Performance stability of in-house developed thermal neutron detector using large size hygroscopic LiI:Eu single crystal

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Introduction

Lithium Iodide activated with Europium is a well known thermal neutron scintillator. It contains ^{6}Li which has higher capture cross section (~ 940 barns) for thermal neutrons and releases around 4.8 MeV of the “Q” value energy in the nuclear reaction with the thermal neutrons. The charged particles (^3_1H and ^4_2He) generated in this reaction deposit their energy which results in the emission from the europium energy levels. The scintillation from the crystal lies in the blue region with peak wavelength at ~ 470 nm which decays within few micro seconds. It match well with the response curve of the Bialkali PMT and standard scintillation electronics can be used to process the signal into electronic and digital form. However, the LiI:Eu is highly hygroscopic in nature and a large number of factors which includes, the dehydration procedure, the single crystal growth parameters and the hermetic sealing of the processed scintillator affects the detector properties and their long term performance.

In this communication, we report the transparent and crack free single crystal growth of about 2 inch diameter and 90 mm length. Scintillators processed form these single crystals were characterized and the long term detector performance has been studied to standardize the hermetic sealing procedure.

Experiments

Synthesis

Single crystals of 0.1 % Europium doped Lithium Iodide (LiI:Eu) were grown using the Bridgman technique. Ultra-dry anhydrous beads of LiI (natural abundance: 7.4 %) and EuI_2 with 99.99% purity were used as the starting charge and were mixed in stoichiometric ratio in a glove box having controlled ambient of both oxygen and moisture under 0.1 ppm. The mixture was then dehydrated in a quartz ampoule at 300^{0}C for 4 hours under a running vacuum of 5 x 10^{-5} mbar to remove any residual moisture or oxygen. Finally, the quartz ampoule was sealed under running vacuum at a pressure of 5 x 10^{-5} mbar. The quartz ampoule was then loaded in a Bridgman furnace that was heated up to 510^0 C and was kept at this temperature for 4 hours to thermalise the melt. The single crystals were grown by lowering the ampoule through a temperature gradient of ~ 12 K/cm with a lowering rate of 0.2 mm/h in the cone region followed by 0.5 mm/h in the cylindrical region. After the completion of the growth, the grown crystals were cooled down to room temperature at a rate of 30^0 C per hour. Single crystals were retrieved by cutting the quartz crucible under silicon oil to avoid any moisture or oxygen contact which may degrade the single crystal properties.

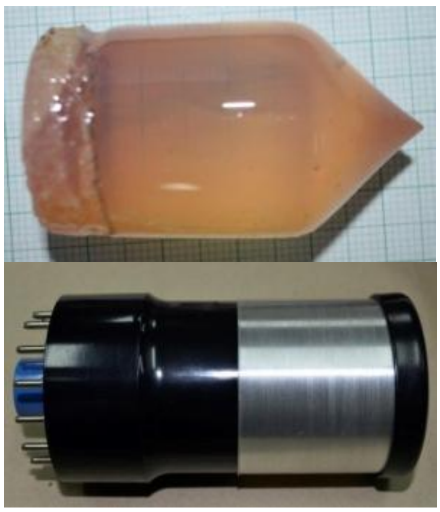

Fig 1: a) As grown single crystals of LiI:Eu of 2 inch diameter and 90 mm length b) A hermetic sealed LiI:Eu detector

Characterization

As grown crystals immersed in oil were cut and polished optically. The luminescence profile of LiI:Eu have been recorded using a monochromator and its compatible software (make: Princeton Instruments Acton spectra pro SP-2300). A white X-ray source with Cu target at an accelerating voltage of 40kV and 30 mA of tube current was used to excitation the samples and record their emission. Scintillators have been processed in cylindrical shape with circular cross section of approx 45 mm diameter and around 1 mm thickness. The processed scintillators were directly mounted over the PMT (R1306) using a silicon gel and were wrapped with thick teflon reflectors for maximising the light collection into the PMT. The entire assembly (PMT and scintillator) was hermetically sealed using a thin aluminium casing which also helps in avoiding the exposure to the ambient light. Pulse height spectra (PHS) have been recorded for both gamma energies and thermal neutron sources. Long term evaluation of the hermetic sealing has been accessed by recording the PHS due to ^{137}Cs gamma source over a period of three months.

Results and Discussion

A photograph of as grown single crystal of LiI:Eu is shown in fig 1(a) whereas the hermetic sealed LiI:Eu detector mounted over PMT is shown in Fig 1(b). It shows a crack free transparent ingot throughout the length. The pulse height spectrum due to thermal neutrons from an Am-Be source is shown in fig 2. It shows a photo peak corresponding to the 4.8 MeV energy deposited by the charged particles produced in the reaction with thermal neutrons. The high energy gamma of Am-Be source could not deposit their full energy in this thin scintillator having low density. The origin of the peaks was confirmed by shielding the detector with the cadmium source, and no photo peaks have been observed in this case. The pulse height spectrum recorded using ^{137}Cs source over a period of three months under identical signal processing settings has been shown in fig 3. It shows the photo peak formed nearly at the same channel with variations below 3 % which may arise due to experimental errors.

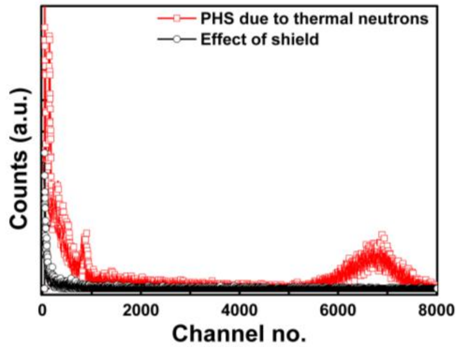

Fig. 2 Pulse height spectrum due to thermal neutrons from a thermalised Am-Be source recoded using LiI:Eu scintillator.

It indicates a successful hermetic sealing of scintillator directly coupled to PMT which holds for a longer durations. Further experiments are in progress to optimize and enhance the detector efficiency under hermetic sealing.

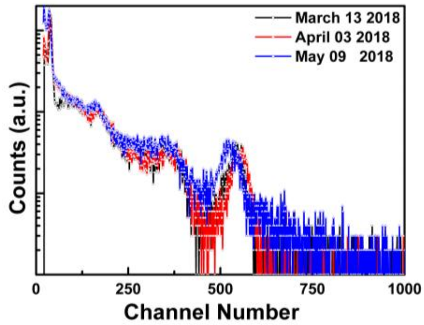

Fig. 3 Pulse height spectrum due to ^{137}Cs recoded under identical settings over a period of 3 months.

Conclusion

Single crystals of 0.1 % Eu doped lithium iodide were grown using Bridgman technique. Thermal Neutron detection has been carried out using the hermetically sealed detector and its long term performance has been evaluated.

References

[1] Sajid Khan, et al, Nucl. Inst. And Meth. A **793** (2015) 31-34.
[2] Boatner, L.A, et al, Nucl. Inst. And Meth. A **854** (2017) 82-88.