Elimination of the effect of alpha contamination in $LaCl_3$ scintillators by pulse shape discrimination

D. Chattopadhyay[1], M. Saha Sarkar[1],* and S. Sharma[1]
[1]*Nuclear Physics Division, Saha Institute of Nuclear Physics, Kolkata - 700064, INDIA*
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Introduction

Commercially available $LaCl_3$ scintillators exhibit good energy resolution (< 3% at 662 keV) along with intrinsic time resolution of about 100 ps that make them useful for low energy nuclear spectroscopy and time of flight measurements and medical imaging purposes. However the self-activity of $LaCl_3$ is observed to be a major issue which reduces the detector sensitivity and interferes with the gamma rays of interest in nuclear physics experiments and complicates data analysis. Natural Lanthanum is composed of ^{139}La of 99.91% abundance and remaining of radioactive ^{138}La with half-life $\sim 10^{11}$ years. Since the chemical separation between the two isotopes is not possible, the contamination due to ^{138}La is unpreventable in all La-halide based scintillator. ^{138}La has two decay modes, in 66.6 % case it captures an electron to form ^{138}Ba in the excited state of 1436 keV that decays into ground state via emission of equivalent energetic gamma and the remaining decays proceed by beta emission to ^{138}Ce that decays via gamma of 789 keV in coincidence with beta having end point energy 255 keV. Actinium and lanthanum have very similar chemical properties, hence all La-halide based scintillator are subjected to alpha contamination of long-lived ^{227}Ac. The alpha contamination is identified by the three major broad peaks in the 1700-3000 keV energy range in the spectrum. As alphas produce less scintillation light than gamma rays of same energy, the emitted alphas in the energy range of 5000-7400 keV, generate peaks in the spectrum at much lower energies. The background spectrum is then dominated by internal gamma, beta and alpha activity which is a severe drawback for the nuclear spectroscopy measurements.

In recent years, the pulse shape discrimination technique have been used for La-halide detector also to separate out the alpha contribution from gamma. But the results are in contradiction. Hoel *et. al.* [1] mentioned that the pulse shape discrimination technique is inadequate for $LaBr_3$ detector due the small difference in pulse shape of gamma and alpha. However, other studies suggest the small but measurable pulse shape difference between gamma and alpha. Later Crespi *et. al.* [2] by using charge comparison method with fast digitizer achieved the suppression of intrinsic alpha background. Overall, the quantitative understanding of pulse shape differences between alpha activity and gamma for La-halide detector remains limited till now.

In this paper, we compare the pulse-shape of signals generated by α-particles and γ-rays detected in $LaCl_3$ scintillator. In addition, an algorithm is developed based on the pulse shape discrimination to separate out the internal α activity from the γ-rays. Different parameters relevant for data acquisition system have been optimized to get the optimal separation between α and γ.

Experimental details

In this research work, a 1 in. x 1 in. cylindrically shaped $LaCl_3$ detector was used, which is commercially available from Saint-Gobain. The photo-multiplier tube of Hamamatsu type was coupled to the scintillator crystal. The PMT has been biased to -1800 V. The anode signal was directly processed by a set of CAEN digitizers: DT5720(250 MHz)

*Electronic address: maitrayee.sahasarkar@saha.ac.in

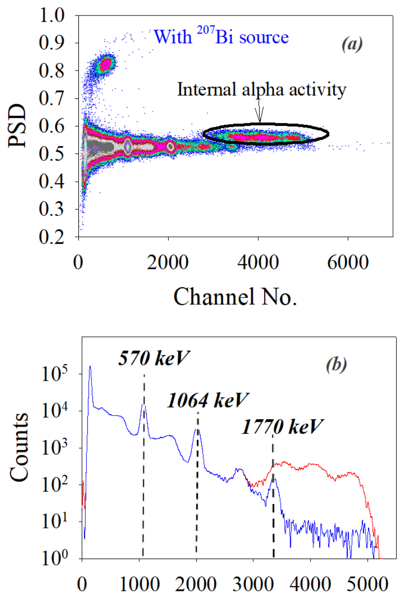

FIG. 1: (a) Two dimensional plot of PSD vs Channel No. with ^{207}Bi source. (b) The projection of the 2D plot on x-axis is shown by red-line and the alpha contamination subtracted projection is marked by the blue line.

and DT5730(500 MHz).

Results and discussions

The number of emitted scintillation photons N from a single scintillation event can be described by linear superposition of two components depending on the prompt and delayed decay times as :

$$N = Aexp(-\frac{t}{\tau_f}) + Bexp(-\frac{t}{\tau_s}) \qquad (1)$$

where, τ_f and τ_s are the fast and slow decay constants. The A and B components vary as function of incident particle type. Thus the pulse shapes differ. Based on this properties, scintillator detectors are used for particle identification in modern day nuclear physics experiments. This property is well known as pulse shape discrimination.

In pulse-shape discrimination(PSD) with scintillators, the most used technique is the so-called charge integration method, which determines the delayed light output with respect to the total light event by event mode. DPP-PSD firmware is based on this method. The PSD parameter is then extracted in event-by-event mode in the FPGA of the digitizers as

$$PSD = \frac{(Q_L - Q_S)}{Q_L} \qquad (2)$$

where, Q_L and Q_s are the integrated charge within Long gate and Short gate respectively. The PSD feature corresponds to the ratio between the integral of the tail ($Q_L - Q_S$) and the total charge (Q_L). The PSD parameter is sensitive on the Pre-gate, Short-gate and Long-gate. To optimize the PSD parameter for the better separation of alpha and gamma, the data has been taken with ^{207}Bi source. ^{207}Bi has three gamma lines at 570 keV, 1064 keV and 1770 keV. But due to the contamination of alpha activity in $LaCl_3$ detector, the 1770 keV peak is mixed with the contamination as shown in Fig. 1 (b). The PSD parameter obtained in event-by-event from the above algorithm has been evaluated and the 2D spectrum of PSD vs Channel No. (Long Gate) has been built, shown in Fig. 1 (a). From the 2D graph in Fig. 1 (a), it is observed that the alpha activities are well separated from the gamma lines. The projection of the 2D graph on the x-axis, is shown by blue-line in Fig. 1 (b) reflects the 1770 keV gamma line of ^{207}Bi source. Efforts are being taken to eliminate the effects of internal beta activities as well.

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References

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