Gamma Imaging

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Development of 2D Scintillator Array from CsI:Tl Single Crystal for Gamma Imaging

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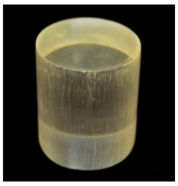

Processed CsI:Tl single crystal of diameter 50 mm and length 50 mm under UV illumination

ABSTRACT

A Gamma camera was developed using a 2 dimensional array of 8 x 8 CsI:Tl single crystals grown at BARC. The scintillator array was mounted on position sensitive PMT (PSPMT) to fabricate the detector. Acquisition and image process algorithm were implemented to achieve a spatial resolution of 5 mm. The device has been integrated to be used as a intra-operative tool to detect tumors using radioactive tracers.

KEYWORDS: *Scintillator array, Crystal, Gamma*

Introduction

CsI:Tl scintillator has been extensively used for X-ray and Gamma-ray imaging which are required in various applications like industrial inspections nuclear medicine imaging, and scientific research [1,2]. In these applications the scintillator is coupled to position sensitive photo-multiplier tube (PSPMT), photo-diodes or Pixelated Si-PM is used. For imaging of a radioactive source with directional information there are various schemes like coded-aperture imaging, Compton imaging, and Directional-Sensitive Array detector. The spatial resolution of the system is governed by the size of the scintillator pixel as well as the electronics.

In this paper, we are reporting on the growth of CsI:Tl single crystal and a cost-effective process for fabrication of scintillation detector array from the single crystal which realizes a spatial resolution of around 5 mm as well as a spectral resolutions (~15% FWHM). We have developed a process where pixels are fabricated with very high precision from the in-house grown CsI:Tl single crystals. The developed 2D scintillator system consisting of a 8 × 8 CsI (Tl) array coupled with a 8 × 8 array of PSPMT and a compact readout along with image processing algorithm is developed.

Experimental

Single crystals of CsI (Tl) of 50 mm diameter and 75 mm length were grown by the vertical Bridgman technique using a furnace having four separately controlled zones. These Bridgman furnaces for the growth of halide single crystals have been designed in-house and fabricated locally. Fig.1 shows various Bridgman furnaces located at CTS, TPD.

For the single crystal growth, all materials used were of 99.999% purity. Tl is used as the dopant in the CsI matrix. The powder material were initially taken in a quartz ampoule (Fig.1(b)) and sealed after dehydrating so as to remove any moisture content from the powder sample. After sealing the quartz crucible was loaded in the Bridgman furnace and heated so as to melt the loaded power. After that the crucible is translated from the hot zone of the furnace to the cold zone at a rate of ~1mm/hr to solidify the melt into a single crystal. After the completion of the growth the quartz is cut and the crystal is retrieved (Fig.2(a)). The grown crystal was characterized for its scintillation characteristics and an energy resolution of <7% at 662 keV was recorded as shown in Fig.2(b).

For fabricating the 2D array of the CsI scintillator, the grown crystal were processed in to the pixels as per the schematic shown in Fig.3. In the first step the cylindrical crystal was shaped into a cube and eight plates of size 50 mm x 40 mm x 5.7 mm were cut using a diamond coated copper wheel. These plates were stacked together and glued to each other

Fig.1:(a) Bridgman furnaces with an operating temperature of 1000^{0}C maximum, located at CTS, TPD used for the growth of halide scintillator single crystals. (b) Quartz crucible used for the growth of CsI single crystal.

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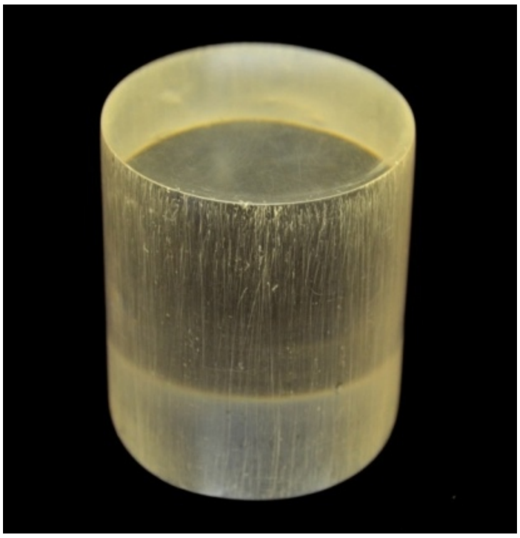

Fig.2: (a) Photograph of a processed CsI:Tl single crystal of diameter 50 mm and length 50 mm under UV illumination.

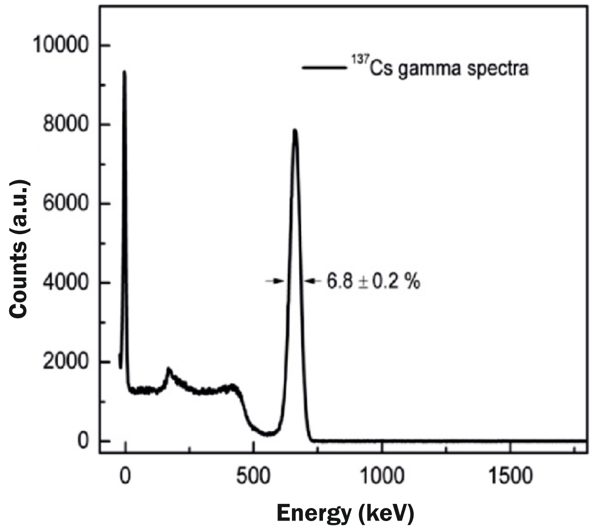

Fig.2: (b)The Pulse height spectra of ^{137}Cs source measured using the grown CsI single crystal.

using optical cement mixed with TiO_2. TiO_2 is used as a reflectent coating which inhibits crosstalk among the pixels. The process of cutting and stacking is repeated so as to get a plate consisting of 8 x 8 matrix of CsI crystal pixels each of size 5 mm x 5 mm x 5 mm.

Results and Discussion

A 8 x 8 pixel array of CsI:Tl is developed with individual pixel size of 5 x 5 x 5 mm^3 with a separation of 0.3 mm to match the pitch of the PSPMT. However the process is suitable to make smaller pixels down to the size of 1 mm and separation of 0.1 mm. To achieve the separation between two pixels a reflective layer based on TiO_2 and Epoxy was developed to get optical isolation as well as good adhesion to keep pixels together. Loading of TiO_2 was optimized to 70 wt% of epoxy to get best results in terms of reflectivity and mechanical stability. Fig.4 shows the photograph of the stacked crystals, the 2D matrix of the crystals and the 2D matrix mounted on the PSPMT forming the full device.

We developed an algorithm that facilitates interaction with the detector, enabling real-time streaming and extended single-frame data acquisition capabilities as shown in Fig.5. The acquisition and imaging processes are designed as a two-threaded system, as illustrated in Fig.6. This can be broken down into key elements as follows:

- ***Buffer Initialization and Network Configuration:*** A data buffer is initialized, and network settings are configured using Winsock libraries.
- ***Data Reception and Buffer Management:*** This function continuously receives data and employs circular buffer management to prevent overflow.
- ***Data Processing and File Handling:*** This function processes and writes data to CSV files, efficiently managing up to 1000 files to avoid overwriting.
- ***Multi-Threading for Continuity:*** Two threads for uninterrupted data reception and file management runs concurrently.
- ***Main Function and Thread Handling:*** The main function directs the entire process, creating threads for data flow and processing, and subsequently closing thread handles upon completion.

In the optimized acquisition algorithm, we have mitigated the inherent latency in reading and displaying the output by integrating the imaging algorithm into the acquisition thread

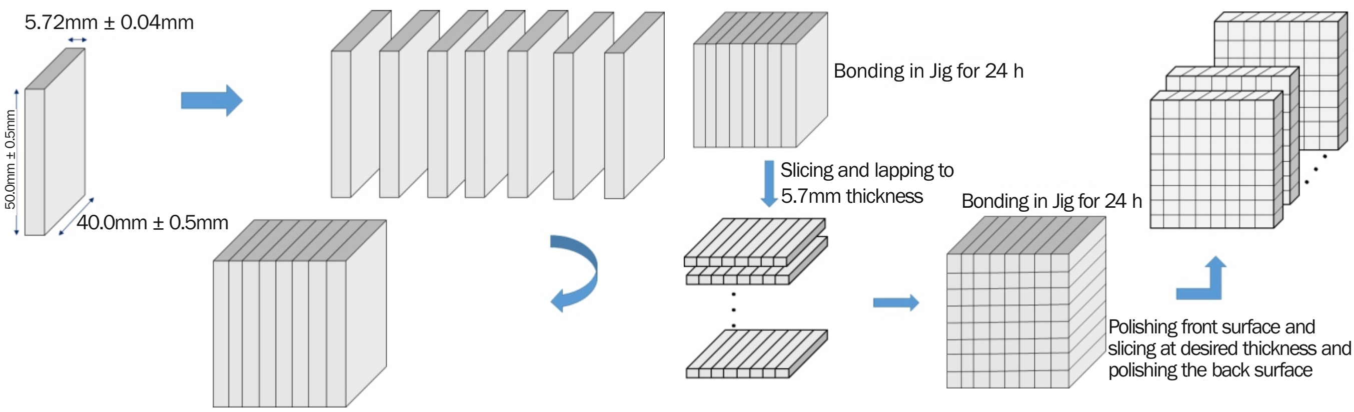

Fig.3: Schematic of process for pixel array fabrication.

Fig.4: 2D-array of CsI:Tl (8x8) mounted on PMT.

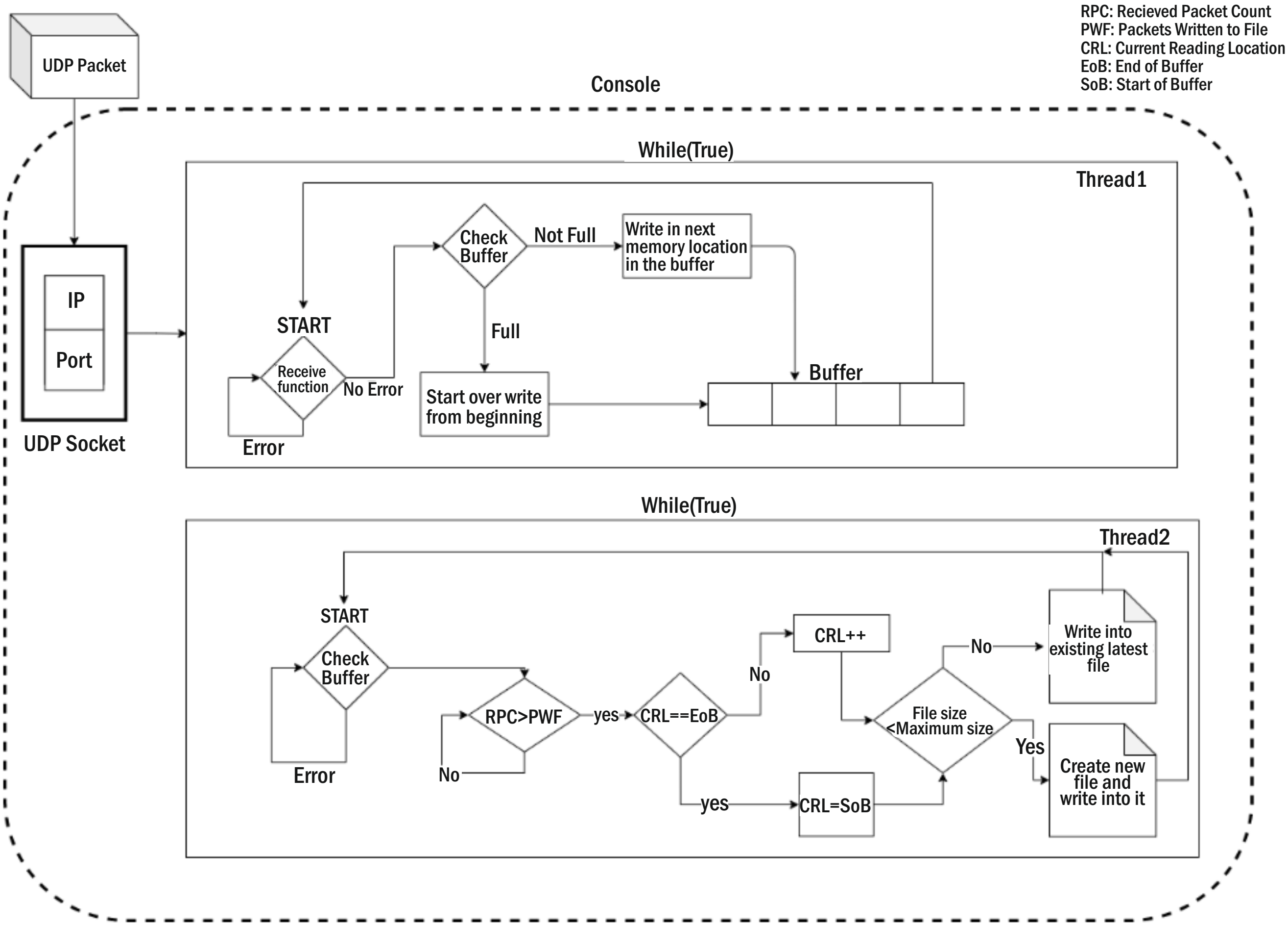

Fig.5: Acquisition Algorithm.

itself. This optimization enables the simultaneous retrieval of both the display and the log file, without dependency on log file creation. As a result, this enhancement has significantly reduced time complexity compared to the unoptimized code. In the trigger-time mode, acquired scintillations are binned into an 8 x 8 format, yielding an average frame rate of 50 frames per second. The algorithm is deployed using the C++ programming language and the detector's performance is assessed using two types of lead slits (horizontal and slant) with an ^{152}Eu 0.5 mCi source kept at 4 inches from the detector.

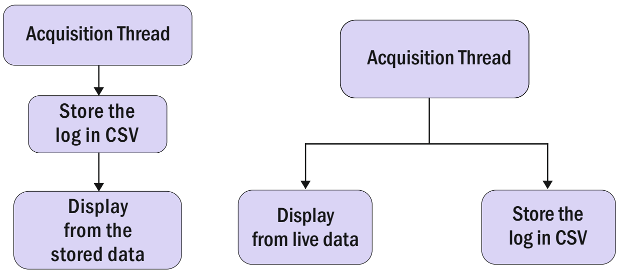

Fig.6: Unoptimized Acquisition (left) ; Optimized Acquisition (right) .

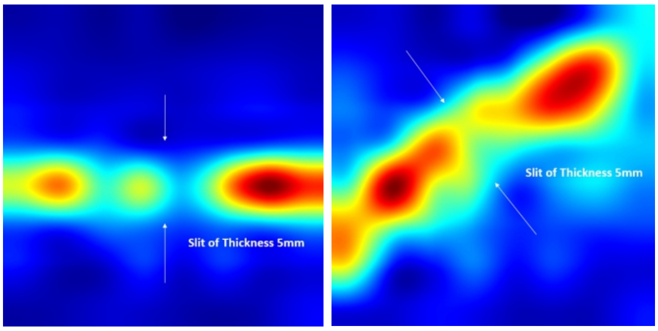

Fig.7: Real-time imaging with optimized code with two slits (left) horizontal and (right) slant.

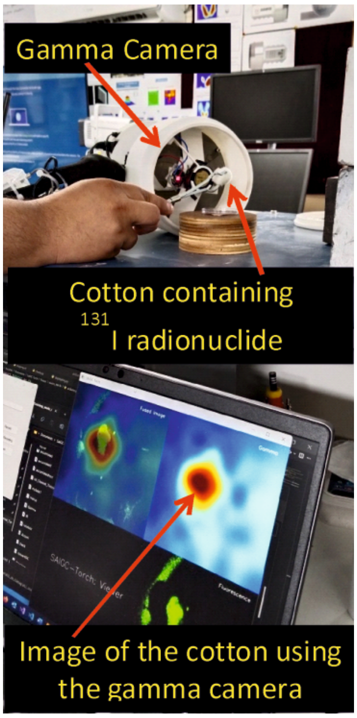

Fig.8: Cotton phantom containing radionuclide (Top); Image of the cotton phantom detected using Gamma Camera (Bottom).

Incorporating the scintillator detector and the slits, a hand held gamma camera was developed. The working of this device was tested in the lab using a cotton ball dipped in liquid radionuclide and the real time image was recorded as seen in Fig.8. Further testing of the device will be carried out in hospital for detection of cancerous tissues in the operation theater.

Conclusion

A gamma camera using a 8 x 8 matrix of CsI:Tl single crystals of dimension 5 x 5 x 5 mm each was developed. The scintillator matrix was coupled with a PSPMT and algorithm was developed to enable real-time streaming of data and image processing. The development is aimed to fabricate a gamma camera which can be used as an intra-operative tool for imaging of cancerous tissues using radioactive tracers.

References

[1] Qianru Zhao et al, Nucl. Inst. Phys. Res. A, 1040 (2022) 166985.

[2] J.R. Deepak et al, Mater. Today Proc. 44 (2021) 3732–3737.