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CZT detector technological development and balloon testing

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Abstract. We report latest results obtained in the frame of the R&D activity on the CZT detectors financed from November 2006 to July 2007 by Italian Space Agency (ASI). Future improvements aA439, pp. 625-633 (re envisaged after the recent INAF support (PRIN '07) and the expected second R&D phase supposed for the beginning of 2009. Target of the R&D activity is an end to end system for domestic growth CZT Crystals and related read out architecture to provide an effective 3D focal plane. Our requirements are: good resolution in terms of Space (<mm), Time (few tens of μs), Energy (2% @100keV) over a range: 7- 400keV for single layer. Few layers assembled in a Compton multilayer structure can extend the detection up to the MeV region with efficiency close to 80%. Finally, in the spirit of the 1ST WORKSHOP on Science And Technology through long duration balloons, we discuss the possibility to test our subsequent prototypes in both Photon Parallel Field (PPF) and Photon Transverse Field (PTF) detectors disposition and propose our desired test plan.

Key words. CZT 3D detectors – Readout electronics – R&D – Balloon Borne Prototypes

1. Introduction

Thanks to the good performance of CdTe/CZT detectors in many applications for space as well for ground and the important support given by ASI and INAF financing the first phase contract for a dedicated R&D development study, today the Italian community is very close to dispose of a domestic source for enhanced detectors. We produce high quality crystals, in line with the actual world production. The detectors performances are going to improve in parallel with the progress in contact deposit and bonding procedure. In the mean time, dedicated read out chains are under study to resolve the tailing problem and reconstruct the photon interaction depth. There are two different configurations under test, PPF and PTF, to have sound 3D spatial resolution detectors. With them we plan to realise efficient Compton multilayer structures extending the Energy range from several keV to few MeV. At this stage a very representative and significant prototype could be produced in a couple of years with a limited cost. The Italian Industry has already being involved about. In particular, it has been evaluated a cost around 200euro for single crystal. In preceding papers we informed on the read out

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philosophy and applied mathematical model (Quadrini et al. 2005, 2007; Uslenghi et al. 2007). Elsewhere, we described concepts for new generation Instruments in X and Gamma Astrophysics based on CZT (Natalucci et al. 2007; Caroli et al. 2007). In the present paper, we report on latest results, after the end of the R&D study first phase. We envisage a possible future considering the present INAF support (PRIN 2007-2008) and the expected ASI R&D second phase contract supposed for beginnings of 2009. These detectors present interesting characteristics. They are well working at environmental condition with high stability in Time, high linearity versus Bias and Temperature and allow simple structures without need of cryogenics, pressurization, annealing cycles and so on, with a great aid for data analysts. Electronic signals come from direct photon conversion, i.e. no concerns about optical contacts and fiber, glues and other, with an implicit higher efficiency. Pixels are defined by only precise photolithographic processes and contacts bonding, providing high flexibility and modularity from cm^2 to m^2 focal/detector planes from 10 to 400 keV for a single layer. Finally, such detectors, have a potential wide applicability in many applications from space, like Instruments for Astrophysics, to devices for all non destructive/not invasive inspections in numerous fields: medical, security, custom, metallurgic, building trade. The ASI offer of long duration balloons, becomes an important tool for testing the subsequent prototypes during the various development phase. In fact, this will give the chance to check scientific performances, technical solutions and reliability versus long permanence in severe environmental conditions associated to significant radiation fields. We also propose our desired test plan for next few years.

2. R&D study: status of the art results

In the R&D study we have addressed arguments like crystal growth, contact deposit, readout development, new Instruments for Astrophysics and Industrial market analysis; here we describe major results from the two first points.

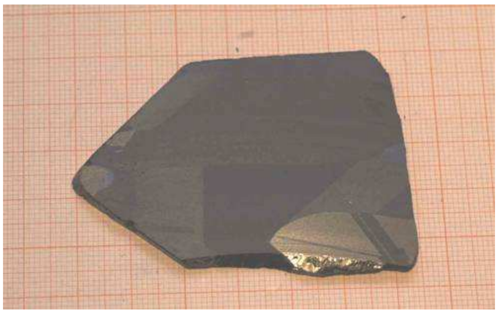

Fig. 1. Progress in CZT crystal growth 2″ ingot longitudinal section. Courtesy A.Zappettini

Since 2006 we passed from large monocrystals by a 1″ ingot to monocrystal covering most of the volume of 2″ ingot. (fig 1 and 2 of Zappettini et al. 2007)

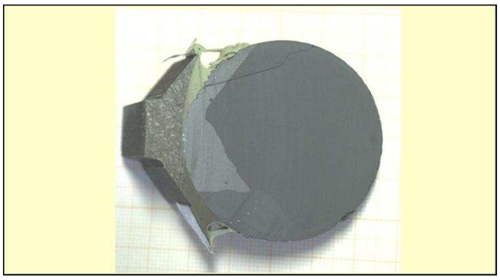

Fig. 2. Progress in crystal growth 2″ ingot transversal section. Courtesy A.Zappettini

In the same time also the spectroscopic qualities improved. In fig 3 we show the present performance at a low energy with the new generation crystals.

Today all these activities are in progress with particular interest toward the optimisation of deposit contact and bonding procedures. This should improve also the response at the high energies. With regard to the read out chain, the passage from a double chain to a 16 channels device allowed to analyse in good detail the behavior of multiple signals collected both from anode an cathode. Preliminary results where presented in (Uslenghi et al. 2007) where it has been described the procedures adopted in order to reduce the tailing effect (Knoll, 2000). The implemented chains pro-

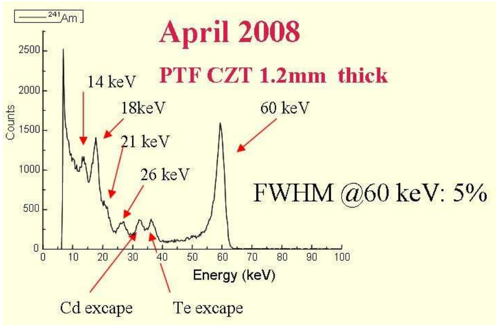

Fig. 3. Progress in CZT crystal growth: Low energy performance. Courtesy N. Auricchio

vide a discriminator and a delay line. At the event occurrence , the signal travel through the delay line while the discriminator provides trigger and information about the pixel address. Then, by a dedicated logic unit and MUX selection, the incoming signal is digitalised and stored in memory. The collected signal are then analysed to extract many parameters like, rise time and related variations during the slope, signal base and amplitude, anode to cathode signal ratio. All the signal amplitudes are then classified versus the selected parameter in order to extract the amplitude to parameter mathematical function. Finally the old amplitudes can be corrected. In fig 4 it is reported the effect of a proper data analysis at the high energy where the tailing effect is more relevant. Other than a sensible improvement in resolution there is an evident correction of the photopeak symmetry. We are

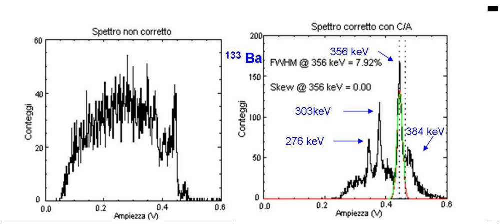

Fig. 4. Cathode signal ^{133}Ba. Before and after correction. Courtesy S. Monti

now working on the signal slope fit for reconstructing the two exponential components due from holes and electrons. These are correlated with the event interaction depth that will provide a 3D signal spatial resolution consistent with the pixel size.

3. New prospective, a different concept for a 3D focal plane.

A different way for suitable 3D detectors is financed by an INAF PRIN 2007 project (2 years). The collaboration includes 4 INAF/IASF institute plus the IMEM/CNR in Parma. It is proposed a prototype for a focal plane detector in high energy focusing telescope. The requirements are, high efficiency (~80%) up to the MeV region, moderate spatial resolution (1-3 mm), 3D sensitivity to photon interaction position for Polarimetry and Background rejection and good spectroscopic resolution (few % at 100 keV). The selected detector was CZT since well in line with the requirements. Although the high Z, also CZT needs several cm of thickness to achieve high efficiency. This implies the use of stack detectors. The proposed focal plane detector configuration reaches several cm thickness with a reduced number of layers and pixels (i.e. electronic channels). Qualificant points are the PTF irradiation configuration coupled with a drift strip configuration for anode electrodes and orthogonal cathode strips. The PTF = Photon

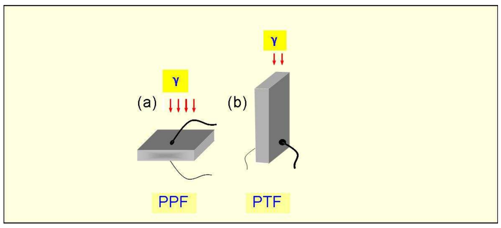

Fig. 5. PPF versus PTF configuration

Transverse Field, is a configuration where the field is perpendicular to the optical axis (Fig. 5b), while the PPF (Photon Parallel Field) refer to a field parallel to the optical axis. The PTF configuration has been proposed several years ago by the Solid State group at the INAF/IASF-Bologna (ex ITESRE). In this case the photon absorption thickness is independent from the charge collection distance, then the charge collection efficiency is independent from energy. As we saw before, today thickness deeper than 2 cm are feasible, this allow a very efficient detector.

A possible drawback for PTF devices is that all the distances between collecting radiation are uniformly hit by the radiation. Therefore the tailing effect plays a more important role as shown in Fig. 6.

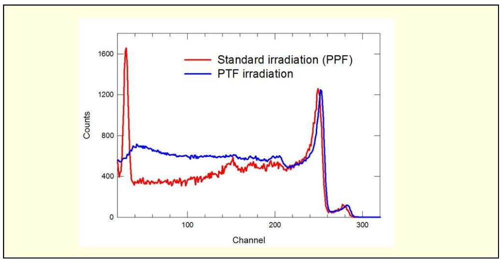

Fig. 6. PPF vs PTF, normalised 122keV peaks

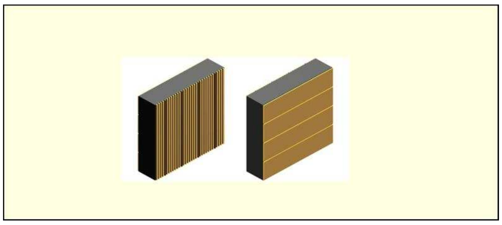

Fig. 7. CZT PTF unit: Contact layout

The drift strip configuration, initially studied by colleagues of DNSC(Coopenaghen) (fig.7), improves the spectroscopic resolution by an electrical field whose strength lines converge to the anode reducing the charge loss in the inter pixel space (Van Pamelen et al. 2000)

Energy spectra obtained with standard planar and drift strip devices with same crystal geometry show as the tailing effect, more evident at the higher energy, is strongly reduced in the latter case due to the small pixel effect enhanced by the contact area reduction. The basic device (Fig. 5 left) is mounted on a customised Alumina support in units of two with the relative CSP chains as reported in Fig. 8. Here the whole 16 basic units detector assembling is sketched. This configuration provides a total of 256 voxel in a total volume of 4 cm^3. The choice of contacts disposed in orthogonal strips allows a reduction of independent chains to 128. In turn, these could be reduced to 96 once the connection of adjacent horizontal contacts will be demonstrated valid (Fig. 8).

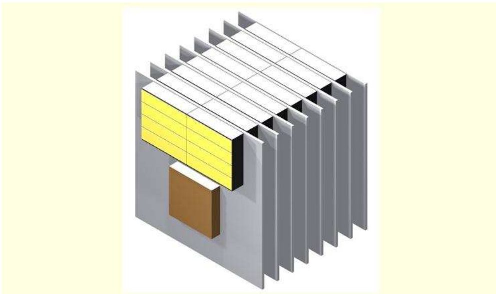

Fig. 8. The prototype detector assembling

4. Balloon born prototype: SIDERALE

Present ASI aperture for long duration Stratospheric Balloons has been welcome for the importance of testing our prototypes in severe conditions and high radiation fields. Dr. Monica Alderighi, proposed ASI to flight a limited area ($1cm^2$) CZT detector 5mm thick, divided in 16 pixels served by individual electronic chains. This proposal, named SIDERALE, has as main objective to validate the system in severe environmental conditions (e.g. space-like radiation field). From a scientific point of view we plan to discriminate photon from charge particles background and reconstruct the event energy. If the minimal requirement is the system survival for the long flight duration, we consider as a complete success the production of valid figures for 10-400 keV range background in the Arctic zone. SIDERALE is a small piggyback, with total volume of $< 10dm^3$ and weight inferior to 10kg not including batteries package [fig 9]. The throughput is ~150 kbit/s in a particle flux of 30p/cm^3/s. Due to the limited

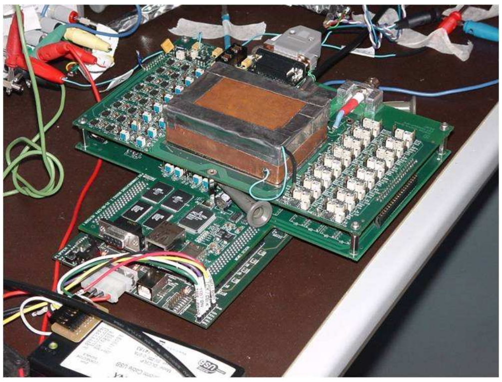

Fig. 9. Sistema Integrato Di Elaborazione e Rivelazione per ALte Energie (SIDERALE): detector and read out electronics.

telemetry (2.4 kbit/s), the data will be stored on board in flash memories; in parallel a small part (<1%) will be transmitted on ground. SIDERALE can offer an ulterior opportunity: the possibility to exploit a tight synergy with STRADIUM, a recent developed Telemetry System acquired by ASI and not yet tested on board. Namely SIDERALE, requiring on board data recording, simple upload command operations and downlink of either scientific and housekeeping data is a natural bench test for STRADIUM main features. In particular STRADIUM have built-in the possibility to record data continuously on flash memory while a TLC selectable percentage can be transmitted to ground with the 2kbit/s band. In the end the easiness of operation commanded through network access allows researchers for a personal training on the on board system during the ground test phase. This reduces in a dramatic way all possible integration troubles.

5. Flight plan for future prototypes

The coincident duration (2 year) of the INAF PRIN 3D CZT and the project for a thin (5 mm) CZT detector of similar area by colleagues of the Coimbra University (Portugal), brings to a prevision for a least two balloon borne tests in configurations of 3D CZT small prototype and CZT Stack prototype (Coimbra detector + 3D CZT prototype) This minimal plan does not consider, for comprehensible reasons, the additional scenario with the Italian detectors system, until the R&D study will be refinanced by ASI. The possible flight scenarios fulfill different scientific-technological purposes: (a) (Ant)Arctic long duration balloon flight to assess prototype reliability and stability in a high charge particle radiation environment as well as to validate the 3D events reconstruction in background rejection. (b) Low latitude balloon flight (e.g. trans-Mediterranean) for evaluation over a wide band (30-1000 keV) at 3mbar of the diffuse and intrinsic X and gamma ray background with and without the 3D reconstruction technique. Budgets of dimensions, weight, power and TLM for the proposed detector configurations will be compatible with small volume balloon as well as hosts in multipurpose payload.

6. Conclusions

Recent results in the CZT detectors development show that with a small residual effort the Italian community is close to obtain a very suitable device with good property of resolution and efficiency at environmental conditions. This from one side brings to new generation X e Gamma Instruments for Astrophysics, from the other side opens a large market to the Italian Industries with tens of possible commercial applications in numerous fields like medical, security, custom, metallurgic, building trade. The chance to exploit long duration stratospheric balloon flight, as a piggyback, would provide a strong tool in analysing and improving the prototype responses in severe environmental conditions.

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