The use of Segmented Silicon Drift Diodes (SSDDs) in Nuclear Identification Systems

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***Abstract*— Recent progresses obtained in the consolidation of the leakage current densities and in the reduction of the series noise of LA-SSD – Linear Anode Silicon Drift Detectors (SSDDs) at room temperature have allowed the reaching of a resolution of 3.5 % @ 662 keV on a 0.9" LASDD detector (area 4 cm^2) coupled to a 0.9" x1.2" $LaBr_3$ scintillator. Resolutions of 4.5 % were reached at 45 °C without any need for cooling the detector with Peltiers. The analog charge Sensitive Amplifiers and the DSP-MCA Digital Signal Processing – Multi Channel Analysers systems that were used for this evaluation were the I-TRP (Integrated – Transistor Reset Pulse Charge Sensisitve Amplifier) and the LYNX of CANBERRA.**

These results and the compact nature of LA-SSDD devices combined with easy interfacing to mainstream read-out electronics qualifies them for being integrated in robust and cost efficient industrial compact spectroscopy systems for monitoring gamma rays. Some of their attributes are their mechanical robustness (no vacuum needed, no fragile glass parts or fragile electrodes), compatibility with interconnects technologies, and their absence of temperature dependency of the gain. This make them interesting alternatives to Photomultiplier Tubes (PM) for medium to high range energies applications where robustness, compactness and gain stability are required.

In addition, the 4 cm^2 LA-SSDD can be used as a beta detector. The measurement of C-14 sources can be carried out with excellent efficiencies since the noise thresholds of such devices is 6 keV for a segment of 3.55 cm^2 at 20°C. Similar PIN diodes generally give thresholds of 27 keV. Combined gamma-beta systems can therefore be devised if small sized electronics can be coupled to the LA-SSDDs.

The LA-SDD detector was developed for scintillation applications. The design of this detector minimises the number of collection anodes and therefore of segments and keeps the drift lengths minimal. Recent improvements in the anodes design described in this article allowed the upscaling of SSDDs from 0.7 " to 0.9",while keeping the same resolution of 3.3 % @662 keV. The reduction of the series noise when transitioning from ring linear anodes to the newly developed micro-linear anodes explains the progress made, allowing an upscaling of detector size. Uscaling to a detector diameter of 1" will be possible by further optimising the design of the micro-linear anodes.

The industrialisation of the LA-SDDs will required smaller sized CSAs such as the VERDI ASIC realised by Polytechnico de Milano. This ASIC is made of 8 charge sensitive amplifiers-shapers on a chip size of 3 mm by 3 mm.Smaller sized LA-SDDs having a diameter of 0.7 " were coupled to the VERDI and to a compact low power back end, resolutions of 4.3 % for Cs-137 have been reached. The total power consumption of the system was under 2 Watts.

***Keywords:* Silicon drift detectors, scintillators**

I. Introduction

The development of new generations of nuclear power plants (4^{th} generation) is offering opportunities for technology evolution. A prerequisite condition for their development the development of reliable, cost efficient compact NID systems for safety, security & safeguards .

This paper describes the progress in the technological and industrial challenges that need to be addressed to develop a compact spectrometer answering to the needs of the next generation nuclear facilities.

This spectrometer will provide the identification of the radionuclide and intensity of the source using radiation with couplings of The Drift Detectors and scintillators whose sensing volumes will range between 30 cm^3 and 60 cm^3 , . The total sensor size being inferior to a cylinder of 6 cm by 6 cm at operation temperatures between -10 °C and 55 °C, running on batteries hand thus having power consumptions inferior to 2 Watts

A. *An Overlook of the Silicon Drift Detector Technology: its Origins and the Reasons of their Popularity*

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Silicon Drift Detectors are multielectrode photodiodes realized with double sided technology. These photodiodes were introduced by Gatti and Rehak. The main differentiator in comparison to the well known PIN technology is that the collection of the charge in the SDD is realized onto a very small read-out anode (∅ 100µm) using a lateral drift field within the detector Radiations (such as X rays or visual photons) absorbed in the detector generate electron-hole pairs. The path of electrons migrating toward the anode is shown in Fig1.

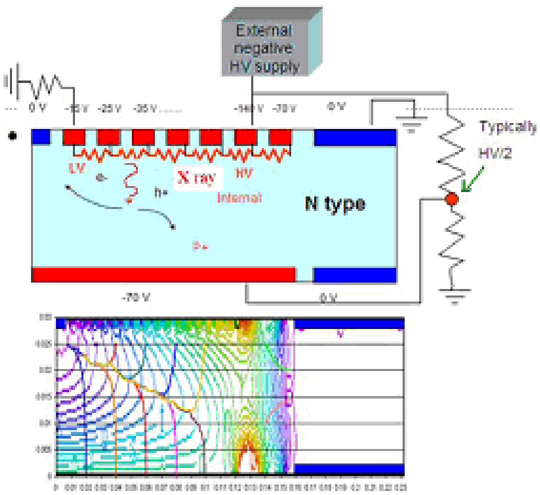

Fig 1. the drift diode

The complexity of the structure depicted above (a double sided multi-electrode diode) is justified by the drastic reduction of capacitance of this device. In a PIN diode of giving an area of 1 cm^2 and a thickness of 300 µm, this capacitance will typically be 90 pF, while with an SDDs of similar size, the detector capacitance will typically be 0.04 pF (for an anode diameter of 100 µm). The dominant detector input capacitance to the electronics is the capacitance between the anode and the first low voltage steering electrode. The lineic capacitance of between an anode and this electrode has been computed by finite elements modelling. and is around 1.3 pF/cm . The JFET transistor capacitance has to be added to the detector capacitance for knowing the total input capacitance to the CSA. Discrete JFETs have capacitances typically ranging between 0.4 pF and 2 pF.

These low anode capacitances . allow the reach resolutions of 150 eV a 5.9 keV at shaping times of 1 µsec on SDD areas of 15 mm2 at -40 °C. [6]

Using, this same estimation of lineic capacitance, ,values of 5.5 pF were computed for the largest segments and 1.8 pF for the smallest segment of a Linear Anode Segmented Drift Detector (LA-SSDD – see further) used in this project. The total capacitance of such a detector is 7.2 pF.

B. The Difference between Direct X ray Absorption and Scintillated Photon Absorption

Due to the limited thickness of these detectors (0.3 mm to 0.5 mm), the absorption of X rays is only efficient in the 0 to 30 keV range. In such applications, the Silicon drift diode is directly absorbing X rays. In this case, electron-hole pairs are generated in a single point and arrive with a quasi simultaneity to the anode.

But SDD diodes can also be used as read-out electrode for scintillators [1], [2] and contribute to the detection of gamma rays of much higher energy (60 keV to 3 MeV range). As shown on Fig 2, the gamma ray is converted into tens of thousands of visual photons reaching the SDD in a continuous distribution from the center to the border of the SDD. In this case, a scintillated event leads to the generation of electron-hole pairs across the whole radius of the SDD as illustrated in Fig2. This situation is therefore different than in the case of direct X ray absorption. Directly absorbed x rays lead to the generation of where electron-hole pairs in a single point that ill arrive with a quasi simultaneity to the anode. In the case of scintillated events , a continuous signal will be generated , its width being the longest drift time.

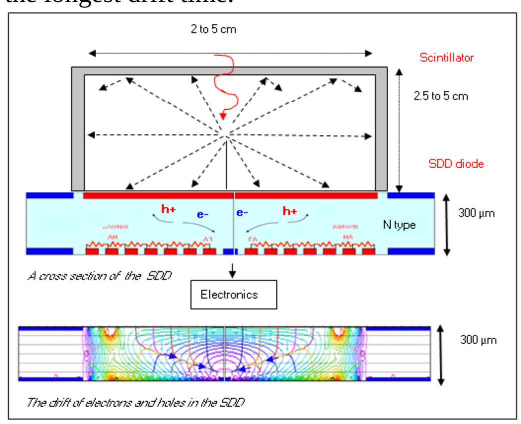

Fig 2.The conversion of a gamma ray into visual photons and the generation of electron-hole pairs in the SDD detector

The key detector parameters to reach optimum resolutions are: a good Quantum Efficiency, a low leakage current density, small drift lengths and a small detector capacitance.

II. THE LA-SSSD DETECTOR CONCEPT

A. The LA-SSDD Detector: a Silicon Drift Detector Optimised for Scintillation Applications

. While the low capacitance of the diodes allows to use SDD X-ray detectors to be used at shaping times as low as 0.2 µsec, the shaping times used for scintillation applications must be at least higher than the largest drift time seen by electrons generated at the border of the SDD. This is required for collecting the complete charge. The use of lower shaping times will lead to incomplete charge collection.

The maximum drift time in an SSDD is the division of the maximal drift distance by the speed of carriers with is the product of the carriers mobility by the electrical field and is expressed in (1.)

$$Maximal\ drift\ time = \frac{maximal\ drift\ distance}{\mu . E_{lateral}} \quad (1)$$

The lateral electrical field is the division of the maximal lateral bias V HV by the maximal distance. And thus, the maximum drift time can be expressed as a function of the maximum drift distance and the maximal lateral bias in (2.)

$$Maximal\ drift\ time = \frac{maximal\ drift\ distance^2}{\mu . V_{HV}} \quad (2)$$

Typical Lateral biases of 120 Volts (V HV) are used for 300 µm thick, 3000 ohm.cm material. Table 1 lists, typical drift times for different lateral dimensions of drift detectors

Segment radius (mm)	2	3	4	5
Lateral electrical field (V/cm)	600	400	300	240
Maximum drift time (µsec)	0.25	0.56	0.99	1.5

Table 1. The lateral electrical fields and the maximum dirft times for maximum lateral biases of 120 Volts in a SDD

Drift lengths of 2 mm require drift times of 0.25 µsec. This drift time (0.25 µsec) is still quite superior to critical values where ballistic deficit can play a significant role.

The pixellisation of segmented SDDs with drift lengths of 2 mm requires a large number of segments which is manageable for medical applications but prohibitive for hand held detectors where the complexity and cost must be kept optimal. For a handheld NID, having active area of 20 cm2of semiconductor coupled to a scintillator, 160 pixels would have to be used

Using higher drift lengths drift lengths of 5 mm would reduce the number of pixels to 25 and can help to reduce the complexity but is translated in drift times of 1.5 µsec. Using shaping times equal to or greater than 1.5 µsec is acceptable at room temperature but can become a problem at temperatures of 55 °C where the parallel noise will start to dominate.

LA-SSDDs (linear anode segmented drift detector) have been developed and optimized for scintillation applications in order to overcome this problem , patent filed [4] . These detectors are circular shaped and have areas of 250 and 300 mm2 and a thickness of 300 µm. The drift length of electrons is minimized by the implementation of a series of concentric ring shaped anodes and is typically between 2 and 2.5 mm. This allows to minimize the number of anodes while keeping very small drift distances, thus allowing the use of small shaping times. For interfacing the equivalent volume of a 2” by 2” scintillator, an interface area of 20 cm2 between scintillator and semiconductor is required and can be covered with 16 segments whose drift length does not exceed 2.5 mm.

Fig 3. shows the anode side of the detector

- In Fig 3, a 3 anodes LA-SSDD is depicted. One anode is a point like anode
located in the center, the second anode is a ring like anode located in the middle of the detector. The third anode is located at the border of the detector.
- In Fig 4, a two anodes LA-SSDD detector such as used in the Nuclear Identification Dosimetry system studied in this paper is shown.

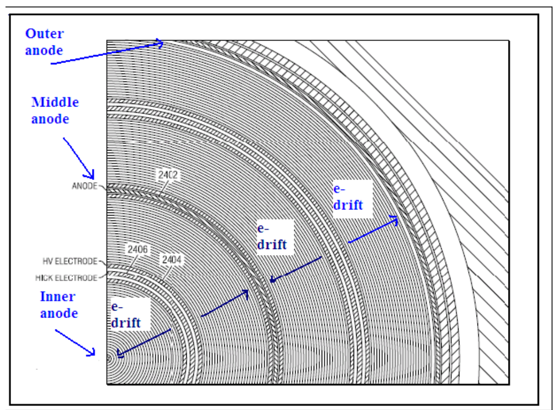

Figure 3: A 3 anodes SSDD: LA-SSDD_3P_250_250 with a central point anode and two concentric ring anodes

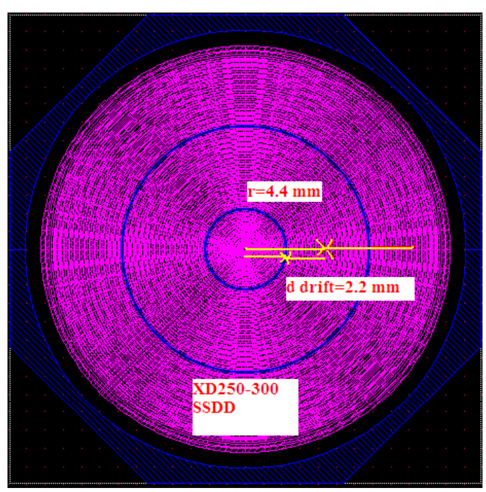

Figure 4 A 2 anodes SSDD LA-SSDD_2NP_250_300 used for this project. Acive area 2.5 cm^2, active diameter 0.7”.The inner anode capacitance is 1.8 pF and the outer anode capacitance is 5.5 pF

B. The possible addition schemes of the partial energies of the LA-SSDD detector

Coincident addition of partial energies collected by individual anodes of the segmented SDDs (SSDD) is used for totalizing the energy collected by all the pixels of the SSDD. Several techniques can be used for totalizing the energy

1) analog addition. This addition can be done after the CSA (Charge Sensitive Amplifier) stage or after the shaper stage

2) time stamped addition after digitization. This can be both done on DSP systems or on MCA systems that are implemented after an analog shaping stage.

An example of time stamped addition realized with two LYNX DSP-MCAs is shown on Fig 5:

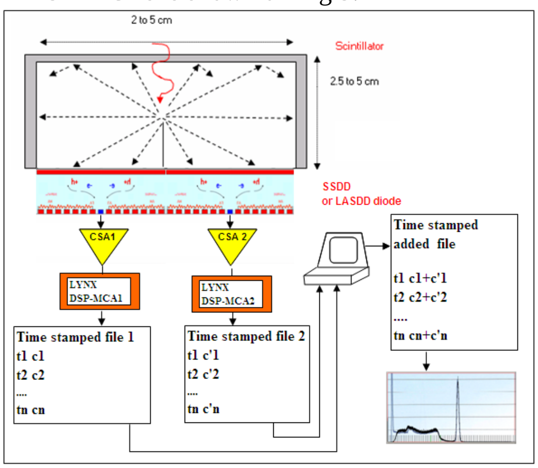

Figure 5.. The digital addition of partial energies collected by a 2 segments SSDD.

In this project, this digital addition processing was implemented after an analog shaping and multiplexing of the shaped signals though a single ADC , the digitized signal being processed by a low power consumption FPGA.

III. THE ARCHITECTURE OF THE DEMONSTRATOR

A. The Detector Configuration

A first generation of SSDDs was devised with areas of 2.5 cm2 so so that the contribution of the detector leakage current remains limited and that a resolution goal of 3.5%@662 keV could be reached.

A second generation of 4 cm2 SSDDs was then devised tyat benefitted from rdcent improvements in leakage current dernsity and allowed the raching og 3.5%@662 keV

<u>Generation 1 configuration (2.5 cm2 SSDDs)</u>

In the frame of this research, four 2.5 cm^2 SSDD (active diameter 0.7”) of the LA-SSDD_2NP_250_300 model, were coupled to four 2.5cm^2x 3cm thick Brilliance 380 $LaBr_3$ scintillators. Each of these 2.5 cm2 SSDDs posses two ring anodes. Such a setup allows the possibility to perform localisation by comparing the countings on each of the scintillatorr-SSDD tandem thus.

These ring anodes are depicted in Fig4. The inner anode has a perimeter of 1.4 cm and a capacitance of 1.8 pF. The outer anode has a perimeter of 4.2 cm and a capacitance of 5.5 pF. The toal capacitance is thus 7.2 pF

This array of 4 clusters is depicted on Fig 6.

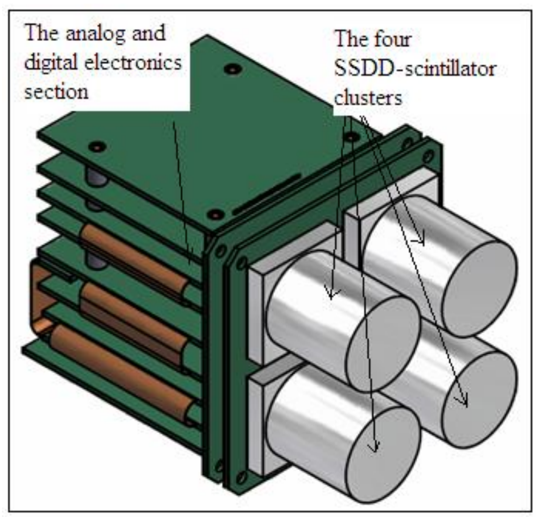

Figure 6 the cluster of 4 2.5 cm2 SSDD-7.5 cm3 LaBr3 scintillators couplings integrated in the ISP demonstrator.

<u>Generation 2 configuration (4 cm2 SSDDs)</u>

No adaptative board was yet designed for These detectors to the ASIC. They were thus coupled to a CSA made with discrete components were not yet mounted on the ASIC.

B. The description of the ASIC used in the ISP application for the Generation 1 detectors

The LASSDD detectors were linked to the 8 channels VERDI 1 ASIC realized in collaboration with Polytechnico de Milano [5]. The ASIC is based on 0.35 µm CMOS technology. The dynamic range of the ASIC is +1.7 V/-1.7 V An option exists to install a second ASIC in our setup extending the number of channels to 16..

The ISP system contains

- 4 clusters of two segment LA-SDD detectors having areas of 3 cm^2 coupled to $2.5cm^2x3cm$ $LaBr_3$ scintillators totalizing a volume of 30 cm^3.
- 8 Charge sensitive amplifiers followed by 8 amplifiers and shaper amplifiers
- 8 peak stretchers and multiplexers for bringing the shaped signals to a single ADC
- A high speed lower power ADC and a 4 inputs MCA.
- An Ethernet output that can be coupled to a readout system.

The front and back end electronic architectures of our ISP system are depicted in Fig 7 and Fig 8.

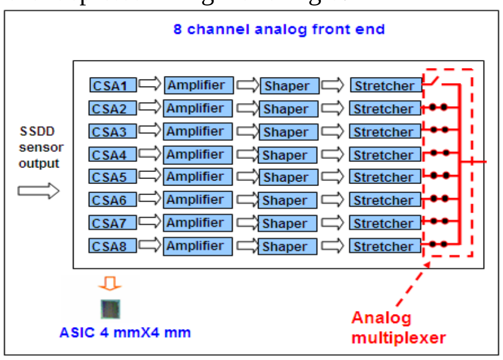

Figure 7. The front end architecture of our ISP system

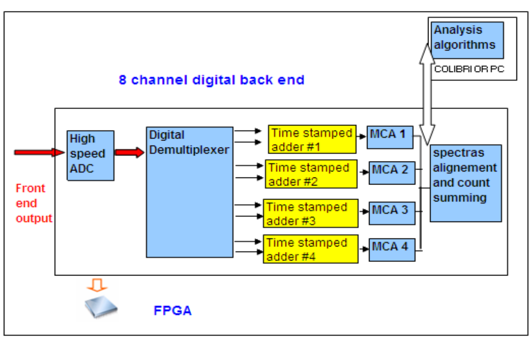

Figure 8. The back end architecture of our ISP system

IV. ISP Performance

A. *Spectroscopic Characterization of generation 1 detectors (2.5 cm2)*

Prior to the coupling with scintillators, the inner and outer anode of every detector were characterised in X ray spectroscopy. The leakage current density has a strong impact on resolution as shown in table 1. The mastering of leakage current is a key for consolidating yields for an industrial production. We have recently evoluted from current densities of 0.8-1nA/cm2 to current densities ranging between 0.1 to 0.2 nAcm2 by optimising the design of the drift rings of the SSDD where surface generation is optimised.

Table 2 lists the resolutions of the inner anode outer anodes of a SSDD LA-SSDD_2NP_250_300 reached for the lower range and higher range leakage current densities reached at CANBERRA

Leakage current density	Resolution of Inner anode (0.6 cm2) for 13.9 keV for a peaking time of 1.26µsec	Resolution of Inner anode (2.4 cm2) 13.9 keV for a peaking time of 1.26µsec
0.1nA/cm2 improved drift ring design	0.64 keV	1.33 keV
0.8 nA/cm2 Old drift ring design	1.21 keV	1.83 keV

Table 2. The ^{241}Am resolutions of individual anodes for the lower and higher range of leakage current density that are typically reached.

Figure 9 overlays Am-241 spectras of the outer segment and the inner segment of the two detectors whose characteristics are mentioned in table1

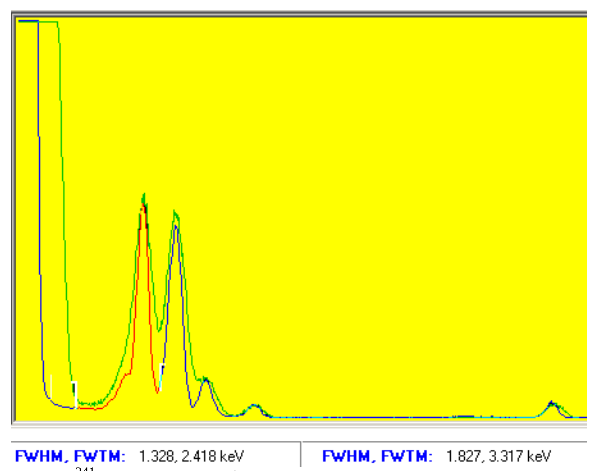

Figure. 9. A ^{241}Am spectrum of the external an SSDD measured at 20°C, making use of a discrete I-TRP amplifier and two LYNX DSP-MCA for the upper and low ranges of leakage current densities of 0.1 nA/cm2 and 0.8 nA/cm2, leading to resolutions of 1.328 keV@1.6 µsec peaking time and 1.827 keV@1.6 µsec peaking time

After direct X ray characterisation, the scintillators were coupled to the detectors with optical grease and evaluated in gamma spectroscopy with a 137Cs source. The sucession of direct X ray spectrocopy and indirect gamma ray scintillation spectroscopy allows the computation of quantum efficiency since direct absorption and scintillated absorption both have their characteristic generation energies. Since an energy of 1MeV produces 60000 visual photons in LaBr3, the energy associated to every per photon is $E_{\text{generation photon}}$= 16.61 eV. The energy needed to generate an electron hole pair in direct X ray absorption is E_{el}

$_{hole}$=3.61 eV. Keeping the X ray energy calibration scale, after having set the scintillator on the SSDD and having a 100 % conversion efficiency, a maximum value of 144 keV would be recorded when a 662 keV photon causes scintillation . The ratio of the measured value by the maximum value will give a measure of the Quantum efficiency. Table 3 lists the fundamental physical parameters for computing QE and the number of photons emitted

Description	**Value**
Energy needed to create a 380 nm photon in LaBr3	16.61 eV
Energy needed to create an electron hole pair in direct absorption in Si	3.61 eV
Energy measured for a 100 % conversion of 662 keV in the SDD	144 keV (662*3.61/16.61)
Maximum number of photons at 662 keV	39720 (662/1000*60000)

Table 3. The physical parameters used for computing the Quantum Efficiency and the number of photons

The 2.5cm^{2}X3cm $LaBr_3$ scintillators have been characterized at St Gobain with a PM tube with a ^{137}Cs-source and had resolutions of 3.2 %. They were then coupled to 3 cm2 LA-SSDDs and have been characterized at CANBERRA by linking each of both anodes to a discrete CANBERRA CSA amplifier at 20 °C. Each amplifier linked to a LYNX DSP-MCA. The coincident events were time stamped added. We have overlaid the spectrum measured at St Gobain (in light grey) and the spectrum measured at CANBERRA (in bold black) on Fig 10.

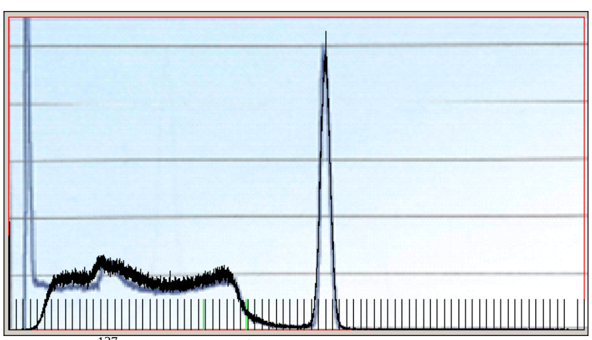

Figure. 10. A ^{137}Cs spectrum of an SSDD-scintillator coupling measured at 20°C, making use of 2 discrete I-TRP amplifiers and two LYNX DSP-MCAs combining coincident signals by time stamped addition. A resolution of 3.2%@1.6 µsec peaking time is reached. Our spectrum (in black) overlaid with the spectrum of a St Gobain PM-scintillator coupling in blue

Table 2 lists the leakage current densities of the detectors, their X ray spectroscopy

Leakage current density	241Am FMWH@13.9 keV Inner anode and outer anodes@1.6 µsec	137 Cs FMWH @662 keV of added segments	Computed quantum efficiency	# visual Photons generated
0.1nA/cm 2	I:0.64 keV, O:1.33 keV	3.2 %	60 %	23832
0.8 nA/cm2	I:1.21 keV O:1.83 keV	3.9 %	62 %	25023

Fig 11 shows the spectrums of a detector having a leakage current density of these detectors was 0.5 nA/cm^2 at 20 °C (average value in our production) irradiated with a source, using the VERDI ASIC coupled to a newly designed 4 inputs low power MCA. A resolution of 4.3 % is reached at 20 °C.

The difference between the results obtained with discrete amplifiers - DSP systems (3.6 %@20°C for 1.6µsec peaking time) and the VERDI CSA-shaper system (4.3%@20°C for 2.4 µsec peaking time) partially comes from the need to optimize further the settings of the shaper amplifiers of the VERDI 1 ASIC and of the reset mechanism. Progress was done on these issues on third version of this ASIC, named VERDI 3 and will be the subject of another publication. Other issues such as shielding, pickup and cross talk are being addressed..

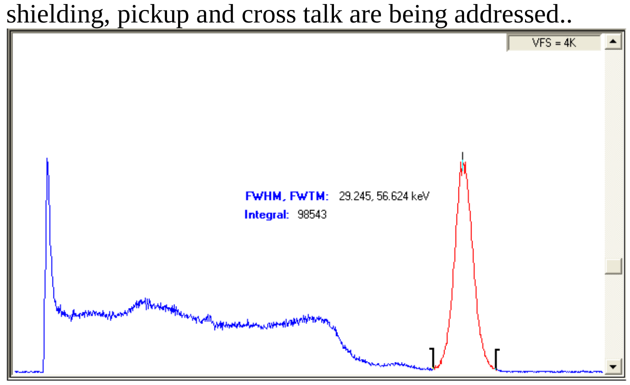

Figure 11 A ^{137}Cs spectrum of a 3 cm2 SSDD-scintillator coupling using 2 channels of the 8 channels VERDI CSA-shaper ASIC with SSDDS , with leakage current densities to levels of 0.5 nA/cm2. The MCA makes use of a Low Power ADC. A resolution of 4.3%@1µsec shaping time (2.4 µsec peaking time) at 662 keV is reached at 20 °C

Fig 12 shows a mixed ^{152}Eu-^{137}Cs spectrum measured with our discrete CSAs.

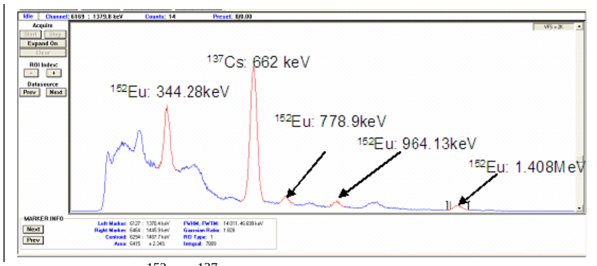

Figure.12: Mixed ^{152}Eu-^{137}Cs spectrum with the demonstrator detector measured with our discrete electronics

B. Spectroscopic Characterization of Size upgrade generation 2 detectors (4cm2)

The progresses carried out in the reduction of the leakage current density allowed a size upgrade from 2.5 cm2 to 4 cm2

A first coupling of a 4 cm2 LA-SSDD to a 4 cm^{2}X3cm LaBr3 scintillator (1 inch diameter)- was performed. Discrete electronics and LYNX digital filtering MCAs were coupled to this detector.

Fig 13. Shows the spectrum of this coupling A resolution of 3.3 % was reached at a rise time of 2 µsec

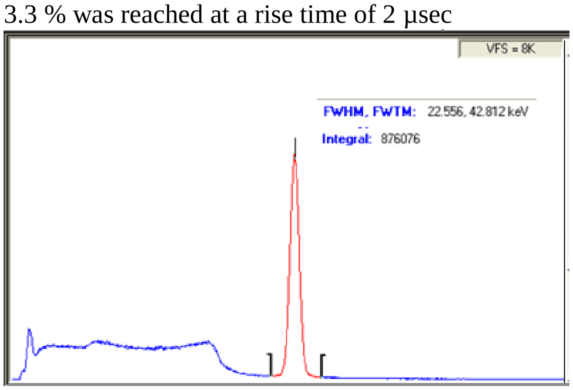

Fig 13 The first coupling of a 4 cm2 SSDD to a 4 cm2X3 cm LaBr3 scintillator (1 inch diameter). Cs-137 spectroscopy at 20 °C, digital rise time 2 µsec, MCA: LYNX

C. Characterisation of a generation B detector with a C14 and an Am-241 source.

A 3.35 cm2 segment of our new 4 cm2 cm2 SSDD was irradiated with two sources: a C14 source, leading to a continuous distribution ending at 150 keV. The noise threshold was around 6 keV. The 13.9 keV peak (in red and the 17.8 keV peak of Am-241 are well visualized on this spectrum as well. These low energy thresholds could allow the measurement of tritium if a small distance is maintained between the surface to be inspected and the SSDD.

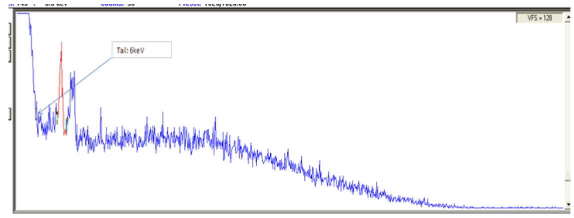

Fig 14 The spectrum of a a 3.35 cm2 segment of the 4 cm2 SSDD in C-14, Am-241 spectroscopy at 2 µsec rise time, MCA: LYNX

The SSDD can thus be used for alpha, beta and Lx spectroscopy which makes them an interesting building block for devising Nucleide Identification Dosimery systems that are able to detect gamma, beta and Lx emitting isotopes

V. Applications

Some of the possible applications planned are listed below:

A. Medical Field

Although not covering the field of applications of this project, it is interesting to mention that the use of SSDDs detectors is envisioned for SPECT gamma camera applications [3] in the medical field. A mixed ^{99m}Tc- ^{57}Co scintigraphy analysis can help practicians to make better medical analysis of brain damage after infarcts. Generally, these analyses are done with 2 to 4 days of spacing. A gamma camera having an energy resolution allowing the discerning of the 120 keV line of ^{57}Co and the 140 keV line of ^{99m}Tc is thus of high interest.

B. Uranium Borehole Logging

One of the applications foreseen is borehole logging of Uranium ore. Today, drillings are done for collecting samples which are then sent to a chemistry lab for analysis. This is a time consuming process. The use of a portable low power system may be of interest for performing isotope equilibrium analysis on site.

C. Applications in the Nuclear Fuel Processing Plants

Active and Passive Rod scanners are in use to characterize the amount of fissile material and its homogeneity within the rod.

In this field, the sensors making use bright scintillators such as $LaBr_3$ or SrI_2 could thus replace existing NaI sensors lined with PM tubes.

VI. Conclusions

The segmented silicon drift detector technology is a versatile technology that can be both used in the gamma detection and alpha and X ray detection applications. SSDDs can be interesting alternative to PM tubes , due to their compactness, the need of small biases (under 200 Volts), and their robustness. They can as well be efficient alpha and beta detectors. They were selected by

CANBERRA because of their versatility and their ease of industrialization on a large scale.

In the frame of the ISP program (Intelligent Sensor Platform) sponsored by AREVA, an area of 12 cm^2 of SSDDs was connected to a cluster of four $2.5cm^2$X3cm $LaBr_3$ scintillators.

Resolutions between 3.2 and 3.9 %@662 keV were reached by coupling the SSDD scintillator units to discrete electronics at 20 °C. Resolutions of 4.2 % @ 662 keV were reached at 20 °C by combining these systems to the 8 channels CSA-shaper array implemented on the VERDI ASIC connected to a low power 4 inputs MCA. The noise of the Gaussian shapers implemented in the ASIC is still higher than in the case for the DSP filtering solution , this section needing further optimisation. This partially accounts for the resolution differences that are witnessed.

A resolution of 3.3 % was reached on an area of 4 cm2 of SSDD at 20 °C.

The NID system can provide handheld spectral and nuclide identification on a small with low power consumption (<3.5 Watts).

Acknowledgment

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References

[1] Gamma-Ray Spectroscopy With LaBr3:Ce Scintillator Readout by a Silicon Drift Detector, C. Fiorini,, A. Gola, M. Zanchi IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 53, NO. 4, AUGUST 2006

[2] Prospects of a Dual Range Photon Detector with SDD and LaBr3(Ce) scintillator, Cristina Plettner, Guntram Pausch, , Claus-Michael Herbach, 2008 IEEE Nuclear Science Symposium Conference Record

[3] Silicon Drift Detectors Arrays for the HICAM Gamma Camera C. Fiorini, , A. Gola, R. Peloso, A. Longoni, 2008 IEEE Nuclear Science Symposium Conference Record

[4] “Simplified silicon drift detector and wraparound neutron detector” M. Morichi , O. Evrard, M. Keters , Appl# 12/838,267.

[5] “VERDI: a versatile readout ASIC for radiation Detectors”, A.Celani, L.Bombelli, C.Fiorini, O. Evrard, 2010 IEEE Nuclear Science Symposium Conference Record, N47-14

[6.] The Silicon Drift Detector for the IXO High Time Resolution Spectrometer Lechner P Amoros P Barret D Proc. of SPIE Vol. 7742 77420W-1

[7.] Fiorini et al., IEEE Trans. Nucl. Sci. 44 (1997) 2553

[8.] Moszynski et al., IEEE TNS, 56 (2009) 1006.