperature [4] [5]. From the linewidths of the monoenergetic peaks and assuming an electron-hole generation energy of 4.43 eV, a Fano factor value of 0.12 ± 0.02 is found. Our measurement at room temperature is in good agreement with the value that can be derived from the data reported by Takahashi at − 25 °C. Moreover, the acquisition of spectra at different detector bias voltages allowed to evaluate the charge collection efficiency (CCE) which is found to be 99.4% at 700V bias. CCE data as a function of voltage was fitted with the well-known Hecht equation leading to a value of 1.2 x 10^{-3} cm^2 V^{-1} which is typical for this material.

IV. Deep Sub-Microsecond Performance

The spectroscopic system has been designed with the goal of studying the spectroscopic capabilities of CdTe detector when deep sub-microsecond signal processing times are employed for theoretically allowing operation at high photon rates. Nevertheless at very short processing times phenomena related to the electron and hole drift velocities and collection times become more severe and can compromise the spectroscopic capabilities of the detectors. Using a fast pulser (2 ns risetime) to inject charge pulses at the CSP input, an experimental evaluation of the speed of our readout electronics was determined to be 10 ns. Such fast response paired with the low noise of the system, enables to accurately acquire and analyze the current signals from the detector, well-discriminating the components due to drift of electrons and holes generated by photons, as can be seen in Fig.1. The fit of the experimental data with a theoretical model allows to extrapolate parameters such as the electron-hole origin coordinate, their mobility and mean drift time and also to gather information on the concentration of the traps and the slope of the electric field.

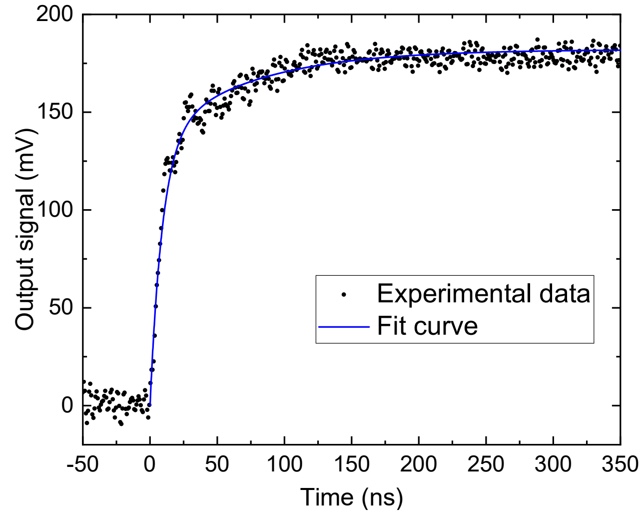

Fig. 1. Example of output signal of the charge amplifier generated by the photoelectric absorption of a 59 keV photon (^{241}Am) and acquired with the custom designed ultra-low noise fast readout electronics. The electron and hole signal components can be discriminated and analyzed with high resolution.

Moreover, as shown in Fig. 2, high energy resolution with ultra-short processing time has been successfully accomplished with the acquisition of ^{241}Am spectra at the minimum available peaking time in the DPP (50 ns): the 59.54 keV line presents a FWHM of 600 eV with an intrinsic resolution of 455 eV. This interesting result demonstrates that high energy resolution with CdTe, and most probably also with CdZnTe, even when the signal processing time is so short. This experimental evidence will be analyzed and explained in detail on the basis of drift velocities and the collection times of electrons and holes and the weight of the related ballistic deficit effect.

References

[1] Sammartini et al., "A CdTe pixel detector-CMOS preamplifier for room temperature…," Nucl. Instr. Meth. A, vol.910, 2018

[2] Ballabriga et al., "Review of hybrid pixel detector readout ASICs for spectroscopic X-ray imaging" JINST, vol.11, 2016

[3] Mele et al., "A New CMOS Charge Sensitive Amplifier for High-Rate and High Energy-Resolution X-γ ray Spectroscopy" submitted for IEEE NSS/RTDS 2019

[4] Takahashi et al., "High-resolution CdTe detector and applications to imaging devices," IEEE Trans. Nucl. Sci., vol.48, no.31, 2001

[5] Takahashi, et al., "High-Resolution Schottky CdTe Diode Detector," IEEE Trans. Nucl. Sci., vol.49, no.3, 2002

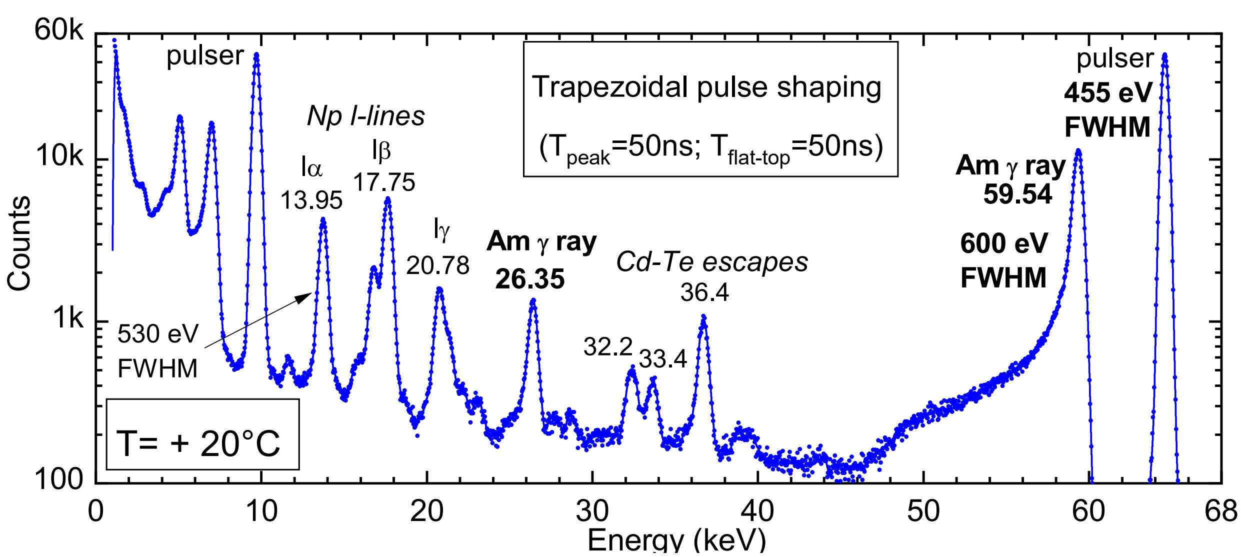

Fig. 2. ^{241}Am spectrum acquired with the CdTe detector and SIRIO preamplifier at + 20°C, 700 V of bias voltage and 50 ns of pulse shaping peaking time.