Timing measurements with $LaCl_3$ (0.9%Ce) detectors and their application in the measurement of speed of light

S. Rawat[1],* A. Kamboj[2], G. Anil Kumar[1]
[1]*Department of Physics, Indian Institute of Technology Roorkee-247667, INDIA.*
[2]*Department of Metallurgical and Materials Engg., Indian Institute of Technology Roorkee-247667, INDIA.*
** email: rawatsheetal1991@gmail.com*

Introduction

The recently developed cerium-doped lanthanum chloride scintillation detector proved to be major alternative to most of conventional scintillation detectors because of its attractive properties such as higher light output and better energy resolution [1], fast response [2,3], very good light output stability over wide range of temperature[4], excellent radiation hardness [5], etc. These properties made them a suitable candidate in various applications such as detection of prompt fission gamma rays in nuclear reactors [6], hand-held gamma ray spectrometers [7], environmental gamma ray dosimeters [8], sea level applications [9], etc. It has a principle decay time constant of 20ns [2] which make them highly suitable in timing applications. The present work aims to carry out detailed timing measurements with $LaCl_3$ detectors doped with 0.9% Ce and explored the possibility of using them in measuring the speed of light.

Several techniques were used in the past to measure the speed of light. These techniques include spectrometric [10], ultra fast plastic scintillators [11], inorganic scintillators [12,13], time-of-flight [14], revolving mirror [15], etc. The advantage of using inorganic scintillators with slow-fast coincidence technique over time-of-flight technique in the measurement of speed light is the whole experiment can be carried out on a laboratory table instead of using a path range of several meters.

Experimental Details

We have made measurements of coincidence resolving time using fast coincidence technique with two 1″ × 1″ cylindrical $LaCl_3$(0.9% Ce) detectors (SCIONIX Holland B.V.) kept at 180° to detect the two oppositely emitted 511 keV gamma rays from a ^{22}Na (~ 643 kBq) source placed at the center of two detectors. The scintillators were coupled to 1.5” PHOTONIS PMTs of type XP2. The PMT have a rise time of 3ns and transit time of 36ns. Our detailed measurements with anode and dynode outputs have clearly shown that the anode signal is best for timing measurements. So, the anode signals were processed through constant fraction discriminators (QUAD CFD Model 454, Canberra). The output of each CFD is triggered with the amplified and shaped dynode output of 511 keV photons band on the oscilloscope (ScientiFic SMO10C). The CFD threshold is set to allow the pulses corresponding to the gamma energies above 400 keV. To determine the time calibration of TAC one output of the CFD is fed to the start and other to the stop of the TAC (Model 2145, Canberra) through the nanosecond delay (Model 2058, Canberra). TAC range was set to be 50ns. The output of TAC is then connected to a 8K multi-channel analyzer (Fast ComTec 3FADC) to record the time spectrum. It has been ensured that the time resolution remains same for any particular range of TAC range. Subsequent to the time calibration of TAC, a meter scale is taped down on the supporting table and the stop detector is moved along this meter scale while the time spectrum of the prompt coincidences is recorded as a function of distance. Stop detector is moved at an interval of 3cm. At each distance, coincidence spectrum is obtained with peak counts of 250. Five coincidence spectra were obtained for distances between 10cm and 19cm. In each case, proper care has been taken in adjusting the CFD settings such as threshold, walk and width.

Results and Discussion

Fig.1 shows the time spectrum with different delays. The position of peak channel versus the delay is fitted to a linear function to obtain the time calibration of the TAC. The measured time resolution is found to be 500ps. At first instance, this time resolution appears to be poorer than the values reported in the literature. For example, Shah *et al.* [2] have reported a time resolution of 256 ps for $LaCl_3$ doped with 10% Ce. However, these measurements were done with detectors of volume of about 1 cm^3 which is much smaller compared to a volume of 12 cm^3 used in the present work. For the same volume of 12 cm^3, Iltis *et al.* [16] also have reported a value of about 496ps using slow-fast coincidence technique, which is comparable to our reported value. Oberstedt *et al.*[3], have done measurements with 1.5″ × 1.5″ $LaCl_3$, i.e. of volume 43 cm^3, doped with 5% Ce detectors and reported a time resolution of about 761 ps. By adjusting the threshold of CFD just below the ^{60}Co peaks i.e. about 1000 keV, they have reported a value of 507 ps. It has been established beyond any doubt that higher concentration of cerium results in better time resolution [17]. It is to be noted that in the present study, the concentration of cerium was 0.9% only and moreover the value of 500 ps is obtained without slow-fast coincidence technique. The measurements were repeated several times and the deviation from 650ps is found to be negligible. We believe that this may be due to proper adjustment of zero-crossover [3] and maintaining threshold just below the 511 keV.

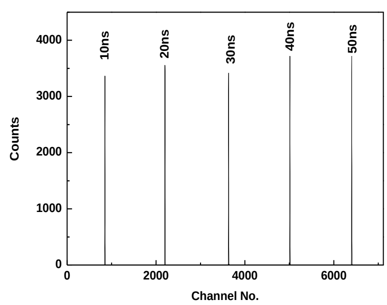

Fig.1: TAC Calibration at different delays

Fig. 2 shows the plot of distance of stop detector from the center of the source versus peak channel number. The slope of this straight line plot results in a value of 323 275 862 m/s for speed of light. An error of 7.8% is due to errors related to the alignment between source and detectors, size of the source, linearity of pulse processing modules used, etc.

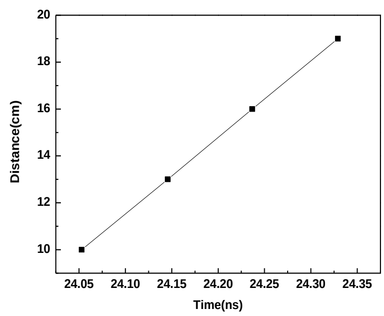

Fig.2: Distance versus time plot

Acknowledgement

The authors would like to acknowledge the financial support received from DST under fast track scheme (No: SR/FTP/PS-032/2011).

References

[1] E.V.D.van Loef *et al.*, Appl. Phys. Lett. 77 (2000) 1467.
[2] Shah *et al.*, NIM-A 505 (2003) 76.
[3] Oberstedt *et al.*, Nucl. Instr. Meth. 668 (2012) 14.
[4] http://www.crystals.saint-gobain.com/ BrilLanCe_380_Scintillator.aspx
[5] Pie *et al.*, Rad. Measur. 42 (2007) 407.
[6] Oberstedt *et al.* PRC 87(2013) 051602R.
[7] Mohini *et al.*, LANL report LA-UR-05-2908.
[8] Tsutsumi et al., NIM-A 557 (2006) 554.
[9] Bernabei *et al.*, NIM-A 555 (2005) 270.
[10] Rogers J *et al.*, Am. J. Phys. 37 (1969) 816.
[11] http://isnap.nd.edu/Lectures/Laboratory/ 02_Speed_of_Light-1.pdf
[12] Chow *et al.*, Eur. J. Phys. 15 (1994) 49.
[13] www.hecr.tifr.res.in/~bsn/INO/Thiru% 20Vol%20report.pdf
[14] Sherbini et al, Am. J. Phys. 48 (1980) 7.
[15] Domkowski et al., Am. J. Phys. 40 (1972) 910.
[16] Iltis *et al.*, NIM-A 563 (2005) 359.
[17] Shah *et al.*, IEEE TNS 50 (2003) 2410.